



# **2002 Peace River HBMP Comprehensive Summary Report**

**September 2004**



**PBSJ**



## Errata

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This report is a revised version of the previous “Final” document submitted to the District in September 2004. The original working title of this document was the *2004 Comprehensive Summary Report*, and was changed between the “Draft” and “Final” versions to the *2003 Comprehensive Summary Report*. However, during preparation for the Scientific Review Panel meeting (September 31<sup>st</sup> and October 1<sup>st</sup>, 2004) the Authority and the District agreed that the title was somewhat confusing and decided that the titles of all future summary HBMP documents should reflect the last year of the data included in the analyese.

Thus, the revised title of this document is now the *2002 Comprehensive Summary Report*. It is hoped that the adoption of this procedure will eliminate any future confusion caused by the sometimes lengthy periods required to produce and review these extensive summary HBMP documents.

This report contains a very large number of graphics. It should be noted, that the figure footnotes (production dates) still reflect the original report date due to the extensive amount of time that would have been required to alter all these graphics to reflect the recent change in the document’s title.

**Peace River Hydrobiological  
Monitoring Program  
2002 Comprehensive Summary Report**

**Required by**

**Southwest Florida Water Management District  
Water Use Permit 2010420.03**

**Prepared for**

**Peace River Regional Water Supply Facility**

**Peace River / Manasota Regional  
Water Supply Authority**



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# Acknowledgments

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- **EarthBalance (Florida Environmental)** – was responsible for conducting and preparing the major portion of the vegetation analyses presented in Section 4.7.
- **U.S. Geological Survey** - was responsible for all data collected by the continuous recorder gages, and all gaged freshwater inflow data used in this study.
  1. Peace River at Arcadia (02296750)
  2. Horse Creek near Arcadia (02297310)
  3. Joshua Creek near Nocatee (02297100)
  4. Shell Creek near Punta Gorda (02298202)
- **Peace River/Manasota Regional Water Supply Authority** - provided daily Facility withdrawal records and technical review of document drafts.
- **Benchmark Laboratory** – has conducted both the HBMP “fixed” and “moving” station water chemistry analyses since February 2002.



# Executive Summary

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## Purpose of the Report

The *2002 Comprehensive Summary Report* presents an in-depth, updated analysis of hydrologic and ecological data collected as part of the Hydrobiological Monitoring Program (HBMP) for the Peace River Water Supply Facility (the Facility). The HBMP is designed to monitor key hydrobiological characteristics of the Lower Peace River / Upper Charlotte Harbor estuary and evaluate the effect of past, present, and projected river withdrawals on the ecology of this resource. An objective of the HBMP report is to provide the Southwest Florida Water Management District (District) with sufficient analyses of HBMP data to determine if the withdrawal schedule for the Facility provides resource protection and prevents adverse impacts to the estuary. The Comprehensive Summary Report also evaluates criteria for determining adverse impacts, proposes a controlled river withdrawal test for the Facility, and discusses possible modifications to the monitoring program.

## Primary Findings and Conclusions

Since its inception in 1976 the HBMP has incorporated numerous physical, chemical, and biological study elements in order to assess the overall “health of the estuary” and evaluate any direct and indirect adverse impacts potentially associated with Facility withdrawals. The primary findings and conclusions of the HBMP are listed below.

- The analyses of HBMP data presented in previous HBMP reports from 1976-2002 have shown that Facility withdrawals have had, or are expected to cause, small changes in salinity gradients and that these changes are within the normal natural range of tidal and seasonal ranges of variability found in the lower Peace River/upper Charlotte Harbor estuarine system. To date, the detected and predicted changes in salinity and/or spatial locations of isohalines resulting from Facility freshwater withdrawals have not been found to cause any pronounced or systematic changes in the salinity structure, water quality, or biological integrity of the affected estuarine communities of the lower Peace River/upper Charlotte Harbor estuarine system.
- The results and findings of the continuous recorder models presented in this report support the overall conclusions of previous reported statistical modeling efforts. These efforts have concluded that the maximum expected increases in salinity due to Facility withdrawals are expected to be difficult to detect within the normal daily range of tidal salinity variations during those periods when the Facility is potentially having its greatest influence.
- As long as salinity changes attributable to Facility withdrawals remain a fraction of the normal typical range of daily (let alone seasonal) salinity variations along the lower Peace River/upper Charlotte Harbor transect, no significant environmental changes in the estuarine system are expected as a result of increased salinity.



- The 130 cfs minimum flow criteria established by District staff in 1988 was based on plots of conductivity versus Peace River at Arcadia flow from HBMP data gathered at fixed monitoring sites located near the Facility's point of withdrawal. Analogous updated plots are presented in this report using period-of-record HBMP data through 2002. The presented series of figures indicate that similar relationships between conductivities and Arcadia gaged freshwater flows occurred between 80 and 150 cfs river flows suggesting that the selected minimum cut off level could have been anywhere from 80 – 150 cfs. As such, the existing 130 cfs minimum threshold for withdrawals represents a fairly conservative estimate to ensure minimal impacts to the lower Peace River/upper Charlotte Harbor estuary during periods of low freshwater inflow.
- The existing withdrawal schedule elements, which combines a 130 cfs minimum Arcadia gaged flow, with the requirement that diversions cannot exceed ten percent of the previous day's gaged flow, have been and are expected to continue to be extremely effective in preventing Facility withdrawals from having any apparent adverse impacts on the lower Peace River estuarine system.

The intent of the following Executive Summary is to provide both an overview of the general goals and objectives, as well as summarize the major findings and conclusions of the sections presented in the *2002 Comprehensive Summary Report*.

### Section 1 – Introduction

The purpose of this introductory section is to provide readers unfamiliar with the history of the Peace River Regional Water Supply Facility and the Southwest Florida Water Management District's permit criteria, a brief overview of the Peace River/Manasota Regional Water Supply Authority's water use permit for the Facility and those conditions of the permit requiring the major study elements that have been associated with the twenty-seven year history of the Hydrobiological Monitoring Program (HBMP).

- The primary goal of the combined HBMP study elements is to provide the District with sufficient information to determine whether the biological communities of the lower Peace River/upper Charlotte Harbor estuarine system have been, are being, or may be adversely impacted by permitted freshwater withdrawals by the Authority's water treatment facility.
- The continually expanding base of ecological information developed by the HBMP will also be used to periodically evaluate the effectiveness of the withdrawal schedule with regard to assuring the prevention of significant adverse estuarine impacts.
- The existing twenty-year Water Use Permit (WUP) issued by the District in 1996 sets a maximum withdrawal quantity. Under the permit, no withdrawals can occur until there is a minimum flow of 130 cfs at the Peace River at Arcadia gage, which is located approximately seventeen miles upstream of the Facility. Beyond 130 cfs, withdrawals

cannot exceed 10 percent of the average daily Arcadia flow and cannot exceeding 90 mgd (139 cfs) on any day.

- The Facility presently has the capacity to supply up to 24 million gallons per day (mgd), which is equivalent to withdrawals from the river of 37.2 cubic feet per second (cfs). The existing raw water river diversion structure has four pumps with a combined maximum capacity of 44 mgd (68.0 cfs). In comparison, the long-term average annual daily total gaged river freshwater flow upstream of the Peace River Facility is approximately 840 mgd (1300 cfs).
- During periods of high river flow, raw river water is stored in the system's off-stream reservoir, while treated water is stored in the existing twenty-one aquifer storage/recovery (ASR) wells. Conversely, when water is unavailable from the Peace River, water can be pumped from the raw water reservoir to the Peace River Facility for treatment, and/or previously treated water can also be recovered from the ASR system to meet the water supply demands of the Authority's service area.

This *2002 Comprehensive Summary Report* follows and extends the summarization and interpretation of long-term HBMP data submitted in the initial *2000 Midterm Interpretive Report*. Its primary goals and objectives are to provide the District with sufficient analyses to:

- Evaluate key relationships between ecological characteristics and freshwater inflows, and determine whether the biological health and productivity of the estuary are showing signs of stress related to natural periods of low freshwater inflow or potential negative influences of Facility withdrawals.
- Assess the presence or absence of long-term trends for important HBMP variables.
- Evaluate the overall HBMP design and make recommendations regarding implementing modifications.
- Assess the presence or absence of adverse ecological impacts and determine the influence Facility withdrawals may have contributed to such impacts.
- Evaluate the environmental considerations that may be associated with additional future increased withdrawals from the river and the feasibility of increased water supplies.
- Assess and evaluate the effectiveness of the withdrawal schedule for preventing adverse environmental impacts.

None of the detailed analyses of HBMP data presented in previous HBMP reports have shown that Facility withdrawals have had, or are expected to cause, measurable physical or biological adverse impacts within the lower Peace River estuarine system. A key objective of this report is to provide the District with sufficient analyses of the HBMP data to date to assure that the withdrawal schedule is providing sufficient continuing resource protection.



### Section 2 – Conceptual Model

This section's objective was to present a conceptual model developed to illustrate the relationships between river discharges or freshwater flow, and other important water quality and biotic variables in the Peace River estuarine system. The purpose of the conceptual model is to qualitatively demonstrate the potential effects of freshwater withdrawals by the Facility to the Peace River Estuary, and to justify the selection of critical indicators for monitoring and analysis as part of the HBMP or removal of those indicators / parameters that are too far removed from the effects of fresh water withdrawals.

1. Estuaries are ecosystems that are, to a large degree, dominated by physical and chemical processes. Furthermore, river discharge, or freshwater inflow, is one of the most important variables determining the spatial limits of, and the physical and chemical interactions within, an estuary. Therefore, the volume and timing of freshwater discharges from rivers is often the most critical factor driving the biological functions of estuaries.
2. Energy flow through estuarine ecosystems is extremely complex involving numerous physical, chemical and biological processes and interactions. Energy transfer from lower to higher trophic levels in estuarine food webs includes both grazing and detritus-based pathways, both of which can be affected by freshwater inflows.
3. Organisms that live in estuaries have evolved to tolerate widely variable water chemistry, including substantial fluctuations in salinity and dissolved oxygen concentrations, and the associated physiological stresses. Consequently, most estuarine plants and animals can persist and flourish within a broad range of salinity. However, despite their tolerance for wide fluctuations in salinity, the distribution and abundance of estuarine plants and animals still tend to segregate across a salinity gradient, indicating that most species have optimal salinity ranges with respect to environmental physiology and ecological competition.
4. The conceptual model of the Peace River estuarine system illustrates that variations in river discharge, whether from natural climatic variability or significant freshwater withdrawals, can affect the structure and function of the estuary in the following ways.
  - Salinity is a major determining factor controlling the distribution, abundance and species composition of all biotic communities in the estuary. The primary mode of action on plants and animals is through ionic and osmoregulatory adaptations to particular salinity regimes.
  - The interactions between the physical, chemical and biological processes and the biological components of the estuarine ecosystem are exceedingly complex. Most of the effects of changes in freshwater flows on trophic energy flow in the estuary are mediated and modulated by numerous steps and feedback loops.

- Changes in freshwater flows generally result in a horizontal shift in the location of the estuarine mixing zone along the river axis. Greater freshwater flows cause a downstream shift, whereas lesser flows cause and an upstream shift.
- The physical, chemical and biological processes, and trophic energy flows, that take place in the estuarine mixing zone (e.g. adsorption, flocculation, assimilation, and regeneration) are translocated upstream or downstream corresponding to changes in the horizontal location and areal extent of the mixing zone.
- The distribution of the planktonic (drifting) and nektonic (swimming) communities, including phytoplankton, zooplankton, and young fishes - and the trophic interactions between these communities - is translocated upstream or downstream primarily in response to advection and corresponding changes in salinity over short time scales (e.g. hours, days).
- Phytoplankton primary production along the estuarine salinity gradient is often characterized by spatially distinct chlorophyll *a* maxima, the location of which are seasonally dependent on variations in freshwater inflows and associated nitrogen inputs. In turn the distributions of these zones of maximum chlorophyll *a* concentrations often results in associated zonation of ichthoplankton and detrital fish nursery energy inputs.
- The distribution of the benthic (bottom) communities - including sediment microbes, and benthic invertebrates, and the trophic interactions between these communities, is translocated upstream or downstream primarily in response to advection and corresponding changes in salinity over longer time scales (e.g. months, years, decades).
- If the magnitude and duration of variations in river discharge are large enough, spatial discontinuities can be created between the stationary and non-stationary variables of the estuarine ecosystem. For example, if freshwater flows are reduced such that there would be a substantial upstream shift in the long-term average position of the bottom isohalines, a discontinuity would exist between the stationary biological resources, such as tidal wetlands or benthic mollusk populations, and the overlying water column. The result would be that the stationary living resources would no longer be spatially distributed within the zone of their optimal salinity range, potentially leading to extirpations and shifts in species composition.
- Strong gravitational circulation patterns can develop in shallow partially-mixed estuaries under high flow and low turbulence conditions, especially during summer months when water temperatures are highest. Persistent water column stratification often leads to hypoxia, and even anoxia, which can significantly alter the distribution and abundance of planktonic, nektonic and benthic plants



and animals. Periodic hypoxia/anoxia has been well documented in the Peace River Estuary during periods of high flow.

### Section 3 – Summaries of Recent HBMP Reports and Primary Conclusions

Since the 1996 Permit renewal, the Authority has prepared a series of reports designed specifically to address particular physical and biological questions and concerns related to potential impacts to the lower Peace River estuarine system from Facility freshwater withdrawals. The primary objective of this section was to provide an overview of the primary conclusions from each of the major HBMP documents (and other relevant reports) that have been prepared since the 1996 renewal.

The following briefly reviews the previous reported major overall findings and conclusions, organized by topic, contained within the major historical HBMP related reports summarized in this section.

- **Standard Reference Center Line** – In conjunction with the *Morphometric Habitat Analysis of the Lower Peace River*, a standard reference centerline was established along the Peace River using the previously established USGS designated “mouth” of the Peace River as the initial zero reference point. The results provide reference points for HBMP sampling stations and EQL station locations, as well as a means of referencing USGS stations.
- **Rainfall** – Analyses conducted in the *2000 Midterm Interpretive Report* indicated no consistent patterns of increasing or decreasing rainfall were identified over the historic period of record for which gaged daily flows were available for each of the major lower Peace River watershed tributaries (1966-1998), or during the time frame of the HBMP (1976-1998) in the upper Peace River watershed. However, more recent increases in rainfall were significant, largely due to unusually heavy rains of 1995, and the 1997/1998 El Niño event.
- **Freshwater Flows and Rainfall** – Analyses presented in the *2002 HBMP Data Report* and the *2000 Midterm Interpretive Report* of gaged freshwater flows in all of the major Peace River tributaries indicated that rates increased or remained unchanged over the past 30 years. Combined flows for the lower river in 2002 were roughly 150 percent of 1976-2001 flows. Long-term declines in stream flows during the late 1950s to the 1980s in the upper reaches of the river were attributed primarily to corresponding rainfall deficits. Similarly, increased flows during the 1990s corresponded with increased rainfall. The variables most effective in modeling freshwater flow/rainfall relationships were those linked directly to flow variations (e.g. salinity, inorganic nitrogen concentrations, color) and those closely associated with directly affected variables (e.g. chlorophyll *a* as a measure of nutrient assimilation).
- **Withdrawals** – The *2002 HBMP Data Report* indicated that withdrawals by the Facility have averaged 5.8 mgd (0.6 percent of measured river flow) since 1980. Facility withdrawals reached 10 percent of the gaged Arcadia flows over 130 cfs on 4.6

percent days of the year in 2002. Total withdrawals in 2002 equaled 1.93 percent of Arcadia flows and 1.04 percent of the lower Peace River flow. Maximum withdrawals increased during the second half of 2002 due to the recently completed Facility expansion. Due to the 2000 – 2001 drought, the Facility did not withdraw any water from the Peace River for 248 days during the 2000, and relied solely on stored reserves another 219 days during 2001.

- **Salinity** – The *2000 Midterm Interpretive Report* and *2002 HBMP Data Report* reported that record high salinities occurred in the river and harbor during the 2000/2002 droughts. No long-term salinity trends were detected for the period 1976-1989 and low salinities upstream of the Facility were attributed to drought conditions. No net upstream or downstream movement of salinity zones was detected. Typical seasonal (within-year) shifts are 15 to 16 km for the 0, 6, and 12 ppt zones to about 27 km for the 20 ppt zone.
- **Impact of Withdrawals on Salinity** – Model results presented in the *2000 Midterm Interpretive Report* indicated maximum salinity changes of less than 0.3 ppt along the lower river between the US 41 Bridge and the Facility due to past withdrawals. A maximum change of < 0.5 ppt between RK 14 and 18 was predicted to occur when Arcadia flows were in the range of 400 to 1000 cfs and farther upstream at 200 cfs. Updated models predicted changes of 0.1 to 0.3 ppt and movement of isohaline by 0.1 to 0.3 km at maximum permitted withdrawals.
- **Water Quality** – The *2000 Midterm Interpretive Report* indicated that except for slightly elevated levels of phosphorus and color, water quality in the lower Peace River was similar to that of other southwest Florida rivers. Phosphorus levels in the lower Peace River/upper Charlotte Harbor estuarine system showed major declines between 1976 and 1985. However, since that time concentrations have been fairly consistent, showing distinct flow-related seasonal patterns. Other studies have historically indicated that water quality degradation to be greater upstream, toward Lake Hancock. The *2002 HBMP Data Report* indicated that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and mid-2002.
- **Plankton/Phytoplankton** – The *Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System* and *2000 Midterm Interpretive Report* indicated that generally there were seasonally distinct phytoplankton assemblages association with each of the four monitored HBMP isohalines. Time series analyzes indicated declines in chlorophyll *a* concentrations and frequency of phytoplankton blooms that commonly occurred during the late 1970s and early 80s in the lower river. Phytoplankton production and biomass in the lower Peace River were low during low freshwater inflow, regardless of water temperature, but increased at intermediate salinities with wet-season flows. The magnitude of increases was temperature-dependent. Higher peaks in production often occurred in the upper harbor at the end of the wet-season, commensurate with high nitrogen and lower water color.

- **Zooplankton** –HBMP isohaline sampling based studies summarized in the *Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System* have indicated that specific zooplankton taxa occurred in each salinity zone, although many were numerous over a wide salinity range, and the most taxa were observed during high freshwater inflows and higher salinities. Freshwater flows alone did not account for variation in species numbers, density, or diversity. Phytoplankton biomass was positively correlated with dominant zooplankton densities in each salinity zone.
- **Benthic Macroinfauna Investigations** – Measuring changes in benthic macroinfauna community structure solely for detecting potential impacts of freshwater withdrawals was not recommended in the *Peace River Benthic Macroinvertebrate and Mollusk Indicators* study due to: 1) salinity tolerances of these taxa; and 2) variability in tidal cycle that exceeds predicted salinity changes due to freshwater withdrawals. About 30 of over 300 observed species were relatively abundant and changes in distributions corresponded to freshwater inflows. Changes in benthic communities were more spatially stratified along the river transect during high flows, although differences were greater in upper and lower reaches of the river when compared with middle reaches.
- **Mollusk Investigations** – The *Peace River Benthic Macroinvertebrate and Mollusk Indicators* study found that *Corbicula* and another 14 taxa made up more than 98 percent of the samples collected. Most rare taxa occurred in higher salinity reaches. In the lower Peace River, the pattern was one of estuarine taxa invading the tidal river, while *Corbicula* already invaded the upstream reaches. Living populations matched relict mollusk assemblages only during low freshwater inflows. Macromollusk ranges were imprecise salinity indicators *per se*, but rather were indicative of long-term, flow related changes in salinity patterns.
- **Fishes** – The *Assessment of the Effects of Fresh Water Inflow on Fish and Invertebrate Habitat Use in the Peace River and Shell Creek Estuaries* found that habitat-use patterns were generally consistent with those of other tidal rivers along the west coast of Florida. Comparisons of life-stage-specific distributions demonstrated the ingress of estuarine-dependent fishes in the river, however, thresholds or critical freshwater flows for individual or groups of species were not identified. Fish assemblages had distinct “wet” or “dry” season distributions and more than 20 types of fishes and invertebrates moved upstream during low-inflow periods and downstream during high-inflow periods. Some organisms decreased during low inflow periods and many exhibited abundance peaks several months after the high flow 1997-98 El Nino period. There was no strong indication that prey distributions were offset from nursery habitats by responses to changes in flows.
- **Vegetation** – The *Development of GIS-Based Maps to Determine the Status and Trends of Oligohaline Vegetation in the Tidal Peace and Myakka Rivers* conducted for the District by FMRI indicated that overall there had been little change in the upstream and downstream distributions of freshwater and estuarine plant species over the past 20



years, although some variability had occurred between years. The extent of seagrasses in the harbor increased by approximately six percent between 1982 and 1996 and was influenced by water temperature, salinity, and water clarity. Co-occurrence of needlerush with other species may be useful in evaluating changes in salinity regime, although breaks in vegetation distributions were often unclear and mean salinities in communities varied tremendously. Historic aerial photography indicated decreases in salt marshes of 541 acres: from 2,390 acres in 1950 to 1,940 acres in 1985 and to 1,870 acres in 1994. Changes after 1970 were less extensive and were consistent with results from other HBMP studies that indicated little change in vegetation along the Peace River since 1970.

- **Expansion of the Facility** – The *Peace River/Manasota Regional Surface Water Supply, Storage, and Interconnect Project. Final Environmental Impact Statement* was prepared to disclose environmental impacts due to the proposed expansion of the existing Facility by the Authority (2003). As part of the EIS, nineteen alternatives were evaluated for potentially significant environmental constraints. Based on the analysis presented in this document, the proposed project was selected as the preferred alternative, and that the proposed withdrawals would not affect flows downstream from the facility intake during times of low flows due to adherence to District regulations.

### Section 4 – Status and Trends of Hydrobiological Indicators in the Lower Peace River/Upper Charlotte Harbor Estuarine System

The purpose of this section was to provide updated and thorough analyses of the status and trends of key specific monitoring program study elements. Summary graphics and analyses are presented for each of these program elements in order to provide both an overview of the current status, as well as indications of longer-term patterns and characteristic. A corollary goal was to describe the influences on both the physical and biological characteristic of the lower Peace River estuarine system of infrequent occurrences including extended periods of extreme drought and/or the unusually wet winter/spring El Niño climatic events.

#### Watershed Rainfall Patterns

- Extended periods of both unusually high and low seasonal rainfalls have characterized lengthy periods during both the longer term “historic” 1932-2002 time period over which Peace River flows have been recorded at the Arcadia gage and the more recent twenty-seven years during which HBMP monitoring has been conducted.
- Statistical comparisons of the monthly patterns of the more inland Bartow and Arcadia gage data suggest some seasonal differences between the longer term historic and HBMP time periods. Specifically, the data indicate slightly higher rainfall frequencies during both May and October over the historic 1932-2002 period, when compared with more recent 1976-2002 HBMP monitoring time frame. This pattern is not apparent for the more coastal Punta Gorda gage.

- The apparent difference between the two inland rainfall gages and the more coastal Punta Gorda site is indicated by the results of the Seasonal Kendall Tau trend analyses.

### Gaged Freshwater Inflows

- Time series plots of flow at the Peace River Arcadia gage over the period of record (1932-2002) clearly show a greater frequency of high flows, between the early 1930's to approximately 1960, when compared to the more recent period of HBMP monitoring (1976-2002).
- Statistical comparisons between the historic and HBMP monitoring periods indicate noticeable differences during the five-months between June and October, with average gaged river flows during these five months being much higher flows over the long-term period of record when compared to the more recent 1976-2002 HBMP period. In contrast, statistical comparisons of the other seven drier months indicate no differences in flows between the two time periods. The data thus indicate that while the wet-season has gotten generally drier, the dry-season months have remained similar over the long-term period of record.
- Seasonal Kendall Tau trend tests indicate that there have been statistically significant declines in both mean and median monthly flows over the period of record at the Peace River at Arcadia gage. Over the shorter 1976-2002 period of HBMP monitoring there has not been a statistically significant trend observed in Peace River at Arcadia flows.
- Conversely, trend tests results indicate that Joshua Creek flows have statistically significantly increased, over both the period of record and the 1976-2002 HBMP period, due to increases in base flow. These increases correspond with increasing agricultural expansion and the use of relatively high conductivity groundwater by farmers during the drier months.
- No significant trends were found in either gaged Horse Creek or Shell Creek flows over either the periods of record or HBMP monitoring.
- Other than these dry-season agriculture-related augmentations of low season flows, the results of the trend analyses clearly indicate that there have not been any statistically significant systematic changes in the seasonally compared amounts of freshwater flow from the major four Peace River watershed sources over the recent twenty-seven year history of HBMP monitoring.
- During the 1966-2002 period over which there have been gaged flows for each of the major lower Peace River tributaries, the Peace River at Arcadia has accounted for 60.4 percent of the total freshwater inflow at the river's mouth. Horse Creek, Joshua Creek and Shell Creek have correspondingly contributed 8.0, 7.1 and 24.5 percent of total river flow, respectively.

### Rainfall/Flow Interactions

- There have not been any conspicuous or statistically significant changes in the relationships between rainfall and flow in any of the four major gaged lower Peace River tributaries during the period of HBMP monitoring (1976-2002).
- Both the unusually high and extended rainfalls of 1995 and the unusually strong 1997/1998 El Niño event resulted in slightly higher flows per unit rainfall than the long-term averages at each of the gages.
- Analyses indicated that rainfall following extended dry periods does not result in the same increases in flow that would occur under similar rainfall conditions following a series of wetter months. Conversely, higher flows per unit rainfall often occur during relatively dry months such as October following extended periods of high rainfall. Flows thus integrate rainfall based to a great extent on cumulative previous existing hydrologic conditions.

### Treatment Facility Withdrawals

- Due to the minimum 130 cfs cutoff there are often extended periods each year when the Facility does not withdraw water from the river. The effects of the recent 2000-2001 drought on Facility water withdrawals are evident in the fact that the Facility did not withdraw any water from the Peace River 248 days during the 2000, and relied solely on stored reserves another 219 days during 2001.
- The analyses presented clearly show that there has been a relatively steady increase in the amounts of freshwater withdrawals by the Facility during the past twenty-three years due to increasing water demands. Also evident is the noticeable increase in maximum Facility withdrawals during the later half of 2002 due to the recently completed Facility expansion.
- Other than during the warm/dry months of April and May, when withdraws are frequently restricted by the 130 cfs cutoff, the statistical distributions of Facility withdrawals are fairly uniform throughout most of the year.
- Facility withdrawals are more dependent on demand and capacity than supply, since very similar amounts of water are withdrawn over a wide range of flows.
- Since withdrawals are not directly related to flows (outside of the 130 cfs cutoff, and a ten percent maximum of Arcadia flow up to a maximum single day withdrawal of 139 cfs), there is no relationship between withdrawals and total monthly watershed rainfall.

### Lower River Water Quality Characteristics

- **Salinity (ppt)** – Observed salinity patterns indicate the presence of a strong distinct spatial salinity gradient along the lower Peace River. The greatest degree of interannual variability in salinity (as much as thirty-five ppt) occurs in the surface waters located



toward the river's mouth. Under the lowest flow conditions, brackish water conditions extend upstream well beyond the point of Facility water withdrawals. Conversely, freshwater at the surface can extend downstream to near the river's mouth under conditions of extended periods of freshwater inflow. The influences of the recent high freshwater inflows during 1997/1998 El Niño event and the extended 1999-2001 drought are clearly evident. Statistical analyses indicate no significant differences between the average annual salinity levels between the 1976-1989 and 1996-2002 sampling periods.

- **Dissolved Oxygen (mg/L)** – The plots suggest that as flows increase, upstream surface water dissolved oxygen concentrations may be depressed. Increasing freshwater inflows result in higher ambient water color, which in turn reduces the penetration of light into the water column and slows phytoplankton growth and consequently the production of oxygen. Near-bottom dissolved oxygen concentrations show clear seasonal cycles in response to summer wet-season freshwater inflows. Both the duration and magnitude of depressed dissolved oxygen concentrations increase toward the river's mouth as higher bottom salinity levels create greater vertical density stratification of the water column occurs during periods of high river flow. Statistical tests of seasonally adjusted mean annual differences in dissolved oxygen levels indicate significant declines of 0.4-0.6 mg/L between the 1976-1989 and 1996-2002 time periods. It is suggested that these observed declines reflect corresponding declines in some of the very high chlorophyll *a* concentrations that were often observed during the 1970s and 1980s and potential differences associated with changes *in situ* dissolved membrane technology.
- **Water Color (Pt-Co Units)** – Under conditions of lower flows, intermediate salinities often have higher ambient color suggesting that during periods when groundwater comprises the major source of water coming from the Peace River watershed, the wetlands immediately surrounding the lower river are the primary source of water color. However these influences are overwhelmed as gaged “blackwater” freshwater flows from the watershed increased during the wet season. Water color throughout the estuarine system steadily increases at higher rates of inflow. At some point however further increases in flow do not correspond to additional changes in water color, and under conditions of extremely high flows, color levels actually begin to decline slightly.
- **Turbidity (NTU)** – Lower Peace River turbidity levels are generally low and do not increase in response to higher levels of freshwater flows, since the relatively slow moving major blackwater tributaries do not carry large amounts of either silt or clay. The data show indications of turbidity maxima typically coinciding with the chlorophyll *a* maxima along the lower river. Time series analyses indicate turbidity levels appear to have been both lower and less variable during the most recent seven years when compared to the earlier 1976-1989 interval. These apparent observations are supported by the statistical analyses that indicated that there have been significant long-term declines in measured turbidity levels in these areas of the lower Peace River.

- **Nitrite+Nitrate Nitrogen (mg/L)** – The observed spatial patterns of inorganic dissolved nitrite+nitrate nitrogen show initially higher ambient concentrations occur in the upper river under conditions of increasing levels of freshwater inflow. However, concentrations actually decline during periods of very high river flow, when groundwater levels are near the land surface, causing surface water runoff (sheetflow) to rapidly move water into the tributaries resulting in greater dilution. Dissolved inorganic nitrogen concentrations in the downstream more saline reaches of the estuary are at or near detection limits except during periods of very highest freshwater inflow. Conversely, only during periods of extended low freshwater inflow are ambient levels low in the upstream freshwater reaches of the river. Statistical results show no significant differences between the average annual concentrations between the 1976-1989 and 1996-2002 sampling periods.
- **Ammonia/Ammonium Nitrogen (mg/L)** – Dissolved inorganic ammonia/ammonium nitrogen concentrations did not exhibit the same degree of seasonal, flow related variability or the distinct spatial patterns exhibited by nitrite+nitrate nitrogen. Inorganic ammonia/ammonium concentrations in surface waters were often near detection limits as a result of preferential phytoplankton uptake, although high “spikes” were occasionally observed often without any distinct causative factor. The data show high near-bottom dissolved ammonia/ammonium concentrations occur in the lower river reaches when increased summer wet-season flows cause salinity induced water column stratification, which results in pronounced periods of hypoxia/anoxia in the bottom waters. This possibly explains why statistically higher ammonia/ammonium concentrations were observed near the mouth of the river over the more recent period when compared with the previous 1976-1989 time frame.
- **Total Kjeldahl Nitrogen (mg/L)** – Spatially total Kjeldahl nitrogen concentrations (which measures both organic nitrogen and ammonia) along the lower river generally shows increasing patterns both moving upstream and with increasing levels of freshwater inflow. Statistical tests indicate no significant differences between the average annual concentrations when comparing the 1976-1989 and 1996-2002 time periods.
- **Total Phosphorus (mg/L)** – Concentrations progressively increase upstream towards the freshwater source, and initially rise in response to higher levels of freshwater inflow. The lower Peace River/upper Charlotte Harbor estuarine system is naturally highly enriched in phosphorus due to the extensive natural watershed phosphate deposits. Seasonally the highest phosphorus concentrations are typically associated with periods of lower river flow, when the influences of groundwater are more pronounced. Probably the most dramatic long-term change in lower Peace River water quality has been the marked, long-term decline in phosphorus concentrations. Long-term temporal patterns indicate that both the magnitude and very high degree of variability in phosphorus levels that was observed during the first six years of HBMP monitoring rapidly declined in response to implementation of stricter regulations and controls covering both point and non-point discharges of surface waters from phosphate mining operations and lands.

- **Silica (mg/L)** – The observed spatial pattern of reactive silica within the lower Peace River estuarine system reflects the influences of freshwater inflows. Seasonally, as freshwater inflows become greater, silica concentrations both increase and move further downstream. Statistical analyses indicate reactive silica concentrations have significantly increased along the entire length of the lower Peace River monitoring transect. It may be that the observed increases in reactive silica levels in the Peace River estuarine system reflect the cumulative influences of the increased use of groundwater and the expansion of water intense agriculture throughout the Peace River watershed.
- **Dissolved and Total Organic Carbon (mg/L)** – Organic carbon levels generally increase both upstream and in response to higher levels of freshwater inflow, and spatially and temporally reflect the influences of freshwater inflows. Comparisons of mean annual average concentrations between the 1976-1989 and 1996-2002 time periods clearly indicate that concentrations, especially toward the river's mouth, have statistically significantly declined during the most recent seven-year monitoring period. To a great extent, the explanation for these observed trends probably lies in the use of new, automated chemistry, analytical procedures that have both lower detection limits and greater accuracy.
- **Chlorophyll *a*** – Concentrations along the lower river exhibit distinct spring and fall peaks that are influenced by both the timing and amounts of freshwater inflow. Normally there are distinct chlorophyll *a* phytoplankton maxima that generally move downstream as flow increases. Statistical analyses show that there has been a marked decline in the periodic very high chlorophyll *a* concentrations or phytoplankton “blooms” that commonly occurred during the late 70s and early 80s throughout the estuarine system.

### Riverine Vegetation

- Long-term analyses of the first and last occurrences of selected indicator riparian plant taxa have indicated that this method is not effective in assessing potential Facility influences. Some species have shown very little variation following extended periods of high and low flows, while the distributions of others have changed back and forth over the extended period of study for reasons apparently unrelated to flow. It was concluded that some of the most apparent changes in first and last occurrences of indicator plant species probably have resulted from the creation or destruction of shallow shoals along the edges of the river during periods of high flow. The causes of other observed changes were found to be less obvious and clearly indicated the difficulty in determining meaningful relationships between freshwater inflows and the long-term distributions of these selected taxa.
- Detailed comparison of aerial photography from 1998 (following an extended period of unusually high flows) and 2002 (following the recent extended drought) using GIS based forward-dating procedures indicates some small upstream changes in the

weighted centers of abundances of two (mangroves and freshwater marsh) of the four selected major riparian vegetation communities along the lower Peace River. The measured changes were small in comparison to the differences in the spatial salinity patterns during the extended wet and dry periods that preceded the two selected vegetation surveys. Given these results, it is extremely doubtful whether any quantifiable changes in long-term vegetation patterns along the lower Peace River will ever be attributable to Facility withdrawals, since the magnitude of the predicted salinity changes due to Facility withdrawals are small relative to the normal daily and seasonal ranges of salinity variations that influence the spatial distributions of these riparian vegetation communities.

- Analyses of recent vegetation data from the fixed vegetation transitional sites indicate that the increasing influence of Brazilian pepper limits tracking changes in upland vegetation patterns along the lower river. The monitoring data indicates that the dominant riparian vegetation at the three sites appears to be relatively well established, stable, and not easily affected by the naturally occurring drought conditions, thus limiting the monitoring programs potential effectiveness in assess potential Facility impacts.

### Section 5 – Salinity/Flow /Withdrawal Relationships at Continuous Recorders

The purpose of this section was to determine the statistical relationships between measured specific conductance values and gaged freshwater inflow, tide stage, and Facility withdrawal at the two USGS continuous recorders located at River Kilometers 15.5 and 26.7. The results of salinity predictions with and without Facility withdrawals based on the application of these new statistical models were compared with the conclusions of previous modeling efforts.

- Cumulative distribution function (CDF) plots were developed to graphically provide overviews of the statistical distributions of the predicted salinity differences under both actual and maximum permitted withdrawal conditions at each of the USGS recording sites.
- The predicted results of the developed salinity models indicate that Facility withdrawals do not cause any salinity change approximately thirty to forty percent of the time, due to the combined influences of the 130 cfs permit cutoff criteria, and the fact that Facility withdrawals cannot change salinity when flows are high enough that salinities are zero at the gaging site over the entire range of the daily tidal cycle.
- Overall, the models indicate that the influences of Facility withdrawals are predicted to be small, being less than 0.2 ppt more than seventy percent of the time, which is far less than the natural salinity variation resulting from the daily tidal cycle.
- Under conditions of maximum permitted withdrawals the models suggest that the greatest differences in salinities at each of the sites would be approximately 0.4 ppt. In addition, the models indicate that the predicted increases in salinity due to actual



withdrawals have exceeded 0.4 ppt approximately ten percent of the time, due to the fact that the real-time USGS gaging data is only provisional and is subject to later revision.

- The conclusions of the modeling of continuous recorder data are very similar to those previously reached by other modeling efforts. If anything, the continuous recorder based models predict slightly lower potential salinity increases due to permitted Facility withdrawals than the results of previous statistical models.
- The results of the statistical models indicate that the small salinity changes predicted due to Facility withdrawals will be extremely difficult to detect given the normal daily range of tidal salinity variation in the lower river.

### Section 6 – Evaluation of the Presence or Absence of Adverse Impacts and Appropriate Indicators

This section presents a proposed approach for determining whether the permitted surface water withdrawals have caused adverse environmental impacts in the lower Peace River Estuary, as well as a hierarchy of management actions or a proactive resource management plan that could be implemented in response to detected changes that could forewarn of or constitute adverse impacts. In addition, the salient findings of the HBMP are discussed with respect to the proposed criteria for determining adverse impacts.

- During the Water Use Permit review process, applicants must provide the District with reasonable assurance that flow rates will not deviate from the normal rate and range of fluctuation such that: 1) water quality, vegetation, and animal populations are not adversely impacted in streams and estuaries; 2) salinity distributions in tidal streams and estuaries are not significantly altered as a result of withdrawals; and 3) recreational use or aesthetic qualities of the water resource are not adversely impacted. The terms *adversely impacted* and *significantly altered* are not defined in District rules.
- The term *adverse impact* has both a technical and legal meaning. From a technical standpoint, adverse environmental impact can be defined using a wide range of metrics that quantify deviations from the pre-withdrawal salinity patterns, water quality conditions, and biological distributions and abundance. As such, technical determinations of adverse environmental impact are not absolute and are subject to interpretation. From a legal standpoint, however, the determination of adverse environmental impact, in the context of Water Use Permit compliance, is absolute and can only be made by the District Governing Board. Such a legal determination establishes a regulatory finding by the Governing Board that the District performance standards for surface water withdrawals have been violated and that the permittee must reverse or mitigate the damage. The Governing Board is, nonetheless, dependent on the findings and recommendations of District technical staff as to what constitutes an adverse environmental impact, and the Scientific Review Panel (Panel) has been established to assist District staff in this responsibility.

- The District has developed a general stepwise process for evaluating adverse environmental impacts as they apply to surface water withdrawals. Steps in this process include the monitoring of important ecological indicators; evaluating changes or trends in these indicators; determining if any such changes represent a degradation of the resource; if so, are these changes related to reductions in freshwater inflows; if so, does the relative effect of the water use permit on the change constitute an adverse environmental impact.
- Pursuant to District rules, any defensible technical criteria used to define and determine the occurrence of adverse environmental impact must take into consideration changes in: salinity; associated water quality constituents; biological communities; natural or historic (pre-withdrawal) conditions; conditions that support economically important resource-dependent activities.
- It is proposed that the term *adverse impact* be supplanted by the term *significant environmental change* with respect to the role of the Panel. As such, District staff with Panel overview is responsible for interpreting scientific data to determine if significant environmental changes have occurred as a result of the permitted withdrawals. Some environmental changes may be considered to be adverse from a technical perspective, while others may not. Furthermore, some changes may be potential harbingers of, or precursors to, greater environmental change that may later be considered to be adverse. However, only the District Governing Board can declare that a significant environmental change constitutes an adverse impact from a legal standpoint.
- A change in salinity and/or water quality attributable to freshwater withdrawals does not necessarily constitute significant environmental change unless that change is of such a magnitude and/or duration to cause a measurable and significant change in a biotic indicator. Therefore, for the limited purposes of the Peace River HBMP, it is proposed that a measurable change in salinity and/or water quality attributable to the permitted freshwater withdrawals does not necessarily constitute a *significant environmental change*.
- A working definition of the term *significant environmental change*, to be used by the Panel and the District as criteria for assessing the findings of the HBMP is proposed as follows: *a detected change, supported by statistical inference or a preponderance of evidence, in the normal or pre-withdrawal abundance, distribution, species composition, or species richness of biological communities of interest in the lower Peace River and upper Charlotte Harbor Estuary that is directly attributable to reductions in freshwater inflows caused by the permitted surface water withdrawals.*
- Changes in salinity can affect the abundance and distribution of biological resources of concern both directly through osmotic stress, and indirectly through more complex processes (e.g. hypoxia caused by density stratification). For these reasons, salinity is typically considered to be the most appropriate estuarine indicator for the development of management targets and guidelines. Therefore, it is recommended that salinity

changes and/or progressive changes in the locations of isohalines continue to be used as the primary indicators for the early detection of significant environmental changes that could lead to potential adverse environmental impacts.

- The results of the continuous recorder modeling, as well as previously summarized salinity and isohaline location modeling efforts, have all concluded that the maximum expected increases in salinity due to Facility withdrawals are expected to be difficult to actually measure within the normal daily range of tidal salinity variations during the periods when the Facility is potentially having its greatest influence. As long as salinity changes attributable to Facility withdrawals remain a fraction of the normal typical range of daily (let alone seasonal) salinity variations along the lower Peace River/upper Charlotte Harbor transect, no significant environmental changes due to increased salinity in the estuarine system are expected.
- The District should define desirable or target statistical distributions of salinity that are spatially-specific to river segments containing resources most in need of protection, and/or most susceptible to adverse impact. In addition, the District should define what constitutes an unacceptable magnitude and corresponding duration of salinity deviations from the target distribution (e.g. a 5 ppt deviation in salinity over a greater than 30-day period), as well as an unacceptable spatial extent of such salinity deviations. Once these general guidelines have been agreed upon, a hierarchy of management responses that is structured according to various possible observed outcomes can be developed.
- An eight-step sequence of management actions is recommended for implementation in response to an observed significant deviation in the statistical distribution of salinity measurements. The initial management actions should focus on determining if the observed deviation is in fact real and not a measurement error or an artifact of the sampling design. If the change is determined to be real, the next series of management actions should focus on better understanding and describing the change, and determining potential cause and affect relationships. Finally, the most intense management actions should involve regulatory enforcement actions as well as remediation and mitigation.
- It should be noted that potentially, other impacts to the estuary (such as decreased primary production) could occur apart from critical changes in salinity. If long-term monitoring concludes that such changes are occurring, and a significant amount of the change is due to withdrawals by the Facility, then a sequence of management actions should be implemented as described for salinity.
- Since its inception in 1976, the HBMP has incorporated numerous physical, chemical, and biological study elements directed toward assessing both the overall “health of the estuary” as well as direct and indirect adverse impacts potentially associated with Facility withdrawals. To date, none of the extensive HBMP analyses have found or suggested that there have been any significant long-term physical, chemical or

biological changes in the lower Peace River/upper Charlotte Harbor estuarine system resulting from either current or historic water withdrawals by the Facility.

### Section 7 – Controlled River Pump Test Design

The District, Scientific Review Panel and Authority have discussed the potential need to conduct a series of actual field “Pump Tests”. These tests would provide an additional line of evidence in support of the overall conclusions reached by existing statistical salinity models that the predicted potential changes due to the permitted withdrawal schedule range from only 0.1 to 0.5 ppt. The primary objective of this Section is to provide an overview and summary of the suggested need to conduct a Facility “Pump Test”, and present options regarding potential experimental design considerations and/or alternatives.

- Probably the most opportune time to potentially detect changes in salinities due to Facility withdrawals would coincide with periods when river flows are both above the minimum 130 cfs cutoff and not high enough to have moved the freshwater/saltwater interface too far downstream from the Facility.
- Data analysis indicates that ideal conditions for field testing salinity changes due to Facility withdrawals commonly occur. However, the specific timing is both extremely difficult to predict and conditions can change rapidly. Therefore, any Facility “Pump Test” design will need to primarily rely on utilizing automated continuous recorders.
- An initial preliminary field investigation was conducted to determine the typical extent of the tidal movement of the freshwater/saltwater interface that might be expected during actual Facility testing. The results indicated that the interface spatially moved approximately three kilometers between high and low slack tides, which was approximately an order of magnitude greater than the potential isohaline movements predicted by the various previously developed HBMP statistical lower river salinity models.
- Data from the existing USGS gage located approximately three kilometers downstream of the Facility were analyzed using a series of criteria to investigate *de facto* “Pump Tests” run as part of normal Facility operations. These analyses clearly showed that the existing statistical salinity models probably slightly overestimated the actual salinity impacts of Facility withdrawals in this reach of the river.
- It is recommended that, rather than relying on a series of short-term field tests, additional continuous recorders should be established as part of the recommended overall HBMP monitoring design modifications. These new gages, combined with the exiting two continuous recorders could then be used to conduct a series of cost-effective “Pump Tests” over an extended period of time, by employing an established series of flow, tide and wind based monitoring criteria.
- Based on recommendations of the Scientific Review Panel, preliminary baseline information was collected to assess potential Facility related changes in the longitudinal



gradient of specific ions (Ca, Mg, Na, Cl, F, Mn, Si, Fe, and SO<sub>4</sub>) along the lower river. The results indicate notable differences among the three major lower Peace River freshwater sources with regards to both the major anion and cation levels. However, there were no notable differences among the ion balances between the samples collected immediately upstream and downstream of the Facility under either high or low slack tidal conditions. The data do indicate higher concentrations of magnesium, sodium and chloride ions downstream of the freshwater/saltwater interface during both slack high and slack low tidal extremes.

### Section 8 – Proposed Monitoring Design Modifications to the Existing Long-term HBMP Elements

The primary objective of this Section was to review and summarize the overall effectiveness of the current key HBMP study elements, and consider potential program additions and/or deletions in order to improve the overall ability of the HBMP design to cost-effectively address the specific critical goals articulated in the District's specific Water Use Permit conditions

Based on the analyses presented in this *Comprehensive Summary Report* and preceding HBMP documents, a series of possible changes to the existing overall HBMP design have been suggested and recommended. The following outlines the objectives, goals and expectations of each of these potential HBMP study element additions. These elements are ranked relative to the expected comparative strengths and importance of the derived information with regard to assessing the temporal and spatial magnitudes of the impacts relative to both natural and Facility related changes in freshwater inputs. It is recommended that all new HBMP components be implemented on an interim or trial test basis and reviewed at the end of the initial five-year period.

#### Recommended Additions to the HBMP

- It is recommended that one or two additional continuous gages be established downstream of the existing USGS gage located at Peace River Heights (RK 26.7). The objective would be to obtain enhanced resolution of the relationships among freshwater flow, stage height and conductivity within the reach of the river characterized by the movement of the freshwater/saltwater interface at flows immediately above the Facility's 130 cfs withdrawal threshold.
- A new study element employing *in situ* fluorometer methodology is recommended to provide the spatial information necessary to accurately define the relative intensity and location of monthly chlorophyll *a* maxima along the lower river in order to better assess previously described seasonal interactions between freshwater flow and phytoplankton abundance.
- It is suggested that an initially limited probability-based sampling element be added to the existing overall HBMP monitoring program design. The generated data would be used to statistically describe and compare, using cumulative distribution functions, the

spatial patterns of selected water quality parameters (salinity, color, nitrate+nitrite nitrogen, and *in situ* chlorophyll *a*) on both a seasonal and annual basis.

Two additional biological study elements are also suggested, depending on the availability of contributing District funds to further assess “health of the estuary” estuarine components in conjunction with the overall HBMP design.

- A limited benthic mollusk study is proposed (depending on the availability of contributing District funds) that would utilize established rapid field assessment methodologies to determine the extent and magnitude of the relationships between preceding seasonal periods of low and high freshwater inflows and the spatial distributions of benthic mollusks within the lower Peace River estuarine system. The resulting seasonal spatial mollusk distributional patterns would be combined with other physical/chemical/biological HBMP data to statistically analyze the responses to natural variations in freshwater flow.
- Preliminary research conducted by USF has indicated that reductions in chlorophyll *a* biomass and mysid numbers during periods of low freshwater inflow reduce the river’s carrying capacities for a number of juvenile fishes. Corollary larval/juvenile studies of other southwest Florida estuaries have indicated that estuarine-dependent fishes exhibit broad salinity tolerances, and are distributed within estuarine systems based on food availability rather than distinct salinity preferences. It is suggested, dependent on availability of contributing District funds, that the plankton net sampling component of the larval fish/zooplankton community be reinstated.

### Recommended HBMP Program Reductions

- The HBMP has established an extensive long-term aerial database documenting the spatial distribution of lower Peace River vegetation extending back to 1976. It is recommended that the frequency of the aerial GIS-based vegetation monitoring be decreased from once every two years to a maintenance schedule where aerial photography is collected, analyzed and changes reported once every five years (or as needed following the occurrences of potential extreme events).
- The monitoring program includes a gage measuring only tide height near Boca Grande. Discussions with USGS staff have revealed the location of this gage is inappropriate for its intended use, and it is recommended that this gage be deleted from the array of HBMP continuous recorders.
- The first and last occurrences of indicator riparian plant species along the lower Peace River and the composition of long shore vegetation at fixed sampling sites have been surveyed at regular intervals since 1976. It is recommended that following 2004, no further routine monitoring be conducted with regard to these study elements.

## Section 9 – Diversion Schedule Assessment

The 1996 Water Use Permit renewal specifically required that the Facility diversion schedule be evaluated in conjunction with the *Comprehensive Summary Reports* to assess if the existing withdrawal schedule has and will continue to adequately protect the lower Peace River estuarine resources. The primary objectives of this section are to address both the specific Permit condition and provide additional answers to issues and questions raised by the Scientific Review Panel at the November 2002 meeting.

- The 130 cfs minimum flow criteria established by District staff in 1988 was based on plots of conductivity versus Peace River at Arcadia flow from HBMP data gathered at fixed monitoring sites located near the Facility's point of withdrawal. The 130 cfs minimum flow criteria was based on the observed inflection in the relationship between measured river conductivity and Arcadia gaged freshwater inflow. Analogous updated plots are presented in this section using period-of-record HBMP data through 2002. The presented series of figures indicate that the observed inflection point in the relationship between conductivities and Arcadia gaged freshwater flows ranges between 80 and 150 cfs over the approximate seven kilometer reach of the river characterized by the five selected HBMP fixed sampling locations. As such, the existing 130 cfs minimum threshold for withdrawals represents a fairly conservative estimate to ensure minimal impacts to the lower Peace River/upper Charlotte Harbor estuary during periods of low freshwater inflow.
- The recent Facility expansion became operational in December 2001. The Facility presently has the capacity to treat and supply up to 24 mgd and a maximum raw water river diversion capacity of 44 mgd. In order to meet future public demands the Authority has started planning for the next expansion of the Peace River Facility. Completion of the next Facility expansion under the current District Water Use Permit is currently envisioned for completion sometime during the 2007-2008 period.
- The results of the empirical modeling analyses presented in this *Comprehensive Summary Report* indicate that the maximum salinity changes predicted within the lower Peace River under the current permit withdrawal schedule are of such a magnitude that they will be extremely difficult to detect given the typical normal daily ranges of tidal and seasonal salinity variations.
- The existing withdrawal schedule elements, which combines a 130 cfs minimum Arcadia gaged flow, with the requirement that diversions cannot exceed ten percent of the previous day's gaged flow, have been and are expected to continue to be extremely effective in preventing Facility withdrawals from having any apparent adverse impacts on the lower Peace River estuarine system.

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### **Appendices**

#### **Appendix A Overview of Statistical Methods**

# 1.0 Introduction

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The purpose of this introductory section is to provide those unfamiliar with the history of the Peace River Regional Water Supply Facility and the Southwest Florida Water Management District's permit criteria, with a brief overview of the Peace River/Manasota Regional Water Supply Authority's Water Use Permit for the facility, and those conditions of the permit requiring the major study elements that have been associated with the Hydrobiological Monitoring Program (HBMP). This section also provides a brief synopsis of the 2002 *Comprehensive Summary Report* organization and summarizes the primary objectives of each of the sections.

## 1.1 History of the Peace River Facility Water Use Permit

Water Use Permit No. 2010420.02 was issued by the Southwest Florida Water Management District (District) to the Peace River/Manasota Regional Water Supply Authority (Authority) in March 1996. The permit contained specific conditions for the continuation and enhancement of the Hydrobiological Monitoring Program for the lower Peace River/upper Charlotte Harbor Estuary. The HBMP study elements specified in the 1996 permit were designed to build upon and add to the HBMP monitoring activities that have been ongoing since 1975 and predate the 1980 completion and initiation of consumptive withdrawals by the Peace River Facility (Facility).

As defined by the District permit, the primary focus and overall objective of the HBMP is to assess the following key issues.

- Monitor withdrawals from the Peace River at the Facility and evaluate data as provided by the District for the gaged tributary flows from Joshua, Horse and Shell Creeks, as well as the primary Peace River flows measured at Arcadia, and direct rainfall to the lower Peace River.
- Evaluate relationships between the ecology of the lower Peace River/upper Charlotte Harbor Estuary and freshwater inflows.
- Monitor selected water quality and biological variables in order to determine whether the ecological characteristics of the estuary related to freshwater inflows are changing over time.
- Determine the relative degree and magnitude of effects of Peace River withdrawals by the Facility on ecological changes that may be observed in the lower Peace River/upper Charlotte Harbor estuarine system.
- Evaluate whether consumptive freshwater withdrawals significantly contribute to any adverse ecological impacts to the estuary resulting from extended periods of low freshwater inflows.



- Evaluate whether the withdrawals have had any significant effects on the ecology of the estuary, based on related information such as nutrient loadings, fish abundance, or seagrass distributions data collected by other studies conducted by the District or other parties.

Overall, the primary goal of the prescribed HBMP study elements is to provide the District with sufficient information to determine whether the biological communities of the lower Peace River/upper Charlotte Harbor estuarine system have been, are being, or may be adversely impacted by permitted freshwater withdrawals by the Authority's water treatment facility. The expanding base of ecological information regarding the lower Peace River and upper Charlotte Harbor resulting from the ongoing HBMP will be further used to periodically evaluate the effectiveness of the withdrawal schedule with regard to preventing significant adverse estuarine impacts.

The permit specifies reporting requirements with respect to data collected and interpreted under the HBMP. Limited Midterm Interpretive Reports are to be submitted to the District after the third year of each five-year interval of the existing twenty-year permit, while more extensive Comprehensive Summary Reports are expected to provide inclusive analytical data analyses and summaries of HBMP study element data to date following each five-year interval.

This *2002 Comprehensive Summary Report* follows and extends the summarization and interpretation of long-term HBMP data submitted as required in the initial *2000 Midterm Interpretive Report* (finalized in 2002). The primary goals and objectives of the periodic comprehensive reports are specified in the permit as follows:

*The year five report will be a comprehensive, interpretive report that analyzes all continuing data collected to that point in time. This report will examine long-term trends for important variables and relationships between ecological characteristics and freshwater inflows. The report will analyze the status of the harbor with regard to freshwater inflows and determine if the biological health and productivity of the estuary are showing signs of stress related to natural periods of low freshwater inflow and potential associated influences of withdrawals at the Peace River Facility. The proportions of the freshwater flow budget of the estuary that is reduced by withdrawals will be determined and the relative effect of withdrawals on the ecology of the estuary will be analyzed.*

*The design of the hydrobiological monitoring program will be reviewed and re-evaluated in each year five report. Modifications to the monitoring program can be recommended in the year five reports, or at an interim time if approved by the District. The year five reports will be the primary documents for evaluating the presence or absence of adverse ecological impacts, the significance of withdrawals to such impacts, and environmental considerations for increased withdrawals from the river. The effectiveness of the withdrawal schedule for preventing adverse environmental impacts will be evaluated. Environmental factors related to expansion of the diversion and water storage facilities and the feasibility of increased water supplies will be evaluated.*

This report fulfills and expands on the minimum reporting requirements specified in the 1996 permit. In addition, as suggested by the Scientific Review Panel, this report addresses other issues related to the efficacy of the current HBMP design in meeting the stated program objectives. As such, the report recommends potential modifications to the current HBMP design, as well as evaluates other proposed additions and modification in future HBMP activities ([Section 8](#)).

### 1.2 Peace River Facility Overview

The Peace River is the largest flowing surface water body in the southern region of the Southwest Florida Water Management District. The Authority's Peace River Facility is located adjacent to a side-branch of Peace River in southwest DeSoto County. Although the system has only been operated by the Authority since 1991, the Peace River Facility has been operating and withdrawing water from the Peace River since 1980. The Facility presently has the capacity to treat and supply up to 24 million gallons per day (mgd), which is equivalent to withdrawals from the river of 37.2 cubic feet per second (cfs). The existing raw water river diversion station has four pumps having a combined maximum capacity of 44 mgd (68.0 cfs). In comparison, the long-term average annual daily total gaged river freshwater flow upstream of the Peace River Facility is approximately 840 mgd (1300 cfs). During periods of high river flow, raw river water is stored in an off-stream reservoir and any excess treated water is stored in the system's twenty-one aquifer storage/recovery (ASR) wells. Conversely, when water is unavailable from the Peace River due to the established minimum 130 cfs cutoff, water can be pumped from the raw water reservoir to the Peace River Facility for treatment, and/or previously treated water can also be recovered from the ASR system to meet the water supply demands of the Authority's service area.

An extensive Hydrobiological Monitoring Program was initially established in 1975, five years prior to completion of construction and actual Peace River Facility withdrawals, to assess the potential for harmful effects of freshwater withdrawals on the estuarine communities of the lower Peace River/upper Charlotte Harbor estuarine system. To date, the detected and predicted changes in salinity and/or spatial locations of isohalines resulting from Facility freshwater withdrawals have not been found to be associated with pronounced or systematic changes in the salinity structure, water quality, or biological integrity of the affected estuarine communities of the lower Peace River/upper Charlotte Harbor estuarine system.

### 1.3 Overview of the Peace River Facility's History and Permits

In the early 1970s, General Development Utilities (GDU) actively began to search for a major regional water supply that would support the projected population growth for a number of large communities in southwest Florida under construction or planned by its parent company, General Development Corporation (GDC). These developments included the city of North Port in Sarasota County, Port Charlotte in Charlotte County, South Gulf Cove in Charlotte County, and two large Developments of Regional Impact (Myakka Estates in Sarasota County and Villages of DeSoto in Desoto County) for which development orders were later abandoned. Projected population estimates at the time suggested that the number of new residents in these planned

communities could well exceed a quarter of a million by the year 2020. The primary goal of General Development Utilities was to establish a reliable and expandable source of potable water to supply this projected population growth. After reviewing a number of potential alternative sources, it was determined that the site of the current Peace River Facility in Desoto County provided the greatest opportunity for a sustainable water supply for the planned future population growth within the three county area.

General Development Corporation determined that an assessment study was needed to evaluate the feasibility of locating a regional water supply system on the Peace River in Desoto County near State Road No. 761, and contracted with staff of the Rosenstiel School of Marine and Atmospheric Science (University of Miami) (Michel *et al.* 1975) to assess the potential environmental impacts of projected freshwater withdrawals. The specific objectives and goals of the University of Miami study was to:

- Collect initial baseline biological and physical water quality data.
- Develop statistical relationships between freshwater flows, tides and salinity for the areas of the Peace River downstream of the proposed Peace River Facility location.
- Investigate potential interactions between salinity and biological communities in the lower Peace River.
- Develop predictive models to assess potential effects of proposed Facility freshwater withdrawals on the distribution of the downstream salinity gradient along the lower river.
- Provide initial data to form the basis for future long-term monitoring studies.

The information on biological communities and salinity/flow relationships developed during these initial field investigations by University of Miami staff were based on data collected between 1973 and 1974. During this period, Peace River flows (measured at the Arcadia gage) ranged from a low of 62 cubic feet per second (cfs) to more than 10,000 cfs. Fortuitously, the relationships between salinity and flow developed during this relatively short period of study, and subsequently used in calibrating these initial numerical models, were characteristic of the normal range of variation in flows that have subsequently occurred during both extended wet and dry periods.

A series of numerical models were then developed to predict changes in salinity at a series of points extending from near the mouth of the river upstream to the planned future site of the Peace River Facility. Changes in salinities were modeled under worst-case conditions assuming freshwater withdrawals during naturally occurring periods of low river flow. The report (Michel *et al.* 1975) concluded that “under these conditions of flow and withdrawal, biological data indicated that such slight salinity increases, above the naturally occurring values of low flow periods, should add little additional stress on the plants and animals of the study area.” This conclusion was based on what was found to be the highly dynamic natural seasonal changes in salinity within portions of the lower Peace River due to difference in flows during wet and dry

periods. The final report also strongly recommended that an extensive monitoring program be implemented to assess the validity of the predicted results.

Specific conditions of the District's initial and subsequent Consumptive Use Permits for the Peace River Facility have set forth requirements that the Regional Water Supply Authority implement a comprehensive HBMP. The District's continuing expressed purpose in mandating this requirement has been to ensure the continuing development of sufficient long-term data needed to establish and assess the responses of various physical, chemical and biological characteristics of the Charlotte Harbor Estuary to seasonal, long-term, and withdrawal related changes in Peace River flow. The long-term HBMP study elements have specifically been designed to evaluate the consequences and significance of natural changes in salinity, water quality and biological characteristics inherently associated with seasonal variations in freshwater input. In particular, a number of monitoring program elements have sought to establish the effects of natural long-term variations in river flow on the overall health of aquatic fauna and flora communities in the lower Peace River and upper Charlotte Harbor. Once having established the influences of natural variations, a corollary goal of the long-term monitoring program has been to determine if freshwater withdrawals by the Peace River Facility can be shown to have measurable impacts or result in quantifiable alterations of the biological communities of the lower Peace River/upper Charlotte Harbor Estuary.

General Development Corporation initiated a background monitoring effort in 1975, and the HBMP began in 1976 with the issuance by the District of the first Consumptive Use Permit (CUP). Construction of the Peace River Facility was completed and withdrawals began in the spring of 1980. As part of the initial construction, a small off-stream surface water reservoir was constructed and soon thereafter construction began on a series of aquifer storage recovery (ASR) wells. Adequate storage was identified as an important component early in the initial evaluation and planning for the Peace River Facility. Unlike many other water treatment facilities that utilize surface waters, there is no in-stream barrier in the Peace River to impound water during the typically dry winter and spring months. In addition, the District mandated as an initial permit condition that no withdrawals could be made below certain low river flow levels. As a result the Peace River Facility has always relied on off-stream storage to maintain supplies during the dry season and/or drought conditions.

At the time of the first permit renewal in 1982, withdrawals had only recently begun and there were only a small number of changes made to the HBMP. However, with the second permit renewal in 1988, extensive amounts of data had been collected as part of the ongoing HBMP and these data were used to make significant modifications to both the monitoring efforts and withdrawal schedule.

Prior to 1988, the regulatory limit for maximum daily withdrawals from the Peace River was 22 mgd (34.0 cfs). This permitted quantity could be withdrawn from the Peace River as long as the measured streamflow at the Arcadia gage was above the regulatory minimum flow for each of the twelve respective months. These monthly minimum flow values were calculated based on a general formula that had been established under the District's first "Water Use Rules" adopted in 1975. This formula used the previous twenty years of streamflow records to establish a separate minimum flow for each calendar month. The monthly minimum flows for the Peace River used

to establish the freshwater withdrawal schedule prior to 1988 ranged from 100 cfs in April and May to 664 cfs in September. As a result, during low flow periods in the spring, maximum daily withdrawals of 34 cfs could reduce flows (as measured at Arcadia) by as much as 25 percent on some days; while conversely, during September, no water could be taken from the river until flows exceeded 664 cfs.

When the permit was renewed in 1988, General Development Utility's consulting scientists and the District agreed that the existing withdrawal schedule caused the Peace River Facility to rely too heavily on periods of low to moderate flows. It was agreed that site-specific information should be used to establish regulatory minimum flows and daily withdrawal limits from the Peace River. Using the long-term data collected under the HBMP, statistical models were developed to analyze the location of the freshwater/saltwater boundary as a function of flow, and predicted salinity changes that might result from permitted withdrawals.

Based on these analyses, the District and GDU agreed that the withdrawal schedule should be modified. A minimum criterion was established with no withdrawals when flows at Arcadia were below 100 cfs during the spring months (March April, and May) and 130 cfs during the remainder of the year. Beyond that, withdrawals could equal up to 10 percent of the daily measured gaged flow at Arcadia, up to a maximum not to exceed 22.0 mgd (34 cfs). This schedule allowed withdrawals to more closely follow the natural variability of rainfall and flow, and established a low flow cutoff that creased low freshwater inflows to the estuary.

In 1990 GDC filed for bankruptcy protection. Charlotte County took control of GDU facilities within Charlotte County, and ownership of the Peace River Regional Water Supply Facility was transferred to the newly formed Peace River/Manasota Regional Water Supply Authority. The Authority was formed and functions through agreements made among Charlotte, Desoto, Manatee, and Sarasota counties. As owners of the Peace River Facility, the Authority soon began making plans for expansion of the treatment facilities to provide more water to the region as originally envisioned by GDU. A further goal of the Authority has been to develop a series of interconnections among the member county's water supplies to reduce potential effects of natural disasters and other interruptions in supply and allow improved regional management of water sources. The Authority recently (2002) completed an initial expansion of the Peace River Facility and its interconnection with the Carlton Water Treatment Facility in Sarasota County as the first step toward this long-term goal.

The District's 1996 twenty-year renewal of the Facility's Water Use Permit (WUP) establishes a series of maximum withdrawal quantities. This newest permit increases the minimum flows measured at the upstream Arcadia gage, under which no withdrawal can occur, to 130 cfs during all months of the year. Beyond that, withdrawals can still not exceed ten percent of the preceding day average daily Peace River at Arcadia gaged flow. Under the existing permit the Authority will withdraw, treat and store more river water under high flows. The permit limits withdrawals under high flow conditions to ten percent, not exceeding 90 mgd (139 cfs).

It should be noted that the permitted withdrawals by the Peace River Facility have always been more conservative and well below the original "safe" levels proposed by the University of Miami Study. The magnitudes of the observed and predicted changes in salinity and isohalines due to



Facility freshwater withdrawals have not indicated any systematic or long-term changes to either the physical, chemical or biological characteristics of the lower Peace River/upper Charlotte Harbor estuarine system related to the mechanisms ([Section 2.0](#)) by which Facility withdrawals might lead to significant adverse impacts ([Section 6.0](#)).

### 1.4 Ongoing HBMP Program Study Elements

An explicit element of the 1996 modified HBMP was the development of standardized station descriptors to be applied across all program elements. The “mouth” of the Peace River was defined using U. S. Geological Survey (USGS) standardized protocols as an imaginary line extending from Punta Gorda Point to Hog Island ([Figure 1.1](#)). [Table 1.1](#) provides a summary of the locations of all of the ongoing long-term fixed study elements, and provides a cross-reference to previous station identifications. The following briefly outlines each of the current HBMP study elements.

#### 1.4.1 Continuous Recorders

The primary goal of this element of the HBMP was to develop an extensive database of short-term (daily or more frequent) changes in surface and near-bottom salinity in the lower Peace River. These data, combined with corresponding gage height, freshwater flows, and withdrawals would then be used to develop detailed spatial and temporal relationships.

In 1996 the USGS installed automated 15-minute interval water level recorders at the following two locations.

1. At Boca Grande, which is the estuary’s largest opening to the Gulf of Mexico.
2. Approximately 15.5 kilometers upstream of the river’s mouth at Harbour Heights. The gaging station at Harbour Heights also measures surface and bottom conductivity at 15-minute intervals.

In November 1997 a third gage was installed at approximately River Kilometer (RK) 26.7 just downstream of the Peace River Facility. This gage also measures water level as well as surface and bottom conductivity at 15-minute intervals. The relative locations of each of these three USGS gages are depicted in [Figure 1.1](#).

#### 1.4.2 Water Chemistry and Water Column Physical Profiles

There are a number of goals associated with the study elements in which physical and chemical water quality are measured over time and track the overall “health of the estuary”. A primary goal is to collect sufficient long-term data to statistically describe spatial and seasonal variability in the water quality characteristics of the lower Peace River/upper Charlotte Harbor Estuary, and test for significant changes over time (trends). A second goal is to determine if significant relationships exist between freshwater inflows and the seasonal/spatial variability of these water quality parameters. If such relationships can be shown, then the ultimate goal is to determine the

potential magnitude of change that might result from permitted withdrawals, and compare such predictions with the range of observed natural variability.

Physical and chemical water quality parameters are measured within the lower Peace River/upper Charlotte Harbor Estuary under two different HBMP study elements.

1. During the first week of each month, water quality measurements (physical and chemical) are conducted at four “moving” salinity based isohaline locations (0, 6, 12 and 20 ppt) along a River Kilometer center-line running from the imaginary “mouth” of the Peace River upstream to above its junction with Horse Creek, and downstream to Boca Grande Pass. The relative monthly location of each sampling is based on the first occurrence of these specific isohalines ( $\pm 0.5$  ppt), with freshwater being defined as the first occurrence of conductivities less than 500  $\mu\text{S}/\text{cm}$ . The isohaline sampling effort is undertaken in conjunction with the long-term phytoplankton elements of the HBMP.
2. Approximately two weeks after the collection of the “moving” isohalines, water column physical profiles are conducted, near high tide, at sixteen locations along a transect running from just below the river’s mouth upstream to a point just above the Peace River Facility (see [Figure 1.1](#) and [Table 1.1](#)). In addition, chemical water quality samples are taken at five of these locations.

Both of these water quality HBMP study elements include physical *in situ* water column profile measurements of characteristic parameters (temperature, dissolved oxygen, pH, conductivity and salinity) at 0.5-meter intervals from the surface to the bottom. In addition both efforts measure the penetration of photosynthetically active radiation (PAR) to determine ambient extinction coefficients at specific sampling locations. Both studies also include the analyses of an extensive list of chemical water quality parameters ([Table 1.2](#)). The only difference is that at the “fixed” sampling stations both sub-surface and near-bottom samples are collected at each of the five sites, while only sub-surface water chemistry samples are taken as part of “moving” isohaline phytoplankton production study element.

### 1.4.3 HBMP Study of Long-Term Changes in Vegetation

Identification of potential adverse effects to emergent vegetation and riverine wetlands caused by freshwater withdrawals initially requires determining the magnitude of the spatial and temporal responses of these vegetative communities to the natural variation resulting from extended periods of drought and flood. This step involves developing methodologies that allow differentiating between long-term natural changes in riverine vegetative patterns and withdrawal induced changes. The vegetative monitoring elements of the HBMP provide information for determining relationships between vegetation patterns and freshwater flows by observing the positions of the freshwater and salt-tolerant plant communities, especially in the salinity transitional zone of the river. A permanent shift of more salt-tolerant plants upriver could be an indication that withdrawals were impacting the river corridor wetlands, as long as natural variability (drought) or man-made causes could be eliminated.

**Photointerpretation** - This long-term element of the HBMP initially began in 1976. Initially aerial infra-red photography was taken yearly of the vegetative communities along the lower Peace River, starting at the US 41 Bridge (River Kilometer 6.6) and extending upstream above the Peace River Facility to near the area where Horse Creek enters the river (River Kilometer 39.5). Under the 1996 HBMP permit modifications, such aerial surveys continue to be conducted at two-year intervals. All post-1996 aerial photography is taken in a corrected, GIS compatible format, thus allowing for accurate quantification of any observed changes. Photointerpretation of these images, in conjunction with field observations, will periodically be used to develop maps of the river's vegetation associations. Both qualitative and quantitative data are being used to assess potential changes associated with extended natural periods of both low and high freshwater inflows.

**First and Last Occurrence of Indicator Plant Species** – Since 1976, at approximately two year intervals, the first and last occurrence of a large number of indicator plant species have been recorded along the banks of the Peace River downstream of the Peace River Facility. As part of the vegetation study element of the HBMP, detailed maps using the standardized River Kilometer scale are made, identifying the first and last occurrences of individual and substantial populations of key indicator species. The current permit requires a detailed photographic record be compiled in conjunction with this effort. These data are used in conjunction with the aerial photography to assess the influences of long-term natural variations in river flow.

**Vegetation Transition Sites** – Under the current permit, this portion of the HBMP study extends and expands the detailed monitoring begun in 1979 of plant communities along the river's banks at fixed locations. The vegetative communities at three permanent transects sites (see [Figure 1.2](#) and [Table 1.1](#)) are sampled at two-year intervals. At each monitoring location, three transects from the top of the bank to the water's edge are surveyed. The vegetation one meter to each side of each transect is identified, and the location and density recorded. These long-term data can be used to further assess the response of the riverine vegetative communities to natural variations in freshwater flows.

### 1.4.4 Phytoplankton Studies

Sub-surface samples are being collected in conjunction with the “moving” isohaline sampling of physical and chemical water quality characteristics described above.

**Chlorophyll *a* Biomass** – Subsurface samples for the measurement of chlorophyll *a* continue to be taken with regard to the estimation of phytoplankton biomass.

**Species Composition** - Since 1989, monthly sub-surface samples have been collected, preserved and identified to the lowest practical taxon in conjunction with the chlorophyll *a* phytoplankton biomass estimates at each of the four isohaline locations.

## 1.5 Significant Changes During the Course of the HBMP

The HBMP has incorporated a wide variety of study elements since its initial inception. A summary of the time-lines for major components is presented in [Table 1.3](#). Summaries of the

findings of these investigations are contained within the 1999 report, *Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System* (PBS&J 1999). Between 1976 and 1996, the staff of EQL conducted all elements of the HBMP. Since the expansion of the permit requirements in 1996, the individual programs have been divided among a number of researchers, including:

- U.S. Geological Survey
- ASCI Laboratory
- Benchmark Laboratory
- EarthBalance (Florida Environmental)
- PBS&J
- University of South Florida
- Mote Marine Laboratory

The HBMP was not conceived to be a rigid monitoring program but rather a flexible study design that could be periodically restructured based on updated findings and identified research needs. When the first discussion began in 1975 about what might be included within such an effort, very little was known about either salinity/flow relationships, or the spatial/temporal distributions of other physical/chemical water quality parameters in the lower Peace River/upper Charlotte Harbor Estuary. Even less was known about the biological communities that studies in other estuarine systems had indicated could potentially be negatively affected by freshwater diversions. As a result, much of the effort under the initial HBMP study design was directed toward developing sufficient data to statistically describe the spatial distribution and seasonal variability of physical and chemical indicators within this estuarine system, and to determine potential relationships with naturally occurring variation in freshwater inflows. Such HBMP investigations included the collection of monthly *in situ* water column profile characteristics, and surface and near-bottom water chemistry at a wide variety of sites located throughout the estuary.

In addition, initial attempts were begun to determine if key indicator species or biological communities could be identified to assess responses to natural variations in freshwater inflows. Determining the presence of such long-term relationships was thought to be especially important because, with only a small percentage of total flow being diverted, the direct effects of withdrawals were projected to be extremely small in comparison to natural variation. These HBMP elements included: 1) the initial long-term study of the seasonal pattern of juvenile fishes in the upper harbor; 2) the studies of benthic indicator species; 3) the investigation of the seasonal distribution of sea stars in the harbor and lower river; and 4) the vegetation study of first and last occurrence of selected plant taxa along the lower Peace River.

In the 1980s, studies of phytoplankton and zooplankton community structure and production were added to the HBMP. These studies were again not intended to directly evaluate the influences of withdrawals, but rather were designed to address issues related to the “health of the estuary” and the influences of naturally occurring extended periods of drought and flood conditions. Two of the most recent short-term HBMP program elements, the benthic invertebrate studies and the fish nursery investigation, were also not designed to directly measure the

influences of withdrawal directly but rather were designed to investigate the response of biological communities to natural variations in freshwater inflows.

To date, the most promising HBMP element for detecting possible changes directly resulting from diversion by the Peace River Facility has been the installation of the two continuous conductivity recorders downstream of the point of withdrawal. Surface and bottom conductivity measurements, as well as water levels, are recorded at 15-minute intervals at these two locations. The goal of this HBMP element is to collect data of sufficient frequency to be able to detect small scale variations in salinity and develop accurate empirical statistical models capable of determining changes in salinity at these locations along the lower river resulting from freshwater withdrawals.

### 1.6 Purpose of the 2002 Comprehensive Summary Report

The current 1996 Water Use Permit requires that the Authority submit *Annual Data Reports* to the District that contain in tabular form all raw data collected during the preceding year. The permit specifies that these data reports contain limited text describing the monitoring efforts, variables measured, problems encountered and any important (or unusual) observations during the reporting period. All data collected are also submitted each year to the District in electronic form. After three years of data collection within each five-year intervals included in the twenty-year 1996 permit, the Authority submit to the District an expanded *Midterm Interpretive Report* that contains basic figures, tables, and statistical summaries of the data for the entire period of record for selected variables.

Based on discussions between Authority and District staff, the initial intent of the permit reporting requirements have been expanded to meet the needs of both parties. The annual data reports have contained graphical and statistical analyses of both current and historical data collected by the HBMP study elements. The initial *Midterm Interpretive Report* submitted in 2000 provided a series of extensive analyses beyond the original scope of the initial permit requirements.

The 1996 Water Use Permit also requires that a Comprehensive Summary Report be submitted to the District after each five-year period of data collection. This *2002 Comprehensive Summary Report* follows and extends the summarization and interpretation of long-term HBMP data submitted in the initial *2000 Midterm Interpretive Report* (finalized in 2002). The primary goals and objectives of this first comprehensive summary report under the 1996 Water Use Permit are to provide the District with sufficient analyses to:

- Determine key relationships between ecological characteristics and freshwater inflows, and whether the biological health and productivity of the estuary are showing signs of stress related to natural periods of low freshwater inflow or the potential associated influences of withdrawals by the Peace River Facility.
- Assess the presence or absence of long-term trends for important HBMP variables.



- Evaluate the design of the hydrobiological monitoring program and determine if modifications should be implemented.
- Assess the presence or absence of adverse ecological impacts and determine the influence Facility withdrawals may have contributed.
- Evaluate the environmental considerations that may be associated with additional future increased withdrawals from the river and the feasibility of increased water supplies.
- Assess and evaluate the effectiveness of the withdrawal schedule for preventing adverse environmental impacts.

### 1.7 Report Organization and Primary Objectives

The following briefly summarizes the organization and primary objectives of each of the following sections of the *2002 Comprehensive Summary Report*.

- **Section 2.0 - Conceptual Model** – The objective of this section is to provide an update of the conceptual estuarine model initially presented in the *2000 Midterm Interpretive Report*. Specifically the update addresses comments initiated by the District and Scientific Review Panel.
- **Section 3.0 - Summaries of Recent HBMP Reports and Primary Conclusions** – This section provides brief overviews of each of the major HBMP related documents that have been prepared since the 1996 permit renewal. Its primary focus is to provide quick overviews of the major conclusions of each study.
- **Section 4.0 - Status and Trends of Hydrobiological Indicators in the Lower Peace River/Upper Charlotte Harbor Estuarine System** – The purpose of this section is to provide updated trend analyses of selected hydrobiological variables. Unusual occurrences, such as periods of extended drought, are documented and compared to the long-term statistical characteristics of the resource.
- **Section 5.0 - Salinity/Flow/Withdrawal Relationships at the Continuous USGS Recorders** – In the *2000 Midterm Interpretive Report* spatial statistical models were developed as predictive tools in assessing the magnitude of potential salinity changes potentially due to both historic and maximum future freshwater withdrawals under the existing permit conditions. Similar separate salinity models have been subsequently developed at “fixed” sampling sites and for the moving isohalines for the District by Janicki Environmental (**Section 3.0**). The primary objective of this section of the report is to determine statistical relationships between flows, tide stage, and withdrawals at each of the two fixed USGS continuous gages, and compare and contrast the results with the other previous salinity models.
- **Section 6.0 - Evaluation of the Presence or Absence of Adverse Ecological Impacts and Appropriate Indicators** – This section provides a generalized discussion of the

appropriate measurable criteria that can be linked to freshwater withdrawals and provides reasonable assurance for determining the potential for, or occurrence of, adverse impacts. A corollary discussion is the development of other potential indicators linked to freshwater inflows that would provide an overall assessment of the long-term health of the lower Peace River/upper Charlotte Harbor Estuary.

- **Section 7.0 - Controlled River Pump Test Design** – The District and Authority have yet to determine if a “Pump Test” is needed to provide another line of evidence to calibrate existing lines of model evidence on the magnitude of salinity changes potentially resulting from water withdrawals. In advance of such a decision, this section of the report outlines a preliminary alternative study design using continuous recorders and discusses a number of key issues for consideration that may directly impinge upon the conclusions reached by any such investigation.
- **Section 8.0 - Proposed Monitoring Design Modifications to the Existing Long-Term HBMP Elements** – Based on the overall preceding conclusions of the report, this section extends the discussions raised in the initial *2000 Midterm Interpretive Report*, and recommend possible reductions/eliminations of specific parameters and elements within the current HBMP, as well as the potential implementation of new long-term study elements. With assistance from the Scientific Review Panel, recommended modifications to the HBMP will focus and improve the sensitivity of the HBMP to better protect the estuary.
- **Section 9.0 - Diversion Schedule Assessment** – The primary objective of this section is to address specific permit conditions. The diversion schedule is evaluated to determine if it is adequate to protect the estuary, and if not, what proposed changes to the diversion schedule would provide additional safety. The section reiterates that the observed and predicted changes in salinities and spatial isohaline distributions resulting from permitted Facility diversion have, to date, not resulted in observed significant negative adverse impacts, and are well within the temporal and spatial extent of both natural tidal and seasonal variability. The potential for projected future permitted withdrawals to adversely impact the estuary are further evaluated and discussed in this section.

### 1.8 Summary

The purpose of this introductory section is to provide readers unfamiliar with the history of the Peace River Regional Water Supply Facility and the Southwest Florida Water Management District’s permit criteria, a brief overview of the Peace River/Manasota Regional Water Supply Authority’s water use permit for the Facility and those conditions of the permit requiring the major study elements that have been associated with the twenty-seven year history of the Hydrobiological Monitoring Program (HBMP).

- The primary goal of the combined HBMP study elements is to provide the District with sufficient information to determine whether the biological communities of the lower Peace River/upper Charlotte Harbor estuarine system have been, are being, or may be

adversely impacted by permitted freshwater withdrawals by the Authority's water treatment facility.

- The continually expanding base of ecological information developed by the HBMP will also be used to periodically evaluate the effectiveness of the withdrawal schedule with regard to assuring the prevention of significant adverse estuarine impacts.
- The existing twenty-year Water Use Permit (WUP) issued by the District in 1996 sets a maximum withdrawal quantity. Under the permit, no withdrawals can occur until there is a minimum flow of 130 cfs at the Peace River at Arcadia gage, which is located approximately thirty-six miles upstream. Beyond 130 cfs, withdrawals cannot exceed 10 percent of the average daily Arcadia flow and cannot exceeding 90 mgd (139 cfs) on any day.
- The Facility presently has the capacity to supply up to 24 million gallons per day (mgd), which is equivalent to withdrawals from the river of 37.2 cubic feet per second (cfs). The existing raw water river diversion structure has four pumps with a combined maximum capacity of 44 mgd (68.0 cfs). In comparison, the long-term average annual daily total gaged river freshwater flow upstream of the Peace River Facility is approximately 840 mgd (1300 cfs).
- During periods of high river flow, raw river water is stored in the system's off-stream reservoir, while treated water is stored in the existing twenty-one aquifer storage/recovery (ASR) wells. Conversely, when water is unavailable from the Peace River, water can be pumped from the raw water reservoir to the Peace River Facility for treatment, and/or previously treated water can also be recovered from the ASR system to meet the water supply demands of the Authority's service area.

This *2002 Comprehensive Summary Report* follows and extends the summarization and interpretation of long-term HBMP data submitted in the initial *2000 Midterm Interpretive Report*. Its primary goals and objectives are to provide the District with sufficient analyses to:

- Evaluate key relationships between ecological characteristics and freshwater inflows, and determine whether the biological health and productivity of the estuary are showing signs of stress related to natural periods of low freshwater inflow or potential negative influences of Facility withdrawals.
- Assess the presence or absence of long-term trends for important HBMP variables.
- Evaluate the overall HBMP design and make recommendations regarding implementing modifications.
- Assess the presence or absence of adverse ecological impacts and determine the influence Facility withdrawals may have contributed to such impacts.

- Evaluate the environmental considerations that may be associated with additional future increased withdrawals from the river and the feasibility of increased water supplies.
- Assess and evaluate the effectiveness of the withdrawal schedule for preventing adverse environmental impacts.

None of the detailed analyses of HBMP data presented in previous HBMP reports have shown that Facility withdrawals have had, or are expected to cause, significant physical or biological adverse impacts within the lower Peace River/upper Charlotte Harbor estuarine system. A key objective of this report is to provide the District with sufficient analyses of the HBMP data to date to assure that the withdrawal schedule is providing adequate continuing resource protection.

## 2.0 Conceptual Model

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The objective of this section is to present a conceptual model developed to illustrate the relationships between river discharges, freshwater inflow, and other important water quality and biotic variables in the Peace River estuarine system. The purpose of the conceptual model is to qualitatively demonstrate the potential effects of freshwater withdrawals by the Facility on the Peace River Estuary. In addition, the conceptual model can be used to justify the selection of critical indicators for monitoring and analysis as part of the HBMP, or the discontinuation of those indicators that are too far removed from the effects of fresh water withdrawals. Relevant physical and chemical processes and interactions are discussed, and logical pathways between freshwater withdrawals and variables of concern are presented.

Although there are numerous definitions of *estuary* in literature, one of the most comprehensive and applicable definitions is that of Fairbridge (1980):

*An estuary is an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors: (a) a marine or lower estuary, in free connection with the open sea; (b) a middle estuary subject to strong salt and freshwater mixing; and (c) an upper of fluvial estuary, characterized by freshwater but subject to daily tidal action. The limits between these sectors are variable, and subject to constant changes in the river discharge.*

From this definition, it should be noted that estuaries are ecosystems that are, to a large degree, dominated by physical and chemical processes. Furthermore, freshwater inflow, is one of the most important variables determining the spatial extent and magnitude of physical and chemical interactions within an estuary. Therefore, it follows that the volume and timing of freshwater discharges from rivers are often the most critical factors driving the biological functions of estuaries. To discern the potential effects of freshwater withdrawals on an estuary it is first critical to have a general understanding of the structure and function of estuaries. The primary physical and chemical processes that drive the biological functions in the Peace River estuarine system are discussed below in relation to freshwater inflow.

### 2.1 Physical Processes

Estuaries represent regions where saltwater mixes with freshwater derived from land drainage. The term *mixing* describes the process by which a parcel of water, or a water mass, is diluted by, or redistributed within, other water masses. The mixing process is both advective and dispersive in nature. The distinction between these two terms is based on the time scale involved but is somewhat arbitrary by definition. Mixing over a longer time scale is generally referred to as *advection*, whereas *dispersion* refers to mixing over a shorter time scale. Estuarine circulation or advective mixing is generally considered most important with respect to biological interactions (Day *et al.* 1989).

The distribution of salt in an estuary is the most commonly used indicator of mixing for three reasons: 1) salinity is a conservative constituent, that is, the salt concentration is essentially not



altered by biogeochemical processes but only by mixing processes – advection and dispersion – and, to a lesser degree, by local rainfall and evaporation; 2) most estuarine salt is derived from one source, the ocean, with a very constant concentration; and 3) salinity is easy and inexpensive to determine, and does not require great geographic precision because of the large temporal and spatial salt gradients within most estuaries (Day *et al.* 1989).

Circulation, or the advective movement and exchange of water masses in an estuary, is a physical process that, in turn, affects or controls many chemical and biological processes. For example, the residence time of a particular parcel of water in an estuary is a function of the circulation patterns, and the ratio of the residence time to various biogeochemical turnover rates indicates the degree to which hydrodynamics may dominate or modify the structure and ecological functions of the estuarine system.

Estuarine circulation is normally defined as the residual or time-averaged water movement, meaning that short-term effects are averaged out. Three main driving forces are responsible for estuarine circulation, and in effect define a particular type of circulation. These include: 1) gravitational circulation; 2) tidal circulation; and 3) wind-driven circulation. Although circulation patterns in all estuaries are driven by all three forces, to some degree, most estuaries are dominated by one type of circulation.

Circulation induced by density and elevation differences between freshwater flows and saltwater is called gravitational circulation. The less dense freshwater river flow has a tendency to remain primarily in the surface layer of an estuary; whereas the more dense saltwater entering from the sea tends to remain along the bottom layers. The effect of tide and wind, however, is to mix the water column, causing a vertical exchange between fresher surface waters and more saline water from below. This mixing process explains the existence of longitudinal and vertical salinity and density gradients observed in “partially mixed” estuaries such as the Peace River Estuary. Furthermore, the pressure surfaces tilt seaward in the less dense surface layer, and landward in the saltier and more dense bottom layers, the net result of which is that the surface is characterized by net seaward flows and the bottom is characterized by net landward flows. This two-way circulation pattern has been termed “classical” estuarine gravitational circulation (Pritchard 1956), and is illustrated in [Figure 2.1](#)

In the absence of the strong density gradients caused by river discharge, circulation in most estuaries is driven primarily by tidal currents associated with the oscillatory rise and fall of water levels caused by the gravitational pull of the moon and the sun on the sea. However, in broad shallow estuaries with relatively low tidal ranges, such as the Peace River Estuary, wind may exert a dominant influence on water levels, water column mixing, and circulation over short-term time scales (e.g. days) during significant meteorological events such as tropical storms and strong winter fronts. Nonetheless, freshwater flow from the Peace River, and the associated density gradients caused by river discharge, is the primary force driving circulation in the Peace River Estuary.

## **2.2 Chemical Processes**

Since estuaries are, by definition, zones where rivers meet the sea, the nature of the chemical processes occurring in an estuary depends on the quantity and kind of materials transported by the fresh and saltwater sources, the different chemical reactions that occur when fresh and saltwater mix, and the residence time of river water in the estuary.

The composition of river water in terms of types and amounts of dissolved substances varies widely, and can even vary substantially between adjacent basins. Seawater, however, is remarkably uniform in terms of its major dissolved constituents no matter where in the world it is measured. The salts and other constituents dissolved in river water arise from three primary sources:

- The products of rock weathering.
- Precipitation-derived salts in rain originally derived from sea spray and wind eroded terrestrial dust.
- Constituents deposited upon the landscape or directly discharged to the river by man.

The most important constituents of seawater are chloride, sodium, sulfate, and magnesium. For globally averaged river water, however, the most important constituents are bicarbonate, calcium, silicon, and sulfate. The majority of the biologically important compounds entering an estuary are from riverine sources (e.g. silicon, iron, nitrogen, phosphorus, and organic compounds). However, other compounds essential to estuarine chemistry are derived predominantly from the sea. (e.g. sulfate and bicarbonate) (Day *et al.* 1989).

As river water mixes with seawater during its retention in an estuarine basin, the dissolved and particulate constituents may behave conservatively (i.e. the concentrations are changed only by dilution), or they may undergo marked transformations in response to physical, chemical, and biological processes. The distribution of salts, as measured by salinity, is the most important conservative constituent in estuarine waters. Many of the most important reactions, however, are transformations between dissolved and particulate forms. These processes include: 1) adsorption upon particle surfaces; 2) flocculation and precipitation; and 3) biotic assimilation or excretion.

Although the chemical composition of estuarine waters is clearly a major determinant of the abundance and distribution of biological communities, it should be noted that biological processes can also readily alter the chemical composition of estuarine waters. Due to the complex chemical and biological interactions that take place when river discharges mix with seawater, some chemical constituents will behave conservatively (e.g. salinity), whereas for others the estuary will serve as either a source or a sink (see [Figure 2.2](#)).

### **2.2.1 Dissolved Ions and Particulates**

In estuaries, both adsorption (the adhesion of chemical ions to particles) and flocculation (the coalescing of colloidal particles into larger aggregates) are strongly affected by salinity. Therefore, these processes tend to vary along the estuarine salinity gradient. Suspended silts, clays, and colloidal humic acids, which are transported into an estuary via river flow, tend to

carry negative electrovalent charges. In freshwater, repulsion between the negatively charged particles dominates so that stable suspensions are formed. But with increasing salinity, the interparticle forces become attractive, so that when particles collide they agglomerate into flocs that may settle to the bottom. This process of flocculation as a result of change in charge has been shown to occur between 0 and 5 ppt salinity (Duinker 1980). Between salinity values of 0 and 18 ppt phosphorus and metals such as iron, manganese, and aluminum are rapidly removed from solution. The removal appears to be closely associated with the flocculation of humic acids and hydrous iron oxides (Sholkovitch 1976).

Direct adsorption of dissolved ions contained in river discharges to estuarine sediments can be particularly important for highly charged ions such as phosphate ( $\text{PO}_4$ ). As much as 80-90 percent of the phosphate entering estuaries from river discharges can be trapped in estuarine sediments via adsorption (Jitts 1959). In the Peace River Estuary, however, far less phosphorus is removed from solution, primarily because of the naturally high concentrations in surface waters derived from phosphate rich soil deposits.

Adsorption and flocculation coupled with estuarine circulation patterns provides an important mechanism for entrapping dissolved chemical constituents, particulate organic matter, and other suspended solids contained in river discharges into estuarine sediments. Bacteria, as discussed below, subsequently utilize organic matter deposited in estuarine sediments anaerobically.

### 2.2.2 Metabolic Gases

A number of important substances in estuarine ecosystems occur primarily as gases, including carbon dioxide ( $\text{CO}_2$ ) and oxygen ( $\text{O}_2$ ). These gases are reactants and products in various key metabolic processes involving estuarine organisms.

The behavior of carbon dioxide in estuarine and other natural waters is markedly different from that of other gases in that it reacts with the water itself. In doing so, the  $\text{CO}_2$ - $\text{H}_2\text{O}$  system establishes a chemical equilibrium that in turn imparts special properties to the aquatic system. In freshwater the addition of dissolved  $\text{CO}_2$ , as from respiration, will cause the equilibrium to change with the consequence of more protons being released, and consequently the pH declines. However, in estuarine waters, with substantially greater amounts of total  $\text{CO}_2$  imported from the ocean, some of the effects of adding this acid ( $\text{CO}_2$ ) is absorbed by the formation of intermediate carbonate species ( $\text{H}_2\text{CO}_3$ ,  $\text{HCO}_3$ ), producing a reduced response in pH compared to what would occur in freshwater. This buffering effect is extremely important to the chemistry of estuaries where the pH generally ranges between 7.5 and 8.8 (in the Peace River estuary pH generally ranges between 6.7 and 8.0).

The presence of dissolved oxygen in sufficient concentrations is critical to numerous biogeochemical reactions as well as to the survival of living organisms in estuaries. Temporal and spatial variations in the concentration of oxygen and dissolved carbon dioxide are commonly used to estimate rates of biological production and consumption of organic matter in aquatic ecosystems. Because dissolved  $\text{CO}_2$  is usually not directly measured, pH is typically used as a surrogate by applying the theoretical inverse relationship between pH and  $\text{CO}_2$ . Diel changes in pH and oxygen can then be used to indicate production and consumption where daytime

increases in oxygen and pH (decreases in CO<sub>2</sub>) represent photosynthetic production, and decreases at night provide a measure of community respiration. Such estimates of production and respiration in estuaries are, however, complicated by the dynamic nature of physical circulation. In most estuaries, physical processes move water masses extensively and hence can dominate observed diel oxygen variations at any one location.

An important problem in partially-mixed estuaries such as the Peace River estuary is that bottom waters often become hypoxic or anoxic during summer conditions when high river flows establish and maintain a marked vertical density stratification. There is evidence from several estuaries that increased inputs of organic matter, either from primary production or riverine delivery of detritus, can substantially increase the magnitude, spatial extent, and temporal duration of hypoxia and anoxia resulting from increased bacterial respiration in the bottom strata water column combined with restricted vertical water column mixing (Day *et al.* 1989). Periodic hypoxia and anoxia have caused fish kills and likely affect the abundance and distribution of benthic organisms in the affected portions of the lower Peace River Estuary.

### 2.2.3 Nutrient Forms and Distribution

Among the most important chemical elements in the functioning of estuarine ecosystems are the nutrients that serve as raw materials for the primary production of organic matter within the estuary. The nutritional requirements of phytoplankton and other estuarine autotrophs include predominantly carbon, nitrogen, phosphorus, silicon, and a host of trace metals. Since carbon is extremely abundant in estuarine waters, the other macronutrients – N, P, and Si - are most likely to be found in limiting concentrations relative to algal requirements, although silicon is used only by diatoms. Because seawater is relatively nutrient depauperate, concentrations of these limiting macronutrients in estuaries are derived primarily from terrigenous runoff delivered in river discharges.

The limiting macronutrients are constantly cycling between organic and inorganic forms, as well as among different organic components in the food chain. They occur in estuarine waters in many forms that can be described primarily in terms of oxidation state, solid-liquid-gas phase, or chemical structure. The forms of nitrogen are most diverse with the oxidation state ranging from nitrate (NO<sub>3</sub>, +5) to ammonium (NH<sub>4</sub>, -3), and compounds exist in all oxidation states in between. Inorganic phosphorus most often occurs as the phosphate ion (PO<sub>4</sub>, +5). Silicon is present in estuaries in three principle forms: detrital quartz, aluminosilicate clays, and dissolved silicon in the form of silicic acid (H<sub>2</sub>SiO<sub>4</sub>, +4).

Concentrations of the limiting macronutrients in estuaries are also constantly changing in time and space due to inputs and outputs from river flows and oceanic exchange, as well as biological uptake and regeneration. Although temporal and spatial patterns in the distribution of nutrients are highly variable among estuaries, certain common patterns have been observed. For example, most estuaries exhibit a mid-summer peak in phosphate concentrations typically resulting from temperature-regulated respiratory regeneration and changes in sediment redox conditions. On the other hand most estuaries exhibit a fall and winter peak in nitrate concentrations primarily driven by high river discharges (Day *et al.* 1989).

In west central Florida estuaries, naturally occurring phosphate mineral deposits tend to maintain phosphorus concentrations above limiting levels virtually year round, whereas maximum nitrate concentrations most often occur during and following periods of prolonged high river discharges (e.g., summer wet-season). In addition to these temporal patterns, nutrient concentrations exhibit both upstream and downstream spatial gradients corresponding with river discharges as well as biological uptake and regeneration.

### 2.2.4 Nutrient Assimilation and Primary Productivity

Dissolved inorganic salts and some organic forms of N, P, and Si are incorporated into particulate organic matter primarily via the assimilative processes of autotrophic and photosynthetic organisms. In the estuarine environment competition for assimilable nutrients is intense among various phytoplankton and macrophytic species, as well as between attached algae and autotrophic bacteria. Although there is a great deal of variability in assimilative capacity (e.g. the kinetic half saturation coefficient  $K_s$ ) of the various photosynthetic taxa, this variability simply indicates that plants have adapted to the average nutrient concentrations they have encountered in their habitats. For example, phytoplankton and benthic microalgae have a distinct competitive advantage over macrophytes for assimilating nutrients in the low nutrient conditions of the water column; whereas, rooted macrophytes such as seagrasses, mangroves, and marsh plants, are able to take greater advantage of the much higher nutrient concentrations typically found in sediment interstitial waters.

Phytoplankton productivity is the major source of primary food-energy for most estuarine ecosystems throughout the world. As with all green plants, photosynthesis by phytoplankton occurs by the conversion of light energy in solar photons into biological energy via the fixation of carbon dioxide, the splitting of the water molecule, and the production of carbohydrates and oxygen. Numerous factors regulate the magnitude, seasonal pattern, and species composition of phytoplankton photosynthesis, including temperature, light, nutrients, physical transport processes, and herbivory (Boynton *et al.* 1982), all of which can be influenced by seasonal and interannual variations in river flow. Changes in river flow can influence phytoplankton production and taxonomic distribution in an estuarine system through several mechanisms, including (Day *et al.* 1989):

- Changing the input of nutrients from the watershed (e.g. river discharges) to the estuary (e.g. internal regeneration).
- Changing the rates of dilution or advection of algal cells out of the estuary (e.g., changes in residence time).
- Changing light availability through gravitational circulation and subsequent vertical stratification, and turbidity pulses.

Annual means of phytoplankton production and abundance have been significantly correlated to riverine nutrient inputs for numerous estuarine systems. The delivery of large pulses of nutrients from river discharges resulting from major rainfall events can cause significant increases in annual productivity over several years, as was observed in the Chesapeake Bay following



Hurricane Agnes in 1972 (Boynton *et al.* 1982). On the other hand, high river flows can lead to low phytoplankton abundance when growth rates are less than the rates of advective removal of cells (Day *et al.* 1989).

Variations in river flow can also control the location of the region of maximum phytoplankton production within an estuary. For example, under summer-fall low flow conditions, Filardo and Dunstan (1985) found peak chlorophyll *a* concentrations occurring in the brackish regions of the James River Estuary. However, with increasing river flow, a portion of this algal biomass was transported downstream and the highest phytoplankton growth was centered in the lower estuary with a markedly different species composition. In addition, Tyler (1986) found that during low flow periods, weaker stratification and greater mixing in the water column of the Patuxant River (Maryland) resulted in an increased dominance by diatoms, reduced zones of hypoxia, and upstream transport of several phytoplankton species typically found in the lower estuary. These trends were reversed during a period of high river flow.

### 2.2.5 Oxidation-Reduction Reactions

Much of the particulate organic matter carried to an estuary by rivers, as well as that produced *in situ* by phytoplankton, seagrasses, mangroves, and marshes, eventually comes to rest on the sediment surface. This detrital material provides the primary energy source for a diverse group of microbial organisms living on and in the sediments. Chemically, this energy source can be viewed as electron donors. The respiratory processes of these microbial organisms are essentially oxidation-reduction (redox) reactions involving a variety of oxidizing agents (electron acceptors). Such redox reactions are defined as the transfer of electrons from one material to another, and much of the energy flow in estuarine sediments is regulated by the availability of suitable electron acceptors. Oxygen gas ( $O_2$ ) is the most important electron acceptor in the biosphere, but in the low layers of the estuarine water column oxygen concentrations may be depleted especially when stratification reduces the rate of replenishment from the atmosphere above. Below the sediment surface, oxygen is rapidly depleted to the point where sulfate ( $SO_4$ ) becomes the dominant electron acceptor.

In most estuarine sediment environments both aerobic respiration and sulfate reduction generally appear to follow seasonal temperature cycles, with rates peaking during the summer months. On an average annual basis, however, it is estimated that roughly half the total respiration in most estuarine sediments is associated with sulfate reduction (Day *et al.* 1989). Microbial and sediment oxygen demand via the sulfur cycle, therefore, can influence oxygen concentrations in the overlying water, especially during periods of stratification.

Comprehensive measurements in estuarine sediments have shown that much of the energy flowing through estuarine ecosystems is modulated through anaerobic microbial metabolism. For example, measurements of sulfate reduction in a Massachusetts salt marsh suggest that an actual majority of the organic matter fixed in photosynthesis is channeled into the sulfur cycle (Howarth and Teal 1980).

### **2.2.6 Nutrient Regeneration**

As discussed above, organic matter resulting from the accumulation of dead plant and animal tissue is subjected to enzymatic decomposition by microorganisms (bacteria and fungi). Microorganisms obtain energy in this process, and the elements composing the organic matter are released in dissolved inorganic forms if the decomposition process is complete. In this case nutrients are released in the same relative proportions as the organic matter from which they were derived, and again become available for photosynthetic assimilation.

In the estuarine environment, microbially mediated decomposition occurs in relatively shallow water depths and rapid settling rates result in fairly short residence times for detrital matter in the water column. Therefore, most of the microbial regeneration of nutrients takes place on or in the sediments. In temperate estuaries seasonal patterns of benthic nutrient regeneration generally exhibit strong summer maxima, which correlate well with water temperature. The rates of nutrient regeneration measured from estuarine sediments are relatively large. From 20 to 200 percent of the respective nutrient demands for phytoplankton assimilation in overlying waters can be supplied by benthic decomposition of organic matter, indicating the large potential importance of nutrient regeneration for primary production by phytoplankton (Day *et al.* 1989).

A portion of the nutrients assimilated by phytoplankton and other microbes in estuarine waters is regenerated from particulate to dissolved form as dead algae sink through the water column. While some of this water column regeneration results from bacterial decomposition of the dead plankton cells, much of it arises from the excretion of waste products by zooplankton. Nitrogen and phosphorus are excreted in the form of ammonium and dissolved organic nitrogen compounds (urea, uric acid, and amino acids), and as phosphate and dissolved organic phosphorus. Whereas this type of planktonic nutrient regeneration may be more significant in support of “recycled” production, “new” production is related more to nutrient inputs from river discharges and benthic regeneration (Kemp and Boynton 1984).

## **2.3 The Estuarine Food Web**

The transfer of food energy from the source in plants through a series of organisms, with sequential steps of consumption from lower to higher-level animals, is referred to as a *food chain*. At each transfer a large proportion, up to 80-90 percent, of the potential energy is lost as heat. Therefore, the number of steps or links in a sequence is limited, usually to four or five. The shorter the food chain, the greater the available energy. Food chains are of two basic types: the *grazing* food chain, which, starting from a green plant base, goes to grazing herbivores and on to carnivores; and the *detritus* food chain, which goes from dead organic matter into microorganisms and then to detritus-feeding organisms (detritivores) and their predators (Odum 1971).

In complex natural communities, organisms whose food is obtained from plants by the same number of steps are said to belong to the same trophic level. Thus, green plants (producers) occupy the first trophic level, plant-eaters the second level (primary consumers), carnivores which eat herbivores the third level (secondary consumers), and secondary carnivores which eat other carnivores (tertiary consumers). The energy flow through a trophic level equals the total

assimilation at that level, which in turn, equals the production of biomass plus respiration (Odum 1971).

Food chains are not isolated sequences, but are interconnected with one another, with the interconnected chains referred to as a *food web*. The estuarine food web includes both grazing and detritus food chain components. A central concept in estuarine ecology through the 1970s was that organic detritus, derived primarily from vascular plants (e.g. mangroves), is the major food source in estuaries. A “picture model” of the estuarine food web, emphasizing the importance of detritivores, is presented in [Figure 2.3](#) (from Odum 1971). Over the past two decades, however, the measurement of naturally occurring carbon isotopes in different estuarine producers and consumers has raised questions regarding the relative importance of vascular plants, and has indicated that phytoplankton are much more important as producers in the estuarine food web than originally thought (Day *et al.* 1989). Nonetheless, the bulk of the evidence continues to support the fundamental role of the detrital food chain in estuarine trophic dynamics

### 2.4 Salinity Tolerance of Estuarine Organisms

Largely in response to widely variable water chemistry, including substantial fluctuations in salinity and dissolved oxygen concentrations, organisms that live in estuaries have evolved to tolerate the associated physiological stress. Consequently, most estuarine plants and animals can persist and flourish within a broad range of salinity. For example, black needlerush marshes (*Juncus roemerianus*) typically occur in the headwaters of tidal rivers and in the upper reaches of bays and estuaries where salinities range between 0 and 30 ppt (Eleuterius 1984). While this species may be an extreme example of hardiness, most plant species that exist in estuaries, as well as many estuarine benthic invertebrates and fishes, can tolerate similar variations in salinity, at least over short time scales (Longley 1994).

Despite their tolerance for wide fluctuations in salinity, the distribution and abundance of estuarine plants and animals still tend to segregate across a salinity gradient, indicating that most species have optimal salinity ranges with respect to environmental physiology and ecological competition. For example, although black needlerush can tolerate salinities ranging from 0 to 30 ppt over the short term, the spatial distribution of this species is generally limited to those portions of the estuary where the long-term average salinity ranges between 5 and 15 ppt (Longley 1994). The species composition of the phytoplankton community at any given point in an estuary is also strongly driven by salinity. However, because algal cells drift with water masses and have very short life cycles, phytoplankton distribution and abundance can be extremely variable both spatially and temporally. Nonetheless, general patterns do exist. In temperate and subtropical estuaries chlorophytes and dinoflagellates tend to dominate in lower salinity areas, whereas in mid to high salinity regions of the estuary diatoms tend to be most dominant (Day *et al.* 1989).

### 2.5 Development of Conceptual Model

The above sections summarize the primary physical and chemical processes, and biological interactions, common to most shallow, partially-mixed estuaries such as the Peace River Estuary. These processes and interactions have been synthesized into a “compartment model” which conceptually illustrates the structure and function of the Peace River Estuary. This conceptual model is presented in [Figure 2.4](#).

The conceptual model frames trophic energy flow within the spatial context of the river axis, and illustrates how variations in river discharge cause a shift in the horizontal (e.g. upstream and downstream) location of the estuarine mixing zone, as well as the physical, chemical and biological processes that occur in the estuary. From this model, the following general effects of variations in river discharge, whether from freshwater withdrawals or natural climatic variability, on the structure and function of the estuary can be discerned.

- Salinity is a major determining factor controlling the distribution, abundance and species composition of biotic communities in the estuary. The primary mode of action on plants and animals is through ionic and osmoregulatory adaptations to particular salinity regimes.
- The interactions between the physical, chemical and biological processes and the biological components of the estuarine ecosystem are exceedingly complex. Most of the effects of changes in freshwater flow on trophic energy flow in the estuary are mediated and modulated by numerous steps and feedback loops.
- Changes in freshwater flows generally result in a horizontal shift in the location of the estuarine mixing zone along the river axis. Greater freshwater flows cause a downstream shift, whereas lesser flows cause an upstream shift.
- The physical, chemical and biological processes, and trophic energy flows, that take place in the estuarine mixing zone (e.g. adsorption, flocculation, assimilation, and regeneration) are translocated upstream or downstream corresponding to changes in the horizontal location and areal extent of the mixing zone.
- The distribution of the planktonic (drifting) and nektonic (swimming) communities, including phytoplankton, zooplankton, and fishes, and the trophic interactions between these communities, are translocated upstream or downstream primarily in response to changes in salinity over short time scales (e.g. hours, days).
- The distribution of the benthic (bottom) communities - including rooted macrophytes, sediment microbes, and benthic invertebrates - and the trophic interactions between these communities, are translocated upstream or downstream primarily in response to changes in salinity over long time scales (e.g. weeks, months, years).
- If the magnitude and duration of variations in river discharge are large enough, spatial discontinuities can be created between the stationary and non-stationary variables of the

estuarine ecosystem. For example, if freshwater flows were to be reduced such that there was a substantial upstream shift in the long-term average position of the bottom isohalines, a discontinuity would exist between the stationary biological resources, such as rooted macrophytes and benthic invertebrates, and the overlying water column. That is, the stationary living resources would no longer be spatially distributed within the zone of their “preferred” salinity range, potentially leading to extirpations and shifts in species composition.

This latter effect can also be extended to more complex interactions between biological variables. For example, Browder and Moore (1981) have postulated that such discontinuities between young fish and macroinvertebrates, which tend to be distributed within physiologically preferred salinity ranges, and critical stationary habitats such as salt marsh vegetation can lead to reduced survival and recruitment. It should be noted, however, that such spatial discontinuities are also temporary by virtue of the fact that estuaries are dynamic, and no natural variable in the estuarine ecosystem is truly stationary or fixed in space. That is, the distributions of variables typically considered as stationary (e.g. rooted macrophyte and benthic invertebrate communities) actually shift over much longer time scales, on the order of years to decades, in response to an environmental change of sufficient magnitude and duration. Although extirpations and shifts in species composition may occur relative to a fixed location in the estuary, the ecosystem as a whole eventually reaches a new equilibrium with respect to the spatial distribution of the “stationary” variables (Flannery et al., 2002).

One significant effect of variations in river discharge that cannot be readily discerned from the conceptual model involves the physical, chemical and biological processes associated with water column stratification. As discussed above, strong gravitational circulation patterns can develop in shallow partially-mixed estuaries under high flow and low turbulence conditions, especially during summer months when water temperatures are highest. Persistent water column stratification often leads to hypoxia, and even anoxia, which can significantly alter the distribution and abundance of planktonic, nektonic and benthic plants and animals. Periodic hypoxia/anoxia has been documented in the Peace River Estuary during periods of high flow.

## 2.6 HBMP Variables and the Conceptual Model

This section provides a discussion of the sensitivity of each of the variables measured under the existing HBMP with respect to changes in freshwater flow potentially attributable to the permitted withdrawals. In addition, each variable is evaluated in the context of the conceptual model presented above.

- **Salinity** – Although it behaves as a conservative variable in estuaries, salinity is perhaps the most important variable measured under the existing HBMP. Vertical salinity gradients drive the development and maintenance of a gravitational circulation pattern, whereas the horizontal salinity gradients largely dictate the spatial distribution and abundance of estuarine plants and animals. The vertical and horizontal distribution of salinity in the estuary is controlled almost entirely by variations in freshwater flow from river discharges. Salinity is considered to be an extremely important variable in the conceptual model.



- **Chlorides** – Chlorides are the primary mineral constituent in the measurement of salinity. Therefore, chlorides behave as a conservative variable in response to variations in freshwater flow, and are essentially a surrogate or redundant measure of salinity in the estuary. Chlorides are not considered to be an important variable in the conceptual model.
- **Alkalinity** – Alkalinity is a measure of carbonate and bicarbonate concentrations, and is used as a means to calculate inorganic carbon concentrations. It is a non-conservative variable in that carbonates are transformed in the carbon cycle; however, variations in freshwater flow do affect the spatial distribution with concentrations increasing downstream. Alkalinity is not considered to be an important variable in the conceptual model.
- **Dissolved Oxygen** – Dissolved oxygen behaves as a non-conservative variable in estuaries in that concentrations are substantially affected by reactive processes (e.g. photosynthesis, respiration, redox). Variations in freshwater flow can affect dissolved oxygen concentrations both directly through advection, and indirectly through numerous mediated steps and processes including translocation of phytoplankton production, and water column stratification combined with benthic respiration. Dissolved oxygen is considered to be an extremely important variable in the conceptual model.
- **Nitrogen (total nitrogen, nitrate/nitrite, ammonia, organic nitrogen)** – Nitrogen is typically the most important macronutrient controlling algal production in most estuaries. In Florida estuaries, nitrogen is almost always the limiting nutrient due to the naturally occurring high concentrations of phosphorus. The cycling of nitrogen through the ecosystem via uptake and regeneration plays a major role in the carbon fixation and energy flow. As such, it is a non-conservative variable. Inorganic nitrogen concentrations in estuaries are derived primarily from river discharges, therefore, they are directly affected by variations in freshwater flow. Nitrogen in its various forms is considered to be an extremely important variable in the conceptual model.
- **Phosphorus (total phosphorus, orthophosphorus)** – Phosphorus is an important macronutrient essential to algal production, and as such, it is a non-conservative variable. Because phosphate concentrations in estuaries are derived primarily from river discharges, they are directly affected by variations in freshwater flow; however, phosphorus is rarely a limiting nutrient to algal growth in west central Florida estuaries due to substantial natural deposits of phosphate in the soils. Therefore, phosphorus is not considered to be an important variable in the conceptual model.
- **Silica** – Silica is a critical macronutrient for diatom production, and as such it is a non-conservative variable. HBMP data have indicated that ambient silica concentrations decline during spring diatom blooms in the lower estuary, however, there is evidence that silica concentrations are never truly limiting. Silica is delivered to the estuary primarily via river discharges; therefore, variations in freshwater flows directly affect

silica concentrations in the estuary. Therefore, silica is considered to be a useful variable in the conceptual model.

- **Carbon (dissolved organic carbon and total organic carbon)** – Both dissolved and particulate forms of organic carbon are delivered to the estuary in river discharges and are deposited via adsorption and flocculation. In addition, inorganic carbon is assimilated in the estuary via photosynthesis. Therefore, carbon compounds behave non-conservatively in the estuary. While variations in freshwater flows do affect the delivery of dissolved and total organic carbon (e.g. dissolved plus particulate forms), it is not clear whether these sources of carbon are ever limiting with respect to the detritus food chain where internal recycling of inorganic carbon may be more important. In addition, any potential impacts associated with changes in dissolved and particulate organic carbon inputs to the estuary will be mediated by numerous steps and processes. For these reasons, both dissolved and total organic carbon are not considered to be important variables in the conceptual model as it applies to the HBMP.
- **Color** – Color is caused primarily by the leaching of tannic and humic acids from tree roots and leaf litter into surface waters. Although some of the tannic and humic acids are adsorbed and flocculated out of the water column in the estuarine mixing zone, color for the most part behaves as a conservative variable. Because the source compounds that cause color in surface waters are derived primarily from runoff from forested areas, changes in freshwater flows directly affect the concentration of those compounds in the estuary. In addition, by reducing light penetration, color can significantly affect phytoplankton production even when nutrients are not limiting. Therefore, color is considered to be an important variable in the conceptual model.
- **Turbidity** – Turbidity is a measure of the sum total of all light scattering particles and dissolved compounds in the water column. As such turbidity can be affected by a variety of sources including suspended solids and phytoplankton cells. Turbidity is typically not closely related to river discharge in most Florida estuaries because river sediment loads are relatively minimal compared to local sources of turbidity in the estuary (e.g. wave turbulence, algal production, etc). Therefore, turbidity is not considered to be an important variable in the conceptual model.
- **Total Suspended Solids** – Total suspended solids include mineral and organic particulates suspended in the water column. As a component of turbidity, suspended solids also scatter and absorb light in the water column, and can periodically cause light limiting conditions for plant production (e.g. following a clay slime spill). Suspended solids are generated by watershed runoff and by internal resuspension caused by water column turbulence. Suspended solids also include phytoplankton cells as well as flocculent organics derived from chemical reactions with seawater. Although sediment loads in Florida rivers are relatively minimal under normal flow conditions, total suspended solids may be directly related to freshwater flows during high flow periods when erosion and scouring are greatest. Nonetheless, on an average annual basis, total suspended solids is not considered to be an important variable in the conceptual model as it applies to the HBMP.

- **Extinction Coefficient** – The extinction coefficient is a composite measure of the net effect of all light scattering and light absorbing particles and dissolved compounds. It is the most direct and comprehensive measure of water column light attenuation, and the attenuation of photosynthetically active radiation is a major limiting factor for algal and vascular plant production. Since light extinction in the Peace River Estuary is primarily driven by color and algal cells rather than suspended solids, the distribution of color and phytoplankton is directly related to variations in freshwater flow, and light extinction is considered to be an important variable in the conceptual model.
- **Chlorophyll *a*** – As a measure of algal biomass, chlorophyll *a* is a non-conservative variable. Variations in freshwater flow can affect chlorophyll *a* concentrations directly through advection and translocation of phytoplankton cells, and indirectly through the delivery of nutrients from river discharge which in turn fuel algal production. Because it is both directly and indirectly related to variations in freshwater flow, chlorophyll *a* is considered to be an important variable in the conceptual model.
- **Carbon Uptake** – Carbon uptake is an instantaneous measure of algal primary production (e.g. carbon fixation) and growth. Algal growth over longer time scales is assessed via other variables (e.g. chlorophyll *a*) in the HBMP, therefore, the measurement of carbon uptake is considered to be redundant with respect to the conceptual model.
- **Phytoplankton Species Composition** – The distribution and abundance of phytoplankton taxa as a function of variations in freshwater flow can be assessed in two different manners: 1) changes in taxa with respect to fixed locations along the axis of the river; and 2) changes in taxa with respect to a moving isohaline. The former can be used to detect changes in algal taxa in response to upstream or downstream movement of isohalines; whereas the latter can be used to detect changes in algal taxa in response to changes in concentrations of nutrients, color and other algal limiting constituents delivered in river discharges. This latter moving isohaline approach has been applied in the current HBMP. Phytoplankton communities are, however, not particularly good indicators of salinity change since species composition is also controlled by seasonal factors and herbivory. In terms of energy flow in the estuarine ecosystem, phytoplankton species composition may be less important than overall algal production and biomass. Therefore, phytoplankton species composition is not considered to be an important variable in the conceptual model as it applies to the HBMP.
- **Vegetation Species Upstream/Downstream Extent** – As discussed above, if freshwater flows were to be significantly reduced such that there was a substantial upstream shift in the long-term average position of river isohalines, a discontinuity would exist between the stationary biological resources, such as rooted macrophytes, and the overlying water column. That is, the stationary rooted macrophyte communities would no longer be spatially distributed within their optimal salinity range, potentially leading to shifts in species composition. Upstream and downstream changes in the distribution of key vegetation species (e.g. mangroves, bulrush) should theoretically serve as a valuable indicator of long-term salinity change in response to major

reductions in freshwater flow. Discontinuities between stationary variables such as emergent vegetation and water column isohalines may in turn significantly affect energy flow through the estuarine ecosystem. The coverage, and upstream/downstream extent, of key vegetation indicators in the Peace River estuary have been monitored as part of the HBMP for almost two decade. To date, however, no significant changes in these metrics have been observed over a wide range of long-term wet and dry conditions (e.g., multi-year droughts). From these findings it is concluded that to effect measurable changes in the upstream/downstream extent of key vegetation indicator species freshwater inflows must be reduced to a greater extent, and/or over a longer period of time, than low flows attributable to natural variability and withdrawals over the past two decades. Therefore, the upstream/downstream extent of key vegetation indicators is not considered to be an important variable in the conceptual model as it applies to the HBMP.

In conclusion, the conceptual model attempts to illustrate the important physical, chemical, and biological processes that take place in the Peace River estuarine ecosystem. In reality, the processes and interactions that take place in the estuary are far more complex than can possibly be depicted on a two-dimensional flow diagram. In defining the variables that have the highest probability of detecting hydrobiological change specifically in response to changes in freshwater flow, it is apparent that those variables that are most directly linked to flow variations, with the fewest number of mediating steps and feedback loops, will be most efficacious.

For this purpose, salinity is perhaps the most useful variable in that:

- It is a conservative variable.
- It changes directly and predictably in response to changes in freshwater flows.
- It directly affects other critical physical and chemical processes, as well as the spatial distribution of biological communities.

Other useful variables include those that are directly affected by changes in freshwater flow (e.g. nutrient concentrations, color), as well as those that are closely associated with the directly affected variables (e.g. chlorophyll *a* as measure of phytoplankton biomass).

On the other hand variables that are related to, but not directly or solely driven by, freshwater flows provide less insight into potential hydrobiological impacts of withdrawals. For example, while variations in freshwater flows do affect the delivery of total organic carbon, it is not clear whether these sources of carbon are ever limiting with respect to the detrital food chain in the Peace River Estuary where autochthonous sources may be more important. In addition, any potential impacts associated with changes in riverine organic carbon inputs to the estuary would likely be expressed in some change in biological productivity which would be mediated by a vast number steps and processes, and confounded by numerous other interacting factors. Consequently, the interpretation of data for variables that are far removed from the direct effects of withdrawals is often speculative at best.

### 2.7 Summary

The objective of this section was to present a conceptual model developed to illustrate the relationships between freshwater inflow and other important water quality and biotic variables in the Peace River estuarine system. The purpose of the conceptual model is to qualitatively demonstrate the potential effects of freshwater withdrawals by the Facility to the Peace River Estuary, and to justify the selection of critical indicators for monitoring and analysis as part of the HBMP or removal of those indicators / parameters that are too far removed from the effects of fresh water withdrawals.

1. Estuaries are ecosystems that are, to a large degree, dominated by physical and chemical processes. Furthermore, freshwater inflow, is one of the most important variables determining the spatial limits of, and the physical and chemical interactions within, an estuary. Therefore, the volume and timing of freshwater discharges from rivers is often the most critical factor driving the biological functions of estuaries.
2. Energy flow through estuarine ecosystems is extremely complex involving numerous physical, chemical and biological processes and interactions. The estuarine food includes both grazing and detritus food chain components.
3. Organisms that live in estuaries have evolved to tolerate widely variable water chemistry, including substantial fluctuations in salinity and dissolved oxygen concentrations, and the associated physiological stresses. Consequently, most estuarine plants and animals can persist and flourish within a broad range of salinity. However, despite their tolerance for wide fluctuations in salinity, the distribution and abundance of estuarine plants and animals still tend to segregate across a salinity gradient, indicating that most species have optimal salinity ranges with respect to environmental physiology and ecological competition.
4. The conceptual model of the Peace River estuarine system illustrates that variations in river discharge, whether from natural climatic variability or significant freshwater withdrawals, can affect the structure and function of the estuary in the following ways.
  - Salinity is a major determining factor controlling the distribution, abundance and species composition of all biotic communities in the estuary. The primary mode of action on plants and animals is through ionic and osmoregulatory adaptations to particular salinity regimes.
  - The interactions between the physical, chemical and biological processes and the biological components of the estuarine ecosystem are exceedingly complex. Most of the effects of changes in freshwater flows on trophic energy flow in the estuary are mediated and modulated by numerous steps and feedback loops.
  - Changes in freshwater flows generally result in a horizontal shift in the location of the estuarine mixing zone along the river axis. Greater freshwater



flows cause a downstream shift, whereas lesser flows cause and an upstream shift.

- The physical, chemical and biological processes, and trophic energy flows, that take place in the estuarine mixing zone (e.g. adsorption, flocculation, assimilation, and regeneration) are translocated upstream or downstream corresponding to changes in the horizontal location and areal extent of the mixing zone.
- The distribution of the planktonic (drifting) and nektonic (swimming) communities, including phytoplankton, zooplankton, and young fishes - and the trophic interactions between these communities - is translocated upstream or downstream primarily in response to advection and corresponding changes in salinity over short time scales (e.g. hours, days).
- The distribution of the benthic (bottom) communities - including rooted macrophytes, sediment microbes, and benthic invertebrates, and the trophic interactions between these communities, is translocated upstream or downstream primarily in response to advection and corresponding changes in salinity over longer time scales (e.g. weeks, months, years).
- If the magnitude and duration of variations in river discharge are large enough, spatial discontinuities can be created between the stationary and non-stationary variables of the estuarine ecosystem. For example, if freshwater flows are reduced such that there would be a substantial upstream shift in the long-term average position of the bottom isohalines, a discontinuity would exist between the stationary biological resources, such as rooted macrophytes and benthic invertebrates, and the overlying water column. That is, the stationary living resources would no longer be spatially distributed within the zone of their optimal salinity range, potentially leading to extirpations and shifts in species composition.
- Strong gravitational circulation patterns can develop in shallow partially-mixed estuaries under high flow and low turbulence conditions, especially during summer months when water temperatures are highest. Persistent water column stratification often leads to hypoxia, and even anoxia, which can significantly alter the distribution and abundance of planktonic, nektonic and benthic plants and animals. Periodic hypoxia/anoxia has been well documented in the Peace River Estuary during periods of high flow.

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The Southwest Florida Water Management District issued the Peace River/Manasota Regional Water Supply Authority (Authority) a Water Use Permit renewal in 1996 for the withdrawal of up to a maximum of 90 million gallons a day (mgd) at the Peace River Regional Water Supply Facility (Facility), located on the lower Peace River in DeSoto County. Since then, a series of reports have been prepared as part of the permit conditions to address concerns regarding potential impacts to the lower Peace River and Charlotte Harbor Estuary due to freshwater withdrawals by the Authority. The primary objective of this section is to provide an overview of the primary conclusions from each of the major Hydrobiological Monitoring Program (HBMP) documents (or other relevant reports) that have been prepared since the 1996 Permit renewal.

### 3.1 *Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System (PBS&J, July 1999)*

The *Summary* document presented a synopsis of previous studies relevant to freshwater flow relationships in the lower Peace River and upper Charlotte Harbor.

**Hydrology** – Gages on four tributaries to the lower Peace River measured streamflows from approximately 89 percent of the Peace River watershed. Streamflow is seasonal and typically highest during the summer wet-season. Long-term declines in streamflows during the late-1950s to the 1980s in the upper reaches of the river were attributed primarily to corresponding rainfall deficits, while streamflow increases during the 1990s corresponded with increased rainfall.

In the upper river basin, decreased flows were also attributed to aquifer drawdown and watershed alterations due to phosphate mining. However, groundwater withdrawals for the phosphate industry decreased dramatically in the mid-1970s, and some recovery in groundwater levels has occurred. In the southern portion of the watershed, declines in streamflow have not occurred since 1965 and may be a result of combined hydrogeologic and human factors.

Since 1980, withdrawals from the river by the Facility averaged 5.8 mgd (0.6 percent) of the total measured streamflow. The largest withdrawal occurred during 1996 and made up 1.42 percent of the total gaged streamflow. Facility withdrawals were limited to 10 percent of the previous day's streamflow above 100 cfs (measured at Arcadia) since 1988 and have not been permitted below 130 cfs since 1996. Records since 1965 indicated that streamflows at Arcadia fall below 130 cfs about 12.6 percent of the time. The Arcadia gage is located 17 miles upstream of the Facility and measured flow from about 58 percent of the watershed. Consequently, a ten percent reduction in withdrawals based on flows at Arcadia was a ten percent reduction in only about half the flows at the river mouth.

**Salinity** – Long-term monthly salinity data collected between 1976 and 1990 indicated brackish water upstream of the Peace River Facility intake during extended periods of drought such as occurred during 1981, 1985, and 1986. Analyses of surface and bottom salinity data at fixed

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points located along the HBMP monitoring transect from upper Charlotte Harbor to above the Facility indicated no long-term trends.

Four “moving” salinity stations (0, 6, 12, and 20 ppt) were monitored monthly in the lower river and harbor since 1983. These stations shift upstream and downstream as a result of seasonal changes in freshwater flows. Typical seasonal, within year shifts ranged from about 15 to 16 kilometers for the 0, 6, and 12 ppt salinity zones to about 27 kilometers for the 20 ppt zone. Trend analyses indicated no net upstream or downstream movements of the salinity zones. Salinity in the lower Peace River was monitored as part of the current HBMP using three methods:

- Monthly salinity measurements at fixed-stations from 1976-1990 and resumed in 1997
- Monthly measurements at four moving salinity stations
- Measurements of specific conductance at 15-minute interval at two USGS recorders

**Water Quality** – Comprehensive, long-term water quality data collections began in 1975 and indicated that water quality in the lower Peace River and upper Charlotte Harbor remained good with the exception of phosphorus. Although dissolved inorganic phosphorus concentrations were extremely high when compared with other estuaries, peak levels declined by as much as an order of magnitude since the early 1980s following the implementation of new environmental regulations that restrict phosphate mining discharges and other point source discharges. Water quality declined markedly upstream and water quality degradation was both more frequent and severe toward the headwaters of the Peace River near Lake Hancock.

While water quality in the upper harbor was good, high freshwater inflows during the summer wet-season resulted in salinity stratification in upper Charlotte Harbor. This in turn resulted in the development of large areas of hypoxia over the bottom of the harbor. Monthly water quality monitoring under the current HBMP will continue at six fixed stations located in the river from the upper harbor to upstream of the Facility and at four moving stations.

**Plankton/Phytoplankton** – Phytoplankton production and biomass in the lower Peace River were low, regardless of water temperature, during periods of low freshwater inflow. As freshwater inflows increased during the wet-season, phytoplankton production and biomass increased at intermediate salinities. The magnitude of the increase was temperature-dependent.

As river flows increased, available light in the water column decreased due to the high color of the freshwater. Consequently, light limitation quickly reduced the initial increase in productivity that resulted from nutrient increases associated with higher freshwater inflows. As a result, the highest carbon-uptake rates and chlorophyll *a* levels often occurred at 6 and 12 ppt salinity, during periods of lower freshwater inputs, higher temperatures, and higher light availability. Higher peaks in phytoplankton biomass and production often occurred in the upper harbor in the fall, at the end of the wet-season, when nitrogen levels were high and water color was declining.

Monthly measurements of phytoplankton primary production and biomass at 0, 6, 12, and 20 ppt salinity and species composition were scheduled to continue until the end of the first five years of the new monitoring program.

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**Zooplankton** – Specific taxonomic groups of zooplankton characterized each of the four salinity zones sampled, although many of the taxa were observed in large numbers over a wide range of salinities. Seasonally, fluctuations in zooplankton densities were more than four orders of magnitude within each of the four salinity zones sampled. The few patterns observed with regard to species numbers, densities, or diversity measurements among seasons or salinity zone are listed below.

- The greatest number of high salinity taxa was observed during high freshwater inflow.
- The number of taxa generally increased with increased salinity.
- Phytoplankton biomass was positively correlated with zooplankton densities for dominant zooplankton taxa within each of the salinity zones.
- The measured variation in freshwater inflows alone could not account for the variation in zooplankton species numbers, density, or diversity.

A limited number of studies of benthic invertebrate communities have included the lower Peace River and upper Charlotte Harbor. Early studies conducted as part of the HBMP were among the first to quantify the conditions, magnitude, and influences of hypoxia/anoxia in upper Charlotte Harbor resulting from density stratification due to high freshwater flows. Consequently, additional macroinvertebrate study elements were included in the 1996 permit renewal to investigate the characteristics and magnitude of changes in community structure resulting from seasonal variations in freshwater flows in the lower Peace River and to determine the value of including future benthic study elements.

**Fishes** – A long-term monitoring program was undertaken in June 1975 by Environmental Quality Laboratory (EQL) to address species composition and abundance of fish communities in upper Charlotte Harbor. The program included collection of monthly trawl samples and associated water quality data at a single sampling location, but was terminated in May 1988.

Fish assemblages occurred in distinct “wet” or “dry” season modes, which were defined as a function of freshwater inflow. No quantitative relationships were developed that were successful in identifying thresholds or critical levels of freshwater inflows, either for individual or groups of species. In addition, fish community responses to variation in freshwater inflow appeared to occur over several years.

Florida Marine Research Institute (FMRI) conducted quantitative monitoring of fish populations in Charlotte Harbor, as well as the tidal reaches of the Peace and Myakka rivers, since 1989 as a component of the Fisheries Independent Monitoring Program. To date, these data had not been analyzed with respect to changes in freshwater inflow and related variables in the lower Peace River. The sampling program is expected to continue indefinitely.

A two-year collaborative study by the SWFWMD, the Authority, University of South Florida Department of Marine Science, and FMRI to study freshwater inflow effects on habitat use by estuarine dependent fishes began in 1997. Systematic monitoring of habitat use was being used to develop regression models for evaluating impacts of proposed freshwater withdrawals and, in the process, contribute to baseline data. This study is part of the current HBMP for the Facility.

**Vegetation** – Emergent and submerged aquatic vegetation were and continue to be monitored along the lower Peace River as part of the HBMP using first and last species occurrence, changes in plant community composition at fixed transition sites, and periodic interpretation of aerial imagery. Data indicated there was little change in the upstream and downstream distributions of freshwater and estuarine plant species along the lower Peace River over the past 20 years, although there was variability between years.

Open water increased along the Peace and Myakka rivers between 1950 and 1994 by five and ten percent, respectively, with the construction of finger canals along the lower reaches of both rivers. Similarly, changes to upland, bottomland hardwood, and mixed hardwood plant communities resulted in decreases in marsh vegetation by 520 acres (22 percent) along the lower Peace River between 1950 and 1994, primarily between 1950 and 1970.

Seagrass coverage in Charlotte Harbor increased by a total of approximately six percent between 1982 and 1996, which included a loss of 600 acres from 1988 to 1992 followed by a gain of 718 acres from 1992 to 1994. Seagrass coverage in the harbor appeared to vary as a function of water temperature, salinity, and water clarity, which in turn were functions of season, rainfall, and freshwater inflow. Seagrass mapping in the harbor will continue on a bi-annual basis as part of the District's Surface Water Improvement and Management Plan.

### 3.2 2000 Midterm Interpretive Report (PBS&J, February 2002)

This report was the first *Midterm Interpretive Report* and, pursuant to the Water Use Permit conditions, examined monitoring progress and changes in streamflow, salinity, and other variables. Issues of the effectiveness of the current HBMP design in meeting program objectives were addressed and recommendations were made regarding the evaluation, modification, and potential removal of certain variables from the current HBMP design.

**Conceptual Model** – A conceptual model was developed to illustrate the qualitative relationships between river discharges or freshwater inflow and other water quality and biota variables in the lower Peace River/ upper Charlotte Harbor system. The variables that were most effective in modeling these relationships were those linked most directly to flow variations (e.g. salinity, inorganic nitrogen concentrations, color) and those that were closely associated with directly affected variables (e.g. chlorophyll *a* as a measure of nutrient assimilation). Variables related to, but not directly or solely driven by, freshwater inflows (e.g. organic carbon) were not successful in evaluating potential impacts of withdrawals.

**Rainfall** – No consistent patterns of increasing or decreasing rainfall were identified during the historic period of record (1966-1998) or during the time frame of the HBMP (1976-1998) in the upper Peace River watershed. However, more recent increases in rainfall were significant, due to unusually heavy rains of 1995, and the 1997/1998 El Niño event.

**Rainfall to Flow Relationship** – Results of “double mass” curve analyses indicated no conspicuous changes in the general relationships between flow and rainfall in the Peace River basin or its three tributary sub-basins (Horse, Joshua and Shell creeks) since 1966, although



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small differences occurred during extended wet and dry periods. However, statistically significant increases in base flow in several tributaries during normally dry periods, in combination with similar increases in mineralization, were reported. These patterns suggested that increased dry-season flows were directly linked to increased agricultural irrigation in these watersheds.

**Freshwater Inflow** – During approximately the last thirty years, gaged freshwater flows in all of the major Peace River tributaries have increased or showed no significant trends.

**Withdrawals** – Freshwater withdrawals by the Authority steadily and progressively increased in response to public demand. However, withdrawals remained extremely small when compared with the natural seasonal variability of freshwater flows and currently comprised less than one percent of total freshwater inflow at the mouth of the Peace River.

**Salinity** – No long-term trends in salinity were detected using trend analyses for the period 1976-1989 at a series of fixed stations in the lower Peace River. A single exception occurred at River Kilometer (RK) 30.4 (upstream of the point of withdrawal) and was attributed to drought conditions that followed the 1983 El Niño rather than a long-term change. Even with the effects of the 1997/1998 El Niño, the distribution pattern of median salinities along the lower Peace River during the most recent three year period (1996-1998) was not substantially different than the long-term average.

**Impact of Withdrawals on Salinity** – As part of the *Midterm Interpretive Report*, predictive statistical models were developed for the influence of withdrawals on downstream salinities. Model results indicated that, on average, past withdrawals historically resulted in maximum changes of less than 0.3 ppt along the lower Peace River between the US 41 Bridge and the Facility and that the greatest changes occurred between RK 14 and 18.

Salinity changes under the maximum permitted daily withdrawals for flows between 200 and 1,000 cfs, measured at Arcadia, were also modeled. Results predicted a maximum salinity change of < 0.5 ppt between RK 14 and 18 for flows between 400 and 1000 cfs. Arcadia flows of 200 cfs resulted in similar changes in salinity (< 0.5 ppt) farther upstream.

**Water Quality** – Surface dissolved oxygen concentrations tended to increase from the Peace River by the Facility downstream to river's mouth. On average, dissolved oxygen concentrations between the Facility and the river mouth were above the State Class III 24 hour average standard of 5.0 mg/L (the instantaneous standard is 4.0 mg/L). In comparison, near bottom dissolved oxygen concentration measurements progressively downstream indicated the seasonal occurrences of hypoxic summer events as high flows result in salinity stratification of the water column.

Except for slightly elevated levels of phosphorus and color, water quality characteristics of the lower river were similar to those of other southwest Florida rivers, despite the fact that the watershed area of the Peace River is much larger than that of most comparable rivers.

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Recent water quality measures in the lower river indicated only small differences between these and the longer-term averages (1976-1998). The most notable exception was a long-term reduction in phosphorus for the period 1984-1998 that probably reflects more stringent regulatory requirements for the treatment of point and non-point discharges in the upper Peace River basin.

**Vegetation** – Long-term comparisons of upstream and downstream occurrences of selected indicator plant species along the lower Peace River indicated that the distribution of most species changed very little over time.

**Evaluation of the Current HBMP Design** – Physical, chemical, and biological parameters that were measured as part of the existing HBMP were evaluated with respect to their continued relevance to the program objectives. Extinction coefficient and vegetation were recommended for further evaluation regarding continued inclusion in the program. The following variables were recommended for removal from the program:

- Turbidity
- Alkalinity
- Chlorides
- Ammonia/ammonium
- Total phosphorus
- Silica
- Inorganic carbon
- Dissolved organic carbon
- Total organic carbon
- Phytoplankton species counts
- Carbon uptake
- Chlorophyll *a* size fractions

The current design sampling strategies for the HBMP included: 1) fixed, continuous sampling at two stations and two depths; 2) fixed, monthly sampling at seventeen stations, and 3) “moving station” monthly sampling at four selected salinities. Under this design, the portion of the river where the relationship between river flow, withdrawals, and salinity were most pronounced, between RK 15.3 and RK 21.1, was under sampled when compared with the portion of the river above RK 21.1. Further evaluation of sampling design as it pertains to the sampling of these areas was recommended.

### 3.3 2002 HBMP Annual Data Report (PBS&J, May 2003)

This document represented the seventh *Annual Data Report* submitted under the expanded HBMP, initiated in 1996 in compliance with Water Use Permit (WUP) 2010420.03. Yearly data reports to the District provide statistical and graphical analyses of data from the current reporting period, comparisons with data from previous years, as well as long-term analyses of flow, water quality and biological measurements for the period of record. This report provided an updated analysis of pre- and post- water withdrawal data collected as part of the HBMP. Comprehensive summary report findings reported in the *2002 Annual Data Report* are listed below.

- The magnitude of withdrawals (by the Facility) was small when compared to the natural seasonal variability in the river. Current withdrawals comprised less than 1 percent of total freshwater flow at the mouth of the Peace River.

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- Based on salinity models, past withdrawals from the lower Peace River between the US 41 Bridge and the Facility resulted in maximum changes of less than 0.3 ppt. in salinities and the greatest changes occurred between RK 14 and 18.
- Model results predicted a maximum salinity change of < 0.5 ppt would occur between RK 14 and 18 when Arcadia flows were in the range of 400 to 1000 cfs. With Arcadia flows of 200 cfs, similar changes in salinity (< 0.5 ppt) were predicted farther upstream.
- Long-term comparisons of upstream and downstream occurrences of selected indicator plant species along the lower Peace River indicated that the distribution of most species changed very little over time.

**Comparisons** – Data collected during 2002 were compared with data from previous years' monitoring events. In comparisons of the 2002 data with averages of similar data collected over the preceding nineteen-year period (1983-2001), it should be noted that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and mid-2002. Comparisons of freshwater inflows, Facility withdrawals, relevant physical and biological parameters are presented in Table 3.1.

**Table 3.1**  
**Comparisons Between 2002 and Long-term Averages for the Selected Physical, Chemical, and Biological Water Quality Factors**

| <b>Factor</b>                 | <b>Summary of Comparison Results</b>                                                                                                                                                                                                                                                                                                                    |
|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Flows</b>                  | Average 2002 mean daily flow at Arcadia were more than eight times that for 2000, which was its lowest during 27 years of HBMP monitoring. Combined flows for the lower river in 2002 were roughly 150 percent of 1976-2001 flows.                                                                                                                      |
| <b>Facility Withdrawals</b>   | Facility withdrawals reached 10 percent of the gaged Arcadia flows over 130 cfs on 4.6 percent days of the year in 2002. Total withdrawals in 2002 equaled 1.93 percent of Arcadia flows and 1.04 percent of the lower Peace River flow. Maximum withdrawals increased during the second half of 2002 due to the recently completed Facility expansion. |
| <b>Temperature</b>            | Lower than average water temperatures in January 2002 were followed by average temperatures until temperatures increased following the 2002 El Niño. Summer wet-season temperatures were lower in the freshwater reaches than in the harbor.                                                                                                            |
| <b>Salinity</b>               | Record high salinities occurred during the 2000/2002 drought. Salinities at the two most upstream sampling sites were generally higher during the recent drought than during the 1984-1985 drought that followed the 1983 El Niño.                                                                                                                      |
| <b>Dissolved Oxygen</b>       | Near-bottom concentrations were low in response to summer wet-season inflows. The duration and magnitude of periods of depressed DO increased towards the river's mouth.                                                                                                                                                                                |
| <b>Water Color</b>            | Low flows during the first half of 2002 resulted in lower water color, followed by higher water color during the El Niño. Water color was higher upstream than near the mouth of the river, although color increased in the harbor during extended high flow.                                                                                           |
| <b>Extinction Coefficient</b> | Light attenuation was influenced by water color and phytoplankton biomass. Low light extinction coefficients during the first half of 2002 reflected low, long-term freshwater inflows.                                                                                                                                                                 |

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**Table 3.1**  
**Comparisons Between 2002 and Long-term Averages for the Selected Physical, Chemical, and Biological Water Quality Factors**

| Factor                                        | Summary of Comparison Results                                                                                                                                                                                                                                                   |
|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>NO<sub>2</sub>/NO<sub>3</sub> Nitrogen</b> | During 2002, average concentrations were similar or above average at monitoring stations. Inorganic nitrogen increased upstream with decreasing salinity. Ambient concentrations were typically lowest during the late spring dry season, in response to phytoplankton changes. |
| <b>Ortho-Phosphorus</b>                       | Average concentrations during 2002 were similar to long-term averages. Differences among monitored isohalines reflected dilution by seawater. Previously reported declines in concentrations prior to 1985 showed fairly consistent seasonal patterns.                          |
| <b>N to P ratios</b>                          | Long-term data indicated nitrogen was the limiting macronutrient throughout the lower Peace River and Charlotte Harbor.                                                                                                                                                         |
| <b>Silica</b>                                 | Concentrations during 2002 reflected a continued pattern of higher values at all HBMP monitoring locations, interrupted by the recent drought. Silica levels were higher at the upstream sampling sites, and showed strong seasonal patterns.                                   |
| <b>Chlorophyll a</b>                          | In general, phytoplankton association with isohalines was similar to long-term averages. However, there was a decline in chlorophyll a concentrations and blooms that commonly occurred during the late 1970s and early 80s.                                                    |

**Conclusions** – Results and analyses presented in this document indicated no substantial changes in the physical or biological characteristics based on data collected during 2002 and previous years. Limited analyses did not indicate any long-term changes resulting due to current or historic water withdrawals by the Facility. Atypical events noted during this study are listed below.

- An extended drought through the first half of 2002 resulted in near or historically high salinity levels upstream into the lower Peace River.
- The onset of a strong El Niño at the end of the year.
- A continued long-term increase in reactive silica concentrations in the lower river.

**Permanent Data** – All historic water quality and *in situ* data collected during the fixed and moving station elements of the HBMP used in the preparation of the document were provided on the 2002 Annual Data Report CD in the directory labeled 2002 Data Sets, as ASCII files and/or SAS format. Table 3.2 provides summary descriptions of the variables within each of the SAS data sets.

**Table 3.2**  
**Description of Data Sets**

| Data Set                  | Time Period | Brief Description                                                                |
|---------------------------|-------------|----------------------------------------------------------------------------------|
| <b>HBMP SAS Data Sets</b> |             |                                                                                  |
| Flwd02.sd2                | 1931-2002   | Historic daily flow data for: Peace at Arcadia; Horse Creek near Arcadia; Joshua |

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**Table 3.2**  
**Description of Data Sets**

| Data Set                                                     | Time Period | Brief Description                                                                                                                                                   |
|--------------------------------------------------------------|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                              |             | Creek near Nocatee; and Shell Creek near Punta Gorda.                                                                                                               |
| Cmov8302.sd2                                                 | 1983-2002   | Water quality and phytoplankton biomass and uptake measurements from monthly surface samples collected at each of the four moving isohalines.                       |
| Hymov02.sd2                                                  | 1983-2002   | Monthly hydrolab <i>in situ</i> water quality measurements taken at 0.5-meter intervals at each of the four moving isohalines.                                      |
| Hyfix02.sd2                                                  | 1996-2002   | Monthly <i>in situ</i> hydrolab water column profile data at 0.5 meter intervals from fixed sample locations from near the river mouth to upstream of the Facility. |
| Cfix9602.sd2                                                 | 1996-2002   | Monthly surface and bottom chemical water quality at five intervals from fixed sample locations from near the river mouth to upstream of the Facility.              |
| Efix9602.sd2                                                 | 1996-2002   | Water column extinction coefficients collected at the fixed sampling locations.                                                                                     |
| Boca02.sd2                                                   | 1996-2002   | Water level at 15-minute intervals from the continuous recording gage near Boca Grande.                                                                             |
| Ph02.sd2                                                     | 1996-2002   | Water level, surface and bottom conductivity, and temperature at 15-minute intervals from the continuous recorder near Harbor Heights (RK 15.5).                    |
| Pr02.sd2                                                     | 1997-2002   | Water level, surface and bottom conductivity, and temperature at 15-minute intervals from the continuous recorder near Peace River Heights (RK 26.7).               |
| <b>Environmental Quality Laboratory Background Data Sets</b> |             |                                                                                                                                                                     |
| Chall_2.sd2                                                  | 1976-1990   | EQL Charlotte Harbor background water chemistry data.                                                                                                               |
| Hydroall.sd2                                                 | 1976-1990   | EQL Charlotte Harbor hydrolab water column profile data.                                                                                                            |

**Problems during 2002** – Some of the problems and errors encountered during data collection for various elements of the 2002 HBMP monitoring program were related to loss of phytoplankton material due to a broken sample bottle, differences in water quality analysis methods between laboratories that invalidated comparisons, and a change in laboratories that resulted in no analysis of some samples for February and March. Also, an instrument failure resulted in the loss of some light profile measurements during the November “fixed” station monitoring, and due to instrument failures, gage height data were unavailable for the Peace River Heights location during two periods, January to March and June to September. Conductivity and temperature data for portions of these two periods were also lost for the Peace River Heights gage.

### **3.4 Morphometric Habitat Analysis of the Lower Peace River (PBS&J, January 2000)**

The goal of this effort was to develop maps and describe the river and adjacent wetland habitat along the lower Peace River. The final report was submitted to the District in January 2000. A key component of this study was the development of a standardized spatial reference system for the lower Peace River/Charlotte Harbor Estuary so that historic, recent, and ongoing HBMP



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monitoring efforts could be compared more easily. Sampling stations were previously established without a permanent reference system, and stations were located “at the mouth of the harbor near Boca Grande” and “near Horse Creek upstream of the future Water Treatment Facility.”

A standard reference centerline was established using the previously established USGS imaginary “mouth” of the Peace River as the initial zero reference point. All HBMP “fixed” monitoring locations were then designated in River Kilometers either upstream (positive) or downstream (negative) of the river mouth. All previous “moving” station locations were converted to the standardized reference system. The results were reference points for HBMP sampling stations and EQL station locations, as well as a means of referencing USGS stations.

Field measurements were made for forty-nine typical cross-sections and a morphometric analysis along segments of the lower Peace River from RK 10.0, between the I-75 and US 41 Bridge, to a location upstream of Horse Creek and the Facility. Data for each 0.5 kilometer river segment along the lower Peace River centerline were then used to develop:

- Typical river cross-section profiles along each of the 49 transect lines
- Total river segment shoreline length
- Areas of open-water within each river segment
- The volume of water in each segment
- Areas of shoreline vegetation habitat type within each river segment

Summary graphics illustrating the spatial distribution of key morphometric river characteristics and shoreline vegetation patterns along the lower Peace River were prepared and findings are listed below.

- There was a high degree of variation in morphometry among typical river cross-sections.
- The lower river had a “funnel like” shape, based on cross-sectional length and area, segment surface and bottom area, and segment volume.
- The largest areas of shallow (0 to 0.9 meters) benthic habitat occurred between RK 7 and 12.
- Shoreline habitat was abundant as a result of islands and a sinuous river bank, ranging between three and seven kilometers of shoreline per one-half kilometer distance along the centerline in many reaches of the tidal river, particularly between RK 11 and 25
- Spatial distributions of freshwater and estuarine vegetation were distinct along the lower river

### 3.5 *Regression Analysis of Salinity-Streamflow Relationships in the Lower Peace River/Upper Charlotte Harbor Estuary (Janicki Environmental, March 2002)*

This report presented salinity models for “fixed” sampling stations along the lower Peace River, and the “moving” isohaline sampling locations using HBMP data updated to 1999. This report supplemented previous analyses presented in the HBMP *Midterm Interpretive Report*, where spatial statistical models were developed as predictive tools in assessing the magnitude of potential salinity changes due to both historic and potential maximum freshwater withdrawals under the existing permit conditions along the lower Peace River and upper Charlotte Harbor Estuary.

**Salinity at “Fixed” Station Locations** – Updated models predicted salinities at seven “fixed” sampling stations along the lower Peace River, from RK 2.4 (downstream of the river mouth) to RK 25.9 (downstream of the Facility). Previous efforts relied on sub-surface and near-bottom salinity, and/or the relative locations of isohalines with respect to gaged freshwater inflows. Models developed for this report also addressed water column depths of one and two meters (where available) at the “fixed” monitoring location. Regression models were then used to predict salinities at four water column depths, at each station for:

- Twenty-one flow scenarios corresponding to percentiles for the range of flow conditions for the historic period 1981-1999.
- Three withdrawal scenarios based on daily freshwater withdrawals *minus*:
  - “no withdrawals”
  - “actual historical withdrawals”
  - “maximum theoretical withdrawals” per 1996 permit schedule.

**Location of Surface Isohalines** – Regression models were updated using data through 1999 to predict spatial locations of four near-surface monitored “moving” isohalines (0, 6, 12 and 20 ppt) relative to freshwater inflows. Isohalines were predicted under the same three withdrawal scenarios described above.

**Summary of Study Findings** – Findings of this study were comparable to previous analyses and HBMP reports. Predicted salinities under maximum permitted withdrawals differed from salinities predicted with no withdrawals by 0.1 to 0.3 ppt. Isohaline locations under maximum permitted withdrawals varied from locations predicted with no withdrawals varying by 0.1 to 0.3 kilometer.

### 3.6 *HBMP Supplemental Analysis (PBS&J, June 2002)*

Eleven supplemental analyses of HBMP data through 2001 requested by the District and completed in conjunction with supplemental analyses performed by the District are listed below.

1. Vertical bar chart of the number of samples by River Kilometer (RK) for the fixed stations only.

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2. Vertical bar chart of the number of samples in 2 km intervals for all the moving stations combined (X-axis scale of -20 to 35 RK).
3. Vertical bar charts of the distribution of four moving stations separately, all four plotted on one page using the same X-axis (scale of -20 to 35 RK).
4. Time series plots for the following variables for each fixed location station: surface and bottom salinity, surface and bottom DO, chlorophyll *a*, color, total Kjeldahl nitrogen (TKN), dissolved inorganic nitrogen (DIN), ortho-P, silica and turbidity.
5. In support of the time series plots in 4 above, produced tables that show the mean concentrations of these variables for the preceding period (1976-1990) and the recent period (1996-2001).
6. Box and whisker plots for the fixed stations for the variables mentioned above, plus total organic carbon, dissolved organic carbon, and total suspended solids.
7. Box and whisker plots for the moving stations for the variables mentioned above, plus total organic carbon, dissolved organic carbon, and total suspended solids.
8. Plots of the flow vs. concentrations of the variables listed in Table 5.19 of the *Midterm Interpretive Report*, plus TSS and chlorophyll *a*. Plots were prepared for each of the fixed location and moving stations separately. Flows were combined flows for Arcadia, Horse and Joshua Creeks for fixed stations at RK 15.5 and above and the 0 ppt isohaline. The sum of these flows plus Shell Creek was used for all other stations.
9. A correlation table of the Pearson product-moment correlations of each variable at each station with the log transformed (ln) flow. The correlation coefficient and the significance of the test were reported for each case.
10. Plots of mean and maximum daily salinity vs. date for the period of record for the two continuous recorders in the lower Peace River Estuary.
11. A plot that shows the percent of flow comprised by withdrawals each month for the period of record. The mean flow and mean withdrawal for each year/month combination were used as percent of gaged Arcadia flow and as percent of total gaged freshwater inflows to the lower Peace River.

### **3.7 Peace River Benthic Macroinvertebrate and Mollusk Indicators (Mote Marine Laboratory, July 2001)**

Mote Marine Laboratory conducted this special study element of the HBMP and a final report was submitted in April 2002. The final report incorporated the major findings and provided summaries of major considerations for any future long-term HBMP benthic sampling elements. The primary objectives of the two investigations conducted as part of this effort were to:

- Describe the distribution of major macroinvertebrate habitats and communities in the lower Peace River
- Determine whether benthic organisms and/or their community structure can be used to assess natural variations in freshwater inflows and, measure potential influences caused by the diversions of the Facility

The time period during which these benthic investigations were conducted (November 1998 - February 2000) was preceded by very wet, high flow conditions associated with the 1997/1998

El Niño and historically dry, low flow environment characterized by the following intense La Niña. During this period, the locations of measured near-surface isohalines in the estuary varied across 20 and 40 kilometers, while near-bottom salinities in the lower river ranged from freshwater conditions to more than 20 ppt.

**Benthic Macroinfauna Investigations** – The macroinfaunal study was comprised of a stratified river interval design, based on historical HBMP data for the seasonal distribution of characteristic near-bottom salinity regimes in the lower Peace River. The experimental sampling design incorporated: 1) sample collections within both intertidal and deeper areas, along four intervals of the lower river; 2) samples from three of the primary oxbow systems; and 3) samples taken near the river's mouth in an area of submerged aquatic vegetation (SAV). Samples were collected during five events (one wet and four dry periods) using cores to obtain quantitative measurements, and both artificial substrates and sweep nets for qualitative measurements. The primary findings of these investigations were summarized as follows.

- More than 60,000 animals were identified, representing 314 specific taxa. Of these, 78 taxa were observed in the core samples, while 86 taxa were found only in the sweep samples.
- During the single moderately wet sampling event, upstream benthic species diversity was lower than the other four drier sample collection periods.
- During each sampling event, relatively distinct faunal zones were observed.
- Inflection points, representing step-wise jumps in species richness, within specific regions along the lower river, were conspicuous.
- Analysis showed that the benthic communities were more longitudinally stratified during high flow periods, with the upper and lower river communities exhibiting the greatest distinctions. The middle river zones were transitional and representative of mixed faunal assemblages.
- Microcrustaceans, an important fisheries food source, were important motile components of the river fauna. Amphipods and cumaceans comprised the most abundant macroinfauna.
- Changes in distribution patterns for five polychaete species (segmented worms) and eight abundant micromollusks were distinct in relation to natural seasonal changes in salinity.

**Benthic Infauna Conclusions** – Most of the observed species survived over broad salinity ranges, and therefore generally reflect shifts among opportunistic euryhaline taxa. However, approximately 30 of the over three hundred observed species were both relatively abundant and exhibited spatial changes in response to variations in freshwater inflows. Of these, crustaceans merited consideration as potential long-term indicators because they are also important fish prey. However, measurements of changes in benthic macroinfauna community structure solely for the

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purpose of detecting potential impacts of freshwater withdrawals was not recommended due to the salinity tolerances of these taxa and the variability in tidal cycle that exceeds potential salinity changes predicted as a result of freshwater withdrawals at the Facility.

**Macromollusk Investigations** – The spatial distributions of mollusk communities sampled in the lower Peace River/upper Charlotte Harbor estuarine system reflected antecedent conditions of many weeks and/or months. Patterns of both living and dead organisms were also influenced by differential reproductive periods, larval development rates, recruitment/life history characteristics, and selective mortality to both biological and physical factors. The literature supported the use of comparisons between living and dead assemblages in interpreting historical changes in distribution patterns and indicated that taxonomic composition (species richness) was more informative than abundance or diversity/evenness indices.

Two surveys (in 1999 and 2000) of sixty-one sampling locations distributed between the river mouth and the point of confluence with Horse Creek were also conducted. The primary findings of these investigations are summarized below.

- Over 70,000 specimens, representing 32 mollusk taxa were identified.
- The introduced Asiatic clam *Corbicula* accounted for two-thirds of all individuals collected.
- *Corbicula* and another 14 taxa accounted for more than 98 percent of the samples. Most of the numerically rare taxa were observed in higher salinity reaches near the river mouth.
- Except for four taxa, the dead (relict) shell footprints differed between 1999 and 2000 samplings and may have been a result of juvenile recruitment and subsequent mortality.
- Few strong relationships were observed between salinity and macromollusk distributions, although higher richness of dead mollusks was generally associated with greater salinity variation.
- As the drought persisted and salinities increased farther upstream, spatial patterns of living mollusk species aligned with historic “footprints” of relict shells, and suggested that freshwater inflows control the long term, upstream/downstream shell patterns in the lower river.

**Macromollusks Conclusions** – Live and dead mollusks can generally be collected, identified and enumerated quickly in the field. In the lower Peace River Estuary, the overall dynamics and spatial distribution of these benthic mollusk assemblages could be understood as estuarine (salt tolerant) taxa “trying to invade” a tidal river, the upstream reaches of which had already been invaded by an exotic (*Corbicula*) freshwater taxa. Very dry periods characterized by extended periods of low freshwater inflows strongly influenced the relict “footprint” of the mollusk assemblages in the tidal river reaches. These patterns were matched by living populations only during periods of low freshwater inflows.



- Macromollusk ranges were imprecise salinity indicators *per se*, but rather were indicative of long-term, flow related changes in salinity patterns.
- Any future HBMP monitoring element should focus on no more than ten subtidal taxa, over no more than a 20-kilometer river reach, sampled once during the height of the dry season each year.

### **3.8    *An Assessment of the Effects of Fresh Water Inflow on Fish and Invertebrate Habitat Use in the Peace River and Shell Creek Estuaries (University of South Florida College of Marine Science, September 2002)***

The University of South Florida College of Marine Science conducted this special short-term, two-year study, which was jointly funded by the Authority and the District. The goal was to define seasonal and spatial patterns of fish nursery use within the lower Peace River/upper Charlotte Harbor Estuary and to determine the potential influences/relationships freshwater inflows have had on such observed patterns. Stratified estimates of the relative distribution and abundance of fishes and selected invertebrate taxa were made from two randomly selected, five minute, three-step (bottom-midwater-surface) oblique tows collected during night, with flood tide conditions using a weighted, flowmeter-equipped plankton net. Monthly samples were collected at seven zones within the lower Peace River. A comprehensive report summarizing the findings of this investigation was submitted in June 2002.

Quantitative ecological criteria were needed to establish minimum flows and levels for rivers and streams within the District, as well as for the more general purpose of improving overall management of aquatic ecosystems. As part of the approach to obtaining these criteria, the ecological relationships between freshwater inflows and downstream estuaries were assessed. A 26-month study of freshwater inflow effects on habitat use by estuarine organisms in the tidal Peace River and Shell Creek began in April 1997, using funds provided by SWFWMD and the Peace River/Manasota Regional Water Supply Authority. The general objective of the study was to identify patterns of estuarine habitat use and organism abundance under variable freshwater inflow conditions. Systematic monitoring was used to develop a predictive capability for evaluating potential impacts of proposed freshwater withdrawals and to contribute to baseline data. The predictive aspect involved development of regressions that described variation in organism distribution and abundance as a function of natural variation in inflows and salinity. These regressions can be applied to any proposed alterations of freshwater inflow or salinity that fall within the range of natural variation documented during the collection period.

For sampling purposes, the lengthwise axes of the tidal Peace River and Shell Creek were divided into seven and four zones, respectively. Monthly sampling of aquatic organisms implemented three gear types: a plankton net deployed in the channel during nighttime flood tides; seines deployed at the shoreline during the day under variable tide conditions; and trawls deployed in the channel during the day under variable tide conditions. Two plankton net tows, two seine hauls and one trawl were made each month in each zone. Salinity, water temperature, dissolved oxygen and pH measurements were taken in association with each gear deployment.

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Daily freshwater inflow estimates for the Peace/Shell Estuary were derived by summing the flows at the Shell Creek, Horse Creek, Joshua Creek, and the Peace River at Arcadia gages.

The fish assemblage sampled with plankton net gear was dominated by bay anchovy, gobies, menhaden, sand seatrout, rainwater killifish, silversides, and hogchoker. The invertebrate catch was dominated by larval crabs, arrow worms, copepods, mysids, amphipods, isopods, cumaceans, larvacean *Oikopleura dioica*, larval and juvenile bivalves, and ctenophores. Water released by the Shell Creek dam was distinctive in having large numbers of phantom midge larvae and freshwater cyclopoid copepods. Higher salinities near the mouth of the Peace River included *O. dioica*, chaetogaths, *Penilia avirostris*, the cumacean *Cyclaspis varians*, the planktonic shrimp *Lucifer faxoni*, and the copepods *Acartia tonsa* and *Labidocera aestiva*. Shoreline seine collections were dominated by the bay anchovy, menhaden, silversides, mojarra, eastern mosquitofish, several killifish, striped mullet, and hogchoker. The trawl catch from the channel was dominated by the bay anchovy, sand seatrout, southern kingfish, hogchoker, and blue crab.

A large body of descriptive habitat-use information was generated and presented in tabular form. In general, observed habitat-use patterns were consistent with findings from other tidal rivers on Florida's west coast. The three gear types documented the distributions of egg, larval, juvenile, and adult stages of estuarine-dependent, estuarine-resident, and freshwater fishes. Estuarine-dependent fishes were spawned at seaward locations and invaded tidal rivers during the late larval or early juvenile stage, whereas estuarine-resident fishes were present within tidal rivers through out their life cycles. Comparisons of life-stage-specific distributions demonstrated the ingress of estuarine-dependent fishes in the Peace River. For example, the mean salinity at capture for the bay anchovy decreased during development, starting at 22 ppt during the egg stage and decreasing from 21 to 14 ppt during various larval stages and finally to 6 ppt as the fish occupied its estuarine nursery habitat during the juvenile stage. Similar patterns of ingress were found for other estuarine-dependent species. Seine data indicated that juvenile snook, red drum, and striped mullet were common within the tidal rivers even though the eggs and larvae of these species were not. Larval ingress, as measured by age-related reduction in salinity at capture, was not as apparent in Shell Creek for two reasons: (1) larvae were relatively uncommon in Shell Creek because anchovies, seatrout, and other species that broadcast their eggs tended to spawn in the bay-like reaches of the tidal Peace River (below I-75) and not in the characteristically riverine portions of the Peace River and Shell Creek, and (2) salinities in Shell Creek were consistently low during most of the survey period, which interfered with the use of salinity-at-capture as a tracking method.

In addition to collecting the early stages of coastal fishes, the plankton net collected large numbers of freshwater and estuarine invertebrate plankton and hyperbenthos, which consisted of substrate-associated invertebrates that rise into the water column at night. These organisms were of particular interest because many serve as important prey for the estuarine-dependent fishes that seek out tidal rivers as nursery habitat. The survey data were used to develop regressions that described shifts in fish and invertebrate distribution as inflow rates and salinities change. It was found that the distributions of more than 20 types of fishes and invertebrates shifted as freshwater inflows fluctuated, moving upstream during low-inflow periods and downstream during high-inflow periods. Some species appeared to be more reluctant to change position than

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others. There was, however, no strong indication that prey distributions were offset from fish nursery habitats by this distributional response to inflow. Some predator-prey pairs appeared to move upstream and downstream in synchrony as inflows fluctuated (e.g. the sand seatrout and mysid shrimps). Another significant finding was that total numbers of some estuarine and estuarine-dependent fishes and invertebrates were reduced during low inflow periods. Regressions were developed to predict decreases in organism number as a function of freshwater inflow. Many organisms exhibited a pronounced peak in abundance several months after the end of the high inflow 1997/1998 El Niño period.

The number of fish taxa in the plankton-net catch increased during spring and decreased during fall, and was generally highest from April through October. However, the fall decrease observed for larval fishes was not observed in the seine catch because older juveniles remained in the tidal river long after larval recruitment diminished. The period from April to June appeared to have had the highest potential for impact due to the coupling of naturally low inflows with increasing nursery habitat use in the estuary. Some species, such as red drum and menhaden, spawn in fall or winter. There was, therefore, no time of year when potential for impacting economically or ecologically important species was absent.

Distribution responses to freshwater inflow were found for >20 taxa of fishes and invertebrates collected by the plankton net. Almost all taxa (94 percent) moved downstream with increasing inflow. Same day inflow and the location of a reference isohaline (7 ppt isohaline) both served as good indicators of organism position in the tidal river. Although most responses were in the same direction, the species distributions were staggered in the river, such that some were generally farther upstream than others.

Positive and negative abundance responses to freshwater inflow were documented for 18 taxa of fishes and invertebrates in the Peace River and 10 taxa in Shell Creek. Most positive responses to high inflow were found for freshwater organisms that shifted downstream during high-inflow periods, increasing their total numbers in the tidal river. Negative responses were found for high-salinity organisms that left the tidal rivers during high inflow periods. Positive responses were also found for sand seatrout and naked goby juveniles and mysids. These organisms congregate within the middle reaches of the tidal river as a characteristic part of their life histories. The positive responses by these organisms were also evident in regressions against referenced isohaline location. Most estuarine and estuarine-dependent organisms, however, appeared to have had a positive response to freshwater inflow that was delayed by 3-6 months. The very high inflows during the 1997/1998 El Niño period were followed several months later by large peaks in abundance of a diversity of estuarine and estuarine-dependent organisms. Many of these taxa had been displaced into the harbor, but later returned to the tidal river in large numbers.

Mysids were important prey for many juvenile estuarine-dependent fishes in tidal river nursery habitat. Reductions in mysid numbers during low-inflow periods likely reduced the carrying capacities of the Peace River and Shell Creek for snook, red drum, sand seatrout, spotted seatrout, and other species.

A second, potentially negative response to reduced inflows was predator-prey offset. Inflow-induced movement of keystone prey groups relative to the fixed structural habitats preferred by

certain fishes could cause prey distributions to become offset upstream or downstream of their fish predators, reducing the carrying capacity of the tidal river for these fishes. In the Peace River, mysids appeared to be frequently offset upstream of the principal juvenile red drum habitat. A more detailed analysis supported the possibility that mysids in Shell Creek were favored as an alternative food supply, causing the red drum to remain downstream of the Peace River's mysid peak. Juvenile spotted seatrout and sand seatrout were more spatially coordinated with their prey in the Peace River, and often congregated upstream of the Shell Creek confluence.

### **3.9      *An Analysis of Vegetation-Salinity Relationships in Tidal Rivers on the Coast of West Central Florida (SWFWMD, Draft 2002)***

The purpose of this study was to identify ecological relationships between plant species distributions and salinity along the tidal portions of seven rivers on the coast of west central Florida. Four northern rivers, the Withlacoochee, Crystal, Chassahowitzka, and Weekiwachee, and three southern rivers, the Little Manatee, Myakka, and Peace, were included in the study and surveys were limited to the river banks.

Four emergent herbaceous species, sawgrass (*Cladium jamaicense*), needlerush (*Juncus roemerianus*), southern cattail (*Typha domingensis*), and one tree species, sabal palm (*Sabal palmetto*), occurred along all seven rivers. A total of 118 different species were identified along the river banks of the rivers. The total number of species was similar for the Peace, Myakka, and Withlacoochee rivers and ranged from 52 to 59 difference species in more than 60 sample sites along each river. Total numbers of species in the remaining four rivers ranged from 19 on the Weekiwachee (41 sample sites) to 42 on the Chassahowitzka (84 sample sites).

There appeared to be differences in plant species distributions between the northern and the southern rivers. The red mangrove (*Rhizophora mangle*) occurred nearest to the Gulf. Saltmarsh cordgrass (*Spartina alterniflora*) was more abundant along the northern four rivers than the southern three rivers, which were characterized more by *R. mangle*. Leather fern (*Acrostichum danaefolium*) was also more apparent along the three southern rivers. Needlerush tended to occur in more saline habitats in the northern rivers and less saline habitats in southern rivers, likely a result of displacement by mangroves that were absent in the northern rivers.

Water column salinity data were collected along the length of each river to examine the distribution of plant species in relation to salinity regimes. Histograms for the median salinity value and 95<sup>th</sup> percentile (P95) salinity were graphed for each site and river for all species. Median salinity was considered the typical salinity experienced by a species population and the range in median salinities at a site was assumed to describe the normal salinity regime for that species. The P95 salinity may be ecologically important because it represents the highest salinity experienced on a regular basis.

Co-occurrence of needlerush with four other species (sawgrass, southern cattail, giant bulrush (*Scirpus californicus*), and red mangrove) along river banks was used to evaluate potential “critical positions” that could be used to indicate a change in salinity regime. Shifts in vegetation occurred from mangrove- or cordgrass-dominated shorelines to needlerush-dominated

shorelines, needlerush-dominated shorelines to mixed species, e.g. sawgrass and cattails, and from mixed species to freshwater species such as *Pontedaria cordata* (pickerel weed) and *Zizania aquatica* (wild rice). The study concluded the following findings.

- Highest mean salinities varied tremendously among several species and central tendencies were better indicators than extremes for interpretation of salinity regimes associated with plant species.
- Breakpoints in vegetation were not always clear due to narrow river bank, and vegetation landward of river bank may be more indicative of vegetation patterns associated with salinity.
- P95 values for the *Juncus/Cladium* vegetation class (16-18 ppt), median salinities for the *Juncus/Typha* class (8-10 ppt), and P95 for the *Juncus/Scirpus* class (14-16 ppt) may prove useful in detecting temporal changes in salinity regimes for rivers.

### **3.10 Development of GIS-Based Maps to Determine the Status and Trends of Oligohaline Vegetation in the Tidal Peace and Myakka Rivers (Florida Marine Research Institute, 1998)**

The objective of this study was to assess possible upstream movement of salt marshes over time as an indicator of long-term salinity changes in the Peace and Myakka rivers. Color infra-red (CIR) and black and white (B&W) aerial photography were used to classify vegetation based on species dominance and co-dominance. Field verification was conducted by boat and truck. A comprehensive plant list was compiled for the report. Spatial analysis was used to evaluate change in distribution of marshes along the rivers from 1950 to 1994.

**Aerial Photography** – Changes in vegetation must be of sufficient size (0.25 acres) and may occur over three to four years to be of sufficient size to be mapped and interpreted. Historical change analyses were difficult due to variability in photography, and post-photography field verification. Consequently, conclusions regarding species-level changes in the oligohaline marshes could not be made using the scale and resolution of available aerial photography. However, larger scale changes were apparent.

Digital imagery and larger-scale photography was recommended. Bottomland hardwoods, mixed forests, salt marsh and mangroves were readily discernible on CIR aerial photography when acquired during optimal periods (leaf-off), during which differences in vegetation communities were more conspicuous, thereby improving the accuracy of interpretations and delineations. Identifications were conducted to Florida Land Use, Cover and Forms Classification System (FLUCFCS) Level 3 classifications and Level 4 where possible.

**Historic Changes** – Vegetation transitions in the Peace and Myakka rivers were similar and marsh habitat in both rivers decreased from the 1950s to the 1990s. Almost half of the change was due to conversion of marshes to uplands. Changes after 1970 appeared smaller. Marshes along the Peace River decreased from 2,390 acres in 1950 to 1,940 acres in 1985 and to 1,870 acres in 1994, for a total decrease of 541 acres. Along the Myakka River, marshes decreased

from 1,040 in 1950 to 880 acres in 1970, to 850 acres in 1994 and amounted to a total loss of 233 acres of marshes.

Historic changes along the Peace River during the last 40 years occurred primarily in salt marshes from river mile (RM) 7 to RM 11, and in bottomland hardwoods and mixed forests between RM 13.5 and RM 16.5 prior to the 1970s. The most dramatic change was the displacement of marshes by woody vegetation during the 1950s to 1970. The minimal loss of marshes that have occurred along the Peace River since the 1970s was documented during this study. These conclusions were consistent with those made from earlier EQL studies, in which little change in vegetation was identified during a 17-year study.

Changes in vegetation distributions along the Myakka River were similar to those described for the Peace River. Changes during the past 40 years were primarily conversions to development, mangroves, and mixed hardwoods. Conversion of salt marsh to mangroves was minimal in comparison to other changes. Changes in the Myakka River appeared more gradual when compared with those for the Peace River.

### **3.11 *Peace River/Manasota Regional Surface Water Supply, Storage, and Interconnect Project. Final Environmental Impact Statement (EIS), 2003.***

This EIS was prepared to evaluate environmental impacts due to the proposed expansion of the existing Peace River Regional Water Supply Facility by the Peace River/Manasota Regional Water Supply Authority, as well as to compare and assess potential alternatives. The lead agency for the EIS was the USEPA. The purpose of the proposed project was to increase the reliable water supply to meet the growing water supply demand in the local four-county area in an environmentally acceptable manner.

The existing Facility has a treatment capability of a maximum 12 mgd. Under the proposed alternative, a maximum withdrawal of 90 mgd would be allowed, as permitted under the existing Water Use Permit. The water would be delivered to the off-stream reservoir and stored for future treatment. Following subsequent treatment, water would be distributed to water users, treated, and stored in the Aquifer Storage and Recovery (ASR) system, or some combination of these. The proposed project included the expansion of the existing Facility and the commensurate increase in the withdrawal, transport, storage, and treatment of water, as well as construction of new ASR wells and transmission facilities. Consequently, the Authority would be able to meet established 2015 water supply demands.

Initially, 20 alternatives were screened to eliminate those with engineering and/or economic constraints, and a potential seawater desalination facility was eliminated. The remaining 19 alternatives were evaluated for potentially significant environmental constraints (e.g. wetlands, protected species, critical habitat, cultural resources), and seven groundwater alternatives were subsequently eliminated. After additional analyses regarding the potential to provide an additional 20 mgd of potable water by 2015, three alternatives remained in addition to the *No Action* alternative. The four alternatives are briefly described below.



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- Peace River alternative (Preferred Alternative). Expand existing facility to accommodate large withdrawals and greater ASR capabilities.
- Shell Creek alternative. Expand the existing Shell Creek Reservoir to increase freshwater diversions, transport up to 10 mgd of raw water to the Peace River Facility via a new pipeline, and expansion of the Peace River Facility to treat additional water.
- Myakka River alternative. Diversion of water from the Myakka River for storage in a newly constructed offstream reservoir or in ASR for use during low flows periods. Requires construction of 120 mgd diversion, treatment, and storage facilities and a 1,500 acre reservoir and/or ASR facilities.
- No Action alternative. No use of federal funding to construct and implement the preferred alternative, which would be developed using other non-federal funding sources.

The alternative preferred by the EPA and the Authority was the Peace River alternative. The proposed plan would be developed in two phases and provide the means for a quality source of water during both wet and dry seasons, allowing the Authority to meet the demands of the member counties with fewer impacts than either of the other two alternatives. The document provided tables that list acres of impacts to wetlands, open water, land use and land cover categories, and habitat edges anticipated as a result of each alternative.

Based on the analysis presented in this document, the proposed project would not affect flows downstream from the intake facility during times of low flows because water would be withdrawn following District guidelines. The Facility is permitted a maximum withdrawal of 90 mgd that may not exceed 10 percent of the flows from the Peace River. The proposed project would allow this withdrawal. Water would be sent to an off-stream reservoir and treated or stored for future treatment, or stored in the ASR system. Under this alternative, the Authority would meet projected annual average water demands of 32.76 mgd by storing excess water during high flows for use during low flows. The Myakka River alternative would impact larger quantities of undeveloped land and impacts due to freshwater withdrawals would be greater. The Shell Creek alternative would require pipeline construction and the amount of terrestrial habitat impacted would be greater than that for the proposed alternative.

### 3.12 Summary

Since the 1996 Permit renewal, the Authority has prepared a series of reports designed specifically to address particular physical and biological questions and concerns related to potential impacts to the lower Peace River estuarine system from Facility freshwater withdrawals. The primary objective of this section was to provide an overview of the primary conclusions from each of the major HBMP documents (and other relevant reports) that have been prepared since the 1996 renewal.

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The following briefly reviews the previous reported major overall findings and conclusions, organized by topic, contained within the major historical HBMP related reports summarized in this section.

- **Standard Reference Center Line** – In conjunction with the *Morphometric Habitat Analysis of the Lower Peace River*, a standard reference centerline was established along the Peace River using the previously established USGS designated “mouth” of the Peace River as the initial zero reference point. The results provide reference points for HBMP sampling stations and EQL station locations, as well as a means of referencing USGS stations.
- **Rainfall** – Analyses conducted in the *2000 Midterm Interpretive Report* indicated no consistent patterns of increasing or decreasing rainfall identified over the historic period of record for which gaged daily flows were available for each of the major lower Peace River watershed tributaries (1966-1998), or during the time frame of the HBMP (1976-1998) in the upper Peace River watershed. However, more recent increases in rainfall were significant, largely due to unusually heavy rains of 1995, and the 1997/1998 El Niño event.
- **Freshwater Flows and Rainfall** – Analyses presented in the *2002 HBMP Data Report* and the *2000 Midterm Interpretive Report* of gaged freshwater flows in all of the major Peace River tributaries indicated that rates increased or remained unchanged over the past 30 years. Combined flows for the lower river in 2002 were roughly 150 percent of 1976-2001 flows. Long-term declines in stream flows during the late 1950s to the 1980s in the upper reaches of the river were attributed primarily to corresponding rainfall deficits. Similarly, increased flows during the 1990s corresponded with increased rainfall. The variables most effective in modeling freshwater flow/rainfall relationships were those linked directly to flow variations (e.g. salinity, inorganic nitrogen concentrations, color) and those closely associated with directly affected variables (e.g. chlorophyll *a* as a measure of nutrient assimilation).
- **Withdrawals** – The *2002 HBMP Data Report* indicated that withdrawals by the Facility have averaged 5.8 mgd (0.6 percent of measured flow) since 1980. Facility withdrawals reached 10 percent of the gaged Arcadia flows over 130 cfs on 4.6 percent days of the year in 2002. Total withdrawals in 2002 equaled 1.93 percent of Arcadia flows and 1.04 percent of the lower Peace River flow. Maximum withdrawals increased during the second half of 2002 due to the recently completed Facility expansion. Due to the 2000 – 2001 drought, the Facility did not withdraw any water from the Peace River for 248 days during the 2000, and relied solely on stored reserves another 219 days during 2001.
- **Salinity** – The *2000 Midterm Interpretive Report* and *2002 HBMP Data Report* reported that record high salinities occurred in the river and harbor during the 2000/2002 droughts. No long-term salinity trends were detected for the period 1976-1989 and low salinities upstream of the Facility were attributed to drought conditions. No net upstream or downstream movement of salinity zones was detected. Typical

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seasonal (within-year) shifts are 15 to 16 km for the 0, 6, and 12 ppt zones to about 27 km for the 20 ppt zone.

- **Impact of Withdrawals on Salinity** – Model results presented in the *2000 Midterm Interpretive Report* indicated maximum salinity changes of less than 0.3 ppt along the lower river between the US 41 Bridge and the Facility due to past withdrawals. A maximum change of < 0.5 ppt between RK 14 and 18 was predicted to occur when Arcadia flows were in the range of 400 to 1000 cfs and farther upstream at 200 cfs. Updated models predicted changes of 0.1 to 0.3 ppt and movement of isohaline by 0.1 to 0.3 km at maximum permitted withdrawals.
- **Water Quality** – The *2000 Midterm Interpretive Report* indicated that except for slightly elevated levels of phosphorus and color, water quality in the lower Peace River was similar to that of other southwest Florida rivers. Phosphorus levels in the lower Peace River/upper Charlotte Harbor estuarine system showed major declines between 1976 and 1985. However, since that time concentrations have been fairly consistent, showing distinct flow-related seasonal patterns. Other studies have historically indicated that water quality degradation to be greater upstream, toward Lake Hancock. The *2002 HBMP Data Report* indicated that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and mid-2002.
- **Plankton/Phytoplankton** – The *Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System* and *2000 Midterm Interpretive Report* indicated that generally there were seasonally distinct phytoplankton assemblages association with each of the four monitored HBMP isohalines. Time series analyzes indicated declines in chlorophyll *a* concentrations and frequency of phytoplankton blooms that commonly occurred during the late 1970s and early 80s in the lower river. Phytoplankton production and biomass in the lower Peace River were low during low freshwater inflow, regardless of water temperature, but increased at intermediate salinities with wet-season flows. The magnitude of increases was temperature-dependent. Higher peaks in production often occurred in the upper harbor at the end of the wet-season, commensurate with high nitrogen and lower water color.
- **Zooplankton** – HBMP isohaline sampling based studies summarized in the *Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System* have indicated that specific zooplankton taxa occurred in each salinity zone, although many were numerous over a wide salinity range, and the most taxa were observed during high freshwater inflows and higher salinities. Freshwater flows alone did not account for variation in species numbers, density, or diversity. Phytoplankton biomass was positively correlated with dominant zooplankton densities in each salinity zone.
- **Benthic Macroinfauna Investigations** – Measuring changes in benthic macroinfauna community structure solely for detecting potential impacts of freshwater withdrawals

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was not recommended in the *Peace River Benthic Macroinvertebrate and Mollusk Indicators* study due to: 1) salinity tolerances of these taxa; and 2) variability in tidal cycle that exceeds predicted salinity changes due to freshwater withdrawals. About 30 of over 300 observed species were relatively abundant and changes in distributions corresponded to freshwater inflows. Changes in benthic communities were more spatially stratified along the river transect during high flows, although differences were greater in upper and lower reaches of the river when compared with middle reaches.

- **Mollusk Investigations** – The *Peace River Benthic Macroinvertebrate and Mollusk Indicators* study found that *Corbicula* and another 14 taxa made up more than 98 percent of the samples collected. Most rare taxa occurred in higher salinity reaches. In the lower Peace River, the pattern was one of estuarine taxa invading the tidal river, while *Corbicula* already invaded the upstream reaches. Living populations matched relict mollusk assemblages only during low freshwater inflows. Macromollusk ranges were imprecise salinity indicators *per se*, but rather were indicative of long-term, flow related changes in salinity patterns.
- **Fishes** – The *Assessment of the Effects of Fresh Water Inflow on Fish and Invertebrate Habitat Use in the Peace River and Shell Creek Estuaries* found that habitat-use patterns were generally consistent with those of other tidal rivers along the west coast of Florida. Comparisons of life-stage-specific distributions demonstrated the ingress of estuarine-dependent fishes in the river, however, thresholds or critical freshwater flows for individual or groups of species were not identified. Fish assemblages had distinct “wet” or “dry” season distributions and more than 20 types of fishes and invertebrates moved upstream during low-inflow periods and downstream during high-inflow periods. Some organisms decreased during low inflow periods and many exhibited abundance peaks several months after the high flow 1997-98 El Nino period. There was no strong indication that prey distributions were offset from nursery habitats by responses to changes in flows.
- **Vegetation** – The *Development of GIS-Based Maps to Determine the Status and Trends of Oligohaline Vegetation in the Tidal Peace and Myakka Rivers* conducted for the District by FMRI indicated that overall there had been little change in the upstream and downstream distributions of freshwater and estuarine plant species over the past 20 years, although some variability had occurred between years. The extent of seagrasses in the harbor increased by approximately six percent between 1982 and 1996 and was influenced by water temperature, salinity, and water clarity. Co-occurrence of needlerush with other species may be useful in evaluating changes in salinity regime, although breaks in vegetation distributions were often unclear and mean salinities in communities varied tremendously. Historic aerial photography indicated decreases in salt marshes of 541 acres: from 2,390 acres in 1950 to 1,940 acres in 1985 and to 1,870 acres in 1994. Changes after 1970 were less extensive and were consistent with results from other HBMP studies that indicated little change in vegetation along the Peace River since 1970.

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- **Expansion of the Facility** – The *Peace River/Manasota Regional Surface Water Supply, Storage, and Interconnect Project. Final Environmental Impact Statement* was prepared to disclose environmental impacts due to the proposed expansion of the existing Facility by the Authority (2003). As part of the EIS, nineteen alternatives were evaluated for potentially significant environmental constraints. Based on the analysis presented in this document, the proposed project was selected as the preferred alternative, and that the proposed withdrawals would not affect flows downstream from the facility intake during times of low flows due to adherence to District regulations.

## 4.0 Status and Trends of Hydrobiological Indicators in the lower Peace River/upper Charlotte Harbor Estuarine System

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The purpose and focus of this section is to provide updated and thorough analyses of data collected through 2002 regarding both the status and trends of key elements associated with the Peace River Hydrobiological Monitoring Program (HBMP). The analyses and discussions contained within this section are presented in relation to the following specific monitoring program study elements:

- Watershed rainfall patterns
- Gaged freshwater inflows
- Rainfall/flow interactions
- Treatment Facility withdrawals
- Selected water quality variables at the “fixed” sampling site locations
- Selected water quality variables at each of the four monitored isohalines
- Riverine vegetation

The primary objectives of the summary graphics and analyses presented for each of these program elements are to provide an overview of the current status, as well as comparisons of long-term patterns and characteristics. A corollary goal will be to describe the influences of more infrequent episodic occurrences such as extended periods of extreme drought or the occurrences of unusually wet winter/spring El Niño climatic events.

### 4.1 Watershed Rainfall Patterns and Tests for Long-term Trends

As an initial step in evaluating the status and trends of hydrologic conditions in the Peace River watershed, historic rainfall data were obtained for three representative long-term Peace River watershed basin rainfall gaging stations. The sites were selected based both on the need to provide a broad spatial range of geographical coverage and the availability of a reliable long-term historical data record.

- **Bartow** – This gage was selected as representative of the northern/upper Peace River watershed, with daily long-term rainfall data having been collected at this site since 1902. The gage is designated #478 in the National Oceanographic and Atmospheric Administrations (NOAA) rainfall monitoring network, and this same location is designated as #142 in the Southwest Florida Water Management District’s (District) web-based data acquisition system.
- **Arcadia** – Historical data from this monitoring site were chosen to characterize rainfall patterns in the central regions of the Peace River watershed. The daily, long-term rainfall record at this location extends back historically to 1908. The Arcadia gage is designated as site #228 in the NOAA monitoring network, and as #148 by the District.



- Punta Gorda** – The data from this final monitoring gage were used to assess seasonal and long-term rainfall patterns in the lower/coastal region of the lower Peace River watershed, and existing daily records at this gaging site extend back to 1915. This rainfall monitoring gage is designated #7397 in the NOAA network, and as #255 by the District.

Times series and box and whisker plots of monthly total rainfall at each of these three rainfall gages, over two historic long-term time periods, are summarized in Table 4.1. The two selected periods correspond with:

- The availability of corresponding measurements by the USGS of gaged freshwater inflows at the Peace River at Arcadia gage (1932-2002).
- The collection of physical, chemical and biological data in the lower Peace River/upper Charlotte Harbor estuarine system in conjunction with HBMP monitoring (1976-2002).

**Table 4.1**

**Monthly Time Series and Box & Whisker Plots of Total Monthly Rainfall at Peace River Watershed Long-term Gages**

| Time Period<br>Rainfall Gage | Time Series Plots of<br>Total Monthly<br>Rainfall | Box and Whisker<br>Plots of Mean<br>Watershed Monthly<br>Total Rainfall | Seasonal Kendall<br>Tau Trend Test<br>Results (Table 4.2) |
|------------------------------|---------------------------------------------------|-------------------------------------------------------------------------|-----------------------------------------------------------|
| <b>1932 to 2002</b>          |                                                   |                                                                         |                                                           |
| Bartow                       | Figure 4.1.1                                      | Figure 4.1.7                                                            | N.S.                                                      |
| Arcadia                      | Figure 4.1.2                                      | Figure 4.1.8                                                            | N.S.                                                      |
| Punta Gorda                  | Figure 4.1.3                                      | Figure 4.1.9                                                            | N.S.                                                      |
| <b>1976 to 2002</b>          |                                                   |                                                                         |                                                           |
| Bartow                       | Figure 4.1.4                                      | Figure 4.1.10                                                           | N.S.                                                      |
| Arcadia                      | Figure 4.1.5                                      | Figure 4.1.11                                                           | N.S.                                                      |
| Punta Gorda                  | Figure 4.1.6                                      | Figure 4.1.12                                                           | N.S.                                                      |

N.S. – Denotes no statistically significant trend (probability greater than 0.10).

▲ – Statistically significant increasing trend with a probability less than 0.05.

▼ – Statistically significant declining trend with a probability less than 0.10.

Tests for the potential presence of long-term systematic changes in total monthly rainfall at each of the gages, over each of the two selected time periods, were conducted using the Seasonal Kendall Tau non-parametric statistical procedure. Table 4.2 summarizes the results of these analyses. More detailed explanations and descriptions of both the Seasonal Kendall Tau procedure and the presented box and whisker plots are presented in Appendix A.

The following observations and conclusions regarding regional long-term patterns, the status and trends of Peace River watershed rainfall can be drawn from the graphical and statistical analyses presented herein:

- Extended periods of both unusually high and low seasonal rainfall have characterized lengthy periods during both the longer term “historic” 1932-2002 time period and the more recent twenty-seven years during which HBMP monitoring has been conducted.
- The box and whisker plots indicate generally similar typical southwest Florida summer wet-season average annual rainfall patterns among the three Peace River watershed regions as well as between the two selected time periods.
- However, comparisons of the monthly patterns of the box and whisker plots from the more inland Bartow and Arcadia gages do suggest some seasonal differences between the longer term historic and HBMP time periods. Specifically, these data plots indicate slightly higher rainfall frequencies during May and October over the historic 1932-2002 period, when compared with more recent 1976-2002 HBMP monitoring time frame.
- This apparent difference between the two inland rainfall gages and the more coastal Punta Gorda site is further indicated by the results of the Seasonal Kendall Tau trend analyses. The results summarized in [Table 4.2](#) clearly indicate that there have been no long-term changes in total monthly rainfall at the Punta Gorda gage over either of the two time periods. Similar analyses of Bartow and Arcadia rainfall data, while showing no indications of any systematic changes during the recent twenty-seven years, do suggest (not significantly) that rainfall in the upper and middle portions of the watershed may have declined over the longer 1932-2002 period.

### 4.2 Lower Peace River Freshwater Inflow Patterns and Trends

The next phase in evaluating the status and trends in hydrological conditions was to conduct similar graphical and trend analyses of the major gaged freshwater inflows into the lower Peace River estuarine system. Fortunately, there are USGS stage height recording gages, from which flows in cubic feet per second (cfs) are calculated based on frequently updated rating curves, on each of the four major freshwater sources to the lower Peace River. It has been estimated that gage flows account for approximately 90 percent of the total Peace River freshwater flow. Unfortunately, the historic periods of record differ among the four sites. However, reliable historical flow data from all four sources extend well back past the initiation of HBMP in 1976.

- **Peace River at Arcadia** – This gage is designated 02296750 by the USGS, and mean daily flows (cfs) are available for the seventy-one year period from 1932 to 2002.
- **Horse Creek near Arcadia** – Designated as USGS gage 02297310, daily mean flow data have been recorded at this site over the fifty-two year period between 1951 and 2002.

- **Joshua Creek at Nocatee** – USGS gage 02297100 was established in 1951 in conjunction with the Horse Creek near Arcadia gage.
- **Shell Creek near Punta Gorda** – This USGS gage, designated 02298202, was established following construction of the Shell Creek Dam (the major potable water source for the City of Punta Gorda) and measures the rate of flow over the structure. Mean daily flows from this major freshwater source to the very lower estuarine region of the Peace River (approximately 16 kilometers downstream of the Authority’s treatment Facility) are available over the thirty-seven year period between 1966 and 2002. (It should be noted that USGS has had to “estimate” flows during several extended time frames during the period of record due to safety concerns of accessing the gage and the City adding plywood along the top of the dam during the recent drought).

Table 4.3 indicates the average overall and seasonal flow contributions from of each of the four main lower Peace River tributaries to the total gaged river flow over the twenty-seven year period of HBMP monitoring.

**Table 4.3**  
**Relative Percent Flow from Each of the Major Peace River Tributaries**

| <b>Tributary</b>             | <b>Overall</b> | <b>Nov. – Feb.</b> | <b>Mar. – Jun.</b> | <b>Jul. – Oct.</b> |
|------------------------------|----------------|--------------------|--------------------|--------------------|
| Peace River at Arcadia       | 60.4           | 63.9               | 62.0               | 55.5               |
| Horse Creek near Arcadia     | 8.0            | 6.8                | 6.5                | 10.6               |
| Joshua Creek at Nocatee      | 7.1            | 6.5                | 8.3                | 6.5                |
| Shell Creek near Punta Gorda | 24.5           | 22.8               | 23.2               | 27.4               |

The four months between November and February are seasonally characteristic in southwest Florida of relatively drier/cooler conditions. In comparison, the period between March and June is typically characterized by very dry/warm seasonal weather patterns. Hot/wet summer conditions generally characterize the final four month period between July and October. As shown in Table 4.3, the relative contributions of both Horse Creek and Shell Creek to the total average gaged lower Peace River freshwater inflows increase during the summer wet-season, while Arcadia flows are proportionally greatest during the drier months when the tributaries with smaller watersheds contribute less to the overall flow of the lower Peace River.

Times series plots and box and whisker plots of both monthly mean and median flows at each of the four USGS flow gages are summarized in Table 4.4. These graphical analyses are depicted in each case over two differing historical time periods.

1. The entire historical period of record available for each gaging location.

2. The more recent twenty-seven year period between 1976 and 2002 corresponding with the HBMP collection of physical, chemical and biological data in the lower Peace River/upper Charlotte Harbor estuarine system.

Additional analyses are also presented for both the total combined freshwater flows upstream of the Facility (Peace River at Arcadia + Horse and Joshua Creeks), and total freshwater flow at the US 41 Bridge (which also includes the gaged flow coming into the lower river from Shell Creek) for the 1976-2002 period of HBMP monitoring.

**Table 4.4**  
**Monthly Time Series and Box & Whisker Plots of Monthly Mean and Median Gaged Freshwater Inflows to the lower Peace River Estuary**

| Time Period<br>Flow Gage | Based on Monthly Mean Flows   |                               |                    | Based on Monthly Median Flows |                               |                    |
|--------------------------|-------------------------------|-------------------------------|--------------------|-------------------------------|-------------------------------|--------------------|
|                          | Time Series Plots             | Box and Whisker Plots         | Trend Test Results | Time Series Plots             | Box and Whisker Plots         | Trend Test Results |
| <b>Period of Record</b>  |                               |                               |                    |                               |                               |                    |
| Arcadia (1932-2002)      | <a href="#">Figure 4.2.1</a>  | <a href="#">Figure 4.2.11</a> | ▼                  | <a href="#">Figure 4.2.21</a> | <a href="#">Figure 4.2.31</a> | ▼                  |
| Horse Creek (1951-2002)  | <a href="#">Figure 4.2.2</a>  | <a href="#">Figure 4.2.12</a> | N.S.               | <a href="#">Figure 4.2.22</a> | <a href="#">Figure 4.2.32</a> | N.S.               |
| Joshua Creek (1951-2002) | <a href="#">Figure 4.2.3</a>  | <a href="#">Figure 4.2.13</a> | ▲                  | <a href="#">Figure 4.2.23</a> | <a href="#">Figure 4.2.33</a> | ▲                  |
| Shell Creek (1966-2002)  | <a href="#">Figure 4.2.4</a>  | <a href="#">Figure 4.2.14</a> | N.S.               | <a href="#">Figure 4.2.24</a> | <a href="#">Figure 4.2.34</a> | N.S.               |
| <b>1976 to 2002</b>      |                               |                               |                    |                               |                               |                    |
| Arcadia                  | <a href="#">Figure 4.2.5</a>  | <a href="#">Figure 4.2.15</a> | N.S.               | <a href="#">Figure 4.2.25</a> | <a href="#">Figure 4.2.35</a> | N.S.               |
| Horse Creek              | <a href="#">Figure 4.2.6</a>  | <a href="#">Figure 4.2.16</a> | N.S.               | <a href="#">Figure 4.2.26</a> | <a href="#">Figure 4.2.36</a> | N.S.               |
| Joshua Creek             | <a href="#">Figure 4.2.7</a>  | <a href="#">Figure 4.2.17</a> | ▲                  | <a href="#">Figure 4.2.27</a> | <a href="#">Figure 4.2.37</a> | ▲                  |
| Shell Creek              | <a href="#">Figure 4.2.8</a>  | <a href="#">Figure 4.2.18</a> | N.S.               | <a href="#">Figure 4.2.28</a> | <a href="#">Figure 4.2.38</a> | N.S.               |
| Total at Facility        | <a href="#">Figure 4.2.9</a>  | <a href="#">Figure 4.2.19</a> | N.S.               | <a href="#">Figure 4.2.29</a> | <a href="#">Figure 4.2.39</a> | N.S.               |
| Total at US 41           | <a href="#">Figure 4.2.10</a> | <a href="#">Figure 4.2.20</a> | N.S.               | <a href="#">Figure 4.2.30</a> | <a href="#">Figure 4.2.40</a> | N.S.               |

N.S. – Denotes no statistically significant trend (probability greater than 0.10).

▲ – Statistically significant increasing trend with a probability less than 0.05.

▼ – Statistically significant declining trend with a probability less than 0.10.

Tests for the presence of systematic changes in both mean and median flows, over both the period of record and during the recent twenty-seven year interval of HBMP monitoring, were performed using the Seasonal Kendall Tau non-parametric statistical procedure. [Tables 4.5](#) (monthly means) and [4.6](#) (monthly medians) summarize the findings of these analyses. Detailed explanations and descriptions of both the Seasonal Kendall Tau procedure and the presented box and whisker plots are described in [Appendix A](#).

The following observations and inferences with respect to both the recent and historical patterns and long-term trends in freshwater inflows to the Peace River estuarine system are apparent based on the presented graphical and statistical analyses:

- Although monthly mean flows are often considerably greater than corresponding monthly median values, both summary flow measurements show very similar long-term and seasonal patterns, as well as comparable trend test results.
- The time series plots of flow at the Arcadia gage over the period of record (1932-2002) clearly show a greater frequency of high flow periods, between the early 1930's to approximately 1960, when compared to the more recent period of HBMP monitoring (1976-2002).
- Comparisons of box and whisker plots of Peace River at Arcadia flows between the two time periods indicate noticeable differences during the five-month period between June and October. Average gaged river flows during these five months exhibit much higher flows over the long-term period of record than the more recent period. In contrast, comparisons of the statistical distributions of flows during the other seven drier months indicate they were generally relatively similar between the longer historical and more recent HBMP time periods. Thus the data indicate that while the wet-season has gotten generally drier, the dry-season months have remained similar over the long-term period of record.
- These graphical observations are supported by the results of the Seasonal Kendall Tau trend tests ([Tables 4.5](#) and [4.6](#)), which indicate that there have been statistically significant declines in both mean and median flows over the period of record at the Peace River at Arcadia gage.
- Conversely, the results of the trend tests indicate statistically significant increases in freshwater flows measured at the USGS Joshua Creek gage, over both the period of record (1951-2002) and during the interval of HBMP monitoring (1976-2002), have statistically significantly increased.
- Analyses conducted in conjunction with the recent Shell Creek HBMP Summary Report (PBS&J 2003) clearly showed that there have been significant increases across the lower 25<sup>th</sup> percentile of flows in a number of the tributaries in the lower Peace River watershed. Other observations of corresponding increasing chloride values in a number of tributaries in the lower watershed confirm the observation of increases in low, dry-

season flows. These increases correspond with increasing agricultural expansion and the use of relatively high conductivity groundwater by farmers during the drier months.

- Other than these dry-season agriculture-related augmentations of low season flows, the results of the trend analyses clearly indicate that there have not been any statistically significant systematic changes in the seasonally compared amounts of freshwater flow from the major four Peace River watershed sources over the recent twenty-seven year history of HBMP monitoring.

### 4.3 Rainfall/Flow Interactions

A method of analyses previously used by the USGS (Hammett 1990) to evaluate long-term changes in rainfall/flow relationships in the upper Peace River basin encompasses the development of “double mass” curves. This procedure plots cumulative daily gaged flows against cumulative measured precipitation, by year, over the entire period of interest. The underlying assumption is that significant long-term changes in the amount of flow, per unit of rainfall, will be demonstrated by a corresponding marked change in the slope of the line resulting from the “double mass” curve.

This procedure was used in developing [Figure 4.3.1](#), which depicts the cumulative long-term interactions between rainfall (average total yearly values for the Bartow and Arcadia rainfall gages) and total yearly Peace River at Arcadia gaged flows. As previously described by Hammett, the slope of a line fitted to the yearly cumulative rainfall and flow totals seems to have followed one pattern from the early 1930s until the early 1960s when there was a “break” in the observed relationship and the slope of the line declined. As [Figure 4.3.1](#) indicates, a new, much “flatter” slope could then be fitted to the cumulative relationship from the early 1960s until the early 1990s when it seems the slope may have started increasing again. A regression line and ninety-five percent confidence intervals have been fitted in this figure over the entire period of record. When viewed over the entire seventy-one year period of record, the “double mass” relationship between rainfall and flow seems to indicate a long-term oscillating pattern around the central pattern. If true, this would further support the recent District work (Marty Kelly, personal communication) tying long-term cyclical increasing/decreasing Florida river flow patterns to the recently described influences of the North Atlantic Oscillation (NOA) on decadal cyclical weather relationships affecting North American rainfall patterns.

Similar “double mass” curves were developed for the more recent twenty-seven year period of HBMP monitoring for each of the four major gaged freshwater sources to the lower Peace River estuarine system. Table 4.7 summarizes both these analyses as well as overall and seasonal plots of total monthly rainfall versus mean monthly flow. The results of these graphical analyses can be summarized as follows.

- Although rainfall/flow relationships have varied below and above the 95 percent confidence limits of the double mass regression lines during extended periods of drought and high rains, there have not been any marked significant, conspicuous changes in the general relationships between rainfall and flow at any of the four major



gaged lower Peace River tributaries during the period of HBMP monitoring (1976-2002).

- During the extended drought that followed the 1983 El Niño event, flows per unit rainfall at each of the four gaged locations declined below the 95 percent confidence limits of the slope for the long-term period. This indicates that during this unusually dry period, typical runoff/groundwater interactions changed resulting in lower than average stream flows for comparable levels of basin rainfall. It is notable that the recent extended drought (2000/2001) did not manifest itself similarly with regard to the long-term rainfall/flow relationships at these gages. However, by design, this analyses procedure is fairly insensitive to all but the most extreme year-to-year variations.
- Both the unusually high and extended rainfalls of 1995 and the unusually strong 1997/1998 El Niño event resulted in slightly higher flows per unit rainfall than the long-term averages at each of the gages.
- The overall and seasonal plots of mean monthly flow versus total monthly rainfall indicate, as expected, that generally increasing amounts of rainfall result in higher average flows. However, when plotted on a monthly basis, the results show an extremely wide degree of variation. Obviously, the amount of rainfall in a particular month is a poor predictor of the resulting flow at each of these gages. Comparisons among the previously presented box and whisker plots of rainfall and flow indicate that rainfall following extended dry periods does not result in the same increases in flow that would occur under similar conditions following a series of wetter months. Conversely, high levels of flow often occur during relatively dry months such as October following extended periods of high rainfall. Flows thus integrate rainfall based to a great extent on cumulative previous existing hydrologic conditions.

**Table 4.7**  
**Rainfall/Flow Interactions**

| Peace River Tributary Gage<br>(1976-2002) | Double Mass<br>Plot | Plot of Flow Versus Rainfall |                            |                          |
|-------------------------------------------|---------------------|------------------------------|----------------------------|--------------------------|
|                                           |                     | Overall                      | Wet-Season<br>(Jun.-Sept.) | Dry-Season<br>(Oct.-May) |
| Peace River at Arcadia                    | Figure 4.3.2        | Figure 4.3.3                 | Figure 4.3.4               | Figure 4.3.5             |
| Horse Creek near Arcadia                  | Figure 4.3.6        | Figure 4.3.7                 | Figure 4.3.8               | Figure 4.3.9             |
| Joshua Creek at Nocatee                   | Figure 4.3.10       | Figure 4.3.11                | Figure 4.3.12              | Figure 4.3.13            |
| Shell Creek near Punta Gorda              | Figure 4.3.14       | Figure 4.3.15                | Figure 4.3.16              | Figure 4.3.17            |

#### 4.4 Status and Trends in Facility Freshwater Withdrawals

A series of graphical and statistical analyses were conducted in order to provide a comprehensive overview of both the current status as well as long-term patterns and trends in freshwater

withdrawals by the Facility since it came on line in 1980. An overview of the graphical analyses is presented in Table 4.8, while [Table 4.9](#) summarizes the results of the Seasonal Kendal Tau statistical procedures used to test for trends in both Facility withdrawals and usage as a percentage of Peace River at Arcadia flows.

**Table 4.8**  
**Facility Freshwater Withdrawals 1980-2001**

| Figure                        | Description                                                                                    |
|-------------------------------|------------------------------------------------------------------------------------------------|
| <a href="#">Figure 4.4.1</a>  | Daily water treatment Facility withdrawals (1980-2002)                                         |
| <a href="#">Figure 4.4.2</a>  | Monthly mean water treatment Facility withdrawals (1980-2002)                                  |
| <a href="#">Figure 4.4.3</a>  | Monthly box plots of Facility withdrawals (1980-2002)                                          |
| <a href="#">Figure 4.4.4a</a> | Water treatment Facility withdrawals versus Arcadia flow                                       |
| <a href="#">Figure 4.4.4b</a> | Water treatment Facility withdrawals versus Arcadia flow (flows up to 2000 cfs)                |
| <a href="#">Figure 4.4.5</a>  | Facility withdrawals as a percent of Peace River Arcadia flow (1980-2002)                      |
| <a href="#">Figure 4.4.6a</a> | Peace River flows at Arcadia vs. % water treatment Facility withdrawals                        |
| <a href="#">Figure 4.4.6b</a> | Peace River flows at Arcadia vs. % water treatment Facility withdrawals (flows up to 1200 cfs) |
| <a href="#">Figure 4.4.7</a>  | Facility withdrawals versus monthly rainfall                                                   |

The following observations and conclusions regarding the status, and long-term patterns and trends in Facility freshwater withdrawals can be drawn from these analyses.

- The time series plots presented in [Figure 4.4.1](#) and [4.4.2](#) indicate a number of patterns. The first is that due to the minimum cutoff of 130 cfs (as measured at the USGS Arcadia gage), there are often extended periods each year when the Facility does not withdraw water from the river. The effects of the recent 2000-2001 drought on Facility water withdrawals are clearly evident in both figures. During 2000 the Facility did not withdraw any water from the Peace River 248 days during the year, and relied solely on stored reserves another 219 days during 2001.
- The time series plots also plainly show that there have been relatively steady statistically significant ([Table 4.9](#)) increases in the amounts of freshwater withdrawals by the Facility during the past twenty-three years due to increasing water demands. Also clearly evident is the noticeable increase in maximum Facility withdrawals during the later half of 2002 due to the recently completed Facility expansion, which has resulted in the Authority's increased ability to treat and store larger daily amounts of freshwater.
- The box and whisker plots ([Figure 4.4.3](#)) of overall seasonal monthly withdrawals show that, other than during the warm/dry months of April and May when the Facility is often not withdrawing water from the Peace River due to the 130 cfs cutoff, the

statistical distributions of Facility withdrawals are fairly uniform throughout most of the year.

- **Figures 4.4.4a** and **4.4.4b** indicate that once flows exceed the 130 cfs cutoff, withdrawals by the Facility are more dependent on demand and capacity rather than supply, since as indicated, very similar amounts of water have been withdrawn over a wide range of flows.
- The series of plots, **Figures 4.4.5, 4.4.6a** and **4.4.6b**, indicate withdrawals as a percent of gaged Peace River Arcadia flows both over the 1980-2002 time period and in relation to flow. As indicated, prior to implementation of the ten percent criteria in 1988, the Facility routinely withdrew more than twenty percent of the Arcadia gaged flow during dry periods.
- It is also apparent that the Facility has periodically exceeded the ten percent withdrawal criteria yearly since it was established in 1988 (see **Table 4.a**). The primary reason for these discrepancies stems from the way that stage/flow data are gathered. The Authority uses “provisional” preceding day flow data from the water level recorder at the USGS gaging station on the Peace River at Arcadia. Currently, these data are taken directly from the USGS Tampa office’s website. However, after the fact, the USGS checks and evaluates the data from the stage recorder and updates the river cross section a number of times each year. Thus, the daily values used by the Authority are only “provisional” and are often changed by the USGS weeks or months after the fact. It is not uncommon for subsequent determinations of percent withdrawals, based on revised USGS calculations of daily flows, to conclude that daily Facility withdrawals, based on provisional flow information, in fact exceeded the established ten percent criteria. The Authority and the USGS Tampa office staff have continued to work to reduce such instances to the greatest possible extent.
- As indicated, withdrawals are not directly related to flows (outside of the 130 cfs cutoff, and then ten percent maximum of Arcadia flow up to a maximum single day withdrawal of 139 cfs). Therefore, as expected, withdrawals and average total monthly watershed rainfall (**Figure 4.4.7**) also fail to show any relationship.

### 4.5 Status and Trends in “Fixed” Station Water Quality Parameters

Historically, between 1976 and 1987, the HBMP included the monthly collection of *in situ* physical measurements of water column profile characteristics at a number of fixed station locations along the lower Peace River and in upper Charlotte Harbor. Under the 1996 expansion of the monitoring program, monthly surface and bottom water chemistry data collections were initiated at five fixed sampling locations along an established transect from near the mouth of the river to upstream of the Facility. *In situ* physical water column profile sampling was also initiated at an additional ten fixed sampling locations, as well as these five water quality monitoring sites. The water quality sampling and *in situ* water column profile measurement are HBMP program elements that were initiated using sampling sites formerly (1976-1990) utilized by EQL for similar long-term lower Peace River background monitoring. Beginning in 1998, an

additional fixed monthly sampling site was added to correspond to the location of the third USGS tide gage that was installed in 1997 at River Kilometer 26.7. The relative locations of these fixed sampling locations were previously described in Section 1.0 ([Figure 1.1](#)). [Table 1.1](#) provides both the currently used River Kilometer designations as well as both the previously used EQL station numbers and USGS sample river mile designations.

Using the combined historic EQL Peace River background water quality monitoring data, combined with the more recent HBMP monitoring information, including both physical *in situ* water column profile information, and sub-surface and near-bottom water chemistry data, has resulted in data that are available monthly for the five fixed HBMP water quality sampling locations for the complete periods 1976-1989 and 1996-2002. These data were used in this section to describe the current status as well as statistically test for the presence of long-term changes in the water quality characteristics at these specific locations along the lower Peace River.

Statistical tests for significant trends in mean annual water quality conditions for the “fixed” Peace River sampling locations were analyzed using methods developed by Coastal Environmental (1996) for the Florida Department of Environmental Protection using seasonally weighted yearly averages. In this instance the procedure was used to examine for statistical differences (trends) between the two disjunct periods of record.

### 4.5.1 Gaged Peace River Flow 1976-1989 and 1996-2002

The following analyses were conducted in order to provide comparisons of freshwater inflows with the same periods for which physical and water chemistry are available from the lower river “fixed” HBMP monitoring locations. Graphical depictions of differences in daily, monthly mean, and monthly median gaged Peace River flows at three river locations were used to incorporate and account for differences in the major gaged river tributaries (see Section 4.2 above) and are presented in Table 4.10.

**Table 4.10**  
**Gaged Peace River Flow**

| <b>Gaged Peace River Flow</b>             | <b>Daily</b>                 | <b>Monthly Mean</b>          | <b>Monthly Median</b>        |
|-------------------------------------------|------------------------------|------------------------------|------------------------------|
| Peace River at Arcadia                    | <a href="#">Figure 4.5.1</a> | <a href="#">Figure 4.5.4</a> | <a href="#">Figure 4.5.7</a> |
| Total Gaged Flow Upstream of Facility     | <a href="#">Figure 4.5.2</a> | <a href="#">Figure 4.5.5</a> | <a href="#">Figure 4.5.8</a> |
| Total Gaged Flow Upstream of US 41 Bridge | <a href="#">Figure 4.5.3</a> | <a href="#">Figure 4.5.6</a> | <a href="#">Figure 4.5.9</a> |

The results of statistical tests to determine seasonally adjusted mean annual differences in total gaged flow at these three Peace River locations between the 1976-1989 and 1996-2002 time periods are summarized in Table 4.11. As indicated, the differences in annual mean flows at each of the three locations were somewhat higher (approximately 100-200 cfs) during the more recent

seven-year HBMP monitoring period. However, the higher mean annual flows during this most recent time period were not statistically significantly different than those observed during the previous fourteen-year period between 1976 and 1989. As indicated, both of these time intervals were characterized by highly variable seasonal and yearly differences in gaged freshwater inflows to the lower Peace River. Extended periods of very high flows during El Niño climatic events, followed by extended unusually dry La Niña rainfall conditions characterized each of these two time periods.

**Table 4.11**  
**Trend Tests Gaged Peace River Flow (1976-1990 & 1996-2002)**

| Gaged Peace River Flow                    | Monthly Mean                  | Diff. Means | P Value of Diff. | Monthly Median                | Diff. Means | P Value of Diff. |
|-------------------------------------------|-------------------------------|-------------|------------------|-------------------------------|-------------|------------------|
| Peace River at Arcadia                    | <a href="#">Figure 4.5.10</a> | 100.0       | 0.644            | <a href="#">Figure 4.5.13</a> | 50.4        | 0.761            |
| Total Gaged Flow Upstream of Facility     | <a href="#">Figure 4.5.11</a> | 160.3       | 0.574            | <a href="#">Figure 4.5.14</a> | 79.2        | 0.707            |
| Total Gaged Flow Upstream of US 41 Bridge | <a href="#">Figure 4.5.12</a> | 191.9       | 0.554            | <a href="#">Figure 4.5.15</a> | 97.3        | 0.691            |

### 4.5.2 Water Quality Comparisons between 1976-1989 and 1996-2002

**Table 4.12** (contains links to Figures 4.16 through 4.255) summarizes both the time series plots as well as the results of the statistical tests used to determine seasonally adjusted mean annual differences in selected water quality parameters from both sub-surface and near-bottom samples collected monthly at each of the five “fixed” HBMP monitoring locations between the 1976-1989 and 1996-2002 time periods. The results of these analyses indicate the following observed patterns as well as variations between the two temporal monitoring periods for each of the selected water quality parameters. It should be noted that all of the water quality data over the 1976-1989 time period were analyzed by EQL, while that from the most recent seven years were sequentially analyzed by the USGS, EQL and Benchmark Laboratories (PBS&J 2003).

**Salinity (ppt)** – As expected, observed salinity patterns indicate the presence of a strong distinct spatial salinity gradient along the lower Peace River monitoring transect. Salinity levels range from much higher levels (near Gulf water conditions) near the river’s mouth, to exhibiting typically near freshwater levels just upstream of the Facility. The greatest degree of interannual variability in salinity generally occurs in the surface waters at those monitoring sites located downstream toward the river’s mouth. This variability is such that seasonal salinity differences of as much as thirty-five parts per thousand can occur between extended periods of low and high freshwater inflow. However, even bottom salinity levels in the area of the US 41 Bridge (River Kilometer 6.6) are shown to exhibit similar large degrees of interannual variation. The influences of the recent high freshwater inflows during 1997/1998 El Niño event and the extended 1999-2001 drought are clearly evident in the presented time series graphics. The results of the

statistical tests indicated no significant differences between the average annual salinity levels at either the surface or bottom of the water column, at any of the five monitoring locations, between the 1976-1989 and 1996-2002 sampling periods.

**Dissolved Oxygen (mg/L)** – Near-bottom dissolved oxygen concentrations show clear seasonal cycles in response to summer wet-season freshwater inflows. Both the duration and magnitude of depressed dissolved oxygen concentrations increase toward the river's mouth as higher bottom salinity levels establish greater vertical density stratification of the water column during periods of high river flow. Bottom dissolved oxygen concentrations at the two most downstream water quality monitoring stations, located at River Kilometers -2.4 and 6.6, are seasonally characterized by hypoxic (less than 2.0 mg/L) and even anoxic (less than 0.2 mg/L) conditions during extended periods of high summer wet-season flows. The statistical tests used to determine seasonally adjusted mean annual differences in dissolved oxygen concentrations indicated significant declines of 0.4-0.6 mg/L in both surface and bottom concentrations at each of the five monitoring locations between the 1976-1989 and 1996-2002 time periods. Although other studies (CHNEP 1999, 2003) have also noted these statistically significant declines in lower Peace River dissolved oxygen concentrations, no clear causative factor has been identified. It has been suggested that these observed declines may reflect corresponding declines in some of the very high chlorophyll *a* concentrations that were often observed during the 1970s and 1980s. The previously noted higher average flows during the more recent time period may have also contributed, or the difference may in fact simply reflect progressive changes associated with *in situ* dissolved membrane technology.

**Water Color (Pt-Co Units)** – Humic compounds derived from the breakdown and leaching of vegetation result in the high water color that characterizes the blackwater river systems of southwest Florida. As shown by the time series graphics, color levels temporally increase quickly in response to higher levels of freshwater inflow. As expected, water color concentrations are typically spatially much higher upstream than near the mouth of the river. Very high color, however, can reach well into the harbor during extended periods of high freshwater inflow such as occurred during the 1997/1998 El Niño and the extremely high flows during 2002. The applied statistical tests indicated no significant differences between the average annual surface and bottom water column color concentrations at any of the five monitoring locations between the 1976-1989 and 1996-2002 sampling periods.

**Turbidity (NTU)** – The time series graphics show that measured turbidity levels, especially at the three more upstream sampling locations, appear to have been both lower and less variable during the most recent seven years than similar observations made during the earlier 1976-1989 interval. These apparent observations are supported by the statistical analyses that indicated that there have been significant long-term declines in measured turbidity levels in these areas of the lower Peace River. It should be noted, that in comparison to many other estuarine systems outside of southwest Florida where rivers transport significant amounts of silts and clays, turbidity levels are naturally relatively low in the lower Peace River/upper Charlotte Harbor estuarine system.

**Nitrite+Nitrate Nitrogen (mg/L)** – Both the concentrations and seasonal patterns of dissolved inorganic nitrite+nitrate nitrogen levels show marked spatial differences among the five HBMP



lower Peace River monitoring locations. The time series plots indicated that inorganic nitrite+nitrate nitrogen levels at the most downstream fixed sampling site (located near the imaginary defined river's mouth) are typically near or at method detection limits. Salinity levels are typically high in this region of the estuary (see above) and, except during periods of very high river flow, phytoplankton primary production is limited by the availability of inorganic nitrogen (Montgomery *et.al.* 1991). Conversely, during extended periods of high freshwater inflows surface salinities decline, bringing increased nutrient loading and higher levels of water color that limit the penetration of light in the water column and subsequently phytoplankton growth and nitrogen uptake. By comparison, inorganic nitrogen levels are shown to progressively increase moving upstream along the HBMP sampling transect, as dilution by low nutrient/high salinity harbor water declines and high water color increasingly limits phytoplankton nitrogen uptake. Only during periods of extended low freshwater inflow, such as often occurs during the spring dry-season, are ambient inorganic nitrogen levels low at the upstream river sampling sites. The presented statistical test results show that there were no significant differences between the average annual surface and bottom dissolved inorganic nitrite+nitrate nitrogen concentrations at any of the five monitoring locations in comparisons made between the 1976-1989 and 1996-2002 sampling periods.

**Ammonia/Ammonium Nitrogen (mg/L)** – The time series graphics show that ambient concentrations of dissolved inorganic ammonia/ammonium nitrogen did not exhibit either the same degree of seasonal, flow related variability or the distinct spatial patterns exhibited by nitrite+nitrate nitrogen. As expected, sub-surface inorganic ammonia/ammonium concentrations were often near detection limits (which often ranged from 0.008 to 0.10 depending on instrument calibration) as a result of preferential phytoplankton uptake. However, as indicated, high “spikes” in concentrations in surface waters were occasionally observed often without any distinct causative factor. As shown, high near-bottom dissolved ammonia/ammonium concentrations occur in the lower regions of the river when increased summer wet-season flows cause salinity induced water column stratification, which results in pronounced periods of hypoxia/anoxia in the bottom waters. In some instances, spikes in surface ammonia/ammonium levels in the lower portion of the river seemed to be related to the fall wind induced breakdown of the seasonal thermocline/halocline and the turnover of high bottom ammonia/ammonium concentrations into the surface waters. It is possible that this mechanism, associated with the slightly higher flows during the most recent seven-year period, may explain why statistically higher ammonia/ammonium concentrations were observed at the two most downstream fixed site monitoring locations when compared with the previous 1976-1989 time frame.

**Total Kjeldahl Nitrogen (mg/L)** – While this gross measurement of combined inorganic ammonia and organic water column nitrogen shows distinct seasonal patterns, spatially the time series graphics show total Kjeldahl nitrogen levels at all five lower Peace River monitoring locations to be relatively similar. Further, the applied different statistical tests indicated no significant differences between the average annual surface and bottom water column concentrations at any of the five monitoring sites when comparing the 1976-1989 and 1996-2002 time periods.

**Total Phosphorus (mg/L)** – Probably the most dramatic long-term change in lower Peace River water quality has been the previously noted (PBS&J 1999, 2002) marked, long-term decline in

total (and dissolved inorganic) phosphorus concentrations. The lower Peace River/upper Charlotte Harbor estuarine system is naturally highly enriched in phosphorus due to the extensive natural phosphate deposits that occur through a number of its major sub-basins. Usually phosphorus concentrations both spatially and temporally reflect the degree of Peace River freshwater inputs. Seasonally the highest phosphorus concentrations are typically associated with periods of lower river flow, when the influences of groundwater are more pronounced. Long-term temporal patterns indicate that both the magnitude and very high degree of variability in phosphorus levels that was observed during the first six years of HBMP monitoring rapidly declined. This decline is in response to the State of Florida's passage in the late 1970s and implementation of stricter regulations and controls covering both point and non-point discharges of surface waters from phosphate mining operations and lands. However, comparison of the average annual mean concentrations between the 1976-1989 and 1996-2002 time periods indicates that phosphorus concentrations have continued to statistically significantly decline, even though the greatest changes in ambient concentrations occurred prior to 1984.

**Silica (mg/L)** – Both the long-term time series plots as well as the results of the statistical comparisons of mean annual average reactive silica concentrations between the two monitored time periods show that reactive silica concentrations at both the top and bottom of the water column have increased along the entire length of the lower Peace River monitoring transect. During the most recent seven years of HBMP monitoring, reactive silica concentrations at each of the five fixed sampling sites have both increased and exhibit much wider ranges of variation when compared with similar data collected during the 1976-1989 period. As indicated, reactive silica levels progressively increase spatially upstream. It may be that the observed increases in ambient reactive silica levels in the Peace River estuarine system reflect the cumulative influences of the increased use of groundwater and the expansion of water intense agriculture throughout the Peace River watershed.

**Dissolved Organic Carbon (mg/L)** – Spatially and temporally dissolved organic carbon concentrations reflect the influences of both the relative contributions and timing of freshwater inflows. Comparisons of mean annual average concentrations between the 1976-1989 and 1996-2002 time periods clearly indicate that total organic carbon concentrations, especially toward the river's mouth, have statistically significantly declined during the most recent seven-year monitoring period. To a great extent, the explanation for these observed trends lies in the availability and implementation in 1992 of the use of new, computer controlled, automated chemistry analytical procedures. Since 1992, all organic carbon data have been obtained using mechanically injected chemistry instrumentation, which employs advanced infra-red detector technology. While this improvement in chemistry technology has provided for both greatly improved data accuracy and precision, the change in instrumentation may have also added to the observed statistical significant trends in organic carbon.

**Total Organic Carbon (mg/L)** – Not unexpectedly, the spatial and temporal patterns, as well as the differences observed between the two monitoring time periods for total organic carbon were very similar and comparable with those described for dissolved organic carbon.

**Chlorophyll *a*** - The long-term data show that there has been a marked decline in the periodic very high chlorophyll *a* concentrations or phytoplankton "blooms" that commonly occurred in

the surface waters during the late 70s and early 80s throughout the lower Peace River/upper Charlotte Harbor estuarine system. Overall, the observed declines in the frequency of these events only resulted in statistically significant changes in average annual seasonally weighted mean chlorophyll *a* concentrations between the time intervals at two of the five fixed River Kilometer based HBMP monitoring locations. (Comparisons of near-bottom levels between the time periods were not possible due to the lack of near-bottom chlorophyll *a* data during the earlier time period.)

### 4.5.3 Spatial Response of Water Quality Parameters to Levels of Freshwater Inflows

Box and whisker graphical analyses were used to determine potential spatial variations under different flow regimes of ambient sub-surface water quality characteristics at each of the five fixed HBMP Peace River monitoring locations. Univariate plots of selected water quality parameters were compared by River Kilometer among the sampling sites under a series of flow ranges (as measured by the USGS Peace River at Arcadia gaging site).

- **Very Low Flows** (0 to 90 cfs) – representative of the lowest ten percent (Q10) of river flows during the 1976-2002 time period.
- **Low Flows** (90-160 cfs) – or flows within the Q10 to Q25 interval.
- **Normal Low Flows** (160-360 cfs) – flows characteristic of the long-term Q25 to Q50 range.
- **Normal High Flows** (360 to 920 cfs) – representative of Peace River Arcadia flows within the Q50 to Q75 statistical interval.
- **High Flows** (920 to 2100 cfs) – characterizing river flows in the Q75 to Q90 range.
- **Very High Flows** (above 2100 cfs) – or the upper ten percent of all observed flows during the 1976-2002 time period.
- **All Flows** – this final series of univariate box and whisker plots depicts the overall spatial differences and the range of observed variation in each of the water quality parameters without regard to flow.

The results of these graphical analyses are presented in Table 4.14.

Table 4.14

### Univariate Plots Of Water Quality Parameters Under Differing Flow Categories

| Water Quality Parameter   | Flow Category – Range in Cubic Feet/Second |                |                |                |                |                |                |
|---------------------------|--------------------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                           | 0-90 cfs                                   | 90-160         | 160-360        | 360-920        | 920-2100       | > 2100         | All Flows      |
| Salinity                  | Figure 4.5.256                             | Figure 4.5.257 | Figure 4.5.258 | Figure 4.5.259 | Figure 4.5.260 | Figure 4.5.261 | Figure 4.5.262 |
| Dissolved Oxygen          | Figure 4.5.263                             | Figure 4.5.264 | Figure 4.5.265 | Figure 4.5.266 | Figure 4.5.267 | Figure 4.5.268 | Figure 4.5.269 |
| Water Color               | Figure 4.5.270                             | Figure 4.5.271 | Figure 4.5.272 | Figure 4.5.273 | Figure 4.5.274 | Figure 4.5.275 | Figure 4.5.276 |
| Turbidity                 | Figure 4.5.277                             | Figure 4.5.278 | Figure 4.5.279 | Figure 4.5.280 | Figure 4.5.281 | Figure 4.5.282 | Figure 4.5.283 |
| Nitrite+Nitrate Nitrogen  | Figure 4.5.284                             | Figure 4.5.285 | Figure 4.5.286 | Figure 4.5.287 | Figure 4.5.288 | Figure 4.5.289 | Figure 4.5.290 |
| Ammonia/Ammonium Nitrogen | Figure 4.5.291                             | Figure 4.5.292 | Figure 4.5.293 | Figure 4.5.294 | Figure 4.5.295 | Figure 4.5.296 | Figure 4.5.297 |
| Total Kjeldahl Nitrogen   | Figure 4.5.298                             | Figure 4.5.299 | Figure 4.5.300 | Figure 4.5.301 | Figure 4.5.302 | Figure 4.5.303 | Figure 4.5.304 |
| Total Phosphorus          | Figure 4.5.305                             | Figure 4.5.306 | Figure 4.5.307 | Figure 4.5.308 | Figure 4.5.309 | Figure 4.5.310 | Figure 4.5.311 |
| Silica                    | Figure 4.5.312                             | Figure 4.5.313 | Figure 4.5.314 | Figure 4.5.315 | Figure 4.5.316 | Figure 4.5.317 | Figure 4.5.318 |
| Total Organic Carbon      | Figure 4.5.319                             | Figure 4.5.320 | Figure 4.5.321 | Figure 4.5.322 | Figure 4.5.323 | Figure 4.5.324 | Figure 4.5.325 |
| Dissolved Organic Carbon  | Figure 4.5.326                             | Figure 4.5.327 | Figure 4.5.328 | Figure 4.5.329 | Figure 4.5.330 | Figure 4.5.331 | Figure 4.5.332 |
| Chlorophyll a             | Figure 4.5.333                             | Figure 4.5.334 | Figure 4.5.335 | Figure 4.5.336 | Figure 4.5.337 | Figure 4.5.338 | Figure 4.5.339 |

The following patterns and observations can be drawn from the presented figures.

**Salinity (ppt)** – The series of figures clearly depict the progressive changes that occur along the River Kilometer based lower Peace River sampling transect as flows increase. Under the lowest flow conditions, brackish water conditions extend upstream well beyond the point of Facility water withdrawals. Conversely, freshwater at the surface can extend downstream to near the river's mouth under conditions of extended periods of freshwater inflow.

**Dissolved Oxygen (mg/L)** – The plots suggest that as flows increase, upstream surface water dissolved oxygen concentrations may be depressed. As previously discussed, increasing freshwater inflows result in higher ambient water color, which results in reduced penetration of light into the water column and slows phytoplankton growth and consequently the production of oxygen. In addition, water column density stratification increases with increasing flow,

especially in the lower reaches of the river. These phenomena, combined with the physical decrease in saturation levels with increasing summer wet-season temperatures, results in the observed changes in surface dissolved oxygen levels with increasing flows in the upper areas of the lower Peace River HBMP transect.

**Water Color (Pt-Co Units)** – The presented series of graphics clearly depict the distinct patterns and marked changes that occur in water color as freshwater flows increase. The figures show the influences that “blackwater” river inflows have on the lower Peace River estuarine system.

**Turbidity (NTU)** – As indicated, lower Peace River turbidity levels are generally low and levels do not increase in response to higher levels of freshwater flows, since the relatively slow moving major blackwater tributaries do not carry large amounts of either silt or clay. The data do show indications of a turbidity maxima generally within the middle reach of the lower river approximately between River Kilometers five and fifteen, coinciding with the region of the lower river where the chlorophyll *a* maxima is often observed.

**Nitrite+Nitrate Nitrogen (mg/L)** – The observed changes in the spatial patterns of inorganic dissolved nitrite+nitrate nitrogen clearly show that initially higher ambient concentrations occur in the upper river under conditions of increasing levels of freshwater inflow. However, concentrations actually decline during periods of very high river flow, when groundwater levels are near the surface causing surface water runoff (sheetflow) to rapidly move water into the tributaries. These figures also show that dissolved inorganic nitrogen concentrations in the downstream more saline reaches of the monitoring transect are at or near detection limits except during periods of very highest freshwater inflow.

**Ammonia/Ammonium Nitrogen (mg/L)** – As previously discussed, ammonia/ammonium nitrogen concentrations spatially increase and high spikes occur at the downstream HBMP monitoring sites during periods of high river flow, probably reflecting salinity stratification induced development of hypoxic/anoxic bottom water conditions.

**Total Kjeldahl Nitrogen (mg/L)** – Spatially total Kjeldahl nitrogen concentrations (which measures both organic nitrogen and inorganic ammonia) along the HBMP fixed station monitoring transect generally show increasing patterns both moving upstream and with increasing levels of freshwater inflow.

**Total Phosphorus (mg/L)** – The observed patterns and response of total phosphorus in the lower Peace River estuarine system is very similar to that exhibited by inorganic nitrite+nitrate nitrogen. Concentrations progressively increase upstream towards the freshwater source, and initially rise in response to higher levels of freshwater inflow. However, as freshwater flows increase and surface water runoff begins to provide an ever greater percentage of total river flow, the actual concentration of total phosphorus (which is usually more than ninety percent dissolved inorganic) declines.

**Silica (mg/L)** – The observed spatial pattern of reactive silica within the lower Peace River estuarine system reflects the influences of freshwater inflows. Seasonally, as freshwater inflows

become greater, ambient reactive silica concentrations are shown to both increase and move further downstream.

**Dissolved and Total Organic Carbon (mg/L)** – The series of box and whisker plots of both dissolved and total organic carbon concentrations show very similar spatial patterns and responses to changes in levels of freshwater inflow. On average organic carbon levels generally increase both upstream and in response to higher levels of freshwater inflow.

**Chlorophyll *a*** – Other studies (PBS&J 1999, 2002) have shown that chlorophyll *a* along the lower Peace River HBMP monitoring transect exhibits distinct spring and fall increases that are influenced by both the timing and amounts of freshwater inflow into the river estuarine system. The presented box and whisker plots show that normally there is a distinct chlorophyll *a* phytoplankton maxima that spatially occurs along the monitoring transect, and that the location of this maxima generally moves downstream as river flow increases.

### 4.5.4 Response of Water Quality Parameters by Sampling Site to Changes in Freshwater Flows

Plots of sub-surface measurements versus gaged Peace River at Arcadia flow (0 to 2100 cfs) for each of the selected water quality parameters are presented in Table 4.15. These analyses provide further increased support for the previously described water quality responses to seasonal changes in freshwater inflow at each of the fixed HBMP sampling locations.

**Table 4.15**  
**Water Quality Parameters Versus Flow**

| Water Quality Parameter   | Monitoring Station River Kilometer |                |                |                |                |
|---------------------------|------------------------------------|----------------|----------------|----------------|----------------|
|                           | -2.2                               | 6.6            | 15.5           | 23.6           | 30.4           |
| Salinity                  | Figure 4.5.340                     | Figure 4.5.341 | Figure 4.5.342 | Figure 4.5.343 | Figure 4.5.344 |
| Dissolved Oxygen          | Figure 4.5.345                     | Figure 4.5.346 | Figure 4.5.347 | Figure 4.5.348 | Figure 4.5.349 |
| Water Color               | Figure 4.5.350                     | Figure 4.5.351 | Figure 4.5.352 | Figure 4.5.353 | Figure 4.5.354 |
| Turbidity                 | Figure 4.5.355                     | Figure 4.5.356 | Figure 4.5.357 | Figure 4.5.358 | Figure 4.5.359 |
| Nitrite+Nitrate Nitrogen  | Figure 4.5.360                     | Figure 4.5.361 | Figure 4.5.362 | Figure 4.5.363 | Figure 4.5.364 |
| Ammonia/Ammonium Nitrogen | Figure 4.5.365                     | Figure 4.5.366 | Figure 4.5.367 | Figure 4.5.368 | Figure 4.5.369 |
| Total Kjeldahl Nitrogen   | Figure 4.5.370                     | Figure 4.5.371 | Figure 4.5.372 | Figure 4.5.373 | Figure 4.5.374 |
| Total Phosphorus          | Figure 4.5.375                     | Figure 4.5.376 | Figure 4.5.377 | Figure 4.5.378 | Figure 4.5.379 |



**Table 4.15**  
**Water Quality Parameters Versus Flow**

| Water Quality Parameter  | Monitoring Station River Kilometer |                                |                                |                                |                                |
|--------------------------|------------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
|                          | -2.2                               | 6.6                            | 15.5                           | 23.6                           | 30.4                           |
| Silica                   | <a href="#">Figure 4.5.380</a>     | <a href="#">Figure 4.5.381</a> | <a href="#">Figure 4.5.382</a> | <a href="#">Figure 4.5.383</a> | <a href="#">Figure 4.5.384</a> |
| Total Organic Carbon     | <a href="#">Figure 4.5.385</a>     | <a href="#">Figure 4.5.386</a> | <a href="#">Figure 4.5.387</a> | <a href="#">Figure 4.5.388</a> | <a href="#">Figure 4.5.389</a> |
| Dissolved Organic Carbon | <a href="#">Figure 4.5.390</a>     | <a href="#">Figure 4.5.391</a> | <a href="#">Figure 4.5.392</a> | <a href="#">Figure 4.5.393</a> | <a href="#">Figure 4.5.394</a> |
| Chlorophyll a            | <a href="#">Figure 4.5.395</a>     | <a href="#">Figure 4.5.396</a> | <a href="#">Figure 4.5.397</a> | <a href="#">Figure 4.5.398</a> | <a href="#">Figure 4.5.399</a> |

Correlation analyses were utilized to determine potential statistical differences in the relationships between differing rates of USGS gaged Peace River at Arcadia flow and the selected surface water quality characteristics at each of the five spatially fixed HBMP sampling sites located along the lower river monitoring transect. The same seven statistically based river flow groupings described above in Section 4.5.3 were used in testing for correlations, and the results are present in the following series of summary tables.

- [Table 4.16](#) (River Kilometer –2.2)
- [Table 4.17](#) (River Kilometer 6.6)
- [Table 4.18](#) (River Kilometer 15.5)
- [Table 4.19](#) (River Kilometer 23.6)
- [Table 4.20](#) (River Kilometer 30.4)

The following briefly summarizes some of the apparent primary conclusions and patterns resulting from these flow based correlation analyses.

**Salinity (ppt)** – At the downstream sampling sites located near the river mouth, as expected there are distinct inverse relationships within each of the statistical flow categories between measured surface salinities and increases in gaged flow. However, these relationships break down further upstream as flows increase, as the water quality characteristics at these points along the sampling transect change from being tidally brackish to always being characteristically freshwater under conditions of increasing freshwater flows.

**Dissolved Oxygen (mg/L)** – The results generally show that surface dissolved oxygen concentrations along the monitoring transect initially increase under moderately higher levels of flow. However, above some level, further increases in flow tend to depress ambient surface dissolved oxygen levels. As previously discussed, initially increased flows result in nitrogen stimulation of phytoplankton production within the lower Peace River estuarine system. However, at some level additional increases in water color associated with higher flows results in

marked reductions in light penetration of the water column and the compensation depth, resulting in reduced phytoplankton dissolved oxygen production.

**Water Color (Pt-Co Units)** – Somewhat analogous to the previously described spatially divergent responses of surface salinities to increases in freshwater flows, levels of water color at the downstream monitoring sites show steady increases under ever higher rates of freshwater inflow. However, further upstream at some point further increases in flow do not correspond to additional changes in ambient water color, and under conditions of extremely high flows, color levels actually begin to decline.

**Nitrite+Nitrate Nitrogen (mg/L)** – The spatial relationships between dissolved inorganic nitrogen concentration and rates of freshwater inflow are complex. Under low to moderate levels of flow, nitrogen stimulates phytoplankton production and ambient levels are often near or at detection limits throughout much of the lower Peace River estuarine system. However, as flows increase and the river estuarine phytoplankton primary production become color rather than nitrogen limited, inorganic nitrogen levels increase with increasing flow. At the upstream sampling locations, a third condition occurs under very high flows as both water color and nutrient levels decline as the water quality characteristic of surface runoff moving to the river's major tributaries changes.

### 4.5.5 Spatial Correlations Among Water Quality Characteristics

A final series of correlation analyses were conducted to test for potential relationships among the previously described water quality parameters at each of the five fixed spatial HBMP sampling sites along the lower Peace River monitoring transect. Matrices of the results of these correlation tests are presented in the following series of summary tables. The first value for each comparison indicates the number of observations that were used, the second is the correlation coefficient, while the last value presents the level of significance. Caution should be used interpreting these correlation results since two parameters may show a significant correlation only because they are both highly related to a third (such as salinity), which as discussed may have varying responses to seasonal changes in freshwater inflows. Also, as a result of the high number of observations, the correlation analyses can indicate a high level of statistical significance for relationships with very small correlation.

- [Table 4.21](#) (River Kilometer –2.2)
- [Table 4.22](#) (River Kilometer 6.6)
- [Table 4.23](#) (River Kilometer 15.5)
- [Table 4.24](#) (River Kilometer 23.6)
- [Table 4.25](#) (River Kilometer 30.4)

## 4.6 Status and Trends in “Moving” Isohaline-Based Station Water Quality Parameters

The initial 1976 HBMP monitoring design incorporated a series of “fixed” sampling site locations, extending from near the mouth of Charlotte Harbor upstream, past the Facility, to the point where Horse Creek flows into the lower Peace River. In 1983, the Environmental Quality

Laboratory undertook monthly monitoring of phytoplankton primary productivity and water quality measurements at four salinity-based “moving” isohalines in addition to General Development’s lower Peace River/Charlotte Harbor general background monitoring programs. The selection of the salinity-based sampling zones was based on a literature review of known spatial estuarine differences among the major plankton groups.

- Oligohaline Conditions = 0 ppt (defined as upstream of 500 us/cm conductivity)
- Lower Mesohaline = 5-7 ppt
- Upper Mesohaline = 11-13 ppt
- Upper Brackish = 20-22 ppt

This second water quality sampling program element was subsequently added to the HBMP in 1987 in conjunction with other program modifications made during renewal of the Water Use Permit. The objective of the isohaline based monitoring HBMP program element was to develop a thorough understanding of the processes controlling phytoplankton production within Charlotte Harbor in order to quantify the estuary's immediate and long-term responses to both seasonal and long-term changes in freshwater flows and nutrient inputs. Phytoplankton production generally represents an immediately available food resource, and is the largest single component of primary production directly accessible to grazing, filtering and detrital feeding organisms. Phytoplankton production and composition, due to the short generation times involved, have been shown to be effective in demonstrating seasonal and long-term changes in water quality, and have been used to provide information on both direct and predictive secondary impacts of external influences such as freshwater withdrawals.

Statistically comparable levels of phytoplankton  $^{14}\text{C}$  fixation rates were measured monthly at each of the four salinity-based isohaline locations between June 1983 and December 1999. Although, direct *in situ* measurements of phytoplankton carbon uptake rates are no longer being measured, monthly determinations continue to be made at the four isohaline locations for phytoplankton biomass (chlorophyll *a*) and population structure, related physical water quality parameters, water column light extinction, and associated major near surface chemical constituents. The four sampling locations in this study represent non-fixed surface salinity zones, such that the monthly location of each isohaline is dependent upon the preceding amount of freshwater inflow from the Peace River. Table 4.26 summarizes the historical statistical distributions of these isohalines along the HBMP Peace River monitoring transect.

**Table 4.26**

**Summary Statistics of the Four Isohaline Locations (River Kilometers) from the Peace River’s Mouth for the Period 1983-2002**

| <b>Isohaline</b> | <b>Minimum</b> | <b>Maximum</b> | <b>Mean</b> | <b>Median</b> |
|------------------|----------------|----------------|-------------|---------------|
| <b>0 ppt</b>     | 3.4            | 37.6           | 21.7        | 20.9          |
| <b>6 ppt</b>     | -16.3          | 27.5           | 12.5        | 12.1          |
| <b>12 ppt</b>    | -30.1          | 24.5           | 7.3         | 8.6           |
| <b>20 ppt</b>    | -36.3          | 18.0           | -0.4        | 2.2           |

To date, the most upstream occurrence of the 0 ppt isohaline sampling location has been just over a quarter mile upstream of the point where Horse Creek joins the Peace River (June 2000). The most downstream occurrence of the 20 ppt isohaline sampling location has been in the Gulf of Mexico just off Boca Grande (September 1988) (see [Figure 4.6.1](#)).

## 4.6.1 Gaged Peace River Flow 1983-2002

Table 4.27 presents graphical time series plots over the 1983-2002 period of the HBMP “moving” isohaline-based monitoring of daily and monthly mean and median gaged Peace River flows at the three river locations used to account for differing contributions of the major gaged river tributaries (see Section 4.2 above). Box plots depicting the average annual monthly hydrograph of mean gaged flows are also presented for each of these three points along the river.

**Table 4.27**  
**Gaged Peace River Flow**

| Combined Peace River Gaged Flows          | Time Series Plots            |                              |                               | Seasonal Box Plots            |                               |
|-------------------------------------------|------------------------------|------------------------------|-------------------------------|-------------------------------|-------------------------------|
|                                           | Daily                        | Monthly Mean                 | Monthly Median                | Monthly Mean                  | Monthly Median                |
| Peace River at Arcadia                    | <a href="#">Figure 4.6.2</a> | <a href="#">Figure 4.6.5</a> | <a href="#">Figure 4.6.8</a>  | <a href="#">Figure 4.6.11</a> | <a href="#">Figure 4.6.14</a> |
| Total Gaged Flow Upstream of Facility     | <a href="#">Figure 4.6.3</a> | <a href="#">Figure 4.6.6</a> | <a href="#">Figure 4.6.9</a>  | <a href="#">Figure 4.6.12</a> | <a href="#">Figure 4.6.15</a> |
| Total Gaged Flow Upstream of US 41 Bridge | <a href="#">Figure 4.6.4</a> | <a href="#">Figure 4.6.7</a> | <a href="#">Figure 4.6.10</a> | <a href="#">Figure 4.6.13</a> | <a href="#">Figure 4.6.16</a> |

Two different statistical methods were used to test for the potential presence of long-term systematic changes in total gage flows at each of the selected river locations. The first statistical method was used to determine whether the data indicate significant trends in seasonally adjusted mean annual total gaged flows at each of these three points along the Peace River over the 1984-2002 time period. The nonparametric Seasonal Kendall Tau statistical procedure was also used to test for the potential presence of significant trends at these locations in seasonally adjusted mean monthly gaged river flows over the nineteen-year interval coinciding with the HBMP isohaline-based monitoring. The results of these trend tests for monthly mean flows are summarized in Table 4.28, while Table 4.29 presents analogous results for trend tests of monthly median Peace River flows.

The two trend testing procedures, the Coastal Environmental (1996) method based on seasonally adjusted annual determinations and the Seasonal Kendall Tau procedure based on comparisons of seasonally adjusted monthly values, both indicated that while gaged freshwater flows

generally increased during the nineteen years between 1984 and 2002, these changes were not statistically significant when calculated for either monthly mean or median values.

**Table 4.28**
**Trend Tests of Gaged Annual Monthly Mean Peace River Flow 1983-2002**

| <b>Gaged Peace River Flow Locations</b>   | <b>Seasonally Adjusted Annual Means</b> |              |                | <b>Seasonal Kendall Tau of Monthly Means</b> |                   |                   |              |
|-------------------------------------------|-----------------------------------------|--------------|----------------|----------------------------------------------|-------------------|-------------------|--------------|
|                                           | <b>Monthly Mean</b>                     | <b>Slope</b> | <b>P Value</b> | <b>Tau Value</b>                             | <b>Un- Adj. P</b> | <b>Adjusted P</b> | <b>Slope</b> |
| Peace River at Arcadia                    | <a href="#">Figure 4.6.17</a>           | 10.7         | 0.336          | 0.03                                         | 0.564             | 0.760             | 2.2          |
| Total Gaged Flow Upstream of Facility     | <a href="#">Figure 4.6.18</a>           | 15.4         | 0.304          | 0.03                                         | 0.565             | 0.761             | 3.4          |
| Total Gaged Flow Upstream of US 41 Bridge | <a href="#">Figure 4.6.19</a>           | 18.1         | 0.345          | 0.03                                         | 0.565             | 0.761             | 2.2          |

**Table 4.29**
**Trend Tests of Gaged Monthly Median Peace River Flow 1983-2002**

| <b>Gaged Peace River Flow Locations</b>   | <b>Seasonally Adjusted Annual Medians</b> |              |                | <b>Seasonal Kendall Tau of Monthly Medians</b> |                   |                   |              |
|-------------------------------------------|-------------------------------------------|--------------|----------------|------------------------------------------------|-------------------|-------------------|--------------|
|                                           | <b>Monthly Median</b>                     | <b>Slope</b> | <b>P Value</b> | <b>Tau Value</b>                               | <b>Un- Adj. P</b> | <b>Adjusted P</b> | <b>Slope</b> |
| Peace River at Arcadia                    | <a href="#">Figure 4.6.20</a>             | 5.3          | 0.577          | 0.01                                           | 0.816             | 0.902             | 0.5          |
| Total Gaged Flow Upstream of Facility     | <a href="#">Figure 4.6.21</a>             | 8.0          | 0.516          | 0.01                                           | 0.824             | 0.906             | 1.1          |
| Total Gaged Flow Upstream of US 41 Bridge | <a href="#">Figure 4.6.22</a>             | 10.1         | 0.522          | 0.01                                           | 0.816             | 0.902             | 0.5          |

**4.6.2 Relative Isohaline Location**

Time series plots of the monthly long-term relative locations of each of the four monitored “moving” isohaline HBMP salinity zones are presented in Table 4.30. Corresponding box and whisker plots depicting the seasonal monthly variability of each of the monitored salinity zones are also included. These figures clearly indicate the large degree of both interannual and seasonal variability that occurs in the relative locations of the monitored isohalines along the established lower Peace River/upper Charlotte Harbor River Kilometer transect. As shown above in Table 4.26, long-term and extreme variations in estuarine freshwater inflows have resulted in as much

as 35 to 55 kilometer variations in the relative spatial distributions among the four monitored isohaline sampling locations.

**Table 4.30**  
**Long-term and Seasonal Variability of Estuarine Isohaline Zones**

| <b>Isohaline</b>                              | <b>Time Series Plot</b>        | <b>Box Plot of the Monthly Variability</b> |
|-----------------------------------------------|--------------------------------|--------------------------------------------|
| 0 ppt Salinity - First Upstream Occurrence    | <a href="#">Figure 4.6.23a</a> | <a href="#">Figure 4.6.23b</a>             |
| 6 ppt Salinity – First Downstream Occurrence  | <a href="#">Figure 4.6.24a</a> | <a href="#">Figure 4.6.24b</a>             |
| 12 ppt Salinity – First Downstream Occurrence | <a href="#">Figure 4.6.25a</a> | <a href="#">Figure 4.6.25b</a>             |
| 20 ppt Salinity – First Downstream Occurrence | <a href="#">Figure 4.6.26a</a> | <a href="#">Figure 4.6.26b</a>             |

Both the Coastal Environmental method of testing seasonally adjusted annual averages and the monthly Seasonal Kendall Tau statistical procedure were next used to test for potential trends over the 1984-2002 time interval in the locations of each of the four monitored “moving” isohaline-based HBMP monitored salinity zones. Table 4.31 presents and summarizes the results of these trend analyses.

(Note: The presented time series plots for the “moving” isohaline-based salinity zones start in 1983 coinciding with the beginning of monitoring, while January 1984 was used as the starting point for all statistical summaries and trend analyses in order to include twelve months of data and equal numbers of seasons within each of the nineteen years of the analyzed time interval.)

**Table 4.31**  
**Trend Tests of Isohaline Locations 1984-2002**

| <b>Salinity-Based Isohaline Location</b>      | <b>Seasonally Adjusted Annual Means</b> |              |                | <b>Seasonal Kendall Tau of Monthly Means</b> |                   |                   |              |
|-----------------------------------------------|-----------------------------------------|--------------|----------------|----------------------------------------------|-------------------|-------------------|--------------|
|                                               | <b>Monthly Mean</b>                     | <b>Slope</b> | <b>P Value</b> | <b>Tau Value</b>                             | <b>Un- Adj. P</b> | <b>Adjusted P</b> | <b>Slope</b> |
| 0 ppt Salinity - First Upstream Occurrence    | <a href="#">Figure 4.6.27</a>           | 0.35         | 0.001          | 0.15                                         | 0.002             | 0.162             | 0.28         |
| 6 ppt Salinity – First Downstream Occurrence  | <a href="#">Figure 4.6.28</a>           | -0.001       | 0.996          | 0.01                                         | 0.840             | 0.924             | 0.01         |
| 12 ppt Salinity – First Downstream Occurrence | <a href="#">Figure 4.6.29</a>           | -0.03        | 0.631          | 0.02                                         | 0.746             | 0.879             | 0.02         |
| 20 ppt Salinity – First Downstream Occurrence | <a href="#">Figure 4.6.30</a>           | -0.04        | 0.700          | 0.01                                         | 0.785             | 0.902             | 0.02         |



The influences of the recent (1999-2002) extended drought that affected rainfalls throughout southwest Florida on the relative locations of each of the four isohalines are clearly depicted. Trend analysis of the River Kilometer location of the freshwater/saltwater interface (0 ppt isohaline) determined based on seasonally (three) adjusted annual means indicated that the influences of this drought resulted in a statistically significant trend in the upstream movement of the freshwater interface. It should be noted, however, that none of the other three isohalines showed any similar significant changes. When the same monthly data were analyzed using the more conservative Seasonal Kendall Tau procedure for trends using probabilities corrected for serial autocorrelation, the observed influences for the extended drought were found not to result in an overall long-term trend in the location of the freshwater/saltwater interface over the entire nineteen-year record.

### 4.6.3 Water Quality Characteristics

Time series plots of selected water quality parameters collected from sub-surface samples at each of the four “moving” HBMP monitoring locations between 1983 and 2002 are presented in Table 4.32. Box and whisker plots of monthly data showing annual seasonal differences are presented in Table 4.33. These graphical analyses provide overviews of the ranges and patterns for each of the selected water quality parameters of both annual and interannual variability during the nineteen-year period of monitoring at the four monitored salinity zones within the lower Peace River/upper Charlotte Harbor estuarine system. All water quality data from 1983 through 2001 were analyzed by EQL, while the recent 2002 water chemistry data were analyzed by Benchmark Laboratories (PBS&J 2003).

**Table 4.32**  
**Time Series Plots of Surface Water Quality Parameters at Isohaline-Based “Moving” HBMP Monitoring Salinity Zones**

| Water Quality Parameter  | 0 ppt Salinity First Upstream Occurrence | 6 ppt Salinity First Downstream Occurrence | 12 ppt Salinity First Downstream Occurrence | 20 ppt Salinity First Downstream Occurrence |
|--------------------------|------------------------------------------|--------------------------------------------|---------------------------------------------|---------------------------------------------|
| Water Color              | Figure 4.6.31                            | Figure 4.6.41                              | Figure 4.6.51                               | Figure 4.6.61                               |
| Turbidity                | Figure 4.6.32                            | Figure 4.6.42                              | Figure 4.6.52                               | Figure 4.6.62                               |
| Nitrite+Nitrate          | Figure 4.6.33                            | Figure 4.6.43                              | Figure 4.6.53                               | Figure 4.6.63                               |
| Ammonia/Ammonium         | Figure 4.6.34                            | Figure 4.6.44                              | Figure 4.6.54                               | Figure 4.6.64                               |
| Total Kjeldahl Nitrogen  | Figure 4.6.35                            | Figure 4.6.45                              | Figure 4.6.55                               | Figure 4.6.65                               |
| Total Phosphorus         | Figure 4.6.36                            | Figure 4.6.46                              | Figure 4.6.56                               | Figure 4.6.66                               |
| Silica                   | Figure 4.6.37                            | Figure 4.6.47                              | Figure 4.6.57                               | Figure 4.6.67                               |
| Total Organic Carbon     | Figure 4.6.38                            | Figure 4.6.48                              | Figure 4.6.58                               | Figure 4.6.68                               |
| Dissolved Organic Carbon | Figure 4.6.39                            | Figure 4.6.49                              | Figure 4.6.59                               | Figure 4.6.69                               |
| Chlorophyll a            | Figure 4.6.40                            | Figure 4.6.50                              | Figure 4.6.60                               | Figure 4.6.70                               |

Table 4.33

### Box Plots of Monthly Data Showing Annual Seasonal Patterns of Surface Water Quality Parameters at Isohaline Monitoring Locations

| Water Quality Parameter  | 0 ppt Salinity First Upstream Occurrence | 6 ppt Salinity First Downstream Occurrence | 12 ppt Salinity First Downstream Occurrence | 20 ppt Salinity First Downstream Occurrence |
|--------------------------|------------------------------------------|--------------------------------------------|---------------------------------------------|---------------------------------------------|
| Water Color              | Figure 4.6.71                            | Figure 4.6.81                              | Figure 4.6.91                               | Figure 4.6.101                              |
| Turbidity                | Figure 4.6.72                            | Figure 4.6.82                              | Figure 4.6.92                               | Figure 4.6.102                              |
| Nitrite+Nitrate          | Figure 4.6.73                            | Figure 4.6.83                              | Figure 4.6.93                               | Figure 4.6.103                              |
| Ammonia/Ammonium         | Figure 4.6.74                            | Figure 4.6.84                              | Figure 4.6.94                               | Figure 4.6.104                              |
| Total Kjeldahl Nitrogen  | Figure 4.6.75                            | Figure 4.6.85                              | Figure 4.6.95                               | Figure 4.6.105                              |
| Total Phosphorus         | Figure 4.6.76                            | Figure 4.6.86                              | Figure 4.6.96                               | Figure 4.6.106                              |
| Silica                   | Figure 4.6.77                            | Figure 4.6.87                              | Figure 4.6.97                               | Figure 4.6.107                              |
| Total Organic Carbon     | Figure 4.6.78                            | Figure 4.6.88                              | Figure 4.6.98                               | Figure 4.6.108                              |
| Dissolved Organic Carbon | Figure 4.6.79                            | Figure 4.6.89                              | Figure 4.6.99                               | Figure 4.6.109                              |
| Chlorophyll a            | Figure 4.6.80                            | Figure 4.6.90                              | Figure 4.6.100                              | Figure 4.6.110                              |

The two previously used statistical methods were used to test for the potential presence of long-term systematic changes in these selected water quality characteristics at each estuarine isohaline. The first statistical method was used to determine if the data indicate significant trends in seasonally adjusted mean annual values, while the nonparametric Seasonal Kendall Tau statistical procedure was used to test for significant progressive trends over the nineteen-year period of monitoring. Table 4.34 presents the results of these analyses.

Table 4.34

### Trend Tests of Isohaline Water Quality Characteristics

| Salinity Based Isohaline Location               | Seasonally Adjusted Annual Means |       |         | Seasonal Kendall Tau of Monthly Means |            |            |       |
|-------------------------------------------------|----------------------------------|-------|---------|---------------------------------------|------------|------------|-------|
|                                                 | Yearly Mean                      | Slope | P Value | Tau Value                             | Un- Adj. P | Adjusted P | Slope |
| <b>0 ppt Salinity First Upstream Occurrence</b> |                                  |       |         |                                       |            |            |       |
| Water Color                                     | Figure 4.6.111                   | 0.85  | 0.239   | 0.08                                  | 0.103      | 0.264      | 1.00  |

**Table 4.34**  
**Trend Tests of Isohaline Water Quality Characteristics**

| Salinity Based Isohaline Location               | Seasonally Adjusted Annual Means |        |         | Seasonal Kendall Tau of Monthly Means |            |            |        |
|-------------------------------------------------|----------------------------------|--------|---------|---------------------------------------|------------|------------|--------|
|                                                 | Yearly Mean                      | Slope  | P Value | Tau Value                             | Un- Adj. P | Adjusted P | Slope  |
| Turbidity                                       | Figure 4.6.112                   | -0.06  | 0.008   | -0.15                                 | 0.014      | 0.238      | -0.06  |
| Nitrite + Nitrate                               | Figure 4.6.113                   | 0.006  | 0.160   | 0.04                                  | 0.416      | 0.519      | 0.006  |
| Ammonia / Ammonium                              | Figure 4.6.114                   | -0.001 | 0.050   | -0.09                                 | 0.066      | 0.096      | -0.001 |
| Total Kjeldahl Nitrogen                         | Figure 4.6.115                   | 0.02   | 0.001   | 0.20                                  | 0.000      | 0.049      | 0.02   |
| Total Phosphorus                                | Figure 4.6.116                   | -0.011 | 0.001   | -0.24                                 | 0.000      | 0.012      | -0.011 |
| Silica                                          | Figure 4.6.117                   | 0.04   | 0.001   | 0.12                                  | 0.016      | 0.153      | 0.03   |
| Total Organic Carbon                            | Figure 4.6.118                   | -0.74  | 0.001   | -0.26                                 | 0.000      | 0.025      | -0.67  |
| Dissolved Organic Carbon                        | Figure 4.6.119                   | -0.17  | 0.316   | -0.11                                 | 0.084      | 0.353      | -0.30  |
| Chlorophyll a                                   | Figure 4.6.120                   | -0.31  | 0.003   | -0.14                                 | 0.005      | 0.094      | -0.12  |
| <b>6 ppt Salinity First Upstream Occurrence</b> |                                  |        |         |                                       |            |            |        |
| Water Color                                     | Figure 4.6.121                   | 1.15   | 0.030   | 0.12                                  | 0.016      | 0.122      | 1.17   |
| Turbidity                                       | Figure 4.6.122                   | -0.08  | 0.035   | -0.17                                 | 0.007      | 0.104      | -0.08  |
| Nitrite+Nitrate                                 | Figure 4.6.123                   | -0.002 | 0.158   | -0.11                                 | 0.019      | 0.053      | -0.001 |
| Ammonia/Ammonium                                | Figure 4.6.124                   | 0.001  | 0.135   | 0.01                                  | 0.839      | 0.877      | 0.001  |
| Total Kjeldahl Nitrogen                         | Figure 4.6.125                   | 0.01   | 0.144   | 0.19                                  | 0.000      | 0.032      | 0.02   |
| Total Phosphorus                                | Figure 4.6.126                   | -0.007 | 0.001   | -0.20                                 | 0.000      | 0.040      | -0.007 |
| Silica                                          | Figure 4.6.127                   | 0.04   | 0.001   | 0.13                                  | 0.007      | 0.121      | 0.02   |
| Total Organic Carbon                            | Figure 4.6.128                   | -0.49  | 0.003   | -0.23                                 | 0.000      | 0.022      | -0.40  |

**Table 4.34**  
**Trend Tests of Isohaline Water Quality Characteristics**

| Salinity Based Isohaline Location                | Seasonally Adjusted Annual Means |        |         | Seasonal Kendall Tau of Monthly Means |            |            |        |
|--------------------------------------------------|----------------------------------|--------|---------|---------------------------------------|------------|------------|--------|
|                                                  | Yearly Mean                      | Slope  | P Value | Tau Value                             | Un- Adj. P | Adjusted P | Slope  |
| Dissolved Organic Carbon                         | Figure 4.6.129                   | -0.15  | 0.257   | -0.11                                 | 0.075      | 0.307      | -0.16  |
| Chlorophyll <u>a</u>                             | Figure 4.6.130                   | 0.01   | 0.962   | 0.00                                  | 0.934      | 0.938      | 0.00   |
| <b>12 ppt Salinity First Upstream Occurrence</b> |                                  |        |         |                                       |            |            |        |
| Water Color                                      | Figure 4.6.131                   | 1.39   | 0.001   | 0.21                                  | 0.000      | 0.006      | 1.33   |
| Turbidity                                        | Figure 4.6.132                   | -0.09  | 0.062   | -0.10                                 | 0.114      | 0.240      | -0.05  |
| Nitrite+Nitrate                                  | Figure 4.6.133                   | -0.002 | 0.133   | -0.01                                 | 0.832      | 0.855      | -0.002 |
| Ammonia/Ammonium                                 | Figure 4.6.134                   | 0.002  | 0.005   | 0.15                                  | 0.002      | 0.020      | 0.002  |
| Total Kjeldahl Nitrogen                          | Figure 4.6.135                   | 0.008  | 0.127   | 0.18                                  | 0.000      | 0.043      | 0.01   |
| Total Phosphorus                                 | Figure 4.6.136                   | -0.004 | 0.002   | -0.13                                 | 0.009      | 0.152      | -0.004 |
| Silica                                           | Figure 4.6.137                   | 0.05   | 0.001   | 0.20                                  | 0.000      | 0.022      | 0.04   |
| Total Organic Carbon                             | Figure 4.6.138                   | -0.52  | 0.014   | -0.24                                 | 0.000      | 0.022      | -0.31  |
| Dissolved Organic Carbon                         | Figure 4.6.139                   | -0.30  | 0.041   | -0.15                                 | 0.015      | 0.159      | -0.20  |
| Chlorophyll a                                    | Figure 4.6.140                   | -0.05  | 0.867   | 0.03                                  | 0.607      | 0.700      | 0.03   |
| <b>20 ppt Salinity First Upstream Occurrence</b> |                                  |        |         |                                       |            |            |        |
| Water Color                                      | Figure 4.6.141                   | 1.21   | 0.001   | 0.27                                  | 0.000      | 0.003      | 1.09   |
| Turbidity                                        | Figure 4.6.142                   | -0.03  | 0.409   | -0.04                                 | 0.573      | 0.649      | -0.01  |
| Nitrite+Nitrate                                  | Figure 4.6.143                   | -0.001 | 0.923   | 0.14                                  | 0.004      | 0.084      | -0.001 |
| Ammonia/Ammonium                                 | Figure 4.6.144                   | 0.002  | 0.136   | 0.26                                  | 0.000      | 0.001      | 0.002  |

**Table 4.34**  
**Trend Tests of Isohaline Water Quality Characteristics**

| Salinity Based Isohaline Location | Seasonally Adjusted Annual Means |        |         | Seasonal Kendall Tau of Monthly Means |            |            |        |
|-----------------------------------|----------------------------------|--------|---------|---------------------------------------|------------|------------|--------|
|                                   | Yearly Mean                      | Slope  | P Value | Tau Value                             | Un- Adj. P | Adjusted P | Slope  |
| Total Kjeldahl Nitrogen           | Figure 4.6.145                   | 0.007  | 0.048   | 0.16                                  | 0.001      | 0.089      | 0.01   |
| Total Phosphorus                  | Figure 4.6.146                   | -0.001 | 0.155   | -0.06                                 | 0.245      | 0.607      | -0.001 |
| Silica                            | Figure 4.6.147                   | 0.05   | 0.001   | 0.25                                  | 0.000      | 0.006      | 0.04   |
| Total Organic Carbon              | Figure 4.6.148                   | -0.55  | 0.004   | -0.16                                 | 0.007      | 0.103      | -0.24  |
| Dissolved Organic Carbon          | Figure 4.6.149                   | -0.48  | 0.003   | -0.17                                 | 0.005      | 0.122      | -0.25  |
| Chlorophyll a                     | Figure 4.6.150                   | 0.03   | 0.825   | 0.06                                  | 0.188      | 0.360      | 0.10   |

The following briefly summarizes the primary conclusions that can be drawn from the observed annual, interannual and long-term patterns for each of the selected water quality parameters during the nineteen-year period of monitoring of salinity zones within the lower Peace River/upper Charlotte Harbor estuarine system.

**Water Color (Pt-Co Units)** – The blackwater systems of southwest Florida are characterized by the breakdown and leaching from decaying vegetation of humic compounds. As shown by the time series and box and whisker graphics, color levels rapidly increase in the lower estuarine salinity zones in response to higher levels of freshwater inflow. During periods of moderate to high levels of freshwater flow, the inflows of highly colored freshwater result in the strong spatial gradients in color concentrations depicted among the monitored four Charlotte Harbor salinity zones. As previously indicated, gaged freshwater inflows during the nineteen-year monitoring interval have shown a positive, although not statistically significant, increase. The applied statistical tests indicate that these increases, however, have resulted in statistically significant increases in ambient water color within the reaches of the estuary characterized by the two higher monitored salinity zones.

**Turbidity (NTU)** – The presented graphical time series plots suggest that turbidity levels in the lower salinity reaches of the estuary generally appeared to have declined during the nineteen-year monitoring period. These apparent declines at the three lowest salinity zones are statistically significant when the data are analyzed for trends on a basis of seasonally corrected annual averages. However, the observed declining patterns do not meet the criteria for statistical significance using the Seasonal Kendall Tau trend procedure, which corrects for monthly

autocorrelations. As indicated by the box and whisker plots of annual monthly variability, the highest turbidity levels typically occur in the lower Peace River/Charlotte Harbor estuarine system during the early spring and late fall, coinciding with the typical periods of peak phytoplankton production (biomass).

**Nitrite+Nitrate Nitrogen (mg/L)** – The time series and box and whisker plots show distinct spatial and seasonal differences in dissolved inorganic nitrite+nitrate nitrogen concentrations among the four monitored lower Peace River/upper Charlotte Harbor salinity zones. These plots indicate that ambient inorganic nitrogen concentrations are typically at or near detection limits in the highest salinity reaches of the estuary throughout most of the spring and summer when light levels are high and phytoplankton production is greatest. Concentrations are conversely greater at all four measured isohalines during the fall and winter months. Overall, ambient inorganic nitrogen levels progressively increase moving upstream from high to low salinities with the increasing influences of freshwater nutrient inputs and as increases in water color limit the penetration of light into the water column and therefore phytoplankton production (nitrogen uptake). The statistical trend tests do not indicate any system-wide progressive changes in inorganic nitrite+nitrate levels, although the Seasonal Kendall Tau procedure suggests that when the data are analyzed on a monthly basis, ambient concentrations may have slightly declined at the 6 and 20 ppt isohalines over the 1984-2002 sampling period.

**Ammonia/Ammonium Nitrogen (mg/L)** – Both the time series and box and whiskers graphics indicate that measured dissolved inorganic ammonia/ammonium levels do not show similar seasonal, flow related or spatial patterns as those previously described for inorganic nitrite+nitrate nitrogen. As expected, sub-surface inorganic ammonia/ammonium concentrations were often near detection limits (which often ranged from 0.008 to 0.10 depending on instrument calibration). However, high “spikes” in concentrations were observed with little indication of a clear causative factor. As indicated, in the region of the estuary characterized by salinities of 12 ppt, fall increases in surface ammonia/ammonium levels may be related to the fall breakdown of the seasonal thermocline/halocline and the turnover of high bottom ammonia/ammonium concentrations caused by flow induced stratification of the water column. It is possible that this mechanism, associated with the slightly higher average overall flows that have characterized the past decade, may explain why small, statistically significant increases in ammonia/ammonium concentrations were observed by the trend tests in the data from the two most downstream isohalines.

**Total Kjeldahl Nitrogen (mg/L)** – Seasonally, gross combined inorganic ammonia and organic nitrogen concentrations in the estuary show distinct patterns, with the highest levels typically occurring at the end and following the summer wet-season. Spatially the presented time series and box and whisker graphics indicate that total Kjeldahl nitrogen levels increase from higher to lower salinity waters, directly reflecting the influences of freshwater inputs. The combined results of the two applied methods of testing for long-term trends indicate that measurements of total Kjeldahl nitrogen have statistically significantly increased within each of the four monitoring isohaline zones over the 1984-2002-period. Again, this may reflect the influences of increased nitrogen inputs due to the increases (non-significant) observed in annual average freshwater inflows to the estuary over this time period.



**Total Phosphorus (mg/L)** – As previously discussed, the most dramatic changes in lower Peace River/upper Charlotte Harbor ambient total (and dissolved) phosphorus concentrations occurred prior to the start of the monitoring of primary production and water quality at the four salinity based isohaline zones (PBS&J 1999, 2002). Seasonally, the box and whisker plots clearly show that the highest phosphorus concentrations within each of the four salinity zones occur during the late spring during periods of lower river flow, when the influences of groundwater are more pronounced. The time series and box and whisker graphics both indicate that phosphorus concentrations increase from higher to lower salinity waters, directly reflecting the influences of freshwater inputs. Statistically, the observed declines in ambient total phosphorus concentrations have been significant over the 1984-2002 time period only within the 0 and 6 ppt salinity zones.

**Silica (mg/L)** – The time series plots clearly show that there have been marked increases in reactive silica concentrations in the surface water of the Charlotte Harbor estuarine system starting approximately after 1999. Using annual seasonally adjusted averages, the temporal changes are shown to be statistically significant at all four salinity zones, while long-term comparisons of seasonally adjusted monthly variations using the Seasonal Kendall Tau procedure indicates that the observed increases are statistically significant only within the two higher isohaline zones. The time series and box and whisker plots show that reactive silica levels increase spatially progressively upstream and that ambient concentrations are typically seasonally highest following the summer period of high freshwater inflows. Again, it is suspected that the observed increases in ambient reactive silica levels in the Peace River estuarine system may reflect the cumulative influences of the increased use of groundwater and the expansion of water intense agriculture throughout the Peace River watershed.

**Total and Dissolved Organic Carbon (mg/L)** – These two measurements of organic carbon were added to the HBMP salinity based monitoring program in 1990. The time series plots clearly indicate that the data collected prior to 1992 appear to be systematically greater than those obtained since that time. The explanation lies in the availability and implementation in 1992 of the use of new, computer controlled, automated chemistry analytical procedures. Since 1992, all organic carbon data have been obtained using mechanically injected chemistry instrumentation, which employs advanced infra-red detector technology. While this improvement in chemistry technology has provided for both greatly improved data accuracy and precision, the change in instrumentation may have added to the observed statistical significant trends in organic carbon observed at all four isohalines. Spatially and temporally organic carbon concentrations reflect the influences of both the relative contributions and timing of freshwater inflows.

**Chlorophyll *a*** - The long-term time series plots, as well as the applied annual and monthly-based trend procedures, indicate that there has been a decline in chlorophyll *a* phytoplankton biomass at the freshwater/saltwater interface (0 ppt isohaline) over the 1984-2002-time period. As previously noted in discussing the results from the “fixed” station HBMP monitoring, this apparent decline reflects a decline in the frequency of phytoplankton blooms in the upriver reaches of the monitoring program. Spatially, the highest levels of chlorophyll *a* occur within the two intermediate salinity zones. During the spring, high levels of phytoplankton biomass often occur in the 6 ppt isohaline, which characterizes the zone of the estuary where nutrient rich freshwater first mixes with low nutrient harbor water. A second, often smaller peak in

phytoplankton chlorophyll *a* usually occurs within this salinity zone during the fall, as water color (inflow) decreases. Conversely, an opposite seasonal pattern occurs in the more saline 12 ppt salinity zone, where nutrients (nitrogen) are more limited and the spring phytoplankton bloom is smaller, and the fall increase in response to the reduction in light limitations is more pronounced. In the reaches of the estuary characterized by the 20 ppt isohaline, phytoplankton production is reduced and shows less seasonal variability, with the highest concentrations occurring at the end of the summer wet-season.

### 4.6.4 Response of Water Quality Parameters to Differing Levels of Freshwater Inflow within the Isohalines

Box and whisker plots were used to depict differences in the location and ambient sub-surface water quality characteristics among the four monitored lower Peace River/upper Charlotte Harbor estuary isohalines under differing flow conditions. Univariate plots of selected water quality parameters compare the four estuarine salinity zones under a series of flow ranges (as measured by the USGS Peace River at Arcadia gaging site).

- **Very Low Flows** (0 to 90 cfs) – representative of the lowest ten percent (Q10) of river flows during the 1976-2002 time period.
- **Low Flows** (90-160 cfs) – or flows within the Q10 to Q25 interval.
- **Normal Low Flows** (160-360 cfs) – flows characteristic of the long-term Q25 to Q50 range.
- **Normal High Flows** (360 to 920 cfs) – representative of Peace River Arcadia flows within the Q50 to Q75 statistical interval.
- **High Flows** (920 to 2100 cfs) – characterizing river flows in the Q75 to Q90 range.
- **Very High Flows** (above 2100 cfs) – or the upper ten percent of all observed flows during the 1976-2002 time period.
- **All Flows** – this final series of univariate box and whisker plots depicts the overall spatial differences and the range of observed variation in each of the water quality parameters without regard to flow.

The results of these graphical analyses are presented in Table 4.35.

Table 4.35

### Univariate Plots Of Water Quality Parameters Under Differing Flow Categories

| Water Quality Parameter   | Flow Category – Range in Cubic Feet/Second |                |                |                |                |                |                |
|---------------------------|--------------------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                           | 0-90 cfs                                   | 90-160         | 160-360        | 360-920        | 920-2100       | > 2100         | All Flows      |
| River Kilometer           | Figure 4.6.151                             | Figure 4.6.152 | Figure 4.6.153 | Figure 4.6.154 | Figure 4.6.155 | Figure 4.6.156 | Figure 4.6.157 |
| Water Color               | Figure 4.6.158                             | Figure 4.6.159 | Figure 4.6.160 | Figure 4.6.161 | Figure 4.6.162 | Figure 4.6.163 | Figure 4.6.164 |
| Turbidity                 | Figure 4.6.165                             | Figure 4.6.166 | Figure 4.6.167 | Figure 4.6.168 | Figure 4.6.169 | Figure 4.6.170 | Figure 4.6.171 |
| Nitrite+Nitrate Nitrogen  | Figure 4.6.172                             | Figure 4.6.173 | Figure 4.6.174 | Figure 4.6.175 | Figure 4.6.176 | Figure 4.6.177 | Figure 4.6.178 |
| Ammonia/Ammonium Nitrogen | Figure 4.6.179                             | Figure 4.6.180 | Figure 4.6.181 | Figure 4.6.182 | Figure 4.6.183 | Figure 4.6.184 | Figure 4.6.185 |
| Total Kjeldahl Nitrogen   | Figure 4.6.186                             | Figure 4.6.187 | Figure 4.6.188 | Figure 4.6.189 | Figure 4.6.190 | Figure 4.6.191 | Figure 4.6.192 |
| Total Phosphorus          | Figure 4.6.193                             | Figure 4.6.194 | Figure 4.6.195 | Figure 4.6.196 | Figure 4.6.197 | Figure 4.6.198 | Figure 4.6.199 |
| Silica                    | Figure 4.6.200                             | Figure 4.6.201 | Figure 4.6.202 | Figure 4.6.203 | Figure 4.6.204 | Figure 4.6.205 | Figure 4.6.206 |
| Total Organic Carbon      | Figure 4.6.207                             | Figure 4.6.208 | Figure 4.6.209 | Figure 4.6.210 | Figure 4.6.211 | Figure 4.6.212 | Figure 4.6.213 |
| Dissolved Organic Carbon  | Figure 4.6.214                             | Figure 4.6.215 | Figure 4.6.216 | Figure 4.6.217 | Figure 4.6.218 | Figure 4.6.219 | Figure 4.6.220 |
| Chlorophyll a             | Figure 4.6.221                             | Figure 4.6.222 | Figure 4.6.223 | Figure 4.6.224 | Figure 4.6.225 | Figure 4.6.226 | Figure 4.6.227 |

The following patterns and observations can be drawn from the presented figures.

**Isohaline Location (River Kilometer)** – The series of plots indicate the effects of increased freshwater on the relative locations of each of the four HBMP isohalines along the lower Peace River/Charlotte Harbor monitoring transect. As shown by the series of figures, under low flow conditions, all four isohalines are confined over limited ranges within the lower river. The pattern of the isohalines changes with increasing flows, both moving more downstream and becoming more variable. Under high flows, the relative locations of the two highest salinity zones become highly variable, since their positions are to a great extent dependent upon the length of the preceding period of high flows. Overall, the variability of the relative locations of the four isohalines increases with salinity.

**Water Color (Pt-Co Units)** – Under conditions of lower flows, the presented series of graphics indicate that the intermediate salinities often have higher ambient color than the lowest or highest salinities. This suggests that during periods when groundwater comprises the major source of water coming from the Peace River watershed, the wetlands immediately surrounding the lower

river are the primary source (ungaged) of water color. However, as gaged freshwater flows from the watershed increase, the presented figures show the influences that “blackwater” river inflows have on the lower Peace River estuarine system.

**Turbidity (NTU)** – As indicated, turbidity levels within the Peace River/Charlotte Harbor estuarine system are generally low and do not proportionally increase in response to higher levels of freshwater inflow, since the blackwater tributaries do not naturally transport large amounts of either silt or clay. The data do show turbidity maxima generally occurring within the intermediate isohalines and corresponding with the zone of maximum phytoplankton production. Thus, within the lower Peace River/upper Charlotte Harbor estuarine system, turbidity levels generally reflect phytoplankton biomass rather than particulate material being carried from the watershed into the estuary.

**Nitrite+Nitrate Nitrogen (mg/L)** – The observed changes in the patterns of inorganic dissolved nitrite+nitrate nitrogen concentrations among the four salinity zones clearly show that, initially under conditions of increasing levels of freshwater inflow, ambient levels increase in the lower isohalines. However, concentrations actually decline during periods of very high river flow, when groundwater levels are near the surface and sheetflow rapidly moves water from the land and into the estuary. These figures also show that dissolved inorganic nitrogen concentrations within the highest salinity zone are typically at or near detection limits except during periods of very highest freshwater inflow.

**Ammonia/Ammonium Nitrogen (mg/L)** – As previously discussed, ammonia/ammonium nitrogen concentrations increase and high spikes are more frequent during periods of high freshwater inflow. These observations coincide with the development of strong salinity stratification in the region of the estuary downstream of the US 41 Bridge (River Kilometer 6.6) and the development of hypoxic/anoxic bottom water conditions over extensive areas of the lower river and upper harbor.

**Total Kjeldahl Nitrogen (mg/L)** – Overall, total Kjeldahl nitrogen concentrations (which measures both organic and inorganic forms of nitrogen) generally show increasing patterns both moving upstream and with increasing levels of freshwater inflow.

**Total Phosphorus (mg/L)** – Spatially, concentration patterns among the isohalines within the lower Peace River/upper Charlotte Harbor estuarine system act conservatively, with ambient levels reflecting the dilution of high freshwater concentrations by saltwater. As freshwater flows increase and surface sheetflow provides a greater percentage of total river flow, the concentrations of total phosphorus from upstream and within the isohalines declines.

**Silica (mg/L)** – Under lower levels of freshwater inflow, the presented series of graphics indicate higher ambient concentrations within the two intermediate isohalines (analogous to the pattern observed for water color). As gaged freshwater flows from the watershed increase, reactive silica concentrations in the estuary increase and the pattern among the isohalines indicates increasing concentrations toward the freshwater source.

**Dissolved and Total Organic Carbon (mg/L)** – The series of box and whisker plots of both dissolved and total organic carbon concentrations show very similar patterns among the four HBMP isohalines and in response to changes in levels of freshwater inflow. Overall average organic carbon levels generally increase both upstream and in response to higher levels of freshwater inflow.

**Chlorophyll *a*** – The presented series of box and whisker plots clearly show that the highest levels of phytoplankton chlorophyll *a* biomass occur spatially in the estuary within the two intermediate salinity zones, as freshwater high in color and inorganic nitrogen mixes with low color, nutrient poor high salinity water. Chlorophyll *a* concentrations are typically slightly higher within the 6 ppt isohaline, however under very high flows the phytoplankton maximum often shifts to the 12 ppt isohaline as increasing water color limits light levels in the lower isohaline.

#### 4.6.5 Response of Water Quality Parameters by Sampling Site to Changes in Freshwater Flows

Plots of the location and sub-surface measurements at each of the four HBMP isohalines versus gaged Peace River at Arcadia flow (0 to 2100 cfs) for each of the selected water quality parameters are presented in Table 4.36. These analyses provide further support for the previously described water quality responses to seasonal changes in freshwater inflow at each of the salinity based sampling locations. As these figures indicate, often a large degree of observed variation occurs at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. For example, water color at an isohaline can differ dramatically at intermediate levels of gage freshwater inflow depending on whether the sampling occurred early as flows were increasing or at the end of the summer wet-season as flows were decreasing.

**Table 4.36**

#### Water Quality Parameters Versus Flow

| Water Quality Parameter   | Estuarine Isohaline |                |                |                |
|---------------------------|---------------------|----------------|----------------|----------------|
|                           | 0 ppt               | 6 ppt          | 12 ppt         | 20 ppt         |
| River Kilometer           | Figure 4.6.228      | Figure 4.6.229 | Figure 4.6.230 | Figure 4.6.231 |
| Water Color               | Figure 4.6.232      | Figure 4.6.233 | Figure 4.6.234 | Figure 4.6.235 |
| Turbidity                 | Figure 4.6.236      | Figure 4.6.237 | Figure 4.6.238 | Figure 4.6.239 |
| Nitrite+Nitrate Nitrogen  | Figure 4.6.240      | Figure 4.6.241 | Figure 4.6.242 | Figure 4.6.243 |
| Ammonia/Ammonium Nitrogen | Figure 4.6.244      | Figure 4.6.245 | Figure 4.6.246 | Figure 4.6.247 |
| Total Kjeldahl Nitrogen   | Figure 4.6.248      | Figure 4.6.249 | Figure 4.6.250 | Figure 4.6.251 |
| Total Phosphorus          | Figure 4.6.252      | Figure 4.6.253 | Figure 4.6.254 | Figure 4.6.255 |
| Silica                    | Figure 4.6.256      | Figure 4.6.257 | Figure 4.6.258 | Figure 4.6.259 |
| Total Organic Carbon      | Figure 4.6.260      | Figure 4.6.261 | Figure 4.6.262 | Figure 4.6.263 |
| Dissolved Organic Carbon  | Figure 4.6.264      | Figure 4.6.265 | Figure 4.6.266 | Figure 4.6.267 |
| Chlorophyll <i>a</i>      | Figure 4.6.268      | Figure 4.6.269 | Figure 4.6.270 | Figure 4.6.271 |

Correlation analyses were utilized to determine potential statistical differences in the relationships between differing rates of USGS gaged Peace River at Arcadia flow and the selected surface water quality characteristics at each of the four moving isohaline based HBMP sampling locations. The same seven statistically based river flow groupings described above in Section 4.6.4 were used in testing for correlations, and the results are presented in the following series of summary tables.

- [Table 4.37](#) (0 ppt Isohaline)
- [Table 4.38](#) (6 ppt Isohaline)
- [Table 4.39](#) (12 ppt Isohaline)
- [Table 4.40](#) (20 ppt Isohaline)

The following briefly summarizes some of the apparent primary conclusions and patterns that have resulted from these flow based correlation analyses. Overall, even when statistically significant, the observed correlations between both overall and categories of freshwater inflow generally can only be used to explain small percentages of the observed annual and interannual variation observed at the four isohaline HBMP monitoring zones in the selected parameters.

**Isohaline Location (River Kilometer)** – The relative locations of each of the four HBMP isohalines along the lower Peace River/Charlotte Harbor monitoring transect show strong inverse correlations with freshwater inflows. However, as the figures indicate, over given ranges of flows there are often no strong relationships between flow and isohaline location along the monitoring transect. The observed confounding of the relationships results from the importance of both short and long-term preceding conditions, as well as physical stratification of the water column.

**Water Color (Pt-Co Units)** – Again, while ambient water color within each of the four salinity zones is significantly positively correlated with increasing flows, the overall patterns differ both among isohalines and flow categories. In general, the strongest relationships between water color and freshwater inflows occur at the lower two salinities over intermediate flows, and within the two higher salinities under much higher rates of freshwater inflow.

**Nitrite+Nitrate Nitrogen (mg/L)** – The observed relationships between dissolved inorganic nitrogen concentrations and rates of freshwater inflow at the four monitored isohalines are complex. Under low to moderate levels of flow, nitrogen stimulates phytoplankton production and ambient levels can be near detection limits throughout much of the lower Peace River estuarine system. However, as flows increase and the river estuarine phytoplankton primary production becomes color rather than nitrogen limited, ambient inorganic nitrogen levels increase with increasing flow. However, under conditions of very high freshwater inflow water color and nutrient levels decline again in the lower salinity reaches of the estuary as the water quality characteristic in the river's major tributaries changes.



#### 4.6.6 Spatial Correlations Among Water Quality Characteristics

A final series of correlation analyses were conducted to test for potential relationships among the selected water quality parameters at each of the four “moving” HBMP isohaline salinity-based sampling zones along the monitoring transect. Matrices of the results of these correlation tests are presented in the following series of summary tables. The first value for each comparison indicates the number of observations that were used, the second is the correlation coefficient, while the last value presents the level of significance. A great deal of care needs to be taken in interpreting these correlation results since two parameters may show a significant correlation only because they are both highly related to a third, which as discussed, may have varying responses to seasonal changes in freshwater inflows. Also, as a result of the high number of observations, the correlation analyses can indicate a high level of statistical significance for relationships with very small correlation that thus explain very little of the observed annual and interannual variation in these characteristics.

- [Table 4.41](#) (0 ppt Isohaline)
- [Table 4.42](#) (6 ppt Isohaline)
- [Table 4.43](#) (12 ppt Isohaline)
- [Table 4.44](#) (20 ppt Isohaline)

#### 4.7 Vegetation Analyses

The primary objective of the following analyses is to summarize the findings of key elements of the HBMP vegetation studies, and to determine the efficacy of their effectiveness regarding assessing potential negative impacts of withdrawals by the Peace River Facility. The oldest continuous (see [Table 1.3](#)) HBMP study elements have been the ongoing investigations designed to identify potential adverse affects to emergent vegetation and riverine wetlands that might potentially be associated with Facility freshwater withdrawals. Over the twenty-seven years of monitoring, the HBMP vegetation study elements have sought to determine the magnitude of vegetative community’s spatial and temporal responses to natural variations resulting from extended periods of both drought and flood along the lower Peace River. The primary goal of these investigations has been to provide a basis for assessing potential methodologies by which to differentiate between long-term natural changes in riverine vegetative patterns and those that might potentially be induced by Facility withdrawals. The overall objective of the vegetative monitoring HBMP study elements has been to provide a basis for determining the relationships between vegetation patterns and freshwater flows by observing the relative spatial positions and community structure of the freshwater and salt-tolerant plant communities in the salinity transitional zone of the lower river. The basic assumption has been that a permanent shift of more salt-tolerant plants upriver could be an indication that withdrawals were impacting lower river corridor wetlands, assuming that the effects of natural variability (drought) or other anthropogenic causes could be isolated in the analysis.

##### 4.7.1 First and Last Occurrence

A thorough analyses and summary of the long-term results of the HBMP “first and last” vegetation study element were conducted in the previous-2000 *Midterm Interpretive Report* .

Since 1976, at approximately two-year intervals, the first and last occurrence of a large number of indicator plant species has been recorded along the banks of the Peace River downstream of the Facility. The primary objective of this long-term study has been to assess the influences of long-term natural variations in river flow.

Seven common representative key plant taxa that characterize the vegetation along the lower Peace River were selected to determine the extent of long-term variability within these representative species and the efficacy of the methodology in determining potential Facility withdrawal impacts. These taxa were selected based on their life history, relative importance along the river, and sensitivity (or lack thereof) to changes in salinity. Table 4.45 summarizes the graphical analyses conducted for each of the selected seven indicator plant species. The graphics depict the first and last occurrence of the species during each of ten sampling events over the period 1977 to 1998. The first and last occurrences are plotted by date along the X-axis and River Kilometer on the Y-axis. A second line has then been added indicating yearly median freshwater total inflows from the three gaged sources upstream of the Peace River Facility over the twenty-two year period..

**Table 4.45**  
**2000 Analyses of First and Last Plant Indicator Species**

| Indicator Species                             | Figure       | Indicator Species                                | Figure       |
|-----------------------------------------------|--------------|--------------------------------------------------|--------------|
| Sawgrass ( <i>Cladium jamaicense</i> )        | Figure 4.7.1 | Leather fern ( <i>Acrostichum danaeifolium</i> ) | Figure 4.7.5 |
| Bulrush ( <i>Scirpus validus</i> )            | Figure 4.7.2 | Black needlerush ( <i>Juncus roemerianus</i> )   | Figure 4.7.6 |
| Southern cattail ( <i>Typha domingensis</i> ) | Figure 4.7.3 | Red mangrove ( <i>Rhizophora mangle</i> )        | Figure 4.7.7 |
| Sand cordgrass ( <i>Spartina bakeri</i> )     | Figure 4.7.4 |                                                  |              |

The 2000 Midterm Interpretive Report concluded that the first and last occurrences of these selected species had not been highly effective in determining the potential influences that might be associated with withdrawals. Some species had shown very little variation even following extended periods of high and low flows, while others have changed considerably back and forth over the extended period of study. It was concluded that some of the most apparent changes in first and last occurrences of indicator plant species had resulted from the creation or destruction of shallow shoals along the edges of the river during periods of high flow. The causes of other observed changes were found to be less obvious and clearly indicated the difficulty in determining meaningful relationships between freshwater inflows and the long-term distributions of these selected taxa (even considering the possible requirements for substantial lag affects).

### 4.7.2 Photointerpretation

An HBMP photographic vegetation study element was initiated in 1976 to assess long-term changes in the patterns of vegetation distributions along the lower Peace River, starting approximately at the US 41 Bridge (River Kilometer 6.6) and extending upstream above the Peace River Facility to near the area where Horse Creek enters the river (River Kilometer 39.5).

Since the 1996 HBMP permit renewal, aerial surveys have been conducted at two-year intervals in a corrected, Geographic Information System (GIS) compatible format, allowing for accurate qualitative and quantitative interpretation of potential changes associated with extended natural periods of low and high freshwater inflows. The following series of analyses were conducted using the GIS based aerial coverages of lower Peace River vegetation taken in 1998 and 2002. The initial 1998 baseline vegetation mapping was conducted following the extended 1997/1998 unusually wet El Niño climatic events (see [Figure 4.6.4](#)). In comparison, the aerial vegetation mapping conducted in December 2002 followed almost three years of severe drought that extended from 1999 through 2002. The primary objectives of these analyses were to determine the relative degrees of sensitivity of the aerial based vegetation surveys, as well as the influences of extended periods of high and low freshwater inflow on the overall structure of the vegetation communities along the lower Peace River.

GIS technology was used to create and perform vegetation change analysis along the lower Peace River study area extending approximately from the area of the I-75 Bridge crossing to just upstream of the Peace River Facility. The primary objective of the change analysis was to compare and assess differences in the spatial extent of dominant vegetation groupings along the lower river following extended periods of high (1998) and low (2002) river inflows ([Figure 4.7.8](#)).

The 1998 baseline GIS coverage was developed by combining existing information gathered for the District by Florida Marine Research Institute (FMRI), as well as HBMP vegetation mapping conducted by Earth-Balance. Both the 1994 FMRI information as well as the 1998 Earth-Balance aerial based vegetation mapping utilized Florida Land Use, Cover and Forms Classification System (FLUCFCS) Level 3/4 classifications. The 2002 aerial photography was flown at 1:12,000 (1" = 1,000ft) and portrayed as color infra-red 1" = 200.' The aerial photography was acquired in December 2002, following a brief cold period, in order to maximize the potential differences in vegetative communities between the two time periods. Earth-Balance biologists ground-truthed and used previous aerial mapping ground truthing field notes to assist in the specific identification of aerial infra-red vegetation signatures for both the 1998 and 2002 events.

A change analysis comparison between the 1998 and 2002 aerial vegetation mapping was undertaken using the GIS based "forward-dating" process, which can be used to compare aerial photography of the study area from different times. "Forward-dating" refers to the process of electronically overlaying the older vegetation patterns onto the more recent available aerials to delineate significant (definitionally defined as greater than the minimum mapping unit of 0.5 acres) differences in the vegetation patterns between the two sets of GIS based aerial images (see [Figure 4.7.9](#)). The "forward-dating" procedure was applied using 1998 lower Peace River mapping ([Figure 4.7.10](#)) to delineate areas of change by mapping differences onto clear acetate overlays, and developing an updated 2002 Level 3 FLUCFCS (Table 4.46) vegetation coverage ([Figure 4.7.11](#)).

The Level 3 1998 and 2002 GIS based FLUCFCS coverages were then used to develop comparisons following extended wet and dry periods of the overall spatial differences in the major vegetation groupings along the lower Peace River. The following outlines the series of steps used to develop the basis for this comparison.

- The initial step was to develop a GIS coverage of vegetation along the lower Peace River, dividing the lower river into 200-meter segments based on the existing HBMP standardized river centerline shapefile ([Figure 4.7.12](#)). A width of 3,500 feet was used for each segment in order to assure complete coverage of both shorelines.
- A 50-foot interval landward of the river shoreline was then designated for all the shorelines adjacent to the main river channel within each of the 200-meter river segments. This interval was selected in order to limit subsequent analyses to the vegetation immediately along the lower river that would be expected to exhibit the greatest influences due to salinity variations caused by shorter-term changes in river freshwater inflows.
- These intervals within the associated river segments were converted into an Arc/INFO coverage that was then intersected with the FLUCFCS coverages previously developed for each year.
- Arc/INFO was then used to develop a final data set of the total areas of each of the Level 3 FLUCFCS codes (Table 4.46) within each of the designated 200-meter segments along the lower river summarized for each of the years (1998 and 2002).

These GIS based vegetation maps and the same “forward-dating” methodology may be similarly used in the future to further quantitatively assess long-term differences, both among and between years.

**Table 4.46**  
**Florida Land Use, Cover and Forms Classification**  
**System (FLUCFCS) Level 3 Classifications**

| Land Use                     | FLUCFCS Code |
|------------------------------|--------------|
| Residential - medium density | 120          |
| Open land                    | 190          |
| Tree crops                   | 220          |
| Other open lands rural       | 260          |
| Herbaceous rangeland         | 310          |
| Shrub and brushland          | 320          |
| Pine flatwoods               | 411          |
| Pine flatwoods, disturbed    | 411-1        |
| Brazilian pepper             | 422          |
| Live oak                     | 427          |
| Sand live oak/cabbage palm   | 428          |

**Table 4.46**  
**Florida Land Use, Cover and Forms Classification**  
**System (FLUCFCS) Level 3 Classifications**

| Land Use                        | FLUCFCS Code |
|---------------------------------|--------------|
| Sand live oak                   | 432          |
| Sand live oak, disturbed        | 432-1        |
| Hardwood - conifer mix          | 434          |
| Streams and waterways           | 510          |
| Lakes > 1 0 acres               | 523          |
| Lakes < 1 0 acres               | 524          |
| Mangrove forest                 | 612          |
| Stream and lake swamp           | 615          |
| Mixed wetland hardwoods         | 617          |
| Wetland forested mix            | 630          |
| Vegetated non-forested wetlands | 640          |
| Freshwater marsh                | 641          |
| Saltmarsh                       | 642          |
| Emergent aquatic vegetation     | 644          |
| Sand                            | 720          |
| Disturbed lands                 | 740          |
| Borrow area                     | 742          |
| Roads and highways              | 814          |

The resulting data from the 1998 and 2002 GIS based aerial coverages were used to develop the series of graphical analyses presented in Table 4.47. The figures show the relative distributions of the four major Level 3 FLUCFCS riparian vegetation assemblages along the lower Peace River following extended wet (1998) and dry (2002) periods. The figures also depict a fitted line showing the maximum salinities observed at the monthly fixed HBMP monitoring sites over the preceding twenty-four months, indicating the major salinity differences along the river between the two periods. The vertical line at approximately RK 30.2 indicates the relative location of the Peace River Facility. Table 4.47 also indicates the calculated weighted relative center of abundances of each of the four major vegetation communities along the lower river based on the 1998 and 2002 GIS based aerial coverages. The relative spatial differences along the lower river (in River Kilometers) of the weighted centers of abundances among the four major riparian vegetation groups presented in Table 4.47 are further graphically depicted in [Figure 4.7.17](#). The two different color tree symbols depict the calculated centers of abundances of the four dominant riparian communities in 1998 following several years of unusually high flows, and in 2002 after an extended period of drought. Overall, these figures show the following patterns:

- Although there were fairly substantial differences in the salinity structure of the lower river between the wet period preceding the 1998 vegetation aerial mapping and the extended drought conditions prior to the 2002 survey, the analyses showed little, if any, differences in the weighted centers of abundances of either the saltwater marsh or hardwood forest communities along the lower river. To a great degree, this probably reflects the extensive period of time needed to result in substantial changes in the distributions of either of these communities. The saltwater marsh vegetation of the lower river is characterized by black needle rush (*Juncus roemerianus*), which becomes dominant in new areas very slowly. The hardwood forest areas that characterize the freshwater reaches of the upper HBMP study transect are comprised of long-lived trees. While visual observations noted some signs of stress in the trees immediately near the river during the driest periods of the extended drought, seasonal periods of higher inflows maintained the relative long-term distributions of the forested areas along the lower river.
- Small upstream movements in the weighted centers of abundances were, however, observed between the two periods in the distributions of mangrove and freshwater marsh vegetation along the lower river. To some extent, the upstream movement of mangroves may simply reflect the lack of the occurrence of any sustained hard freezes between the time periods rather than the occurrence of higher salinities during the drought. In comparing Figures [4.7.13a](#) and [4.7.13b](#) it is apparent that most of the observed change reflects the expansion of mangroves approximately between River Kilometers 14.0 and 17.0 along the lower river. Historically, the mangroves in this region of the river have been subject to extensive natural die offs resulting from periodic freezes.
- The net upstream movement of the weighted center of abundance of freshwater marsh communities following extended wet and dry periods may more directly reflect the influences of increased salinities along the lower river. In comparing Figures [4.7.15a](#) and [4.7.15b](#), most of the observed differences would seem to have resulted from the expansion of existing freshwater marsh communities between River Kilometers 17.5 and 21.0, an area of the river which was influenced by much higher salinities during the extended drought that preceded the 2002 vegetation mapping.
- In summary, a comparison of 1998 and 2002 aerial photography using GIS based forward-dating procedures indicates some small changes in the weighted centers of abundances of only two of the major riparian vegetation communities (mangroves and freshwater marsh) along the lower Peace River. The measured changes were small in comparison to the differences in the spatial salinity patterns during the extended wet and dry periods that preceded the two selected vegetation surveys. Based on these analyses, freshwater marsh may be the most sensitive indicator vegetation community for assessing salinity based impacts. Given these results, however, it is extremely doubtful whether any quantifiable changes in long-term vegetation patterns along the lower Peace River will ever be attributable to Facility withdrawals, since the magnitude of the predicted influences of Facility withdrawal are small relative to the normal



ranges of daily and seasonal salinity variations that influences the spatial distributions of these riparian vegetation communities.

**Table 4.47**  
**Comparisons Between 1998 and 2002 in the Spatial Distributions**  
**of Major Lower Peace River Plant Communities**

| Indicator Species | 1998                           |                     | 2002                           |                     |
|-------------------|--------------------------------|---------------------|--------------------------------|---------------------|
|                   | Figure                         | Center of Abundance | Figure                         | Center of Abundance |
| Mangrove          | <a href="#">Figure 4.7.13a</a> | 12.5                | <a href="#">Figure 4.7.13b</a> | 12.7                |
| Saltwater Marsh   | <a href="#">Figure 4.7.14a</a> | 12.7                | <a href="#">Figure 4.7.14b</a> | 12.7                |
| Freshwater Marsh  | <a href="#">Figure 4.7.15a</a> | 17.8                | <a href="#">Figure 4.7.15b</a> | 18.3                |
| Mixed Hardwoods   | <a href="#">Figure 4.7.16a</a> | 27.4                | <a href="#">Figure 4.7.16b</a> | 27.4                |

### 4.7.3 Vegetation Transition Sites

Under the current Permit, this portion of the HBMP study extends and expands the detailed monitoring of plant communities along the river's banks at fixed locations begun in 1979. The vegetative communities at three permanent transect sites (see [Figure 1.2](#) and [Table 1.1](#)) are sampled at two-year intervals. At each monitoring location, three transects are surveyed from the top of the bank to the water's edge. The vegetation one meter to each side of the transects is identified, and the location and percent density recorded. The primary objective of this long-term monitoring effort is to assess small scale changes of riverine vegetative communities in response to natural variations in freshwater flows.

There is a strong gradation in the vegetative associations that naturally occur along the river corridor from Charlotte Harbor upstream to the river's freshwater reaches. As previously discussed, the vegetation of the lower Peace River exhibits a gradual transition from fringing mangrove and salt marsh species near the harbor to freshwater swamp forest species upstream. The observed vegetation gradient results from the combined influences of brackish Charlotte Harbor water tidally moving upriver, and freshwater from the Peace River basin flowing downstream into the estuary. Tides and river flow interact to create a gradient of habitats ranging from those inhabited by salinity-tolerant species in the lowest reaches of the river to those completely dominated by freshwater species farther inland along the gradient. The inland extent of mangroves is also limited by the influences of periodic freezes. The causal relationships involved in the observed vegetation transitions along the lower river are therefore complex, and involve the interactions of:

- Seasonal and longer-term changes in the relative positions of isohalines along the river transect
- Small scale variations in river bank elevations and profiles

- Small scale variations in upland runoff and bank seepage
- A progressive change to more frost tolerant species inland

The primary concern associated with freshwater withdrawal is the potential for induced long-term alterations in riverine vegetative patterns and associations as a result of induced changes in the average position of fresh and salt water mixing zones. A decrease in freshwater inflow, either naturally occurring or induced, may move the average position of the mixing zone upstream resulting in higher river salinities at fixed points and a concomitant change in the vegetation community structure along the river over time.

The purpose of this portion of the HBMP is to examine long-term spatial vegetation patterns along the lower river corridor in the primary brackish mixing zones and identify changes in vegetation composition that may be attributable to changes in long-term freshwater inflow patterns. The objective of the following analyses is to compare recent observations at the fixed transitional riverine vegetation sites taken between 1997 and 2002, with comparable data collected over the ten-year period between 1983 through 1993.

### 4.7.3.1 Methodology

Initially, two HBMP transitional vegetation sites (Sites I and II) were selected along the eastern bank of the Peace River to assess long-term changes of emergent riparian and adjacent upland vegetation. Following the most recent permit renewal, a third site was added in 1997 midway between the previous two monitoring locations.

Site I was originally selected as being representative of the downstream portion of the lower Peace River, characteristic of the primary transitional zone from brackish conditions to the more saline harbor waters. A mangrove fringe, bordered by a narrow strip of upland vegetation, characterizes this Site.

Site II, by comparison, was selected as being more representative of a more upstream reach of the lower river, typical of the transitional zone from brackish to freshwater conditions. A wet, low-lying peninsula that grades into an adjacent upland plant community characterizes this monitoring location.

Previous analyses of the vegetation data collected at these two transitional sites were summarized in the HBMP 1993 *Summary Report*, which summarized the results of the vegetation monitoring over the 1976–1993 period. In this report, the vegetation at the transitional sites were classified as:

- Species growing in the water.
- Species growing on uplands above the top of bank at each site.
- Species along a single line-transect beginning above the shoreline and extending 10 meters waterward (starting in 1990).

Under the most recent Water Use Permit renewal, the transitional site component of the vegetation monitoring program was expanded by the inclusion of two new transect locations at

Sites I and II. In addition to the original single-line site transect these vegetation studies now also included conducting surveys along belt transects to either side of the original line transects. The procedures utilized included the identification of not only the plant species present, but also recording their location and determining the relative densities of each taxa within 1-meter plots along the length of the upstream side and the downstream side of the transect ([Figure 4.7.18](#)).

These investigations of the vegetation transition sites were further expanded by new Permit conditions to include the addition of a third fixed monitoring location. Site III was established between Sites I and II along a segment of the lower Peace River characterized by more seasonally variable salinity conditions than those typical of either Site I or Site II ([Figure 1.2](#)). Thus, beginning in 1997, the HBMP transitional riparian vegetation study element included three sampling site locations at which three fixed vegetation transects were monitored. The modified design included:

- One single-line transect based on previous monitoring procedures.
- One belt transect located 25 feet upstream of the line transect, with an upstream side and downstream side.
- One belt transect located 25 feet downstream of the line transect with an upstream side and downstream side.

Following the previous single-line transect methodology, vegetation along these three transects began upland above the shoreline and extended waterward 10 meters. In 2000, at the District's suggestion, this line was extended to the waterward limit of the riparian vegetation. Photographic stations were also established along the midlines of the waterward ends of the 10-meter transects. Photographs have been taken of each transect from these locations back toward the shoreline.

In addition, at each of the three transitional sites, upland vegetation is identified in an area measuring 25 feet x 50 feet immediately adjacent to the transects. These results plus a species list of "upland," "shoreline" and "transect vegetation" are recorded for each transect at each monitoring site. The resulting transitional site vegetation data have been reported in recent annual HBMP Data Reports.

Due to the 1997 changes of the survey methods, the data previously reported in the 1993 *Summary Report* are considered separately from the more recent 1997-2002 time period in the following summary of the long-term results of the transitional vegetation site data. Even the single-line transect data, collected from 1990 through 2000, are not completely comparable since the transect length was extended in 2000. In addition, the 1995 survey data was dropped from the analyses since staff involved in the pre-1993 data collection nor the post-1997 data collection were involved in the collection of the 1995 data. Data inconsistencies preclude the use of this information. It is possible that the 1995 differences occurred because the sites were surveyed in December rather than in the spring.

The 1983 transect data were used as a basis for the start of long-term vegetation comparisons. The data collected from 1983 to 1993 were categorized in the HBMP 1993 *Summary Report*

simply as “growing on land” or “growing in water”. Growing on land obviously includes the vegetation at each site found in the upland area adjacent to the shoreline. There is, however, a transitional area between upland and the water line that has been termed either “littoral zone” or “shoreline” in previous reports. In order to provide comparisons with previous data, the littoral zone or shoreline vegetation category has been grouped for this analysis with the “growing in water” category. This assumes that species growing along the water’s edge are subject to similar seasonal changes in isohaline locations, physical alteration of the shoreline, and the cyclical tidal and flow regimes of the Peace River as those species growing totally in the water.

#### **4.7.3.2 Results**

##### **Site I Growing on Land**

**1983–1993** Data reported in the 1993 *Summary Report*, and shown in [Table 4.48](#), indicate that twenty-four mostly stable taxa, characterized by large and small shrubs or woody trees, persisted throughout the preceding ten-year period. These included such species as live oak (*Quercus virginiana*), cabbage palm (*Sabal palmetto*), red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), Brazilian pepper (*Schinus terebinthifolius*), saw palmetto (*Serenoa repens*), and smaller shrubs or vines such as poison ivy (*Toxicodendron radicans*), winged sumac (*Rhus copallina*), Spanish bayonet (*Yucca aloifolia*), and beauty berry (*Callicarpa americana*).

**1997–2002** As shown in [Table 4.48](#), eleven species remained stable over this four-year sampling period. The sampling methods were more standardized than those used previously, while the aerial extent of the upland site was somewhat smaller. Ten species were persistent over the entire twenty years between 1983 and 2002. In 1997 the field survey observed a noticeable growth in the larger woody trees, especially Brazilian pepper and live oak, that contributed to a significantly increased overstory and a considerable decrease in the understory species. During and following the extended drought, the 2000 and 2002 surveys showed the fewest total number of plant species (twelve), although this was not a large drop from two years before. The taxa still present included the larger woody trees, noxious shrubby plants and vines such as poison ivy, winged sumac, Spanish bayonet, and shrubby buckthorn (*Bumelia reclinata*), and other shrubby plants such as saw palmetto and beauty berry that normally do well in xeric, sandy soils

##### **Site I Growing in Water**

**1983–1993** The data indicate a downward trend in the number of recorded plant species over this eleven-year period. Fifteen species tolerant of brackish water conditions, however, were observed throughout the period. These included woody species such as red mangrove, white mangrove, and buttonwood (*Conocarpus erecta*), and herbaceous and grass species such as black needlerush (*Juncus roemerianus*), sand cordgrass (*Spartina bakeri*), giant bulrush (*Scirpus validus*), giant leather fern (*Acrostichum danaeifolium*), swamp fern (*Blechnum serrulatum*), and St. Augustine grass (*Stenotaphrum secundatum*).

**1997–2002** The overall total species counts ([Table 4.49](#)) included the shoreline data, the single line transect, and the newly added belt transect data collected waterward of the shoreline. In spite

of this extended coverage, there was a dramatic decline in the observed number of species with only ten persisting at this site throughout the four years. These included the larger woody tree species, such as live oak and Brazilian pepper, along the shoreline that extended over the transects, coinvine (*Dalbergia ecastophyllum*) in the tree branches, red and white mangroves that grew beyond the shoreline into the true littoral zone, and the smaller mid-story and groundcover herbaceous species such as giant leather fern, St. Augustine grass, black needle rush, and myrsine (*Myrsine guianensis*). There was a marked drop in the total number of species between 1993 and 1997. The fewest number of species (seven) were identified in 2000 during the height of the drought, although the number of taxa appeared to have recovered by the time of the 2002 survey. Only six emergent plant species were observed to have persisted throughout the entire twenty-years of surveying.

### Site I Transects

Line transect data from 1983 to 2002, reported in previous annual HBMP Data Reports, show the progression in Brazilian pepper growth along the shoreline to the 3.7-meter mark and the resultant disappearance of most mid-canopy and groundcover species. The transects show the establishment and growth of scattered red mangrove in the water from about 3.0 meters in 1983 to about 5.0 meters in 2002.

Belt-transect data from 1997 to 2002 provide a more quantifiable temporal and spatial estimation of species composition, coverage, and change through time. The belt transects were surveyed 25 feet upstream and downstream of the single line transect and each belt transect had an upstream side and a downstream side. Therefore, for each belt transect, a 2-meter wide swath was surveyed from the shoreline waterward, until the vegetation is no longer present.

The upstream belt transect at Site I ([Tables 4.50](#) and [4.51](#)) clearly showed the dominant species along the shoreline as Brazilian pepper and the dominant species growing in the water as red mangrove. There was virtually no giant bulrush or black needlerush. This Site remained essentially the same in specie composition over the six-year period.

The downstream belt transect ([Tables 4.52](#) and [4.53](#)) was somewhat different with live oak as the dominant upland species along the shoreline, extending approximately to about the 2.0-meter mark and red mangrove growing out to 10 meters. White mangrove was present in the middle area of the transect from about 2 meters waterward to 6 meters.

### Site II Growing on Land

**1983–1993** Nineteen plant taxa were observed throughout the eleven-year survey period ([Table 4.54](#)). Many included large shrub or tree species that would be expected to remain once established, including species such as swamp bay (*Persea palustris*), Brazilian pepper, cabbage palm, button bush, live oak, buckthorn and poison ivy.

**1997–2002** Only six species persisted throughout the six-year period ([Table 4.54](#)). By 1997, Brazilian pepper dominated the site and canopy cover continued to increase through the 2002 sampling event. Almost the entire understory had disappeared with only a few shade-tolerant

species such as buckthorn, poison ivy, Virginia creeper (*Parthinocissus quinquefolia*), and wild coffee (*Psychotria nervosa*) remaining. The fewest number of species (seven) were observed in 1997, a marked drop from the twenty-eight species identified in 1993, and the number of taxa has not totally recovered since then. Only nine taxa were present over the entire twenty-year sampling period.

### **Site II Growing in Water**

**1983–1993** Fourteen species were observed throughout the entire eleven-year period, including two of the larger woody species, red maple (*Acer rubrum*) and pond apple (*Annona glabra*), as well as a number of herbaceous species such as giant bulrush, giant leather fern, sawgrass, lance-leaved arrowhead (*Sagittaria lancifolia*), pickerel weed (*Pontederia lanceolata*), and camphorweed (*Pluchea purpurascens*) ([Table 4.55](#)). A number of species disappeared after the 1983 census, perhaps since it was preceded by back-to-back wet years.

**1997–2002** This site has been characterized by a large stand of giant bulrush that gradually became invaded with cattail by 2002. In spite of the expanded survey coverage, only ten species persisted throughout this six-year period ([Table 4.55](#)). The lowest total number of species (seventeen) was identified in 2000 during the drought. While the total number of species remained at approximately the same level over the six-year period, and was similar to the number observed between 1983 and 1993, there was a noticeable shift in taxa identified, with only seven species persisting over the entire twenty-year period.

### **Site II Transects**

As expected, transect data ([Tables 4.56](#) through [4.59](#)) show a much different group of taxa than those observed at Site I, with the dominant wetland species being giant bulrush. The single-line transect drawings as well as the belt transects clearly show the growth of the Brazilian pepper along the shoreline from about the 1.0-meter mark in 1983 waterward to 7.3 meters by 2002. The landward edge of giant bulrush emigrated waterward from about 4.0 meters in 1997 to about 7.0 meters in 2002 and extended into the Peace River to about 14 meters. Both the line transect and the downstream belt transect show an area of shoaling approximately 4 meters wide that developed from around the 9.0-meter mark and extended to about the 13-meter mark. This area was above the water line during the 2002 transect survey.

### **Site III Growing On Land**

**1997–2002** The overall observed number of taxa at this site was low with only six (6) species persisting throughout the six-year survey period ([Table 4.7.60](#)). As reported at the other sites, Brazilian pepper, mixed with live oak, has become dominant with heavy canopy cover and minimal understory. The lowest number of total species was identified in 2000 and 2002 after the extended period of drought.



### **Site III Growing In Water**

**1997–2002** A large number of species were identified growing in water at this site ([Table 4.61](#)). Fourteen species persisted throughout the entire six years of monitoring at this site. A large stand of giant bulrush extends out to 15 meters in some areas, although density per square meter declined in 2000 and 2002.

### **Site III Transects**

The shoreline of the upstream belt transects was dominated by Brazilian pepper and live oak to about 5 meters ([Tables 4.62](#) and [4.63](#)). Other species consisted mostly of viney species like poison ivy, catbriar, and coinvine. Wetland species were dominated by giant bulrush with extensive coverage in 1997, that had started thinning in 2000 and became sparse in 2002 following the extended period of drought. The downstream belt transects ([Tables 4.64](#) and [4.65](#)) also showed Brazilian pepper dominating the shoreline to about 5 meters waterward. Black needlerush persisted at this station from about 1 to 4 meters. Giant bulrush generally started where the black needlerush stopped and extended out into deeper water approximately 10 meters. Red mangrove, which was not identified in the belt transects, appeared in the mid-line transect at 4.0 meters

### **4.7.3.3 Discussion**

#### **Growing On Land**

A relatively stable number of upland species were observed during the period between 1983 and 1993. However, starting with the 1997 sampling, there was a noticeable drop in the number of species at both Site I and Site II ([Figure 4.7.19](#)). Long-term species changes of taxa growing above the water line are not expected to be represented by minor year-to-year changes in average isohaline locations as much as other factors such as droughts or major freezes. Once established, large upland shrubs or woody trees such as oaks, cabbage palm, Brazilian pepper, and saw palmetto would not be expected to significantly change easily or rapidly except to grow in size and canopy cover over time. Changes in the species composition would be more likely to come from major climatic changes such as hard freezes, extended wet periods or droughts, rather than subtle changes in average isohaline locations that might be brought about by gradual freshwater flow increases or decreases.

Since the 1995 data were not included, a four-year data gap exists between the 1993 and 1997 surveys. In the interim period, there were no extreme peaks in freshwater flows (as measured at the Arcadia gage), no extended droughts (although 1996 was a low flow year with a mean annual flow of 598 cubic feet per second), and no temperature extremes for the Arcadia area as reported by the National Climatic Data Center. The changes in species composition are likely to have occurred as a result of a combination of factors:

- Large woody tree species, such as Brazilian pepper and live oak, grew to a size that shaded out understory shrubs, grasses, and herbs.

- The upland area sampled was standardized in 1997 and somewhat smaller in size than the previous sampling area.
- Sampling personnel changed after 10 years.

Due to the apparent extreme influence of Brazilian pepper at these sites, further surveying of the uplands or along the shorelines no longer appears an appropriate approach to long-term tracking of riparian vegetation at these sites.

### **Growing In Water**

The single-line transect survey methodology was initiated in 1990, and consisted of identifying the vegetation along a single line stretching from the shoreline to 10 meters waterward. In 2000, this line transect was extended to include any vegetation growing beyond the 10-meter mark.

An additional transitional vegetation monitoring location (Site III) was added in 1997 mid-way between Sites I and II, and belt transects were added both upstream and downstream of the original line transect. Percent coverage estimates of species composition within one-meter plots along each transect have been conducted during each monitoring event along the upstream and downstream sides of a centerline moving from the shoreline waterward.

Although the addition of the belt transects in 1997 substantially increased the sampling effort, there was a marked reduction in the total number of species noted at Sites I and II in comparison with previous observations. Belt transects indicated that Brazilian pepper and/or live oak were dominant along the shoreline at each of the sites. Over the twenty years of transitional vegetation monitoring, these massive trees had grown to a size that shaded out most of the understory and the branches extended significantly, in some cases, waterward over the transects. The majority of remaining mid-canopy and understory species included predominantly viney species such as coinvine, poison ivy, and catbrier climbing and within the branches of the canopy trees. Although changes in sampling methodology limit directly comparing the number of observed taxa over the entire twenty years of monitoring, all three sites have shown dynamic shifts in species composition over time, with a smaller number of core taxa persisting over the entire period.

Waterward of the Brazilian pepper/live oak influences, red mangrove have been dominant at Site I, along with some scattered white mangroves. This is characteristic of the surrounding habitat in this portion of the lower river. Once established, these species have increased in size and canopy cover over time. The recent extended period of drought and the resulting marked upstream movement of the freshwater/saltwater interface did not seem to influence the dominant riparian vegetation at this transitional monitoring site.

At Site II, giant bulrush has been the dominant long-term riparian species maintaining a stand waterward to approximately 19 meters, even following the unusually high peak flow event in 2001. Very noticeable during the 2002 survey, however, was the shoaling that occurred parallel to the shoreline, approximately 9 meters out, which is not an uncommon occurrence along certain areas of the Peace River shoreline after high peak flows.

Site III also had a good stand of giant bulrush growing in the water that was spreading waterward, but was also less dense in 2002. Although it is difficult to directly compare the 1997/1998 transect data with that collected during the 2000/2002 sampling events since the transect lengths were extended in 2000, it is unlikely that the extended drought and increased salinity substantially affected bulrush at this location since it continues to appear in abundance approximately another 7.5 kilometers along the river corridor downstream of this site.

The lowest number of observed taxa growing in water for all of the sites was in 2000 after back-to-back drought years, with only a small increase in 2002. It is tempting to conclude that this is an indication that riparian vegetation, especially at Site I, may have responded to prolonged upstream movement of the salinity interface during the extended drought. However, the difference in the total number of species reported in 1998 and 2002, but not in 2000 was only eight and most of these taxa were shoreline upland species such as saw palmetto, live oak, strangler fig, wild lime, and wild coffee.

### 4.7.3.4 Findings

The two factors that appeared to most likely affect the vegetation at a transitional vegetation site have been:

- The growth and increase in canopy cover of large, woody trees such as Brazilian pepper and, to a lesser degree, live oak.
- Shoaling and shoreline erosion during extreme flow events.

The majority of species living in the transitional areas along the lower Peace River have salinity tolerances that, once established, appear to enable them to do well even during periods of extended drought when salinity levels increase, as well as when salinities are levels are low during extended periods of high flows.

The increasing influence of Brazilian pepper at the transitional sites suggests that the continued surveying of the uplands and the areas along the shorelines may no longer be an appropriate approach to tracking long-term riparian vegetation patterns along the lower Peace River. The recent transect monitoring indicates that the dominant riparian vegetation at the three sites appears to be relatively well established, stable, and not easily affected by the naturally occurring drought conditions, which resulted in the marked upstream movement of the freshwater interface exceeding, by many orders of magnitude, any potential influences of water withdrawals under the permitted withdrawal schedule. Tracking vegetation growing in the water beyond the influence of the shoreline trees over a longer period of time (longer than two years of comparable data) should have more long-term value if continued with the current belt transect method.

## 4.8 Summary

The purpose of this section was to provide updated and thorough analyses of the status and trends of key specific monitoring program study elements. Summary graphics and analyses are

presented for each of these program elements in order to provide both an overview of the current status, as well as indications of longer-term patterns and characteristic. A corollary goal was to describe the influences on both the physical and biological characteristic of the lower Peace River estuarine system of infrequent occurrences including extended periods of extreme drought and/or the unusually wet winter/spring El Niño climatic events.

### **Watershed Rainfall Patterns**

- Extended periods of both unusually high and low seasonal rainfalls have characterized lengthy periods during both the longer term “historic” 1932-2002 time period over which Peace River flows have been recorded at the Arcadia gage and the more recent twenty-seven years during which HBMP monitoring has been conducted.
- Statistical comparisons of the monthly patterns of the more inland Bartow and Arcadia gage data suggest some seasonal differences between the longer term historic and HBMP time periods. Specifically, the data indicate slightly higher rainfall frequencies during both May and October over the historic 1932-2002 period, when compared with more recent 1976-2002 HBMP monitoring time frame. This pattern is not apparent for the more coastal Punta Gorda gage.
- The apparent difference between the two inland rainfall gages and the more coastal Punta Gorda site is indicated by the results of the Seasonal Kendall Tau trend analyses.

### **Gaged Freshwater Inflows**

- Time series plots of flow at the Peace River Arcadia gage over the period of record (1932-2002) clearly show a greater frequency of high flows, between the early 1930's to approximately 1960, when compared to the more recent period of HBMP monitoring (1976-2002).
- Statistical comparisons between the historic and HBMP monitoring periods indicate noticeable differences during the five-months between June and October, with average gaged river flows during these five months being much higher flows over the long-term period of record when compared to the more recent 1976-2002 HBMP period. In contrast, statistical comparisons of the other seven drier months indicate no differences in flows between the two time periods. The data thus indicate that while the wet-season has gotten generally drier, the dry-season months have remained similar over the long-term period of record.
- Seasonal Kendall Tau trend tests indicate that there have been statistically significant declines in both mean and median monthly flows over the period of record at the Peace River at Arcadia gage. Over the shorter 1976-2002 period of HBMP monitoring there has not been a statistically significant trend observed in Peace River at Arcadia flows.
- Conversely, trend tests results indicate that Joshua Creek flows have statistically significantly increased, over both the period of record and the 1976-2002 HBMP

period, due to increases in base flow. These increases correspond with increasing agricultural expansion and the use of relatively high conductivity groundwater by farmers during the drier months.

- No significant trends were found in either gaged Horse Creek or Shell Creek flows over either the periods of record or HBMP monitoring.
- Other than these dry-season agriculture-related augmentations of low season flows, the results of the trend analyses clearly indicate that there have not been any statistically significant systematic changes in the seasonally compared amounts of freshwater flow from the major four Peace River watershed sources over the recent twenty-seven year history of HBMP monitoring.
- During the 1966-2002 period over which there have been gaged flows for each of the major lower Peace River tributaries, the Peace River at Arcadia has accounted for 60.4 percent of the total freshwater inflow at the river's mouth. Horse Creek, Joshua Creek and Shell Creek have correspondingly contributed 8.0, 7.1 and 24.5 percent of total river flow, respectively.

### Rainfall/Flow Interactions

- There have not been any conspicuous or statistically significant changes in the relationships between rainfall and flow in any of the four major gaged lower Peace River tributaries during the period of HBMP monitoring (1976-2002).
- Both the unusually high and extended rainfalls of 1995 and the unusually strong 1997/1998 El Niño event resulted in slightly higher flows per unit rainfall than the long-term averages at each of the gages.
- Analyses indicated that rainfall following extended dry periods does not result in the same increases in flow that would occur under similar rainfall conditions following a series of wetter months. Conversely, higher flows per unit rainfall often occur during relatively dry months such as October following extended periods of high rainfall. Flows thus integrate rainfall based to a great extent on cumulative previous existing hydrologic conditions.

### Treatment Facility Withdrawals

- Due to the minimum 130 cfs cutoff there are often extended periods each year when the Facility does not withdraw water from the river. The effects of the recent 2000-2001 drought on Facility water withdrawals are evident in the fact that the Facility did not withdraw any water from the Peace River 248 days during the 2000, and relied solely on stored reserves another 219 days during 2001.
- The analyses presented clearly show that there has been a relatively steady increase in the amounts of freshwater withdrawals by the Facility during the past twenty-three

years due to increasing water demands. Also evident is the noticeable increase in maximum Facility withdrawals during the later half of 2002 due to the recently completed Facility expansion.

- Other than during the warm/dry months of April and May, when withdraws are frequently restricted by the 130 cfs cutoff, the statistical distributions of Facility withdrawals are fairly uniform throughout most of the year.
- Facility withdrawals are more dependent on demand and capacity than supply, since very similar amounts of water are withdrawn over a wide range of flows.
- Since withdrawals are not directly related to flows (outside of the 130 cfs cutoff, and a ten percent maximum of Arcadia flow up to a maximum single day withdrawal of 139 cfs), there is no relationship between withdrawals and total monthly watershed rainfall.

### Lower River Water Quality Characteristics

- **Salinity (ppt)** – Observed salinity patterns indicate the presence of a strong distinct spatial salinity gradient along the lower Peace River. The greatest degree of interannual variability in salinity (as much as thirty-five ppt) occurs in the surface waters located toward the river's mouth. Under the lowest flow conditions, brackish water conditions extend upstream well beyond the point of Facility water withdrawals. Conversely, freshwater at the surface can extend downstream to near the river's mouth under conditions of extended periods of freshwater inflow. The influences of the recent high freshwater inflows during 1997/1998 El Niño event and the extended 1999-2001 drought are clearly evident. Statistical analyses indicate no significant differences between the average annual salinity levels between the 1976-1989 and 1996-2002 sampling periods.
- **Dissolved Oxygen (mg/L)** – The plots suggest that as flows increase, upstream surface water dissolved oxygen concentrations may be depressed. Increasing freshwater inflows result in higher ambient water color, which in turn reduces the penetration of light into the water column and slows phytoplankton growth and consequently the production of oxygen. Near-bottom dissolved oxygen concentrations show clear seasonal cycles in response to summer wet-season freshwater inflows. Both the duration and magnitude of depressed dissolved oxygen concentrations increase toward the river's mouth as higher bottom salinity levels create greater vertical density stratification of the water column occurs during periods of high river flow. Statistical tests of seasonally adjusted mean annual differences in dissolved oxygen levels indicate significant declines of 0.4-0.6 mg/L between the 1976-1989 and 1996-2002 time periods. It is suggested that these observed declines reflect corresponding declines in some of the very high chlorophyll *a* concentrations that were often observed during the 1970s and 1980s and potential differences associated with changes *in situ* dissolved membrane technology.



- **Water Color (Pt-Co Units)** – Under conditions of lower flows, intermediate salinities often have higher ambient color suggesting that during periods when groundwater comprises the major source of water coming from the Peace River watershed, the wetlands immediately surrounding the lower river are the primary source of water color. However these influences are overwhelmed as gaged “blackwater” freshwater flows from the watershed increased during the wet season. Water color throughout the estuarine system steadily increases at higher rates of inflow. At some point however further increases in flow do not correspond to additional changes in water color, and under conditions of extremely high flows, color levels actually begin to decline slightly.
- **Turbidity (NTU)** – Lower Peace River turbidity levels are generally low and do not increase in response to higher levels of freshwater flows, since the relatively slow moving major blackwater tributaries do not carry large amounts of either silt or clay. The data show indications of turbidity maxima typically coinciding with the chlorophyll *a* maxima along the lower river. Time series analyses indicate turbidity levels appear to have been both lower and less variable during the most recent seven years when compared to the earlier 1976-1989 interval. These apparent observations are supported by the statistical analyses that indicated that there have been significant long-term declines in measured turbidity levels in these areas of the lower Peace River.
- **Nitrite+Nitrate Nitrogen (mg/L)** – The observed spatial patterns of inorganic dissolved nitrite+nitrate nitrogen show initially higher ambient concentrations occur in the upper river under conditions of increasing levels of freshwater inflow. However, concentrations actually decline during periods of very high river flow, when groundwater levels are near the land surface, causing surface water runoff (sheetflow) to rapidly move water into the tributaries resulting in greater dilution. Dissolved inorganic nitrogen concentrations in the downstream more saline reaches of the estuary are at or near detection limits except during periods of very highest freshwater inflow. Conversely, only during periods of extended low freshwater inflow are ambient levels low in the upstream freshwater reaches of the river. Statistical results show no significant differences between the average annual concentrations between the 1976-1989 and 1996-2002 sampling periods.
- **Ammonia/Ammonium Nitrogen (mg/L)** – Dissolved inorganic ammonia/ammonium nitrogen concentrations did not exhibit the same degree of seasonal, flow related variability or the distinct spatial patterns exhibited by nitrite+nitrate nitrogen. Inorganic ammonia/ammonium concentrations in surface waters were often near detection limits as a result of preferential phytoplankton uptake, although high “spikes” were occasionally observed often without any distinct causative factor. The data show high near-bottom dissolved ammonia/ammonium concentrations occur in the lower river reaches when increased summer wet-season flows cause salinity induced water column stratification, which results in pronounced periods of hypoxia/anoxia in the bottom waters. This possibly explains why statistically higher ammonia/ammonium concentrations were observed near the mouth of the river over the more recent period when compared with the previous 1976-1989 time frame.

- **Total Kjeldahl Nitrogen (mg/L)** – Spatially total Kjeldahl nitrogen concentrations (which measures both organic nitrogen and ammonia) along the lower river generally shows increasing patterns both moving upstream and with increasing levels of freshwater inflow. Statistical tests indicate no significant differences between the average annual concentrations when comparing the 1976-1989 and 1996-2002 time periods.
- **Total Phosphorus (mg/L)** – Concentrations progressively increase upstream towards the freshwater source, and initially rise in response to higher levels of freshwater inflow. The lower Peace River/upper Charlotte Harbor estuarine system is naturally highly enriched in phosphorus due to the extensive natural watershed phosphate deposits. Seasonally the highest phosphorus concentrations are typically associated with periods of lower river flow, when the influences of groundwater are more pronounced. Probably the most dramatic long-term change in lower Peace River water quality has been the marked, long-term decline in phosphorus concentrations. Long-term temporal patterns indicate that both the magnitude and very high degree of variability in phosphorus levels that was observed during the first six years of HBMP monitoring rapidly declined in response to implementation of stricter regulations and controls covering both point and non-point discharges of surface waters from phosphate mining operations and lands.
- **Silica (mg/L)** – The observed spatial pattern of reactive silica within the lower Peace River estuarine system reflects the influences of freshwater inflows. Seasonally, as freshwater inflows become greater, silica concentrations both increase and move further downstream. Statistical analyses indicate reactive silica concentrations have significantly increased along the entire length of the lower Peace River monitoring transect. It may be that the observed increases in reactive silica levels in the Peace River estuarine system reflect the cumulative influences of the increased use of groundwater and the expansion of water intense agriculture throughout the Peace River watershed.
- **Dissolved and Total Organic Carbon (mg/L)** – Organic carbon levels generally increase both upstream and in response to higher levels of freshwater inflow, and spatially and temporally reflect the influences of freshwater inflows. Comparisons of mean annual average concentrations between the 1976-1989 and 1996-2002 time periods clearly indicate that concentrations, especially toward the river's mouth, have statistically significantly declined during the most recent seven-year monitoring period. To a great extent, the explanation for these observed trends probably lies in the use of new, automated chemistry, analytical procedures that have both lower detection limits and greater accuracy.
- **Chlorophyll *a*** – Concentrations along the lower river exhibit distinct spring and fall peaks that are influenced by both the timing and amounts of freshwater inflow. Normally there are distinct chlorophyll *a* phytoplankton maxima that generally move downstream as flow increases. Statistical analyses show that there has been a marked decline in the periodic very high chlorophyll *a* concentrations or phytoplankton

“blooms” that commonly occurred during the late 70s and early 80s throughout the estuarine system.

### Riverine Vegetation

- Long-term analyses of the first and last occurrences of selected indicator riparian plant taxa have indicated that this method is not effective in assessing potential Facility influences. Some species have shown very little variation following extended periods of high and low flows, while the distributions of others have changed back and forth over the extended period of study for reasons apparently unrelated to flow. It was concluded that some of the most apparent changes in first and last occurrences of indicator plant species probably have resulted from the creation or destruction of shallow shoals along the edges of the river during periods of high flow. The causes of other observed changes were found to be less obvious and clearly indicated the difficulty in determining meaningful relationships between freshwater inflows and the long-term distributions of these selected taxa.
- Detailed comparison of aerial photography from 1998 (following an extended period of unusually high flows) and 2002 (following the recent extended drought) using GIS based forward-dating procedures indicates some small upstream changes in the weighted centers of abundances of two (mangroves and freshwater marsh) of the four selected major riparian vegetation communities along the lower Peace River. The measured changes were small in comparison to the differences in the spatial salinity patterns during the extended wet and dry periods that preceded the two selected vegetation surveys. Given these results, it is extremely doubtful whether any quantifiable changes in long-term vegetation patterns along the lower Peace River will ever be attributable to Facility withdrawals, since the magnitude of the predicted salinity changes due to Facility withdrawals are small relative to the normal daily and seasonal ranges of salinity variations that influence the spatial distributions of these riparian vegetation communities.
- Analyses of recent vegetation data from the fixed vegetation transitional sites indicate that the increasing influence of Brazilian pepper limits tracking changes in upland vegetation patterns along the lower river. The monitoring data indicates that the dominant riparian vegetation at the three sites appears to be relatively well established, stable, and not easily affected by the naturally occurring drought conditions, thus limiting the monitoring programs potential effectiveness in assess potential Facility impacts.

## 5.0 Salinity/Flow/Withdrawal Relationships at the Continuous Recorders

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The objective of this section is to determine and present the statistical relationships between measured conductivities and gaged freshwater inflow, tide stage, and Facility withdrawal on both a long-term and seasonal basis at each of the established U.S. Geological Survey (USGS) continuous recorders located at River Kilometers 15.5 and 26.7 ([Figure 5.1](#)). These recorders are approximately 11.2 kilometers apart within the estuarine reach of the lower Peace River. As part of the *2000 Midterm Interpretive Report* (PBS&J 2002), a series of statistical models were developed. These models were used as predictive tools to assess the spatial extent and magnitude of possible salinity changes due to both historic and future potential maximum freshwater withdrawals under the Facility's existing twenty-year permit. In addition, the District has also recently updated (Janicki Environmental, 2003) the statistical salinity/flow/withdrawal models at a series of fixed long-term sampling sites along the lower Peace River/upper Charlotte Harbor monitoring transect ([Section 3](#)). The results of the application of the statistical models developed in this section are compared with the conclusions presented in conjunction with these previous modeling efforts. The following summarizes the principle objectives of the analyses presented in this section.

- Provide a general overview using time series plots and frequency distributions of the salinity and tidal ranges at each of the two continuous recorders established in the lower tidal Peace River.
- Develop statistical models of surface and near-bottom salinities as related to observed variations in gaged freshwater inflows, tide stage and Facility withdrawals at each of the two continuous recorder locations.
- Apply the developed statistical models to predict the magnitude of salinity changes at each location of both historical and future maximum permitted Facility freshwater withdrawals.
- Compare the results of the current modeling effort with and among the previous spatial and fixed salinity models developed for the lower Peace River.

### 5.1 Overview

The USGS began a cooperative water quality data collection program with the Peace River/Manasota Regional Water Supply Authority in August 1996. As part of the initial program, the USGS initiated continuous (15-minute intervals) monitoring at two locations.

1. Water level, as well as surface and bottom specific conductance and temperature are recorded at Harbour Heights on the Peace River. The USGS designates this site as 2297460, and it is located at River Kilometer 15.5 (see [Figure 5.1](#)).

2. Water level is recorded near Boca Grande at the USGS designated site 264312 0821530000, and is located approximately near River Kilometer –31.8.

In November 1997 the USGS added a third gaging station designated by USGS as site 2297350 (Peace River Heights) located at River Kilometer 26.7. Measurements taken at this upstream location include water level and surface and bottom specific conductance and temperature.

Water level is measured at each of the continuous recording sites using a float sensor in a PVC stilling well. Data are recorded at 15-minute intervals using an electronic data logger. Near surface and near-bottom specific conductance and temperature are measured using USGS combination temperature and specific conductance probes. Readings are averaged over a two-minute interval and are recorded at 15-minute intervals.

Near-surface sensors are suspended one foot below the surface using a float in a stilling well. The near-bottom sensors are suspended about one foot from the bottom in the same stilling well as the near surface sensor.

Data are retrieved at approximately monthly intervals. Once data are retrieved, the calibration stability of the specific conductance and temperature sensors is checked using a field thermometer and specific conductance standards with values that bracket the range of expected values in the Peace River. The sensors are cleaned, inspected, and rechecked with the thermometer and specific conductance standards. If needed, the sensor readings are adjusted to the standard values.

## 5.2 Time Series Analyses

Average hourly gage height, as well as sub-surface and near-bottom salinities at each of the two USGS continuous monitoring locations are presented yearly over the periods of record in Table 5.1. The following long-term and seasonal patterns are depicted by these graphical analyses.

### Gage Height

- Gage height at the Harbour Heights location (River Kilometer 15.5) typically ranges over approximately three feet. The lowest gage heights (tides) have been recorded during the period between December and February. Although, due to the orientation of the harbor, high winds from the north can result in unusually low tides throughout the year. Conversely, strong sustained winds from the south periodically result in unusually high water levels in the upper Harbor and lower Peace River. The data also show that average gage heights are also higher (0.5 to 2.0 ft) during sustained periods of high river flow.
- These same seasonal patterns are also apparent at the other upstream USGS continuous gaging site at Peace River Heights (River Kilometer 26.7). However, the data also indicates that water levels in the more upstream regions of the lower Peace River are influenced to a much greater degree by periods of high freshwater inflow. **Figure 5.5a** shows that the 1997/1998 El Niño event resulted in water levels more than two feet

above normal, while similar events also seasonally occur during the summer wet-season ([Figure 5.5d](#)).

### Salinity

- As expected, near-bottom salinities at the downstream Harbour Heights gaging site are greater than corresponding measurements of sub-surface levels except during periods of very high river freshwater inflow. During such events, freshwater conditions can characterize the entire water column over an extended period of time ([Figure 5.4b](#)). In comparison, high salinities can characterize both surface and bottom conditions within this area of the lower Peace River during extended dry periods, and then rapidly change in response to summer wet-season flows ([Figures 5.3d](#) and [5.4d](#)).
- Generally, the data indicate that there is usually very little difference in sub-surface and near-bottom salinities at the more upstream Peace River Heights gaging site. The time series plots for 1998 show the influences of the 1997/1998 El Niño event, when slightly brackish conditions only occurred in this area of the lower river at the end of the spring. However, during subsequent unusually dry La Niña that followed over the next several years, unusually high salinities (greater than 15 ppt) were recorded during the typical spring dry-seasons.

**Table 5.1**

### Times Series Graphics of USGS Continuous Recorder Information

| Continuous Recorder Parameter                     | 1997                      | 1998                      | 1999                      | 2000                      | 2001                      | 2002                      |
|---------------------------------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| <b>Harbour Heights (River Kilometer 15.5)</b>     |                           |                           |                           |                           |                           |                           |
| Gage Stage Height (feet)                          | <a href="#">Fig. 5.2a</a> | <a href="#">Fig. 5.2b</a> | <a href="#">Fig. 5.2c</a> | <a href="#">Fig. 5.2d</a> | <a href="#">Fig. 5.2e</a> | <a href="#">Fig. 5.2f</a> |
| Surface Salinity (ppt)                            | <a href="#">Fig. 5.3a</a> | <a href="#">Fig. 5.3b</a> | <a href="#">Fig. 5.3c</a> | <a href="#">Fig. 5.3d</a> | <a href="#">Fig. 5.3e</a> | <a href="#">Fig. 5.3f</a> |
| Bottom Salinity (ppt)                             | <a href="#">Fig. 5.4a</a> | <a href="#">Fig. 5.4b</a> | <a href="#">Fig. 5.4c</a> | <a href="#">Fig. 5.4d</a> | <a href="#">Fig. 5.4e</a> | <a href="#">Fig. 5.4f</a> |
| <b>Peace River Heights (River Kilometer 26.7)</b> |                           |                           |                           |                           |                           |                           |
| Gage Stage Height (feet)                          | NA                        | <a href="#">Fig. 5.5a</a> | <a href="#">Fig. 5.5b</a> | <a href="#">Fig. 5.5c</a> | <a href="#">Fig. 5.5d</a> | <a href="#">Fig. 5.5e</a> |
| Surface Salinity (ppt)                            | NA                        | <a href="#">Fig. 5.6a</a> | <a href="#">Fig. 5.6b</a> | <a href="#">Fig. 5.6c</a> | <a href="#">Fig. 5.6d</a> | <a href="#">Fig. 5.6e</a> |
| Bottom Salinity (ppt)                             | NA                        | <a href="#">Fig. 5.7a</a> | <a href="#">Fig. 5.7b</a> | <a href="#">Fig. 5.7c</a> | <a href="#">Fig. 5.7d</a> | <a href="#">Fig. 5.7e</a> |

Time series analyses over the entire period of record were then determined in order to graphically summarize both daily mean surface and bottom salinities at each of the two USGS continuous recorder sites, as well as the observed daily ranges of salinity variations. These summary figures are presented in Table 5.2.



**Table 5.2**  
**Daily Means and Ranges of Salinity at the Continuous Recorders**

| USGS Continuous Recorder                   | Mean Daily Salinity (ppt) |                           | Daily Range of Salinity (ppt) |                           |
|--------------------------------------------|---------------------------|---------------------------|-------------------------------|---------------------------|
|                                            | Surface                   | Bottom                    | Surface                       | Bottom                    |
| Harbour Heights (River Kilometer 15.5)     | <a href="#">Fig. 5.8a</a> | <a href="#">Fig. 5.8b</a> | <a href="#">Fig. 5.8c</a>     | <a href="#">Fig. 5.8d</a> |
| Peace River Heights (River Kilometer 26.7) | <a href="#">Fig. 5.9a</a> | <a href="#">Fig. 5.9b</a> | <a href="#">Fig. 5.9c</a>     | <a href="#">Fig. 5.9d</a> |

As shown, the daily range of observed variation at the downstream (River Kilometer 15.5) gaging location was typically (except during periods of high freshwater flow) between 5 ppt and 10 ppt salinity at the surface and slightly higher near the bottom. Although the measured ranges in daily salinity variability were overall less at the more upstream USGS gaging site (River Kilometer 26.7), the influences of winds and tides during periods of low river flow can result in similar magnitudes of observed short-term salinity variation.

### 5.3 Analyses of Continuous Monitoring Salinity Cumulative Distributions

Plotting cumulative distribution functions is often a useful graphical method of evaluating the statistical frequency distributions of data sets containing large series of observations, such as those collected at the USGS continuous recorders. In simple terms, the cumulative distribution function (CDF) is the probability that a measured variable (in this case salinity) has a value less than or equal to  $x$ , and can be expressed by the following equation.

$$F(x) = \Pr(X \leq x) = a$$

The expression for variables with continuous distributions can be calculated using the following formula.

$$F(x) = \int_{-\infty}^x f(u) du$$

Where  $F(x)$  is the estimated accumulated probability of the integrated change in the continuous variable (salinity).

Table 5.3 summarizes the application of this statistical procedure to both the period of record surface and bottom salinity data collected at each of the two lower Peace River USGS continuous gaging sites, as well as the calculated daily ranges of variability measured at each of these locations. Further comparisons are also provided among the overall statistical frequency distributions, and those within both the typical four month summer wet-season and the remainder of the year.

Reference lines have been placed on Figure 5.10a in order to provide aids in practically explaining the application of the depicted cumulative distribution functions. As indicated, the 50<sup>th</sup> percentile (or Q50) represents that point along the curve where half of the collected observations are less than and half exceed that level (the median). Drawing a line from this point on the y axis to the calculated CDF line and then back down to the X-axis indicates that half of all surface salinity measurements taken at the Harbor Heights gage have been less (or more) than approximately 5.3 ppt. Analogously, the second set of lines shown on this figure indicate that twenty percent of the measured surface salinity values have been in excess of 13.5 ppt salinity.

**Table 5.3**  
**Cumulative Distribution Functions of Salinity**

| USGS Continuous Recorder                   | Salinity (ppt)             |                            | Daily Range of Salinity (ppt) |                            |
|--------------------------------------------|----------------------------|----------------------------|-------------------------------|----------------------------|
|                                            | Surface                    | Bottom                     | Surface                       | Bottom                     |
| <b>Overall</b>                             |                            |                            |                               |                            |
| Harbour Heights (River Kilometer 15.5)     | <a href="#">Fig. 5.10a</a> | <a href="#">Fig. 5.10b</a> | <a href="#">Fig. 5.11a</a>    | <a href="#">Fig. 5.11b</a> |
| Peace River Heights (River Kilometer 26.7) | <a href="#">Fig. 5.12a</a> | <a href="#">Fig. 5.12b</a> | <a href="#">Fig. 5.13a</a>    | <a href="#">Fig. 5.13b</a> |
| <b>Wet and Dry Seasonal Differences</b>    |                            |                            |                               |                            |
| Harbour Heights (River Kilometer 15.5)     | <a href="#">Fig. 5.14a</a> | <a href="#">Fig. 5.14b</a> | <a href="#">Fig. 5.15a</a>    | <a href="#">Fig. 5.15b</a> |
| Peace River Heights (River Kilometer 26.7) | <a href="#">Fig. 5.16a</a> | <a href="#">Fig. 5.16b</a> | <a href="#">Fig. 5.17a</a>    | <a href="#">Fig. 5.17b</a> |

As expected, comparisons among the overall and seasonal CDF salinity curves indicate the greatest overall differences at the downstream gaging site between summer wet-season and non-summer measurements.

## 5.4 Statistical Models of Salinity Versus Freshwater Inflow and Water Level

Many concerns regarding Facility withdrawals have historically centered on the potential direct and indirect effects of alterations of salinities that might occur in the lower river downstream of the point of intake. Previous discussions (see [Section 2.0](#)) have summarized many of the effects that could potentially be associated with significant, sustained alterations to the spatial and temporal salinity gradients in the estuary's upper reaches. Many of the existing "Health of the Harbor" elements of the HBMP are in large part designed to assess the variability of the lower river/upper harbor estuarine system's abiotic and biotic characteristics to natural seasonal salinity gradient fluctuations in response to changes in freshwater inflows. An overall understanding of such responses to natural variability in freshwater patterns is needed to provide a better understanding of the potential magnitude of any effects that might be associated with withdrawals by the Facility.

### **5.4.1 Development of Statistical Models**

A series of statistical models were developed using the data gathered at the two USGS continuous recording sites in order to further quantify the magnitude of potential salinity alterations resulting from past and future permitted withdrawals along the lower river downstream of the Peace River Facility. The data were used to develop statistical models of salinity versus flow relationships using measured sub-surface and near-bottom salinities as the dependent variables, and expressions of combined gaged freshwater inflows minus withdrawals as well as measured stage (water level) as independent variables. The following assumptions and criteria were applied during the development of these statistical models.

- Total daily gaged freshwater inflows were combined using the Peace River at Arcadia, Horse Creek near Arcadia, and Joshua Creek near Nocatee in order to determine the overall flow term used for the upper river Peace River Heights site models. Correspondingly, Shell Creek flows near Punta Gorda were added to the combined flows used in the models for the lower river Harbour Heights recording site.
- Actual daily withdrawals by the Facility were subtracted from the above cumulative flows for each observation in order to determine the final applied cumulative flow terms.
- Graphical analyses were used to determine the range of flow data to be used in the development of both the sub-surface and near-bottom salinity models at each site. The applied ranges of modeled flows were limited to the normal ranges of total gaged freshwater inflows at each site and depth over which measured salinities were typically greater than zero.
- A second lagged, long-term cumulative flow term was applied in each of the statistical models to establish some indication of background conditions and the “resident memory” associated with the characteristic of the longer-term salinity gradient within the upper estuary.
- All gaged continuous recorder data were averaged over one-hour intervals. Gage heights corresponding with the same interval of the measured salinity were added to account for the daily variability in the influences of tides on salinity (see previous discussion in Section 5.3).
- A final term was tested for each model to account for the longer-term interactions of flow with tide stage and tidal influences. As the figures in Table 5.4 indicate, when freshwater inflows are low (such as the spring dry-season), there are very close correlations between tidal stage and the observed daily variability in measured conductivities (salinity). However, as flow increases and overall conductivities decline, the influences of daily tidal variability on observed salinity patterns declines.
- As an initial step in the development of each statistical model, the SAS Stepwise General Linear Model and RSREG procedures were used to screen the potential

significance of a number of possible applied linear, non-linear, and interactive terms. Logs of the flow term were used to account for the often-observed curvilinear response of salinity to increasing freshwater flow. Conversely, non-transformed variables were used within the models for those independent terms found to have more linear interactions. (All model parameters were tested and met the statistical requirements for normal distributions due to the very large number of observations.)

- Using an iterative process, surface and bottom salinity models were developed for each of the USGS continuous recorder sites using the fewest number of independent variables that were both significant at the 0.01 level and added appreciably (at least one percent) to the overall explained error of the model. In developing the statistical models, enhancement of the explained error (R-square) was considered secondary to increasing the establishment of enhancement of the relationships between predicted and observed salinities (model fit).

**Table 5.4**  
**Seasonal Comparisons of the Tidal Influences on Salinities**

| USGS Continuous Recorder                   | Surface Salinity           |                            |
|--------------------------------------------|----------------------------|----------------------------|
|                                            | Dry Season (May)           | Wet Season (September)     |
| Harbour Heights (River Kilometer 15.5)     | <a href="#">Fig. 5.18a</a> | <a href="#">Fig. 5.18b</a> |
| Peace River Heights (River Kilometer 26.7) | <a href="#">Fig. 5.19a</a> | <a href="#">Fig. 5.19b</a> |

Independent models using the same form were developed for surface and bottom salinities in the upper and lower river gaging sites using the following formula:

$$\text{Salinity} = b_a + (b_1 \times \text{Flow1}) + (b_2 \times \text{Flow2}) + (b_4 \times \text{Stage}) + (b_5 \times (\text{Stage} / \text{Flow}))$$

where:

$b_a$  = specific intercept

$b_1$  = “short-terms” flow slopes (linear and/or non-linear)

$b_2$  = “long-terms” flow slopes (linear and/or non-linear)

$b_3$  = gage height specific slope

$b_4$  = gage height/flow interaction specific slope

### 5.4.2 Finalized Statistical Models

The relationships between the paired predicted modeled salinities and the actual observed salinities (relative fit) resulting from each of the four models are graphically presented in Table 5.5. The table also indicates the R-Square values for each of the final models.

**Table 5.5**  
**Seasonal Comparisons of the Tidal Influences on Salinities**

| USGS Continuous Recorder/<br>Depth                | Model Fit                 | R-Square |
|---------------------------------------------------|---------------------------|----------|
| <b>Harbour Heights (River Kilometer 15.5)</b>     |                           |          |
| Sub-surface                                       | <a href="#">Fig. 5.20</a> | 0.86     |
| Near-Bottom                                       | <a href="#">Fig. 5.21</a> | 0.86     |
| <b>Peace River Heights (River Kilometer 26.7)</b> |                           |          |
| Sub-surface                                       | <a href="#">Fig. 5.22</a> | 0.78     |
| Near-Bottom                                       | <a href="#">Fig. 5.23</a> | 0.79     |

As indicated, the degrees of fit between predicted and actual observed salinities were slightly better for the models developed at the more downstream Harbour Heights gaging site. This resulted from both the observed wider range and much larger number of greater than zero salinity measurements available to assess the changing salinity response to variations in freshwater inflows. By comparison, the fit of the more upper river site models were slightly less since, even under moderate levels of flow, a large proportion of observed salinities (and associated variability) were near zero, thus reducing the number of observations that could be used in developing the statistical models. Overall, the plots of predicted versus observed salinities indicate that the models slightly over-predict salinities at low levels and correspondingly under-predict at higher levels. However, over the typical range of salinities observed at each of the gaging sites, the developed models provide a good fit and explain most of the observed variation in measured salinities.

### 5.4.3 Changes in Salinity Under Maximum Withdrawals

Once these models had been developed, they were then used to answer the question: What would have been the average differences in salinities at each of these sites if freshwater withdrawals had not taken place? To do this, hourly salinities were calculated at the surface and bottom for each location, both with and without actual withdrawals using gaged flows for each of the major upstream tributaries. A second question was then asked: What would the predicted changes in salinities have been at these two locations downstream of the Peace River Facility under the maximum withdrawals allowed under the current permit?

The developed statistical models were used to answer these two questions using hourly averaged measured stage height data available over the period of record for each of the two continuous recorder sites, and daily measurements of USGS gaged upstream freshwater inflows, daily Facility withdrawals, and calculated potential maximum daily withdrawals based on reported Peace River flows at the Arcadia gage. Cumulative distribution function plots (see above discussion) of the results were then developed to provide overviews of the statistical distributions

of the predicted salinity differences under both actual historical (1996-2002) and maximum permitted withdrawal conditions (90 mgd) at each of the two continuous recorder sites. The resulting graphical CDF plots are presented in Table 5.6.

**Table 5.6**  
**Predicted Differences in Salinities With and Without Withdrawals**

| USGS Continuous Recorder                   | CDFs of Predicted Differences |                           |
|--------------------------------------------|-------------------------------|---------------------------|
|                                            | Sub-surface                   | Near-Bottom               |
| Harbour Heights (River Kilometer 15.5)     | <a href="#">Fig. 5.24</a>     | <a href="#">Fig. 5.25</a> |
| Peace River Heights (River Kilometer 26.7) | <a href="#">Fig. 5.26</a>     | <a href="#">Fig. 5.27</a> |

The following conclusions and inferences can be drawn from these summary results.

- Immediately noticeable is the fact that the predicted salinity differences under the maximum permitted withdrawals are less than those predicted to have occurred as a result of actual freshwater withdrawals. As has been noted in the annual data reports, the primary reason for these discrepancies stems from the way that stage/flow data are gathered. The Authority uses “provisional” preceding day flow data from the water level recorder at the USGS gaging station on the Peace River at Arcadia. These data are taken directly from the USGS Tampa Office’s website. However, after the fact, the USGS checks and evaluates the data from the stage recorder and also “post adjusts” the flow data based on recalculations of the river cross section a number of times each year. Thus, the daily Peace River at Arcadia flow values used by the Authority as a basis of withdrawals are only “provisional” and are often changed by the USGS weeks or even months after-the-fact. It is not uncommon for subsequent determinations of percent withdrawals, based on revised USGS calculations of daily flows (subsequently used in the submitted HBMP reports), to indicate that daily withdrawals, based on provisional flow information, have exceeded the District’s 10 percent permit withdrawal criteria. The Authority, District and USGS have continued over the years to improve the reliability of the provisional flow data to reduce these instances.
- Facility withdrawals have no effect on salinity approximately thirty to forty percent of the time, due to the combined influences of the 130 cfs permit cutoff criteria, and the fact that Facility withdrawals cannot change salinity when flows are high enough that salinities are zero at the gaging site over the entire range of the daily tidal cycle.
- Overall, the models indicate that the influences of Facility withdrawals are predicted to be small, being less than 0.2 ppt more than seventy percent of the time, and far less than the daily range of variation resulting from the daily tidal cycle.



- Under conditions of maximum permitted withdrawals the models suggest that the greatest differences in salinities at each of the sites would be approximately 0.4 ppt. The models indicated that the predicted increases in salinity due to actual withdrawals have exceeded this approximately ten percent of the time.
- The differences in salinity due to withdrawals are predicted to be slightly greater at the downstream gaging site, since salinities are very low (or zero) throughout much of the year at the more upstream gaging site.

### 5.4.4 Comparisons with Previous Modeling Efforts

A number of previous modeling efforts have historically been conducted in attempts to quantify the potential impacts of Peace River Facility withdrawals on both the salinity structure of the lower river and the movement of the freshwater/saltwater interface (as well as isohalines). A series of statistical models were developed of salinity versus flow and withdrawal relationships at the series of “fixed” lower Peace River monitoring sites as part of previous HBMP Summary Reports in the late 1980s and early 1990s. The District has recently received similar updated (Janicki Environmental 2003) statistical salinity/flow withdrawal models developed at these fixed long-term sampling sites along the HBMP monitoring transect. Both of these modeling efforts predicted daily differences between actual and permitted withdrawals and no withdrawal scenarios. The conclusions of these modeling efforts similarly suggested that the predicted effects of freshwater withdrawals on salinity would typically be between 0.1-0.3 ppt and probably could not easily be detected given the normal distributions or daily tidal ranges of salinity along the lower Peace River/upper Charlotte Harbor HBMP monitoring transect.

As part of the *2000 Midterm Interpretive Report* (PBS&J 2002), a series of statistical models were developed as predictive tools used to assess the spatial magnitude of potential salinity changes due to both historic and future potential maximum freshwater withdrawals under the Facility’s existing twenty-year permit. Again, these daily averaged models suggested that the changes in salinity predicted due to maximum permitted withdrawals would typically be less than 0.5 ppt and again probably not easily measured given the normal tidal variability of salinity in the lower river.

The following briefly summarizes the objectives and significant conclusions of each of the historic lower Peace River salinity/isohaline modeling efforts (see [Table 5.7](#)).

#### University of Miami

The Rosenstiel School of Marine and Atmospheric Science (University of Miami) (Michel *et al.* 1975) evaluated potential environmental impacts in conjunction with General Development Corporation’s initial assessment of the feasibility of locating a regional water supply system on the Peace River in Desoto County near State Road No. 761. The university research team developed a series of statistical relationships for selected areas of the lower river downstream of the proposed Peace River Facility location using freshwater flow, tide and salinity based on data collected between 1973 and 1974. These data were subsequently used to calibrate the first initial numerical models utilized to characterize the salinity distributions with and without Facility

withdrawals under the normal range of variation in flows during both extended wet and dry periods.

Worst-case conditions were modeled assuming freshwater withdrawals during naturally occurring periods of low river flow (50 cfs) well below the current permitted Peace River at Arcadia gage 130 cfs cutoff. The developed models suggested that increased salinities in the range of 1.3 to 3.2 ppt would be observed under withdrawals of 30 mgd (46 cfs) during periods when Arcadia gaged Peace River flow was only 100 cfs. The report (Michel *et al.* 1975) concluded that “under these conditions of flow and withdrawal, biological data indicated that such slight salinity increases, above the naturally occurring values of low flow periods, should add little additional stress on the plants and animals of the study area.” This conclusion was based on what was found to be the highly dynamic natural seasonal changes in salinity within portions of the lower Peace River due to difference in flows during wet and dry periods.

### Environmental Quality Laboratory

A series of statistical models were developed based on the long-term accumulation of HBMP fixed station salinity and isohaline information. Statistical models of sub-surface and near-bottom salinity, and/or the relative locations of isohalines, were used to assess the spatial magnitude of seasonal salinity variations in response to annual and long-term patterns in gaged freshwater inflows, as well as projected changes resulting from Facility withdrawals. The results of these ongoing modeling efforts were historically presented in conjunction with previous HBMP summary reports (EQL 1982, 1984, 1989, 1996). Overall, the results of these long-term HBMP modeling efforts suggested that the predicted increases in salinity would be less than 0.5 ppt, and that the potential movement of isohaline locations would be less than 0.4 kilometers. The previous HBMP Summary Reports have concluded that such predicted changes are far less than the observed typical natural daily tidal variations, and that any impacts due to Facility withdrawals should be buried within the order of magnitude greater natural “noise” of daily and seasonal variability.

### 2000 Midterm Interpretive Report

As part of the *2000 Midterm Interpretive Report* analyses, statistical models were developed with the objective of establishing “predictive” relationships between gaged inflows and the spatial salinity structure of the lower Peace River. These models were then applied in order to discern the incremental effects of permitted withdrawals on the salinity structure of the estuary downstream of the Facility.

Model results indicated that, on average, the influences of past withdrawals on the spatial distribution of salinity patterns in the lower Peace River have historically resulted in maximum changes of less than 0.3 ppt. These model results also indicated that the largest changes resulting from past withdrawals have occurred between River Kilometers 14 and 18 in the lower Peace River. Statistical models were then used to predict the potential magnitude of salinity changes expected under maximum future permitted daily withdrawals under conditions of Peace River at Arcadia flows between 200 and 1,000 cfs. The modeled results predicted maximum salinity increases < 0.5 ppt occurring between River Kilometers 14 and 18 when Arcadia flows range

between 400 and 1000 cfs. Under conditions of flows of 200 cfs at Arcadia, the models predicted similar maximum increases in salinity (< 0.5 ppt) occurring further upstream.

### Janicki Environmental

The Southwest Florida Water Management District (Janicki Environmental 2003) recently completed a re-evaluation of regression analyses of salinity/streamflow interactions in the lower Peace River estuarine system in order to further quantify salinity and isohaline location relationships with inflows using updated HBMP data through 1999. The study's primary objective was to assist review of the HBMP in evaluating the salinity regime of the lower Peace River/upper Charlotte Harbor system, by determining the relative potential magnitude of salinity changes directly associated with Peace River Facility freshwater withdrawals.

Updated salinity models were developed for a series of seven "fixed" sites located along the lower Peace River transect from just downstream of the river's mouth (RK -2.4) upstream to a point (RK 25.9) below the Facility. Best-fit regression models were used to predict salinities at each location, at the four water column profile depths, for incremental percentiles of flow under three differing withdrawal scenarios.

- "No Withdrawals"
- "Actual Historical Withdrawals"
- "Maximum Theoretical Withdrawals" as per the 1996 permit schedule

A corollary task was to develop updated regression models of the predicted spatial locations of the four monitored "moving" isohaline locations (0, 6, 12 and 20 ppt) in relation to variations in freshwater inflows under the same three withdrawal scenarios.

The key findings of this study indicated that:

- A considerable amount of natural variation in salinity occurs independent of flow over a wide range of freshwater inflows.
- The modeled salinity increases predicted at the "fixed" sampling sites along the lower Peace River ranged from between 0.1 and 0.3 ppt as a direct result of Facility withdrawals under the maximum permitted conditions.
- The predicted differences in relative spatial locations of the four surface isohalines due to withdrawals were found to be small, projected as being only 0.1 to 0.3 kilometers under maximum permitted withdrawals.

### 5.4.5 Conclusions

The results of these previous studies and the current modeling of the continuous recorder data reach very similar conclusions. If anything, the hourly integrated continuous recorder based models predict slightly lower overall average potential salinity increases due to permitted Facility withdrawals than previous modeling efforts that have been based on monthly fixed

station data. The mean overall predicted differences in salinities due to withdrawals (permitted and actual) at the downstream Harbour Heights continuous gaging site are estimated to be approximately 0.1 ppt, while that at the upstream Peace River Heights locations is less than half that.

Based on the combined results of these statistical modeling efforts it is predicted that actually measuring these small salinity changes (due to Facility withdrawals) in the field will be difficult or impossible given the normal daily range of tidal salinity variations during periods when the Facility is potentially having its greatest influence.

### 5.5 Summary

The purpose of this section was to determine the statistical relationships between measured specific conductance values and gaged freshwater inflow, tide stage, and Facility withdrawal at the two USGS continuous recorders located at River Kilometers 15.5 and 26.7. The results of salinity predictions with and without Facility withdrawals based on the application of these new statistical models were compared with the conclusions of previous modeling efforts.

- Cumulative distribution function (CDF) plots were developed to graphically provide overviews of the statistical distributions of the predicted salinity differences under both actual and maximum permitted withdrawal conditions at each of the USGS recording sites.
- The predicted results of the developed salinity models indicate that Facility withdrawals do not cause any salinity change approximately thirty to forty percent of the time, due to the combined influences of the 130 cfs permit cutoff criteria, and the fact that Facility withdrawals cannot change salinity when flows are high enough that salinities are zero at the gaging site over the entire range of the daily tidal cycle.
- Overall, the models indicate that the influences of Facility withdrawals are predicted to be small, being less than 0.2 ppt more than seventy percent of the time, which is far less than the natural salinity variation resulting from the daily tidal cycle.
- Under conditions of maximum permitted withdrawals the models suggest that the greatest differences in salinities at each of the sites would be approximately 0.4 ppt. In addition, the models indicate that the predicted increases in salinity due to actual withdrawals have exceeded 0.4 ppt approximately ten percent of the time, due to the fact that the real-time USGS gaging data is only provisional and is subject to later revision.
- The conclusions of the modeling of continuous recorder data are very similar those previously reached by other modeling efforts. If anything, the continuous recorder based models predict slightly lower potential salinity increases due to permitted Facility withdrawals than the results of previous statistical models.
- The results of the statistical models indicate that the small salinity changes predicted due to Facility withdrawals will be extremely difficult to detect given the normal daily range of tidal salinity variation in the lower river.

## 6.0 Adverse Impact

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This section presents a proposed approach for determining whether the permitted surface water withdrawals have caused adverse environmental impacts in the lower Peace River Estuary, as well as a hierarchy of management actions that could be implemented in response to detected changes that could forewarn of or constitute adverse impact. In addition, the salient findings of the HBMP are discussed with respect to the proposed criteria for determining adverse impacts+.

### 6.1 Regulatory Basis of Review

The regulatory basis for the issuance of Water Use Permits is described in the Southwest Florida Water Management District (District) rules. Chapter 40D-2.301 of the Florida Administrative Code states:

*In order to obtain a Water Use Permit, an applicant must demonstrate that the water use is reasonable and beneficial, is in the public interest, and will not interfere with any existing legal use of water, by providing reasonable assurances, on both an individual and a cumulative basis, that the water use: ... (C.1) Will not cause adverse environmental impacts to wetlands, lakes, streams, estuaries, fish and wildlife, or other natural resources.*

Furthermore, the specific performance standards for streamflow listed in Section 4.2.C.1 of the District's *Basis of Review* for Water Use Permits addressing withdrawals from natural surface waterbodies state that:

- a. *Flow rates shall not deviate from the normal rate and range of fluctuation to the extent that water quality, vegetation, and animal populations are adversely impacted in streams and estuaries.*
- b. *Flow rates shall not be reduced from the existing level of flow to the extent that salinity distributions in tidal streams and estuaries are significantly altered as a result of withdrawals.*
- c. *Flow rates shall not deviate from the normal rate and range of fluctuation to the extent that recreational use or aesthetic qualities of the water resource are adversely impacted.*

During the Permit review process, applicants must provide the District with reasonable assurance that the above cited conditions will be met. Furthermore, the requirement of the HBMP as a condition of Permit approval essentially obligates the Authority to demonstrate continued compliance with the above cited rule language following the construction and operation of the permitted facilities, and for the lifetime of the Permit. Unfortunately, the terms *adversely impacted* and *significantly altered* are not defined in District rules.

It should be noted that the term *adverse impact* has both technical and legal meaning. From a technical standpoint, adverse environmental impact can be defined using a wide range of metrics that quantify deviations from the pre-withdrawal salinity patterns, water quality conditions, and biological distribution and abundance. As such, technical determinations of adverse environmental impact are not absolute and are subject to subjectivity and interpretation. From a legal standpoint, however, the determination of adverse environmental impact, in the context of Water Use Permit compliance, is absolute and can only be made by the District Governing Board. Such a legal determination establishes a regulatory finding by the Governing Board that the District performance standards for surface water withdrawals have been violated and that the permittee must reverse or mitigate the damage. The Governing Board is, nonetheless, dependent on the findings and recommendations of District technical staff as to what constitutes adverse environmental impact. The Peace River HBMP Scientific Review Panel (Panel), on the other hand, has been established primarily to assist District staff in assessing the continued technical efficacy and ability of the HBMP to detect potential adverse impacts caused by the Facility, and secondarily to assist District staff in the interpretation HBMP data.

District staff has developed a general process for determining adverse environmental impact as it relates specifically to surface water withdrawals. This seven-step process is summarized below.

1. Specify resource management goals for the potentially affected waterbodies, as well as resource assessment objectives for the monitoring program.
2. Identify hydrobiological indicators related to the resource management goals, and define appropriate measures of change for each.
3. Monitor the identified hydrobiological indicators to measure changes over time.
4. If changes in the hydrobiological indicators are detected, then determine if the detected changes are related to changes in freshwater flows, and if they represent a potential degradation of the affected resources.
5. If the detected changes in the hydrobiological indicators are both related to changes in freshwater inflows, and represent a potential degradation of the affected resources, then determine the incremental effect of the permitted withdrawals on the detected changes.
6. If the incremental effect of the permitted withdrawals on the detected changes is significant, then determine if the detected changes could constitute *adverse impact* pursuant to District performance standards.
7. If the detected changes are determined to constitute adverse impact pursuant to District performance standards, determine appropriate management response(s) to reverse or mitigate the adverse impacts.

The process summarized above establishes a logical sequence of steps aimed at determining compliance with District performance standards.



## **6.2 Resource Management Goals and Relevant Hydrobiological Indicators**

Pursuant to the seven-step process described in [Section 6.1](#), the District has identified the primary resources of interest, as well as resource management and protection goals for the lower Peace River and upper Charlotte Harbor estuarine system. These goals are listed below.

1. Protect the extent, distribution, and diversity of physical and biological habitats in the lower Peace River and upper Charlotte Harbor.
2. Protect the abundance of fish and invertebrate species of sport and commercial importance in the lower Peace River and upper Charlotte Harbor.
3. Protect the estuarine fish nursery function in the lower Peace River and upper Charlotte Harbor.
4. Protect the spatial and temporal distributions of organisms that are important food sources for fish in the lower Peace River.
5. Protect seasonal patterns of nutrient delivery to the estuary so that trophic interactions are maintained in the lower Peace River, so that Goals 1 through 4 are met.
6. Protect seasonal patterns of organic matter delivery to the estuary so that trophic interactions are maintained in the lower Peace River, so that Goals 1 through 4 are met.
7. Protect the temporal and spatial characteristics of salinity distributions in the estuary so that Goals 1 through 4 are met.
8. Protect dissolved oxygen concentrations in the estuary so that Goals 1 through 4 are met.
9. Protect the abundance of any rare, threatened or endangered species that use the lower Peace River or upper Charlotte Harbor.
10. Protect suitable habitats and water quality for fish and wildlife that are not of sport or commercial importance.

In addition to the resource management goals summarized above, District staff has identified many relevant hydrobiological indicators. The scope and design of the HBMP have evolved since the issuance of the first Water Use Permit in 1976 authorizing surface water withdrawals from the Peace River Facility. Throughout the HBMP period of record, the various components of the program have been designed and modified to generate data for a range of indicators related to the resources of interest in the lower Peace River and upper Charlotte Harbor. [Table 6.1](#) summarizes the indicators associated with the various HBMP components and resources of interest.

Although resource management goals have been defined, and numerous hydrobiological indicators in the lower Peace River and upper Charlotte Harbor have been monitored for over twenty-seven years, the issue of what constitutes adverse environmental impact in these systems has never been comprehensively addressed as it relates to the permitted surface water withdrawals. In addition, a process for dealing with hydrobiological changes that could potentially forewarn of adverse environmental impact has never been developed. The sections that follow address these two critical functions.

### 6.3 Rationale for Defining Adverse Impact

Inherent in the District rules is the recognition that surface water withdrawals are linked to potential changes in: salinity; associated water quality constituents; and biological communities. It should be noted that, while freshwater withdrawals have a direct and instantaneous physical affect on salinity, the effects of freshwater withdrawals on other water quality constituents, and biological communities in particular, are typically indirect and more complex. Such indirect impacts are mediated by physical and chemical processes, and are typically manifested on slower time scales (e.g. weeks, months, seasons).

For example, a reduction in freshwater inflows may result in increased salinity values within the geographic range of a population of a particular benthic organism; but if the changed salinity still remains within the salinity tolerance range of the organism, the abundance and distribution of the organism will likely not be significantly affected. However, if that same change in freshwater inflow results in increased density stratification, which in turn leads to hypoxic conditions on the bottom, the abundance and distribution of the organism could be affected. The potential mode of impact associated with surface water withdrawals is conceptually depicted in [Figure 6.1](#).

In addition to the linkage between freshwater withdrawals, water quality, and biological communities, the District performance standards also link adverse impact to: a significant deviation from *natural* or *historic* conditions; and a significant degradation of conditions necessary to support *economically important* activities such as sport and commercial fishing, and water-dependent recreation and aesthetics. Therefore, pursuant to District rules, any defensible technical criteria used to define and determine the occurrence of adverse environmental impact must take into consideration changes in:

- Salinity
- Associated water quality constituents
- Biological communities
- Natural or historic (pre-withdrawal) conditions
- Conditions that support economically important resource-dependent activities

District staff, with assistance from the Panel, is responsible for the interpretation of hydrobiological data collected from the HBMP and other sources to determine if the permitted surface water withdrawals have caused harm to the lower Peace River and/or upper Charlotte Harbor estuarine systems. As discussed above, the term *adverse impact* has distinct legal meaning in the context of Water Use Permitting. Therefore, it is proposed that this term be

supplanted by the term *significant environmental change* with respect to the role of the District staff and the Panel.

Some environmental changes may be considered to be adverse from a technical perspective, while others may not. Furthermore, some changes may be viewed as potential harbingers of, or precursors to, greater environmental change that may subsequently be considered to be adverse. However, as stated above, only the District Governing Board can declare that a significant environmental change constitutes an adverse impact from a legal standpoint. The remainder of this section presents a discussion of various ways to define *significant environmental change* in estuarine systems as it relates to surface water withdrawals.

The HBMP has been developed and implemented based on the assumption that the following three critical premises are generally met:

- The monitoring program is adequately designed to detect significant environmental change attributable to the permitted surface water withdrawals.
- Significant environmental change can be detected before adverse environmental impact occurs.
- Cause and effect relationships are sufficiently well understood to justify management actions that can be implemented to avert adverse environmental impact before it happens.

Perhaps the simplest means of defining significant environmental change is on the basis of a detected violation of applicable regulatory water quality standards. Since no applicable standards exist for salinity in estuaries, dissolved oxygen is probably the most applicable parameter for which a violation of the standard could be related to the affects of the permitted withdrawals. However, because natural violations of the dissolved oxygen standard are well documented in Florida surface waters, sufficient documentation of the magnitude and duration of such violations, and a scientifically defensible linkage of the violations to the permitted withdrawals would be required before determining if such violations constitute significant environmental change.

Another water quality standard that could potentially be applicable is *biological integrity*. The biological integrity standard is a non-numerical standard that is typically applied with respect to nutrient enrichment and is open to a great deal of interpretation. Furthermore, compliance with this standard is dependent upon the routine collection of benthic invertebrate data, which is not currently a fixed component of the HBMP. It is concluded that the violation of a regulatory water quality standard as a sole means of defining adverse impact may be too simplistic in scope to address the District's performance standards or to define significant environmental change.

In consideration of [Figure 6.1](#), it can be argued that a change in salinity and/or water quality attributable to freshwater withdrawals does not constitute significant environmental change unless that change is of such a magnitude and/or duration to cause a measurable and significant change in a biotic indicator. Even though this argument appears to be inconsistent with the plain

language of *Basis of Review*, a reasonable interpretation of the term *significantly altered* with respect to salinity distributions, as referenced in Section 4.2.C.1.b. of the *Basis of Review*, is a change in salinity of sufficient magnitude and/or duration to cause a measurable and significant change in a biotic indicator. Therefore, for the limited purposes of the Peace River HBMP, it is proposed that a measurable change in salinity and/or water quality attributable to the permitted freshwater withdrawals does not necessarily constitute a *significant environmental change*. Nonetheless, a substantial or prolonged change in salinity and/or water quality alone, in advance of any observed effects on biotic indicators, should be considered an early detection mechanism to initiate appropriate management responses aimed at averting potential adverse environmental impact.

Based on the discussion presented above, the following is a proposed working definition of the term *significant environmental change*, to be used by District staff and the Panel as criteria for assessing the findings of the HBMP.

### **Significant Environmental Change**

***A detected change, supported by statistical inference or a preponderance of evidence, in the normal or pre-withdrawal abundance, distribution, species composition, or species richness of biological communities of interest in the lower Peace River and upper Charlotte Harbor that is directly attributable to reductions in freshwater inflows caused by the permitted surface water withdrawals.***

It should be noted that while the working definition of significant environmental change stated above integrates the salinity, water quality, and biological factors embodied in the District performance standards, it does not specifically address adversely impacted *recreational uses* or *aesthetic qualities*, as referenced in Section 4.2.C.1.c. of the *Basis of Review*. This District performance standard is aimed primarily at non-tidal streams and rivers where withdrawals could significantly affect water levels, and thus fish passage and navigability. In the tidal lower Peace River, however, such concerns are not applicable. Furthermore, while the direct measurement of recreational and aesthetic qualities is considered to be outside the scope of the HBMP, it is likely that any adverse impact to recreational and aesthetic qualities in the lower Peace River would first be expressed in terms of detected changes in salinity distributions and/or water quality, and later via changes in biological communities.

Conditions meeting the working definition of *significant environmental change* stated above could be measured and described in many different ways. Some simple examples are described below.

- **Change in species richness or community balance** - numerous measures and indices exist to describe species richness, community balance, and biodiversity (e.g. Shannon-Weaver index) for various biotic indicators.

- **Dislocation of an indicator species' distribution** - the “center of abundance” statistic and observed first and last occurrences have been used in the HBMP with respect to the distribution of larval and juvenile fish, benthos, and vegetation.
- **Elimination or reduced abundance of a “desirable” indicator species** - the elimination, or a significant reduction in the abundance, of a desirable (e.g. economically or ecologically important) indicator species would likely be considered an adverse environmental impact.
- **Introduction or increased abundance of an “undesirable” indicator species** - the converse of the above described scenario, the introduction, or a significant increase in the abundance, of an “undesirable” (e.g. non-native or nuisance) indicator species within a reporting unit would also likely be considered an adverse environmental impact.

There are some biological changes that would meet the working definition stated above, but would not readily be considered to constitute an adverse environmental impact. For example, reductions in freshwater inflow have been associated with an increase in the coverage and upstream extent of seagrass in some tidal rivers. While technically meeting the above recommended definition, a statistically significant increase in the coverage of submerged aquatic vegetation would likely be viewed as a positive ecological change by the public, and in the absence of other detected changes would not constitute a violation of the District performance standards. However, a measurable increase in the coverage of seagrass in the lower Peace River would likely be considered by District staff to be a significant environmental change worthy of further investigation. If the observed increase in seagrass coverage was linked to a significant increase in salinity that was clearly caused by the permitted surface water withdrawals then the District could ultimately determine that such a change constitutes an adverse environmental impact.

In addition to the simple examples cited above, statistically significant differences between the pre- and post-withdrawal data for numerous biological indicators could be determined using many different analytical procedures including: analyses of variance; trend analyses; deviations from baseline cumulative frequency distributions; and BACI (Before-After/Control-Impact) analyses. Given the extensive number of biological indicators for which such analyses could be applied, those that are most directly affected by the permitted surface water withdrawals, and that best integrate potential impacts to other indicators, are most desirable. For example, benthic invertebrate populations are generally sessile and respond relatively quickly to changes in salinity and dissolved oxygen, whereas adult fish populations are motile and are affected by impacts far removed from surface water withdrawals (e.g. fishing pressure).

As discussed above, the most directly measurable impact potentially resulting from the permitted surface water withdrawals is an increase in salinity downstream of the withdrawal point. Pursuant to the working definition proposed above, a measurable salinity change alone would not necessarily constitute a significant environmental change. However, a measurable salinity change of sufficient magnitude, duration, and spatial extent would likely be a precursor to

changes in biotic indicators that could meet the working definition of *significant environmental change* proposed herein.

Changes in salinity can affect the abundance and distribution of biological resources of concern both directly through osmotic stress, and indirectly through more complex processes (e.g. hypoxia caused by density stratification). For these reasons, salinity is typically considered to be the most appropriate estuarine indicator for the development of management targets and guidelines. Therefore, it is recommended that salinity change continue to be used as the primary indicator for the early detection of significant environmental changes that could lead to potential adverse environmental impacts.

Salinity variability is a natural phenomenon in estuaries, and unlike dissolved oxygen which is unidirectional for regulatory purposes (i.e. low numbers are bad and high numbers are good), excessive increases or decreases in salinity may be undesirable. Therefore salinity target concentrations for a particular reach of a tidal river should not be defined as a static statistic such as the mean or median, but rather in terms of a range or distribution that is protective of more than one resource of concern. Significant deviations from long-term cumulative frequency distributions of salinity observations in a particular river reach can be used to determine significant changes over seasonal (e.g. wet-season and dry-season), annual, or longer time periods, and confidence limits can be statistically determined for these cumulative frequency distributions. **Figure 6.2** conceptually illustrates this approach to determining significant environmental change.

In addition to temporal variability in salinity, the spatial extent of salinity change is important. Therefore, an unbiased estimate of the areal extent of a particular salinity value or range may be a useful analysis. Unbiased areal estimates of salinity and other HBMP indicators can be derived following methods such as the Horowitz-Thompson estimators described in Cochran (1977). If salinity is to be used as the primary indicator of significant environmental change associated with surface water withdrawals, District staff, with assistance from the Panel, must define desirable or target statistical distributions of salinity that are spatially-specific to river segments containing resources most in need of protection, and/or most susceptible to adverse impact. This information can be derived from empirical data on the movement of isohalines in response to withdrawals, and/or models developed from such empirical data. In addition, the District with assistance from the Panel, must define what constitutes an unacceptable magnitude and corresponding duration of salinity deviations from the target distribution (e.g. a 5 ppt deviation in salinity over a greater than 30-day period), as well as an unacceptable spatial extent of such salinity deviations.

Once the framework for identifying significant environmental change has been established, a hierarchy of management responses that is structured according to various possible observed outcomes can be developed. This approach is discussed in the following section.

### **6.4 Management Responses to Significant Environmental Change**

The last step in the evolving District process for determining adverse environmental impact for surface water withdrawals presented in **Section 6.1** involves the identification of appropriate



management actions or remedial measures to be undertaken if significant environmental change is detected or appears likely. Waiting until an adverse environmental impact has occurred to initiate appropriate management actions or remedial measures reduces the opportunity to adequately protect resources that may be at risk. Therefore, proactive resource management is needed to protect the resources of concern in the lower Peace River estuarine system.

It is recommended that salinity deviations be used as the primary indicator of significant environmental change that could lead to potential adverse environmental impact. In addition, salinity deviations could be used as the triggering mechanism for a range of management responses aimed at reversing or minimizing the change to prevent potential adverse environmental impact. Salinity deviations from the target distribution could be evaluated in terms of magnitude, spatial extent, and/or temporal duration to develop a decision tree that is linked to various management actions ([Figure 6.3](#)). Using this approach, the intensity and urgency of the management response would be appropriately linked to the degree of the observed salinity deviations ([Figure 6.4](#)).

Various management actions could be implemented in response to an observed significant deviation in the statistical distribution of salinity measurements. The initial management actions should focus on determining if the observed deviation is in fact real and not a measurement error or an artifact of the sampling design. If the change is determined to be real, the next series of management actions should focus on better understanding and describing the change, and determining potential cause and affect relationships. Finally, the most intense management actions may involve regulatory enforcement actions as well as remediation and mitigation.

A hierarchy of management actions, listed sequentially in order of increasing intensity and urgency, is recommended below.

1. **Data QA/QC Audit** - This action would involve the performance of an intense QA/QC audit to determine if the detected change was the result of laboratory problems, data entry errors, violation of sampling protocols, etc.
2. **Data Comparison (Correlates)** - This action would involve a review of data correlates (e.g., specific conductance is a correlate to salinity) to determine if there is more than one line of evidence reflecting the detected change.
3. **Scientific Review Panel Meeting** - If Steps 1 through 2 indicate that the detected change is not due to quality control problems, and is reflected in multiple lines of evidence, the next step would involve convening a special meeting of the HBMP Scientific Review Panel. The purpose of the meeting would be to review the findings of Steps 1 through 2, and to determine a possible modified course of action to refine the understanding of the magnitude and extent of the detected change. If deemed appropriate, the Panel could recommend additional data analyses, or a redirected and focused sampling effort to better elucidate the detected change. Recommendations of the Panel would be subject to further review and approval by District staff.

4. **Redirected Sampling Effort** - This action would involve conducting more focused supplemental sampling in the affected river segments with the objective of gaining a better understanding of the detected change. The additional data collected from this effort could then be subjected to Steps 1 and 2 above if deemed appropriate. This action would determine if detection of the change is repeatable under a more focused sampling program. Although this step could be valuable, it may not be necessary for a redirected sampling effort to be conducted for all hydrobiological changes detected by the HBMP. For some hydrobiological changes, District staff could recommend proceeding directly to Step 5 without conducting any redirected or additional sampling.
5. **Determination of Significant Environmental Change** - Based on the findings of Steps 1 through 4, the next step would be to reconvene the Scientific Review Panel with the objective of evaluating whether the detected change is substantial enough to potentially constitute an adverse environmental impact. This step would involve a detailed assessment of the data analyses conducted in Steps 1 through 4 to ascertain whether conditions consistent with the working definition of significant environmental change presented above have been met. A formal determination of significant environmental change would be made via a consensus of professional opinion by District staff and the Panel members in consideration of technical and scientific factors only. Following this determination, the Peace River/Manasota Regional Water Supply Authority Board would be briefed on the findings and recommendations of District staff and the Panel.
6. **Regulatory Summit Meeting** - If after the completion of Step 5 District staff and the Panel conclude that a significant environmental change has occurred, the next step would be to convene a meeting with all applicable regulatory agencies and affected parties to determine the appropriate regulatory course of action. At a minimum, the regulatory agencies represented would include SWFWMD and FDEP, however, depending on the environmental changes involved other state and federal agencies may be involved (e.g., Florida Fish and Wildlife Conservation Commission; U.S. Fish and Wildlife Service). Actions could include revisiting Steps 1, 2 and 4 above, or immediate enforcement of regulatory actions such as temporary modification of the withdrawal schedule. If more substantial regulatory actions such as permanent modifications to the withdrawal schedule and/or mitigation were determined to be appropriate, preparations would be made for presenting recommendations to the District Governing Board for formal action.
7. **District Governing Board Hearing** - This step would involve the presentation of data and other evidence indicating the occurrence of significant environmental change to the District Governing Board. The formal determination of adverse impact from a regulatory and legal standpoint would be made by the District Governing Board. If it is determined that the detected change constitutes an adverse environmental impact, then the Governing Board could require appropriate remediation and or mitigation.
8. **Remediation** - The requirement of appropriate remedial measures by the District Governing Board could include such actions as permanent modifications to the

permitted withdrawal schedule. Modifications to the withdrawal schedule could include provisional or temporary reductions in withdrawal rates, or modifications to the schedules such that greater withdrawals would occur during high flows, but lesser withdrawals would occur during low flows. Given the regional need for additional water supplies, a permanent reduction in the total permitted withdrawal volumes would likely be viewed as the most intense response to detected adverse impact. In the event that the permitted withdrawals resulted in irreversible significant harm to resources of concern, mitigation could be required.

In the implementation of the sequence of management responses described above, the primary objective is the prevention of any adverse impacts. However, the intensity of the management response should not be the only criteria considered. The detection of any hydrobiological change must always be framed within the degree of certainty that the detected change is real, and not solely due to chance. Therefore, the intensity of the management response should be tied not only to the magnitude or severity of the hydrobiological change, but also to the degree of certainty that the detected change is real, and if it is caused by Authority withdrawals. Table 6-2 below presents a conceptual matrix approach that integrates the magnitude of the detected change and the probability that the change is due to chance alone (e.g. alpha).

As shown in Table 6.2, the intensity of the selected management response is a function of both factors. If the detected change is relatively large, but the degree of certainty is low (e.g. high alpha) then a less intense management response would be appropriate. If, on the other hand, the detected change is considered to be moderate, but the degree of certainty is high (e.g. low alpha), then a more intense management response would be indicated. The application of this approach would obviously vary with the specific hydrobiological changes and statistical measures of certainty involved. The approach of the selected management response would also depend on whether the observed change was found to be attributable directly to Facility withdrawals or potentially to anthropogenic upstream activities.

**Table 6.2**  
**Conceptual Decision Matrix For Determining An Appropriate Management Response To Detected Hydrobiological Change**

| Probability of Making<br>a Type I Error | Magnitude of Detected<br>Hydrobiological Change |                                     |                                     |
|-----------------------------------------|-------------------------------------------------|-------------------------------------|-------------------------------------|
|                                         | Small                                           | Moderate                            | Large                               |
| Alpha                                   |                                                 |                                     |                                     |
| 0.20                                    | Data Comparison                                 | Scientific Review Panel Meeting     | Redirected Sampling                 |
| 0.10                                    | Scientific Review Panel Meeting                 | Redirected Sampling                 | Determination of Significant Change |
| 0.05                                    | Redirected Sampling                             | Determination of Significant Change | Regulatory Summit Meeting           |

## 6.5 Assessment of Permitted Withdrawals

Since its inception in 1976 the HBMP has incorporated numerous physical, chemical, and biological study elements directed toward assessing both the overall “health of the estuary” as well as direct and indirect adverse impacts potentially associated with Facility withdrawals (see [Table 1.3](#)). These studies have included:

- A nine-year monthly study of the seasonal distribution of the sea star (*Luidia clathrata*) at twenty-six monitoring locations distributed throughout Charlotte Harbor and the lower Peace River (between RK -28 and 8).
- A monthly benthic ponar grab sampling program was conducted between 1976-1984 to determine seasonal responses of key benthic indicator invertebrates to changes in flows, salinity, and dissolved oxygen at 19 locations distributed along the lower river salinity gradient approximately between the river’s mouth and the point where Horse Creek enters the river (between RK 0 and 34).
- A monthly monitoring program was conducted at RK -2.4 over twelve years to determine the influences of freshwater inflows on the abundance and structure of juvenile fishes in the upper harbor.
- The HBMP program currently includes three ongoing long-term vegetation studies (see [Section 4.7](#)), including infrared aerial photography, the first and last occurrences of indicator species, and the monitoring of emergent riparian community structure and selected transitional sites.
- The seasonal effects of freshwater inflows on phytoplankton primary production was assessed based on monthly measurements at four isohalines between 1983 and 1998. The assessment of the phytoplankton community species composition at these locations has been ongoing monthly since 1989. The collection of chlorophyll *a* samples has been ongoing since 1976.
- The structure and response of zooplankton communities at each of the four phytoplankton-study isohalines were investigated monthly between 1989 and 1996.
- The HBMP has included extensive long-term monitoring elements associated with both the physical and chemical water quality characteristics of the lower river and upper harbor at “fixed” and “moving” isohaline-based monitoring locations. These data have been utilized to assess both physical and chemical seasonal responses to changes in freshwater inflows, as well as long-term trends in water quality characteristics in the estuary.
- Starting in 1997, continuous recorders have been used to assess both short- and long-term relationships of freshwater inflows and tide stage on river salinities (see [Section 4.6](#)).

To date none of the extensive analyses that have been conducted in conjunction with these long-term monitoring program elements, and reported in numerous previous HBMP documents submitted to the District, have found or suggested that there have been any significant long-term physical, chemical or biological changes in the lower Peace River/upper Charlotte Harbor estuarine system resulting from either current or historic water withdrawals by the Facility.

The results of the continuous recorder modeling presented in [Section 5.0](#), as well as previously summarized salinity and isohaline location modeling efforts, have all concluded that the maximum expected increases in salinity due to Facility withdrawals are expected to be difficult to actually measure within the normal daily range of tidal salinity variations during the periods when the Facility is potentially having its greatest influence. Consequently, no measurable changes in biological indicators addressed by other HBMP study elements have yet been detected. As long as salinity changes attributable to Facility withdrawals remain a small proportion of the normal typical range of daily (let alone seasonal) salinity variations along the lower Peace River/upper Charlotte Harbor transect, no significant environmental changes in the estuarine system are expected.

### 6.6 Summary

This section presents a proposed approach for determining whether the permitted surface water withdrawals have caused adverse environmental impact in the lower Peace River Estuary, as well as a hierarchy of management actions or a proactive resource management plan that could be implemented in response to detected changes that could forewarn of or constitute adverse impact. In addition, the salient findings of the HBMP are discussed with respect to the proposed criteria for determining adverse impact.

- During the Water Use Permit review process, applicants must provide the District with reasonable assurance that flow rates will not deviate from the normal rate and range of fluctuation such that: 1) water quality, vegetation, and animal populations are not adversely impacted in streams and estuaries; 2) salinity distributions in tidal streams and estuaries are not significantly altered as a result of withdrawals; and 3) recreational use or aesthetic qualities of the water resource are not adversely impacted. Unfortunately, the terms *adversely impacted* and *significantly altered* are not defined in District rules.
- The term *adverse impact* has both a technical and legal meaning. From a technical standpoint, adverse environmental impact can be defined using a wide range of metrics that quantify deviations from the pre-withdrawal salinity patterns, water quality conditions, and biological distribution and abundance. As such, technical determinations of adverse environmental impact are not absolute and are subject to subjectivity and interpretation. From a legal standpoint, however, the determination of adverse environmental impact, in the context of Water Use Permit compliance, is absolute and can only be made by the District Governing Board. Such a legal determination establishes a regulatory finding by the Governing Board that the District

performance standards for surface water withdrawals have been violated and that the permittee must reverse or mitigate the damage. The Governing Board is, nonetheless, dependent on the findings and recommendations of District technical staff as to what constitutes adverse environmental impact. The Peace River HBMP Scientific Review Panel (Panel), on the other hand, has been established primarily to assist District staff in assessing the continued technical efficacy and ability of the HBMP to detect potential adverse impacts caused by the Facility, and secondarily to assist District staff in the interpretation HBMP data.

- Pursuant to District rules, any defensible technical criteria used to define and determine the occurrence of adverse environmental impact must take into consideration changes in: salinity; associated water quality constituents; biological communities; natural or historic (pre-withdrawal) conditions; conditions that support economically important resource-dependent activities.
- District staff has developed a general process for determining adverse environmental impact as it relates specifically to surface water withdrawals. This process establishes a logical sequence of steps aimed at determining compliance with District performance standards. This seven-step process is summarized below.
  1. Specify resource management goals for the potentially affected waterbodies, as well as resource assessment objectives for the monitoring program.
  2. Identify hydrobiological indicators related to the resource management goals, and define appropriate measures of change for each.
  3. Monitor the identified hydrobiological indicators to measure changes over time.
  4. If changes in the hydrobiological indicators are detected, then determine if the detected changes are related to changes in freshwater flows, and if they represent a potential degradation of the affected resources.
  5. If the detected changes in the hydrobiological indicators are both related to changes in freshwater inflows, and represent a potential degradation of the affected resources, then determine the incremental effect of the permitted withdrawals on the detected changes.
  6. If the incremental effect of the permitted withdrawals on the detected changes is significant, then determine if the detected changes could constitute *adverse impact* pursuant to District performance standards.
  7. If the detected changes are determined to constitute adverse impact pursuant to District performance standards, determine appropriate management response(s) to reverse or mitigate the adverse impacts.



- It is proposed that the term *adverse impact* be supplanted by the term *significant environmental change* with respect to the role of the Panel. As such, District staff and the Panel are responsible for interpreting scientific data to determine if significant environmental changes have occurred as a result of the permitted withdrawals. Some environmental changes may be considered to be adverse from a technical perspective, while others may not. Furthermore, some changes may be potential harbingers of, or precursors to, greater environmental change that may later be considered to be adverse. However, only the District Governing Board can declare that a significant environmental change constitutes an adverse impact from a legal standpoint.
- A change in salinity and/or water quality attributable to freshwater withdrawals does not necessarily constitute significant environmental change unless that change is of such a magnitude and/or duration to cause a measurable and significant change in a biotic indicator. Therefore, for the limited purposes of the Peace River HBMP, it is proposed that a measurable change in salinity and/or water quality attributable to the permitted freshwater withdrawals does not constitute a *significant environmental change*. Nonetheless, a substantial or prolonged change in salinity and/or water quality alone, in advance of any observed effects on biotic indicators, should be considered an early detection mechanism to initiate appropriate management responses aimed at averting potential adverse environmental impact.
- A working definition of the term *significant environmental change*, to be used by the Panel and the District as criteria for assessing the findings of the HBMP is proposed as follows: *a detected change, supported by statistical inference or a preponderance of evidence, in the normal or pre-withdrawal abundance, distribution, species composition, or species richness of biological communities of interest in the lower Peace River and upper Charlotte Harbor that is directly attributable to reductions in freshwater inflows caused by the permitted surface water withdrawals.*
- Changes in salinity can affect the abundance and distribution of biological resources of concern both directly through osmotic stress, and indirectly through more complex processes (e.g. hypoxia caused by density stratification). For these reasons, salinity is typically considered to be the most appropriate estuarine indicator for the development of management targets and guidelines. Therefore, it is recommended that salinity change continue to be used as the primary indicator for the early detection of significant environmental changes that could lead to potential adverse environmental impacts.
- The District, with assistance from the Panel must define desirable or target statistical distributions of salinity that are spatially-specific to river segments containing resources most in need of protection, and/or most susceptible to adverse impact. In addition, the District, with assistance from the Panel, must define what constitutes an unacceptable magnitude and corresponding duration of salinity deviations from the target distribution (e.g. a 5 ppt deviation in salinity over a greater than 30-day period), as well as an unacceptable spatial extent of such salinity deviations. Once these general guidelines have been agreed upon, a hierarchy of management responses that is structured according to various possible observed outcomes can be developed.

- An eight-step sequence of management actions is recommended for implementation in response to an observed significant deviation in the statistical distribution of salinity measurements. The initial management actions should focus on determining if the observed deviation is in fact real and not a measurement error or an artifact of the sampling design. If the change is determined to be real, the next series of management actions should focus on better understanding and describing the change, and determining potential cause and affect relationships. Finally, the most intense management actions should involve regulatory enforcement actions as well as remediation and mitigation.
- Since its inception in 1976 the HBMP has incorporated numerous physical, chemical, and biological study elements directed toward assessing both the overall “health of the estuary” as well as direct and indirect adverse impacts potentially associated with Facility withdrawals. To date none of the extensive HBMP analyses have found or suggested that there have been any significant long-term physical, chemical or biological changes in the lower Peace River/upper Charlotte Harbor estuarine system resulting from either current or historic water withdrawals by the Facility.
- The results of the continuous recorder modeling, as well as previously summarized salinity and isohaline location modeling efforts, have all concluded that the maximum expected increases in salinity due to Facility withdrawals are expected to be difficult to actually measure within the normal daily range of tidal salinity variations during the periods when the Facility is potentially having its greatest influence. Consequently, no measurable changes in biological indicators addressed by other HBMP study elements have yet been detected. As long as salinity changes attributable to Facility withdrawals remain a fraction of the normal typical range of daily (let alone seasonal) salinity variations along the lower Peace River/upper Charlotte Harbor transect, no significant environmental changes in the estuarine system are expected.

## 7.0 Controlled River Pump Test Design

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The purpose of this Section is to provide an assessment of the suggested need to conduct a Facility “Pump Test”, and to present options regarding potential experimental design considerations and/or alternatives.

The District, Authority and Scientific Review Panel have over the past several years discussed the potential utility of conducting a series of controlled withdrawal experiments, or field “Pump Tests”, in order to provide an additional line of evidence in support of the overall conclusions reached by the various statistical models developed using existing HBMP data. These statistical models have been utilized to estimate the magnitude and spatial extent of salinity changes potentially resulting along the lower Peace River from both historic and predicted future Facility water withdrawals. These models have uniformly suggested that the predicted potential salinity changes due to the permitted freshwater withdrawal schedule range from only 0.1 to 0.5 ppt. Such salinity changes are far below both the typical daily tidal and seasonal salinity variations that naturally occur along the lower river, and probably could not be detected using either fixed, moving, or randomized monitoring designs.

It has been suggested that conducting actual field measurements during comparable flow conditions during which the Facility would withdraw controlled volumes of water would provide an additional experimental line of evidence needed to defend the conclusions reached by the existing statistical lower river salinity models. However, in advance of any decision to conduct such a field experiment, the Scientific Review Panel suggested that a discussion be included in this *Comprehensive Summary Report* briefly outlining the specific initial preliminary design considerations that would need to be addressed. These considerations include the following:

- Timing (appropriate flows and season)
- Appropriate spatial extent of monitoring
- Number, frequency, and types of sampling
- Methodology for data analysis

It was further suggested that such a discussion of the potential need and feasibility of any future series of Facility “Pump Tests” also specifically address:

- The explicit goals and objectives associated with conducting a Facility “Pump Test”.
- The range of flows and conditions expected to provide the clearest evidence of the actual magnitude of salinity changes potentially resulting from Facility withdrawals.
- The need to conduct initial preliminary field investigations to determine the normal extent of tidal movement of the freshwater/saltwater interface under Peace River flows conditions expected to be utilized during Facility testing.
- An initial review of existing continuous recorder data.

- A determination if such a Facility test could be accomplished following a set of protocols utilizing slight modifications of typical normal plant operations.
- The need to assess potential Facility related changes in the longitudinal gradient of specific ions (Ca, Mg, Na, Cl, F, Mn, Si, Fe, SO<sub>4</sub>).

### 7.1 Predicted Facility Salinity Impacts Resulting from Facility Withdrawals

A number of statistical modeling efforts have historically been conducted in conjunction with continuing efforts to refine the HBMP's ability to quantitatively predict the magnitude of potential Facility withdrawal impacts on both the lower river's salinity structure and movement of the freshwater/saltwater interface (see detailed discussion in [Section 5](#)). A series of statistical models were developed in the late 1980s and 1990s testing the relationships of lower river salinities and isohaline locations to both Peace River flows and Facility withdrawal using HBMP data from the series of long-term "fixed" monitoring sites along the lower Peace River. The District has recently funded ([Section 2](#)) additional updated statistical salinity/flow withdrawal models developed at these fixed sampling sites along the HBMP monitoring transect. The conclusions reached by these different modeling efforts have similarly suggested that the predicted influences of Facility freshwater withdrawals on salinity along the lower river are typically in the range of 0.1-0.3 ppt. To date, these efforts have suggested that any Facility salinity impacts probably could not easily be detected given the normal distributions or daily tidal ranges of salinity along the lower Peace River/upper Charlotte Harbor HBMP monitoring transect, and that the Facility has not significantly affected the seasonal or annual salinity structure of the estuarine reach of the lower Peace River.

### 7.2 Preliminary Design Study Investigations

#### Timing

The initial question that must be addressed regarding the design of a Facility "Pump Test" pertains to whether there are specific ranges of flows and/or seasons when potential Facility salinity impacts would be expected to be more easily detected. [Section 5](#) presents a series of graphical and statistical analyses regarding hourly salinity observations and the interactions between freshwater inflows and tidal gage height at the two existing USGS continuous HBMP gaging sites along the lower river ([Figure 5.1](#)). The results of these analyses strongly suggest that the greatest probability of actually being able to detect salinity changes due to the Facility's withdrawals increases both closer to the point of withdrawal and under low river flow conditions. The higher ambient salinity levels that naturally occur further downstream, when taken in conjunction with the confounding influences of both the increasing volumes of tidal exchange and daily variations in wind patterns, make detecting the small salinity differences caused by the Facility withdrawals increasingly difficult further downstream away from the point of withdrawal.

Probably the most opportune time to potentially detect changes in salinities due to Facility withdrawals would coincide with periods when river flows are both above the minimum 130 cfs

cutoff but not high enough to have moved the freshwater/saltwater interface too far downstream from the Facility. Seasonally, extended periods meeting these flow criteria typically occur during both the late fall/winter low flow interval and the spring dry-season. **Figures 7.1a** and **7.1b** depict gaged Peace River at Arcadia flows during these two potential periods for several recent typical years, and indicate the degree of variability that can be expected during the implementation of any future “Pump Test”. As shown, gaged river flows between the 130 cfs cutoff and 225 cfs occur during both periods. However, the brief periods of rain associated with the passage of cold fronts during the fall and winter often result in marked spikes in flow, which could disrupt an experimental design expected to continue over a number of weeks and complicate the timing of deploying field crews. Conversely, while river flows are typically more stable during the spring dry-season, they are often too low for the Facility to be consistently taking a full permitted ten percent of flow for any consistent period of time.

The data therefore suggest that while ideal conditions for implementing actual field testing of salinity changes due to Facility withdrawals commonly occur, the specific timing will be difficult to predict very far in advance, and that conditions can change rapidly. This is especially true regarding both southerly or northerly winds preceding and following fall/winter cold fronts, which can be sustained over several days and then rapidly reverse. During periods of low to moderate rates of river inflow, wind shifts can be as or more important than tides in determining the salinity structure along the lower river. These confounding influences will make the scheduling and deployment of field crews to conduct field sampling problematic and extremely difficult. The design of any Facility “Pump Test” will therefore need to primarily rely on the implementation of an array of automated continuous recorders similar to those USGS recorders already in place.

### Location

Another major “Pump Test” design issue is determining the appropriate spatial extent of a proposed monitoring array. In order to develop baseline information applicable to this issue, an initial preliminary field investigation was conducted to determine the normal extent of the tidal movement of the freshwater/saltwater interface under Peace River flow conditions expected to be utilized during actual Facility testing. A series of idealized criteria and conditions were established for this investigation. These criteria are expected to be similar to those used in actually conducting the future Facility “Pump Test”.

- Preceding day gaged Peace River at Arcadia flows need to be between 160 and 230 cfs.
- Sustained southerly or northerly winds need to be less than 5 mph.
- The predicted tidal difference between high and low slack needs to be between 1.2 and 1.6 feet.

An additional “field crew” requirement, which would not be needed with automated recorders, was that the predicted high and low tides needed to determine the spatial movement of the freshwater/saltwater interface have to occur within (or near) daylight hours to facilitate navigation.

Applying these conditions, the HBMP field crew started attempting to collect the desired information in October 2003. After a number of failed attempts due to unexpected rain and wind conditions, field observation data under expected “Pump Test” conditions were finally obtained on January 13, 2004. **Figure 7.2** depicted the tidal range predicted on that day. Due to the upstream differences in the tidal lags, the expected high slack and low slack tidal conditions were predicted downstream of the facility at approximately 7:55 am and 3:20 pm. The locations of the freshwater/saltwater interface are indicated at approximately one-hour intervals on **Figure 7.3**. Table 7.1 indicates the spatial movement of the freshwater/saltwater interface over the January 13, 2004 tidal cycle from approximately high slack, to just after the turn of the tide following low slack.

Hydrolab<sup>TM</sup> profiles taken during the monitoring event indicated that the water columns both above and below the designated 500 us/cm interface were well mixed. Upstream of the interface river conductivities generally ranged from 460 to 490 us/cm, while immediately downstream of the interface conductivities were in the range of 700 to 800 us/cm.

During the first three hours immediately following high slack tide, the freshwater/saltwater interface rapidly moved downstream and was clearly distinct (confined to a narrow band of less than 0.01 kilometers). However, when the interface reached the area of the river near river kilometer 23.2 its further downstream movement rapidly declined, even though the tide continued to go out. During this period the exact location of the interface also became far less distinct, often covering as much as 0.1 kilometers.

**Table 7.1**  
**Relative Spatial Movement of the**  
**Freshwater/Saltwater Interface Over the Tidal Cycle**

| Time            | 7:47 | 8:59 | 10:00 | 11:06 | 11:59 | 1:04 | 1:58 | 2:55 | 4:05 |
|-----------------|------|------|-------|-------|-------|------|------|------|------|
| River Kilometer | 25.9 | 25.0 | 23.5  | 23.2  | 23.1  | 23.0 | 22.9 | 23.0 | 23.1 |

During this monitoring event, the interface was observed to have moved approximately three kilometers between high and low slack tides. The results provide an indication of the spatial extent of the river over which the interface might be expected to fluctuate when Facility withdrawals would be expected to exhibit the greatest influences on upper river salinity patterns. It should also be noted that the observed tidal movement of the interface was approximately an order of magnitude greater than the potential isohaline movements predicted by the various statistical salinity models developed for the lower Peace River estuarine system (**Section 5**).

The day prior to the January 13, 2004 sampling event the provisional estimated Peace River at Arcadia flows provided on the USGS web site indicated a rate of approximately 225 cfs. Since that time, this original estimated flow has been revised upward to 285 cfs, which is slightly higher than the original established idealized sampling criteria. This difference between the real-time provisional estimated gaged flows used by the Facility for establishing daily withdrawals, and the subsequent final published USGS river flows provides a basis for “data mining” the



existing continuous recorder data collected upstream at river kilometer 26.7 to investigate the results of *de facto* “Pump Tests” that have been run during normal Facility operations over the past several years.

### 7.3 Comparisons Using Existing Continuous Recorder Data

As has been pointed out in the annual HBMP Data Reports, the Authority uses “provisional” preceding day flow data from the water level recorder at the USGS gaging station on the Peace River at Arcadia. These data are taken directly from the USGS Tampa Office’s website. However, after the fact, the USGS checks and evaluates the data from the stage recorder and may “post adjust” the flow data based on recalculations of the river cross section, which are conducted a number of times each year. The daily Peace River at Arcadia flow values used by the Authority as a basis of withdrawals are thus only “provisional” and are often changed by the USGS weeks, months or even years after-the-fact. It is not uncommon for subsequent determinations of percent withdrawals, based on revised USGS calculations of daily flows to indicate that daily withdrawals, based on provisional flow information, have exceeded the District’s ten percent permit withdrawal criteria. The Authority, District and USGS have continued over the years to improve the reliability of the provisional flow data to reduce these instances. However, the occurrence of such events provides an opportunity to investigate the results of “Pump Tests” that have unknowingly been conducted below the 130 cfs minimum cutoff and/or the 10 percent criteria.

A series of queries were sequentially applied to the USGS continuous (fifteen minute) recorder data collected between 1997 and 2002 in order to develop a subset of paired dates meeting consistent criteria to compare “Pump Test” conditions with and without Facility withdrawals. These criteria include:

- Peace River at Arcadia flow was less than 250 cfs.
- There were no Facility withdrawals.
- The Facility had however withdrawn water on the preceding day.
- Withdrawals on the preceding day had been at least five percent of flow.
- Peace River at Arcadia gaged flows on both days were similar.
- The daily patterns of recorded stage heights between the two days were also similar.

Thirteen paired dates met these criteria, and ten representative examples ranked from low to higher flows are provided in Table 7.2. As indicated, the fact that the real-time provisional USGS gage readings can be subject to major revisions provides the unexpected opportunity to compare *de facto* “Pump Test” results from events occurring both well below the established 130 cfs minimum flow threshold and above the maximum ten percent permitted rate of withdrawal.

As shown in **Figures 7.4a** and **7.4b**, it is fortuitous that this discrepancy between real-time provisional and finalized calibrated gaged flows exists, since the upstream USGS continuous recorder at river kilometer 26.7 is typically upstream of the freshwater/saltwater interface at gaged flows when the Facility should be able to begin actual withdrawals.

The following conclusions can be made from the results of the paired date comparisons provided in Table 7.2:

- In comparing these graphics it should be noted that a change of 1000 us/cm in conductivity is approximately equivalent to a change of 0.6 ppt in salinity.
- Figures 7.5a and 7.5b show that under very low flow conditions and withdrawals equal to twenty-five percent of gaged Peace River at Arcadia flow (e.g. 2.5 times greater than the permitted maximum), the maximum changes in salinity over the tidal cycle that could be attributed to Facility withdrawals was only approximately 0.6 ppt at both the surface and near the bottom.
- Figures 7.6a and 7.6b, and 7.7a and 7.7b show very close, matching patterns between gage height and observed conductivities, and little indication of salinity changes that could be attributed to Facility withdrawals.
- Figures 7.8a and 7.8b both show salinity increases during withdrawals greater than would be expected simply due to the observed tidal differences. Again, flows were well below the 130 cfs threshold and withdrawals exceeded ten percent of flow. However, at most, the salinity differences were less than 1.0 ppt over a small portion of the tidal cycle.
- The remaining six potential events all occurred at flows greater than 100 cfs, and as the data indicate, the freshwater/saltwater interface was too far down stream from the continuous recorder for conductivities to be influenced by withdrawals.
- Comparisons among these paired figures for consecutive days clearly indicate that ambient conductivities in this reach of the river are more strongly influenced by differences in tidal patterns than flows.

**Table 7.2**  
**Selected Dates Comparing Gage Heights and Conductivities**  
**on Paired Days With and Without Facility Withdrawals**

| Year | Month | First Day | First Day<br>Peace Flow (cfs) | Withdrawal (cfs) | Second Day | Second Day<br>Peace Flow (cfs) | Withdrawal (cfs) | Graphics    |             |
|------|-------|-----------|-------------------------------|------------------|------------|--------------------------------|------------------|-------------|-------------|
|      |       |           |                               |                  |            |                                |                  | Subsurface  | Near Bottom |
| 2000 | 7     | 14        | 42                            | 10.7             | 15         | 50                             | 0                | Figure 7.5a | Figure 7.5b |
| 2000 | 7     | 19        | 65                            | 13.9             | 20         | 57                             | 0                | Figure 7.6a | Figure 7.6b |
| 1999 | 3     | 30        | 80                            | 13.3             | 31         | 75                             | 0                | Figure 7.7a | Figure 7.7b |

**Table 7.2**  
**Selected Dates Comparing Gage Heights and Conductivities**  
**on Paired Days With and Without Facility Withdrawals**

| Year | Month | First Day | First Day<br>Peace Flow (cfs) | Withdrawal (cfs) | Second Day | Second Day<br>Peace Flow (cfs) | Withdrawal (cfs) | Graphics                     |                              |
|------|-------|-----------|-------------------------------|------------------|------------|--------------------------------|------------------|------------------------------|------------------------------|
|      |       |           |                               |                  |            |                                |                  | Subsurface                   | Near Bottom                  |
| 1999 | 5     | 14        | 89                            | 12.8             | 15         | 79                             | 0                | <a href="#">Figure 7.8a</a>  | <a href="#">Figure 7.8b</a>  |
| 1999 | 6     | 8         | 110                           | 9.2              | 9          | 109                            | 0                | <a href="#">Figure 7.9a</a>  | <a href="#">Figure 7.9b</a>  |
| 2001 | 12    | 12        | 123                           | 8.0              | 13         | 122                            | 0                | <a href="#">Figure 7.10a</a> | <a href="#">Figure 7.10b</a> |
| 1999 | 12    | 16        | 126                           | 13.8             | 17         | 124                            | 0                | <a href="#">Figure 7.11a</a> | <a href="#">Figure 7.11b</a> |
| 2000 | 8     | 22        | 134                           | 11.5             | 23         | 117                            | 0                | <a href="#">Figure 7.12a</a> | <a href="#">Figure 7.12b</a> |
| 2000 | 9     | 12        | 138                           | 14.6             | 13         | 116                            | 0                | <a href="#">Figure 7.13a</a> | <a href="#">Figure 7.13b</a> |
| 2000 | 10    | 14        | 142                           | 13.7             | 15         | 120                            | 0                | <a href="#">Figure 7.14a</a> | <a href="#">Figure 7.14b</a> |

## 7.4 Recommended “Pump Test” Design

The results of these limited *de facto* “Pump Tests” closely support the overall conclusions of the statistical models developed from continuous recorder data presented in [Section 5](#). These statistical models indicated that changes in salinities as high as 0.8 ppt may have resulted from actual Facility withdrawals that have occurred outside of the established permit conditions. This conclusion closely matches the actual field data presented in Table 7.2.

As part of the recommended modifications of the existing HBMP design detailed in [Section 8](#) it is suggested that two additional continuous recorders be established downstream of the current USGS recorder at river kilometer 26.7. The existing upstream recorder provides needed information regarding the upstream movement of salinity under very low flow conditions, but as indicated ([Figure 7.4a](#)) its location is generally too far upstream to effectively monitor potential changes due to Facility withdrawals.

The addition of such continuous recorders within the expected spatial extent of the tidal movement of the freshwater/saltwater interface under Peace River flow conditions between 130 and 250 cfs is anticipated to provide enhanced resolution of potential changes in salinity due to Facility withdrawals. It is suggested that these added continuous recorders could be used to conduct a series of cost-effective operational “Pump Tests” over an extended period of time, by employing an established series of criteria rather than having to rely on after-the-fact data mining. Recommended criteria include:

- Predicted tide tables could be used to establish potential pairs of days with expected comparable tides.

- Potentially longer test periods could be utilized if a series of days with comparable predicted tidal cycles were forecast to occur.
- Whenever real-time provisional Peace River at Arcadia flows are within the selected target range (approximately 150 to 250 cfs), the Facility would check both the predicted tides and expected weather (rainfall and wind) to determine if a “Pump Test” event could be conducted.
- If conditions meet the established criteria the facility would then withdraw water on one day of the pair and not the second.
- This procedure could be repeated as frequently as practical over a period of several years.
- Based on finalized USGS gage data, the “Pump Tests” could be grouped into differing classes based on both flows and tides.
- Graphical analyses similar to those used above could be utilized to determine the potential magnitude of salinity changes due to withdrawals under differing conditions.
- Potential modifications to the design could be made based on initial summary results or coincide with potential future Facility or withdrawal schedule modifications.

### 7.5 Baseline Investigation of Lower River Ion Balances

A recent recommendation of the Scientific Review Panel concerned the need to establish preliminary baseline information with regard to assessing potential Facility related changes in the longitudinal gradient of specific ions (Ca, Mg, Na, Cl, F, Mn, Si, Fe, SO<sub>4</sub>) along the lower river. In conjunction with the monitoring of the tidal movement of the freshwater/saltwater interface on January 13, 2004 a series of specific ion samples were collected in order to provide such information. Triplicate samples were collected and analyzed for the recommend series of ions at a series of locations:

#### Primary Upstream Freshwater Sources

- The Peace River at Arcadia
- Joshua Creek at Highway 17
- Horse Creek at Kings Highway

#### High Slack Tide (see [Figure 7.3](#))

- Upstream of the Facility
- Downstream of the Facility
- Upstream of the Interface
- Downstream of the Interface

### Low Slack Tide (see [Figure 7.3](#))

- Upstream of the Facility
- Downstream of the Facility
- Upstream of the Interface
- Downstream of the Interface

The results of this study are presented in [Table 7.3](#), which indicates a number of interesting patterns and differences among measured ion concentrations.

- There are some notable large differences among the three major lower Peace River freshwater sources with regard to both the major anion and cation levels.
- The ion levels from Joshua Creek characteristically show very strong influences of ions commonly associated with agricultural groundwater pumping.
- Peace River at Arcadia ambient fluoride concentrations were observed to be considerably higher than waters from the other two watershed, potentially reflecting the influences of both natural phosphate deposits and mining activities.
- Both ambient magnesium and sodium ion levels were notably lower in the Horse Creek samples.
- There were no notable differences among the ion balances between the samples collected upstream and downstream of the Facility under either high or low slack tidal conditions.
- As expected, the data indicate similar higher concentrations of magnesium, sodium and chloride ions downstream of the freshwater/saltwater interface during both slack high and slack low tidal extremes.

Previous long-term data collected by both EQL and USGS have also indicated substantial seasonal variations in the ion balances both within and among the major freshwater lower Peace River tributaries.

## 7.6 Summary

The District, Scientific Review Panel and Authority have discussed the potential need to conduct a series of actual field “Pump Tests” to provide an additional line of evidence in support of the overall conclusions reached by existing statistical salinity models that the predicted potential changes due to the permitted withdrawal schedule range of only 0.1 to 0.5 ppt. The primary objective of this Section is to provide an overview and summary of the suggested need to conduct a Facility “Pump Test”, and present options regarding potential experimental design considerations and/or alternatives.

- Probably the most opportune timing to potentially detect changes in salinities due to Facility withdrawals would coincide with periods when river flows are both above the minimum 130 cfs cutoff and not high enough to have moved the freshwater/saltwater interface too far downstream from the Facility.
- Data analysis indicates that ideal conditions for field testing salinity changes due to Facility withdrawals commonly occur. However, the specific timing is both extremely difficult to predict and conditions can change rapidly. Therefore, any Facility “Pump Test” design will need to primarily rely on utilizing automated continuous recorders.
- An initial preliminary field investigation was conducted to determine the typical extent of the tidal movement of the freshwater/saltwater interface that might be expected during actual Facility testing. The results indicated that the interface spatially moved approximately three kilometers between high and low slack tides, which was approximately an order of magnitude greater than the potential isohaline movements predicted by the various previously developed HBMP statistical lower river salinity models.
- Data from the existing USGS gage located approximately three kilometers downstream of the Facility were analyzed using a series of criteria to investigate *de facto* “Pump Tests” run as part of normal Facility operations. These analyses clearly showed that the existing statistical salinity models probably slightly overestimated the actual salinity impacts of Facility withdrawals in this reach of the river.
- It is recommended that, rather than relying on a series of short-term field tests, additional continuous recorders should be established as part of the recommended overall HBMP monitoring design modifications. These new gages, combined with the exiting two continuous recorders could then be used to conduct a series of cost-effective “Pump Tests” over an extended period of time, by employing an established series of flow, tide and wind based monitoring criteria.
- Based on recommendations of the Scientific Review Panel, preliminary baseline information was collected to assess potential Facility related changes in the longitudinal gradient of specific ions (Ca, Mg, Na, Cl, F, Mn, Si, Fe, SO<sub>4</sub>) along the lower river. The results indicate notable differences among the three major lower Peace River freshwater sources with regards to both the major anion and cation levels. However, there were no notable differences among the ion balances between the samples collected immediately upstream and downstream of the Facility under either high or low slack tidal conditions. The data do indicate higher concentrations of magnesium, sodium and chloride ions downstream of the freshwater/saltwater interface during both slack high and slack low tidal extremes.



## 8.0 Monitoring Design Modifications

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The primary objectives of this section are to review the effectiveness and address potential modifications of the current HBMP study elements based on the results of the analyses presented and overall conclusions developed in this *Comprehensive Summary Report*, as well as those contained within the previous *2000 Midterm Interpretive Report* (PBS&J 2002).

### 8.1 Monitoring Objectives

In order to be effective, the HBMP design needs to cost-effectively address the articulated goals and objectives delineated in the District's specific Water Use Permit conditions. The program design needs to meet the specific expectations and objectives set forth in the permit as well as provide sufficient long-term information on which to base the development of answers to future questions.

The stated primary monitoring objectives of the HBMP study elements, as defined by the specific Permit conditions, are to:

- Monitor withdrawals from the Peace River at the Facility and evaluate data as provided by the District for the gaged tributary flows from Joshua, Horse and Shell Creeks, as well as the primary Peace River flows measured at Arcadia, and direct rainfall to the lower Peace River.
- Evaluate relationships between the ecology of the lower Peace River/upper Charlotte Harbor Estuary and freshwater inflows.
- Monitor selected water quality and biological variables in order to determine whether the ecological characteristics of the estuary related to freshwater inflows are changing over time.
- Determine the relative degree and magnitude of effects of Peace River withdrawals by the Facility on ecological changes that may be observed in the lower Peace River/upper Charlotte Harbor estuarine system.
- Evaluate whether consumptive freshwater withdrawals significantly contribute to any adverse ecological impacts to the estuary resulting from extended periods of low freshwater inflows.
- Evaluate whether the withdrawals have had any significant effects on the ecology of the estuary, based on related information such as nutrient loadings, fish abundance, or seagrass distributions data collected by other studies conducted by the District or other parties.

The overall primary goal of the combined HBMP study elements is to provide the District with sufficient information to determine whether the water quality characteristics and biological communities of the lower Peace River/upper Charlotte Harbor estuarine system have been, are being, or may be significantly adversely impacted by permitted facility withdrawals. In addition, the ongoing base of ecological information developed in conjunction with the HBMP regarding the lower Peace River and upper Charlotte Harbor estuarine system provides the District with critical information with regards to issues related to the estuarine systems overall status and relative “health”, by evaluating the status and trends of selected water quality and biological

### 8.2 HBMP Design Criteria

In order to effectively address the primary monitoring goals and objectives specified in the District’s Water Use Permit, the overall design of the combined HBMP study elements must address:

- The mechanisms (and specific indicators) by which Facility withdrawals may potentially cause significant changes in the physical and/or biological characteristics of the lower Peace River/upper Charlotte Harbor estuarine system (see [Section 2.0](#)).
- The geographical regions of the lower river where both naturally occurring and Facility induced changes would be expected to result in the greatest potential observed changes in key estuarine characteristics.
- The periods of time when measurable changes in selected physical/chemical or biological parameter changes resulting from changes in freshwater inflows would be most likely to be detected.

In order to meet these necessary design criteria, and provide technically sound and practical data collection, it is important the following be clearly defined for all HBMP study elements:

- The goals and objectives, and associated specific sampling parameters for each study element.
- The specific purpose and application of each defined monitoring parameter.
- Where and when all HBMP data parameters should be acquired.
- Specific sampling and analytical data gathering procedures.
- Data acquisition quality control and assurance methodologies.
- Potential data analysis methods and procedures.
- Difference in required reporting frequencies among study elements.

It is important that each monitoring element, as well as the overall HBMP, clearly identifies specific articulated goals and objectives in order to cost-effectively establish the design criteria necessary to meet the monitoring program’s key multiple expectations. The goals and objectives need to clearly establish the scientific basis to providing sufficient information to meet the District’s criteria for required reasonable assurance, as well as provide meaningful information to both the public and the Scientific Review Panel. It is also essential that the HBMP provide the

types and amounts of monitoring data necessary to construct, calibrate, and verify the quantitative predictive models needed to evaluate both current as well as possible future alternative withdrawal strategies (see [Section 9.0](#)).

Often a well-designed monitoring program results in unanswered questions concerning key environmental processes or potential impacts. It is therefore important that the HBMP design criteria provide for opportunities, where feasible, for the incorporation of short-term, intensive monitoring elements to provide answers to specific questions or issues that may arise periodically during the review process. The HBMP design elements further need to be sufficiently flexible to allow for modifications when and where changes in conditions or new gathered information suggests the need for specific monitoring program changes.

### 8.3 Indicators of Environmental Change

The following provides a brief overview of a number of the principle considerations and idealized criteria associated with the selection of potential indicators (or parameters) that should be considered during the development and application of HBMP study elements utilized to temporally and spatially assess environmental changes relative to changes in freshwater inflows. Possible monitoring indicators (parameters) can generally be divided into three primary categories relative to their proportional degree of importance in assessing potential impacts associated with Facility withdrawals.

- Those **critical** to the overall success of the monitoring program
- Parameters that would provide **desirable** additional information
- Indicators that may have some **potential** future application

Cost-effective modifications to the HBMP study elements require that key selected indicators exhibit specific and robust direct or indirect quantifiable relationships with changes in freshwater inflows (see [Section 2.0](#)). As discussed relative to the previous development of the “Conceptual Estuarine Model,” those primary indicators that show direct relationships to variations in freshwater inflows are typically physical or chemical in nature. Usually, such parameters are characterized by rapid measurable responses to even relatively small changes in flows. In comparison, commonly utilized indicators characterized by indirect relationship with variations in flow are typically biological in nature. The relationships between changes in freshwater inflows and the distribution, structure and abundance of biological populations/communities within estuarine systems are mediated by preceding alterations of physical and chemical conditions. Thus, these indirect relationships generally exhibit much slower responses over time scales measured in days, months, seasons or even years. However, not only does the time scale potentially lengthen between variations in flow and observed responses with each trophic step up the food web ([Figure 8.1](#)), often the strength of the response lessens relative to other seasonal factors associated with particular life-cycles and/or feeding-prey relationships.

A cost-effective HBMP monitoring design needs to focus on identifying and incorporating those *critical indicators* known to exhibit marked direct responses to variations in freshwater inflow, since it is these parameter measurements that present the greatest probability of both detecting and assessing the principle underlying causative factor(s) to observed environmental changes.

The further incorporation of accompanying *desirable indicators* within the HBMP study elements should include those lower trophic level biological indicators that provide insight into the overall “health of the estuary,” or those that afford the integration of longer-term patterns. The utilization of *potential indicators* should be strictly limited to those few associated parameter measurements that can be quickly made with minimal additional effort or additional cost, and that may provide some further useful insight, without specifically being directly related to the study element’s primary goals or objectives. The following basic criteria should be evaluated in assessing the relative efficacy of various potential indicators.

- New Information - provides new information; does not merely duplicate data already collected by other agencies or investigators.
- Spatially Responsive – the indicator should reflect changes in ecosystem conditions in response to an environmental stressor across a broad spatial range.
- Anticipatory - provides an accurate early warning of potential ecosystem changes.
- Cost-Effective - has low incremental cost relative to its information value.
- Available Methodology - should be generally accepted and standardized.
- Unambiguously Interpretable - must be indicative of either a direct or indirect pathway describing the structure and function of the overall conceptual estuarine model.
- Simple Quantification – indicator measurements can be quantified relatively quickly with limited known variability among investigators.
- Low Measurement Error – parameter values should have known estimated levels of error than can be defined spatially and temporally.
- Low Among-Year Variability – in order to detect ecologically significant changes within reasonable time frames, parameter values need to have low natural inter-annual variation relative to variables outside the environmental stressor of interest.
- Sampling Stability - measurements of the indicator should be spatially stable over the course of each sampling period.
- Historical Record – the availability of a historical database from acceptable data sources.
- Retrospective - can be related to past conditions via retrospective analyses.

## **8.4 HBMP Study Elements**

Since the initiation of HBMP monitoring in 1976, the program has incorporated a number of differing physical, chemical, and biological study elements (see [Table 1.3](#)) that have been directed toward assessing both the overall “health of the harbor” as well as direct and indirect potential impacts that might be associated with Facility withdrawals. These HBMP studies have included the following program elements.

- A nine-year monthly study was conducted of the seasonal distribution of the sea star *Luidia clathrata* at twenty-six monitoring locations distributed between River Kilometers –28.0 and 8.0 throughout Charlotte Harbor and the lower Peace River.
- A benthic ponar sampling program conducted monthly between 1976–1984 at nineteen monitoring sites distributed between the river’s mouth (RK 0.0) and the point upstream of the Facility where Horse Creek enters the river (RK 34.0). This nine-year HBMP monitoring element was conducted to assess temporal and spatial responses of key benthic indicator invertebrates to both seasonal and long-term variations in freshwater inflows, salinity and dissolved oxygen.
- Monthly, night-time otter trawls were performed around a fixed monitoring location in upper Charlotte Harbor (RK –2.4) over twelve years in order to determine the influences of freshwater inflows on the abundance and structure of juvenile fishes in the upper harbor.
- The HBMP program currently incorporates three ongoing long-term vegetation studies along the lower Peace River downstream of the Facility (see [Section 4.7](#)). These vegetation HBMP elements include infra-red aerial photography, the first and last occurrences of indicator species, and the monitoring of emergent riparian community structure at selected transitional sites.
- The seasonal effects of freshwater inflows on phytoplankton primary production were assessed based on monthly measurements of radioactive carbon uptake rates at four isohalines between 1983 and 1998. Corresponding chlorophyll *a* measurements of phytoplankton biomass have continued since 1983 at the isohaline-based sampling sites. The associated composition of the phytoplankton communities at these locations has also been ongoing monthly since 1989.
- A corollary study of zooplankton community structure was conducted monthly between 1989 and 1996 at each of the four monitored phytoplankton isohalines. The objectives of this eight-year HBMP study were to assess correlations among variations in freshwater inflow, phytoplankton production and biomass, and zooplankton populations.
- Since its inception, the HBMP has included extensive long-term monitoring elements associated with both the physical and chemical water quality characteristics of the lower river and upper harbor at “fixed” and “moving” isohaline-based monitoring

locations. These data have been utilized to assess both physical and chemical seasonal responses to changes in freshwater inflows, as well as long-term trends in water quality characteristics in the estuary.

- Starting in 1997, continuous recorders have been used to assess the interactions and relationships of freshwater inflows and tide stage with regard to both short- and long-term variations in estuarine salinities (see [Section 5.0](#)).
- A morphometric investigation was undertaken in the late 1990s to establish a river kilometer-based centerline transect against which to standardize all historic and future HBMP monitoring data. Additional analyses were conducted to determine typical cross-sections, open-water areas, water volumes, shoreline lengths, and the areas/types of adjacent wetland habitat along 0.5 kilometer segments of the lower Peace River study area.
- Intensive short-term investigations were conducted of the relative influences of variations in freshwater flows on the relative temporal/spatial distributions of both benthic macroinvertebrates and mollusks (1998-2000), and juvenile fishes and selected invertebrates (1997-2000). One of the objectives of both investigations was to determine potential monitoring strategies relating to future inclusions of additional HBMP study elements.

The specific objectives, methods and results of these historic and ongoing HBMP study elements have been presented in the extensive series of HBMP Annual Data Reports and periodic Summary and Interpretive Reports submitted to the District since 1979. Comprehensive summaries of the objectives and conclusions of the major HBMP-related documents prepared since the 1996 Permit renewal are presented in [Section 3.0](#). To date none of the extensive analyses conducted in conjunction with these HBMP study elements have indicated or suggested that there have been any significant physical, chemical or biological changes within the lower Peace River/upper Charlotte Harbor estuarine system resulting from water withdrawals by the Peace River Regional Water Supply Facility. All modeling efforts of changes in either salinities or isohaline locations (see [Section 3.0](#) and [Section 5.0](#)) have concluded that the maximum expected changes potentially resulting from Facility withdrawals would be difficult or impossible to actually measure within the range of the normal daily tidal and seasonal ranges of variation.

### 8.5 HBMP Design Modifications

Modifications have been made to the elements of HBMP throughout its history. While the overall cost (inflation adjusted) of the monitoring program has remained relatively constant, study elements have been added and deleted in order to enhance the overall knowledge base of the lower Peace River/upper Charlotte Harbor estuarine system. Historically, those major monitoring elements aimed at assessing direct relationships with variations in freshwater inflow have had the longest histories (vegetation and water quality – see [Table 1.3](#)). Other program elements, primarily those focused on assessing indirect biological indicators, have extended over



a number of years and then ended once a sufficient baseline basis of information had been accumulated.

The HBMP Scientific Review Panel met in November 2002 and reviewed the monitoring program modifications recommended in the *2000 Midterm Interpretive Report*, which focused on reducing the number of water quality parameters included in both the “fixed station” and “moving” isohaline-based HBMP study elements. The panel agreed that both the “fixed” and “moving” water quality monitoring programs were important, and that if a water chemistry parameter wasn’t providing useful information relative to seasonal variations in freshwater inflows and potential Facility impacts, it should be deleted from the HBMP. The Scientific Review Panel recommended that the District accept the suggested chemical parameters revisions with the caveat that chlorides and silica continue as HBMP parameters. Based on these recommendations, the District agreed to the revised HBMP water chemistry parameter list ([Table 8.1](#)) starting in January 2003.

Other suggestions and recommendations made by the Scientific Review Panel regarding the monitoring program included:

- Continue collecting non-size fractioned phytoplankton biomass estimates at both the “fixed” and “moving” physical/chemical water quality monitoring locations.
- Continue enumeration of phytoplankton taxonomic composition at the “moving” isohalines for at least major taxonomic groupings (blue greens, diatoms, flagellates, dinoflagellates, etc.).
- Determine if either the benthic invertebrate/mollusk investigations conducted by Mote Marine Laboratory, or the juvenile fish/zooplankton study undertaken by the University of South Florida should be incorporated in part into HBMP study elements.
- Evaluate the need to continue monitoring at the existing spatial and temporal intensity.

Overall the panel recommended that the HBMP should focus monitoring primarily on assessing long-term trends in key physical, chemical and biological characteristic directly related to the Facility’s potential influences and less on “health of the estuary” issues that should be the task of other (District) monitoring efforts.

### 8.5.1 Sampling Designs

Truly unbiased population estimates are based on subpopulation sample metrics comprised of measurements taken from a universe of all possible samples, thus providing an accurate estimate measure of the overall total target population. Cochran *et al.* (1954) points out that the actual sampled population should coincide both in space and time with the target population about which inferences intend to be drawn. In practice, however, reasons of practicability and/or convenience generally result in the actual sampled population being typically far more restricted than the target population (Cochran 1977). It is therefore necessary to remember that conclusions drawn from restricted sampled populations theoretically actually only apply to the monitored

subsets, and judgments have to be made regarding the extent to which subsequent conclusions can be extended to the greater overall target population. The simplest way to avoid this potential problem is to ensure during the design phase of a monitoring program that the sampled population is carefully defined to closely agree with the target population definition.

Generally, monitoring designs fall into one of two commonly applied monitoring strategies, both of which, given the right conditions, provide useful results.

- **Probability-Based Sampling** – This approach requires defining the subset of samples from a specific population, such that all possible samples have a known probability of being selected. A random process is then utilized to select samples in such a manner that all potential samples have the same probability of being selected.
- **Nonprobability-Based Sampling** – Nonprobability-based sampling designs are limited to restricted portions of the population, and typically rely on fixed sampling sites based on the selection of “typical” or “representative” monitoring locations.

The only way to actually verify that nonprobabilistic sampling estimates might result in unbiased results would be to compare the resulting data directly with population estimates derived from a comparable probability-based sampling approach. However, even this comparison would not mean that nonprobabilistic sampling might continue to provide unbiased estimates under variable conditions. Probability-based sampling approaches by comparison yield unbiased estimates regardless of potential changing conditions. Paulsen *et al.* (1998) recently evaluated a number of the benefits that can be gained from employing probability-based sampling strategies over more traditional nonprobability-based approaches.

Probability-based sampling designs have recently been utilized by a number of both small and large scale monitoring programs. At the national level, the U.S EPA’s Environmental Monitoring and Assessment Program (EMAP) employs probability-based sampling designs for a variety of waterbody types, including rivers and estuaries. The states of Alabama, Florida, and Maryland are currently implementing statewide surface water monitoring programs (including water quality and biological sampling efforts) based on probability-based sampling approaches. Locally, monitoring programs in Tampa Bay and Charlotte Harbor have endorsed similar probability-based sampling approaches. The Florida Marine Research Institute (FMRI) is currently employing probability-based sampling designs in its Fisheries Independent Monitoring Programs.

### 8.5.2 Spatial HBMP Sampling Considerations

Given the above theoretical considerations, the question arises: Should the overall design of the current HBMP sampling efforts, which are based on nonprobabilistic “fixed”, and spatially variable “moving” isohaline sampling strategies, be redesigned in order to provide unbiased estimates of the actual spatial patterns along the HBMP monitoring transect?

The current long-term monitoring design of the HBMP physical/chemical water quality study element incorporates sixteen “fixed” sites, sampled monthly, along approximately thirty-four

kilometers of the lower river/upper harbor transect ([Table 1.1](#)). Theoretically, these sites provide information regarding conditions relative to only that particular defined specific location and are biased because it is unknown how representative each are of the surrounding reach of the river. Hypothetically, inferences can only be made regarding these specific locations independently and inferences cannot easily be extended to the entire spatial reach of the estuary as a whole. However, on a practical basis the existing “fixed” station monitoring network provides a wide basis of spatial coverage with comparable data extending back to the mid 1970s.

An alternative probability-based sampling approach could allow inferences to be drawn not only about the entire sampling transect (target population), but also individual river segments (subpopulations). Such a design would entail dividing the areas of interest along the monitoring transect into a series of subpopulations or strata (Summers and Maddox 1999). Employing such a stratified random sampling design enhances the ability to detect differences because it optimizes the design based on the natural variability characteristics of the indicators (Cochran 1977). A probability-based sampling design would allow for cumulative distribution functions (CDF) to be developed (see discussion in [Section 5.3](#)) depicting the statistical characteristics of measured water indicators (such as the percent of area along the transect having a salinity greater than a given value). Horvitz-Thompson estimator methodology could then be applied to make statistical comparisons of the frequency distributions among time intervals (years and/or seasons).

**Figure 8.2** depicts dividing the current HBMP fixed station water quality sampling area that extends from River Kilometer 0.0 upstream to 32.3, into approximately sixteen, two kilometer long monitoring strata (which generally approximates the average distance between the existing “fixed” HBMP hydrolab profile sampling sites, as well as the intervals utilized in the Tampa Bay HBMP). Probabilistic sampling would entail randomly selecting individual monitoring locations within each stratum based on both the river kilometer and location along the channel (left side, middle or right side). In order to accurately define a cumulative distribution function, at least thirty samples would need to be collected over each reach of the river segments and time intervals over which statistical inferences are desired.

- Monthly random samples within each of sixteen strata would result in a total of 192 observations per year. This would be far more than enough samples to develop CDFs and compare differences among years for the river as a whole. This sampling intensity would also allow strata to be grouped or post-stratified into approximately six-kilometer intervals, allowing for further yearly inferences and comparisons. This sampling intensity would not, however, allow for yearly inferences to be made within each strata.
- If yearly inferences with regard to each of the sixteen two-kilometer strata were desired, then three samples would need to be randomly collected monthly within each individual stratum for a total of 576 samples per year.
- Analyses of the HBMP data ([Section 4.0](#)) have indicated that a number of the water quality parameters in the lower Peace River/upper Charlotte Harbor estuarine system show distinct seasonal patterns relative to the timing of freshwater inflow. Three seasonal patterns, each approximately four months in duration, commonly characterize

conditions in southwest Florida: a summer wet season; a cool/damp winter period; and a hot/dry spring. If within-year inferences comparing such seasonal differences were desired, then the frequency of monitoring would have to be correspondingly adjusted. Otherwise, years could be grouped to provide seasonal comparisons.

The entire premise and underlying foundation associated with implementing such a probability-based HBMP sampling strategy fundamentally differs from that of the current HBMP monitoring design. It would therefore seem doubtful if the existing historical long-term information derived from the nonprobabilistic “fixed” or “moving” sampling could be statistically integrated into such a new probability-based sampling design through post-stratification. This results in three potential HBMP sampling alternatives:

- Drop the current “fixed” and “moving” HBMP monitoring designs and completely redesign all applicable sampling elements. Existing historical HBMP information could be used as baseline information, and for calibrating future models. The existing statistical models derived from these data could be used to synthetically generate “estimated” historical information within the new selected river strata against which to make future comparisons.
- Add a limited probability-based sampling HBMP study element to the existing monitoring program design. The utility of such an additional program element would be its use in statistically describing and comparing the overall frequency distributions of sampled water quality parameters over a selected spatial extent between inference periods (years). In order to cost-effectively implement such a program it is suggested that it initially be limited to monthly physical water column profile measurements at single randomly selected locations within each of sixteen strata, along with the collection of surface water samples for critical water quality indicators (color, nitrate+nitrite nitrogen, and *in situ* chlorophyll).
- Continue only the existing long-term nonprobabilistic “fixed” and “moving” station HBMP study elements. While the information derived from the existing HBMP monitoring designs cannot be applied to statistically describing the spatial distributions of key indicators along the HBMP monitoring transect, the established existing long-term databases have allowed for extensive nonparametric analyses and have provided insight into the status and trends of the lower river and upper harbor, and supported the development and application of statistical models. The existing network of “fixed” monitoring sites has also been used to provide insight into the relative spatial influences of seasonal changes in freshwater inflows on key physical, water quality and biological estuarine characteristics.

Reviews comparing the application of monitoring designs in the presence of known strong environmental gradients (Cressie 1993 and Harries *et al.* 2000) have suggested that uniform or fixed sampling designs can reduce the observed increased variances inherently associated with the application of random or stratified probabilistic sampling designs in estuarine systems. Table 8.2 compares the variances in two recent years (1999 and 2002) at sampling sites located approximately two kilometers apart along the Peace River HBMP monitoring transect.

Obviously, including sampling over only a two-kilometer interval into a single stratum along the known lower river salinity gradient would result in higher observed variances than occur utilizing a “fixed” sampling site.

It is therefore recommended than an initial limited probability-based sampling element be incorporated within the existing overall HBMP monitoring program design. The generated data would be used to statistically describe and compare, using cumulative distribution functions, the spatial patterns of selected water quality parameters (salinity, color, nitrate+nitrite nitrogen, and *in situ* chlorophyll *a*) on both a seasonal and annual basis.

**Table 8.2**

**Univariate Comparisons of Salinities at “Fixed” Stations During 1999 and 2002**

| Fixed River Kilometer Monitoring Locations | 10.5 & 12.8 | 21.9 & 23.6 | 23.6 & 25.9 |
|--------------------------------------------|-------------|-------------|-------------|
|                                            | Figure 8.3  | Figure 8.4  | Figure 8.5  |

### 8.5.3 Continuous Recorders

The HBMP study design currently includes continuous (fifteen-minute interval) measurements of subsurface and near bottom water column conductivities at two fixed USGS monitoring gages located at river kilometers 15.5 and 26.7 (**Figure 8.6**). The particular locations of these two gages on existing docks were established in part due to the USGS need to be able to have land based access for the ease of routine maintenance and the downloading of data. As Table 8.3 indicates, the influences of tide, wind and antecedent conditions can result in an extremely wide range of observed variation in daily averaged conductivity measurements at the Harbour Heights gage located at River Kilometer 15.5 over a wide range of flows. At the upstream USGS Peace River Heights gaging site, located at River Kilometer 26.7, the influences of these confounding affects is less. However, as indicated, the Facility cannot begin freshwater withdrawals until after Peace River at Arcadia flows have reached 130 cfs, when this reach of the river generally is characterized by freshwater conditions. Thus, while the location of this gage is in a good location to detect potential long-term systematic shifts in the freshwater/saltwater interface during low levels of freshwater inflow, it is extremely doubtful if the direct influences of the facility can be measured at this location.

**Table 8.3**

**Average Daily Conductivity Versus Flow at USGS Recorders**

| USGS Gage / River Kilometer | Subsurface Conductivity | Near Bottom Conductivity |
|-----------------------------|-------------------------|--------------------------|
| Harbour Heights 15.5        | Figure 8.7              | Figure 8.8               |
| Peace River Heights 26.7    | Figure 8.9              | Figure 8.10              |

It is therefore recommended that one or two additional continuous gages be established downstream of the existing Peace River Heights (RK 26.7) location. The primary objective of such additions to the existing current continuous recorder HBMP study element would be to obtain greater resolution of the direct relationships among freshwater flow, stage height and conductivity downstream of the Facility within the reach of the river characterized by the movement of the freshwater/saltwater interface at flows immediately above the 130 cfs threshold (see [Section 7.0](#)).

There are several possible alternative sites and deployment methodologies that could be utilized in establishing these new continuous conductivity monitoring gages.

- A third land based gage similar in design could be located on one of the single family docks located just upstream (between River Kilometers 24.5 and 25.0) of the entrance to Navigator Marina ([Figure 8.11](#)). The drawbacks with locating a recorder at this location would be that it would only be approximately 1.5 kilometers further downstream of the existing gage, and that it could potentially be somewhat influenced by inputs from the Lettuce Lake system.
- A series of other potential sites exist further downstream, due to the recent placement of Manatee Speed Zone markers along the river. It is possible that the Authority/District could receive permission to establish continuous recorders similar to those currently utilized by USGS on one or more of these existing markers. Calibration, maintenance and downloading of data could be accomplished in conjunction with other HBMP physical/water quality monitoring study elements.

The HBMP monitoring program currently also includes a gage measuring only tide height near Boca Grande. The original purpose of this gage was to assess the potential influences of long-term sea level rise on salinity patterns in the lower Peace River estuarine system. However, subsequent discussions with USGS staff have revealed the location of this gage would be inappropriate for its intended use. Therefore, it is recommended that this gage be deleted from the array of HBMP continuous recorders.

### 8.5.4 Chlorophyll *a* Phytoplankton Biomass Measurement

The HBMP water chemistry study element currently includes monthly monitoring of chlorophyll *a* levels spatially at both “fixed” and “moving” isohaline sampling locations along the lower river/upper harbor monitoring transect. As a common photosynthetic pigment among all major primary producers, chlorophyll *a* is widely used as an estimate of phytoplankton biomass in both freshwater and estuarine systems. The spatial and temporal distribution of phytoplankton chlorophyll *a* concentrations is widely applied in estuarine ecology as a relative indicator of overall integrated levels of primary production. As a measure of phytoplankton biomass, chlorophyll *a* has a number of distinct advantages.

- Measured values can be quantitatively coupled to important physical and chemical water quality characteristics.



- Measurements integrate phytoplankton cell types, sizes, and growth stages, and to some degree the relative overall cell health/viability.
- Applied methods of measurement are relatively simple and direct.

It should, however, also be noted that even though widely used as a standard relative measure, chlorophyll *a* concentration can be inherently an imperfect absolute measure of phytoplankton biomass, since cellular pigment contents are influenced both by relative phytoplankton community structure and a wide array of commonly variable ambient physical (water color, shading, temperature) and chemical (nutrients) environmental conditions.

As **Figure 8.1** indicates, the development of a comprehensive understanding of phytoplankton production (biomass) is fundamental to the development of an integrated understanding of the interrelated physical/chemical systems and biological processes within the lower Peace River estuarine system (**Section 2.0**). Increasing the overall knowledge and comprehension of the processes controlling the basis of phytoplankton production within the lower Peace River would provide additional insight into determining the potential changes in estuarine trophic dynamics relative to both immediate and long-term variations in freshwater inflows. Phytoplankton production represents the largest, immediately available food resource directly accessible to many lower rivers' grazing, filter and detrital feeding estuarine organisms. As such, phytoplankton production represents the most basic, integrated estuarine food-web component directly influenced by variations in freshwater inflows. Due to the very short generation times involved (hours/days), phytoplankton production, when compared with many other potential biological indicators, can potentially be more directly quantitatively linked to changes in freshwater inflows. The observed numbers and spatial distributions of other potential biological estuarine indicators (**Figure 8.1**) are subject to the confounding additional influences associated with both longer generation times and intricate life-cycles, as well as the increasing complexity of predatory/prey interactions with each additional trophic step.

Advances in fluorescence technology have resulted in the recent capability of semi-quantitatively measuring of *in situ* phytoplankton chlorophyll *a* estimates, without extensive filtering and expensive laboratory chemical extraction and analyses. *In situ* fluorometer chlorophyll *a* measurement procedures also present the potential utility of particularly near-real-time data acquisition in synoptically identifying spatial phytoplankton biomass patterns along the lower river salinity gradient. The accuracy of such *in situ* measurements can be greatly enhanced through employing pre- and post-sampling fluorometer calibrations and comparisons to field measurements with "reference" values obtained utilizing standard laboratory (extraction) procedures.

Previously reported results from both the "fixed" and "moving" HBMP study elements have indicated the presence of a distinct, seasonally-variable chlorophyll *a* maxima along the lower Peace River/upper Charlotte Harbor monitoring transect. A new HBMP study element employing *in situ* fluorometer chlorophyll *a* methodology could provide the types of fine-grained spatial information needed to accurately define on a monthly basis both the magnitude and spatial extent of variations in chlorophyll *a* patterns along the existing HBMP monitoring transect. Accurate spatial determinations of the relative intensity and location of monthly

chlorophyll *a* maxima patterns along the lower river would provide additional information regarding the known seasonal interactions between changes in freshwater flow (relative to both additions of nutrients and color) and phytoplankton primary production.

The primary objective of implementing a new additional ambient *in situ* chlorophyll *a* monitoring element in conjunction with the other HBMP physical and biological sampling programs would be to provide enhanced information with regard to spatial and temporal variations of phytoplankton biomass in the lower Peace River estuarine system. The overall goal of such a monitoring effort would be to quickly and efficiently determine, on a monthly basis, the spatial patterns of primary production in the lower Peace River downstream of the Facility, utilizing a submersible fluorometer (such as a Turner SCUFA<sup>®</sup>) to directly estimate relative phytoplankton biomass. The resulting high resolution data could then be graphically analyzed using standardized GIS kriging procedures and relative weighted centers of abundance determined using Spatial Analyst routines. The resulting spatial pattern metrics could then be statistically seasonally analyzed relative to natural variations in flow and measured water quality parameters obtained from other HBMP study elements. The overall design of such a monitoring effort would include:

- Synoptically measuring *in situ* chlorophyll *a* levels using a submersible fluorometer.
- Standardizing all sampling within a defined temporal period relative to noon (EST) in order to avoid known daily variations in apparent chlorophyll *a* levels.
- Measuring sub-surface (0.2 meter) concentrations at regular defined “fixed” 0.5 kilometer intervals along the HBMP centerline monitoring transect in order to facilitate both kriging and estimating the weighted center of chlorophyll *a* abundance.
- Thorough analyses of the utility of this HBMP study element, and recommendations for its continuance, should be made at specific intervals as part of future major summary monitoring program reports.

### 8.5.5 Benthic Invertebrate Sampling

Mote Marine Laboratory conducted a special HBMP study between 1998 and 2002 in order to both describe the distribution of major macroinvertebrate habitats and associated community structure in the lower Peace River, and to determine whether the relative abundance distributions and population structure of these benthic communities could be used to assess natural variations in freshwater inflows, and further measure potential influences caused by Facility diversions (see detailed discussion in [Section 3.0](#)). The benthic invertebrate study was comprised of two separately designed investigations. The first was an inventory of macroinfauna conducted using a spatially stratified river interval design, based on historical HBMP data of the seasonal distribution of characteristic near-bottom salinity regimes in the lower Peace River. The findings of this part of the investigation indicated:

- Amphipods and cumaceans comprised the most abundant macroinfauna taxa, and upstream benthic species diversity was higher during drier sample collection periods.

- Conspicuous inflection points, representing step-wise jumps in species richness within specific spatial regions along the lower river.
- Changes in distribution patterns for five polychaete and eight abundant micromollusks species were distinct in their relation to natural seasonal changes in salinity.

Overall, the macroinfaunal study indicated that the vast majority of the observed species occurred and survived over broad salinity ranges. Only approximately thirty of the over 300 species collected were both abundant and shown to exhibit spatial changes in response to variations in freshwater inflows. The study did not, however, recommend measuring changes in benthic macroinfauna community structure solely for the purpose of detecting potential impacts of freshwater withdrawals since the salinity tolerances of the taxa far exceeded the potential salinity changes predicted as a result of Facility withdrawals.

The second part of the benthic invertebrate study entailed investigations of the spatial distributions of living and dead or “relic” mollusk communities along the lower river/upper harbor HBMP monitoring transects. The observed spatial patterns of both living and dead mollusks are influenced by differential reproductive periods, larval development rates, recruitment/life history characteristics, and selective mortality due to both biological and physical factors. The salient findings of the mollusk investigation indicated:

- The introduced Asiatic clam *Corbicula* and another fourteen taxa accounted for more than 98 percent of the taxa collected.
- Spatial comparisons of the patterns of living mollusks with historic relic shell “footprints” suggest that freshwater inflows control the long-term, upstream/downstream shell depositional patterns in the lower Peace River estuarine system.

These findings indicate that live and relic mollusks can generally be collected, identified and enumerated quickly in the field, and that the overall dynamics and spatial distribution of benthic mollusk assemblages reflect estuarine (salt tolerant) taxa “trying to invade” the upstream river reaches that have already been invaded by an exotic (*Corbicula*) freshwater taxa. Specific macromollusk ranges *per se* reflect imprecise salinity indicators, but may be indicative of long-term, flow related changes in overall salinity patterns.

It is concluded that the study of benthic mollusk distributions has some potential utility as a biological indicator of change of freshwater flows in the lower Peace River. A recommended redesign and implementation of a new benthic mollusk component to the HBMP would include:

- Using developed field identification protocols to enumerate the numbers of ten selected sub-tidal taxa along 21 benthic sampling transects set at “fixed” one kilometer intervals perpendicular to the primary HBMP centerline transect between River Kilometers 10.0 and 31.0 ([Figure 8.12](#)).

- Sampling conducted once during the height of the dry-season (late April to mid-May) and at the end of the wet-season (late September to early October) each year.
- The level of information being gathered by such a study element and its future utility needs to be reevaluated at approximately five-year intervals in conjunction with future major summary monitoring program reports.

The primary objective this recommended benthic study element would be to determine the extent and magnitude of the relationships between preceding seasonal periods of low and high freshwater inflows and the spatial distributions of benthic mollusks within the lower Peace River estuarine system. The resulting data could then be graphically analyzed using standardized GIS kriging procedures and relative weighted centers of abundances of selected taxa could be determined using Spatial Analyst routines. Resulting spatial pattern metrics could then be statistically seasonally analyzed relative to natural variations in flow and measured water quality characteristics obtained from other HBMP study elements.

### 8.5.6 Vegetation HBMP Study Elements

The primary objective of the series of analyses presented in [Section 4.7](#) was to summarize the findings of key elements of the ongoing, long-term HBMP vegetation studies ([Table 1.3](#)) and determine the further efficacy of these study's effectiveness regarding assessing potential affects of Facility withdrawals. Over the 27-year period of monitoring, the HBMP vegetation study elements have sought to determine spatial and temporal responses of vegetation communities to natural variations resulting from extended periods of both drought and flood along the lower Peace River. The overall objective of the vegetative monitoring HBMP study elements has been to provide a basis for determining the relationships between vegetation patterns and freshwater flows by observing the relative spatial positions and community structure of the freshwater and salt-tolerant plant communities in the salinity transitional zone of the lower river. The basic assumption has been that a permanent shift of more salt-tolerant plants upriver could be an indication that withdrawals were impacting lower river riparian wetlands, assuming that the affects of natural variability (drought) or other anthropogenic causes could be distinguished.

#### First and Last Occurrence

The first and last occurrence of a number of selected indicator plant species has been recorded at approximately two-year intervals since 1976 along the banks of the lower Peace River. The primary objective of this investigation has been to assess the influences of long-term natural variations in river flow. The series of analyses presented in the *2000 Midterm Interpretive Report* and summarized in [Section 4.7](#) concluded that this element of the HBMP vegetation study had not been highly effective in determining the potential influences that might be associated with withdrawals. Some species had shown very little variation even following extended periods of high and low flows. It was concluded that some of the most apparent changes in first and last occurrences of these indicator plant species had resulted from the accretion or erosion of shallow shoals along the edges of the river during periods of high flow. The causes of other observed changes were found to be less obvious and clearly indicated the difficulty in determining

meaningful relationships between freshwater inflows and the long-term distributions of these selected taxa (even after considering the possible requirements for substantial lag affects).

A very long baseline period of data has been established by the HBMP regarding variations in relative occurrences of these selected indicator taxa along the lower river. It is recommended that following 2004, no further routine monitoring be conducted with regard to this particular study element. Should other lines of evidence in the future suggest that Facility withdrawals might be significantly altering seasonal salinity patterns along the lower river, new first and last occurrence data could be easily collected and compared to the existing long-term historical data.

### Photointerpretation

An HBMP photographic vegetation study element was initiated in 1976 to assess long-term vegetation patterns along the lower Peace River ([Figure 8.13](#)), starting approximately at the US 41 Bridge (River Kilometer 6.6) and extending upstream above the Facility to near the area where Horse Creek enters the river (River Kilometer 39.5). Since the 1996 HBMP Permit renewal, aerial surveys have been conducted at two-year intervals in a corrected, Geographic Information System (GIS) compatible format, allowing for accurate qualitative and quantitative interpretation of potential changes associated with extended natural periods of low and high freshwater inflows. Comparisons are presented in [Section 4.7](#) using the GIS based aerial coverages of lower Peace River vegetation obtained both following the extended 1997/1998 unusually wet El Niño climatic events and the severe drought that occurred between 1999 and 2002. The primary objective of these analyses was to determine the relative sensitivity of the aerial-based vegetation analyses, as well as the influences of extended periods of high and low freshwater inflow, on the overall structure of the vegetation communities along the lower Peace River.

Comparisons of 1998 and 2002 aerial photography using GIS based forward-dating procedures indicated some small changes in the weighted centers of abundances of two (mangroves and freshwater marsh) of the four selected major riparian vegetation communities along the lower Peace River. However, the measured changes were extremely small in comparison to the differences in the spatial salinity patterns observed during the extended wet and dry periods that preceded the two selected vegetation surveys. Given these results, it is extremely doubtful whether any quantifiable changes in long-term vegetation patterns along the lower Peace River will ever be attributable to Facility withdrawals, since the magnitude of the predicted influences of Facility withdrawals is small relative to the normal ranges of daily and seasonal salinity variations that influence the spatial distributions of the riparian vegetation communities along the lower river.

The HBMP has established an extensive long-term aerial database that documents the spatial distribution of lower Peace River vegetation extending back to 1976. Given the previous results developed by the Florida Marine Research Institute ([Section 3.0](#)) and those presented in [Section 4.7](#), it is recommended that the frequency of the aerial GIS based vegetation monitoring be decreased from once every two years, to a maintenance schedule where aerial photography is collected once every five years (with sufficient flexibility to include the special monitoring of infrequent events). It is proposed that the GIS based coverage presented in this document be

updated, and comparisons and analyses continued in conjunction with future *Comprehensive Summary Reports*.

### Transitional Vegetation Sites

Under the current Permit, this portion of the HBMP study extends and expands the detailed monitoring of plant communities along the river's banks at fixed locations begun in 1979. The vegetative communities at three permanent transect sites ([Figure 1.2](#)) are sampled at two-year intervals. At each monitoring location, three transects are surveyed from the top of bank to the water's edge. The vegetation one meter to each side of established transect lines is identified, and the location and percent density recorded.

The primary objective of this long-term vegetation monitoring effort has been to assess the response of riverine vegetative communities to natural and potentially withdrawal induced variations in freshwater flows. A decrease in freshwater inflow, either naturally occurring or induced, may move the average position of the mixing zone upstream, resulting in higher river salinities at fixed points and concomitant measurable changes in the vegetation community structure along the river over time.

Analyses of the recent transect monitoring data ([Section 4.7](#)) indicate that the dominant riparian vegetation at the three sites appears to be relatively well established, stable, and not easily affected by the naturally occurring drought conditions. These drought conditions resulted in the marked upstream movement of the freshwater interface exceeding, by many orders of magnitude, any potential influences of water withdrawals under the permitted withdrawal schedule. In addition, the increasing influence of exotic Brazilian pepper at the transitional sites suggests that the continued surveying of the uplands and the areas along the shorelines is no longer an appropriate approach in tracking long-term riparian vegetation patterns. The influences of shoaling have also been shown to affect vegetation growing in the water beyond the influence of the shoreline trees.

Extensive databases of vegetation patterns at these three fixed vegetation monitoring sites have been established. It is recommended that following 2004, no further routine monitoring be conducted with regard to this particular study element. Should other lines of evidence in the future suggest that Facility withdrawals might be significantly altering seasonal salinity patterns along the lower river, additional data could be collected at these locations and compared to the existing historical data.

### 8.5.7 Larval Fishes/Zooplankton

Dr. Ernst Peebles of the University of South Florida conducted a special short-term, two-year study, the goal of which was to define seasonal and spatial patterns of fish nursery use within the lower Peace River/upper Charlotte Harbor Estuary jointly supported by the District and the Authority ([Section 3.0](#)). The overall primary objectives of the study were to determine the potential influences/relationships that freshwater inflows have on such observed spatial and seasonal patterns of zooplankton/ichthoplakton abundances and distributions. The study would



also assess whether these metrics and zooplankton community structures could be effectively used to assess potential affects of Facility diversions.

The study's results indicated that the larval/juvenile fish assemblage sampled with plankton net gear was dominated by bay anchovy, gobies, menhaden, sand seatrout, rainwater killifish, silversides, and hogchoker. The corresponding invertebrates caught were dominated by larval crabs, arrow worms, copepods, mysids, amphipods, isopods, cumaceans, larvacean *Oikopleura dioica*, larval and juvenile bivalves, and ctenophores. Samples taken in higher salinity waters near the river's mouth were characterized by *O. dioica*, chaetogaths, *Penilia avirostris*, the cumacean *Cyclaspis varians*, the planktonic shrimp *Lucifer faxoni*, and the copepods *Acartia tonsa* and *Labidocera aestiva*. The bay anchovy, menhaden, silversides, mojarra, eastern mosquitofish, several killifish, striped mullet, and hogchoker dominated sample collections along the shoreline using seines. In comparison, bay anchovy, sand seatrout, southern kingfish, hogchoker, and blue crab dominated the catch using trawls within the river channel.

In general, the observed habitat-use patterns were consistent with findings from other tidal rivers on Florida's west coast. The three gear types document the distributions of egg, larval, juvenile, and adult stages of estuarine-dependent, estuarine-resident, and freshwater fishes. Estuarine-dependent fishes are spawned at seaward locations and invade tidal rivers during the late larval or early juvenile stage, whereas estuarine-resident fishes are present within tidal rivers through their life cycles. Comparisons of life-stage-specific distributions demonstrated the ingress of estuarine-dependent fishes in the Peace River. For example, the mean salinity at capture for the bay anchovy decreased during development, starting at 22 ppt during the egg stage and decreasing from 21 to 14 ppt during various larval stages and finally to 6 ppt as the fish occupied its estuarine nursery habitat during the juvenile stage. Similar patterns of ingress were found for other estuarine-dependent species. Seine data indicated that juvenile snook, red drum, and striped mullet were common within the tidal rivers even though the eggs and larvae of these species were not.

In addition to collecting the early stages of estuarine-dependent fishes, the plankton net collected large numbers of freshwater and estuarine invertebrate plankton and hyperbenthos, which consist of substrate-associated invertebrates that rise into the water column at night. These organisms are of particular interest because many serve as important prey for the estuarine-dependent fishes that seek out tidal rivers as nursery habitat. The survey data were used to develop regressions that describe shifts in fish and invertebrate distribution as inflow rates and salinities change. It was found that the distributions of more than 20 types of fishes and invertebrates shift as freshwater inflows fluctuate, moving upstream during low-inflow periods and downstream during high-inflow periods. The data indicate that some species appeared to be more reluctant to change position than others. There was, however, no strong indication that prey distributions were offset from fish nursery habitats by this distributional response to inflow. Some predator-prey pairs appeared to move upstream and downstream in synchrony as inflows fluctuated. Another significant finding was that total numbers of some estuarine and estuarine-dependent fishes and invertebrates were reduced during low inflow periods. Regressions were developed to predict decreases in organism number as a function of freshwater inflow. Many organisms exhibited a pronounced peak in abundance several months after the end of the high inflow 1997/1998 El Niño period.

The number of fish taxa in the plankton-net catch increased during spring and decreased during fall, and was generally highest from April through October. However, the fall decrease observed for larval fishes was not observed in the seine catch since older juveniles remained in the tidal river long after larval recruitment diminished. The period from April to June would appear to have the highest potential for impact due to the coupling of naturally low inflows with increasing nursery habitat use in the estuary. However, some species, such as red drum and menhaden, spawn in fall or winter, and therefore there is no time of year when the potential for impacting economically or ecologically important species is absent.

Mysids are important prey for many juvenile estuarine-dependent fishes in tidal lower Peace River nursery habitat. Reductions in chlorophyll *a* biomass and mysid numbers during periods of low freshwater inflow (nutrients) likely reduce the river's carrying capacities for a number of juvenile fishes, including snook, red drum, sand seatrout, spotted seatrout, and other species. The results of the larval/juvenile studies on a number of southwest Florida estuaries conducted by Dr. Peebles has indicated that these estuarine-dependent fishes exhibit broad salinity tolerances, and are distributed within each estuarine system based on food availability rather than distinct salinity preferences. Thus, the centers of distribution for these species within individual river systems generally correspond with (or is offset from) the flow dependent location of the chlorophyll *a* maxima within each river system, rather than salinity *per se*. In other words, their location and numbers reflect the location and availability of food rather than mirroring the salinity gradient.

Based on these findings, it is therefore proposed that the HBMP initially focus on defining the seasonal interactions between freshwater inflow and the spatial distribution/magnitude of the chlorophyll *a* maxima in the lower river (see [Section 8.5.3](#) above) directly, rather than focusing on the next trophic levels ([Figure 8.1](#)). Directly monitoring the relationship between freshwater inflow and the seasonal fine-grained spatial patterns of chlorophyll *a* within the lower river should be expected to provide far greater potential resolution of possible negative impacts due to Facility withdrawals. Monitoring of the seasonal and spatial patterns of fish nursery use within the lower Peace River/upper Charlotte Harbor estuarine system is an important "health of the harbor" issue, and if included as part of the overall HBMP effort, should be primarily funded by the District.

### 8.6 Potential Short-Term HBMP Studies

During its November 2002 meeting, the Scientific Review Panel suggested a number of potential short-term studies or analyses of existing data. These included:

- Revise the conceptual estuarine model to clarify certain pathway functions ([Section 2.0](#)).
- Focus on measuring central tendency in conjunction with analysis of riparian vegetation analysis, specifically in the region of the hardwood interface ([Section 4.7](#)).

- Develop a conceptual “Pump Test” design to assess the effectiveness of existing statistical salinity models ([Section 7.0](#)). The Panel suggested a series of activities that the Authority (and/or District) could do and bring the results back to the panel for their input.
  - o Determining the tidal movement of low isohalines very close to the plant.
  - o Perform a short study this fall/winter/spring when flows are in the 200 to 400 cfs range to test tidal movement of the freshwater/saltwater interface and look at major ion concentrations: Ions Na, K, Ca, Mg, Si, Fe, Mn, Cl, SO<sub>4</sub> and F at an array of sampling points at low and high slack tides.
  - o Evaluate the extreme and variable flows that have already occurred.
- Examine the longitudinal gradients of specific ions (Ca, Mg, Na, Cl, F, Mn, Si, Fe, SO<sub>4</sub>) within the major tributaries, upstream and downstream of the Facility’s point of withdrawal, and above and below the designated freshwater interface boundary ([Section 7.0](#)).
- Prepare a discussion of projected long-term water demands and projected supply needs ([Section 9.0](#)).
- Conduct summary analyses of existing phytoplankton data primary production/biomass/species composition data, and assess whether species identifications should be continued in conjunction with the HBMP (task currently under consideration.)
- Develop a Peace River hydrodynamic model (finite difference vs. finite element methods) for the lower river, to be used to test existing statistical models and investigate seasonal variations in residence times. (This effort is currently being conducted by the District in conjunction with establishing minimum flows for the lower Peace River.)
- Determine whether the District should support a short-term special stable isotope study to delineate trophic pathways in the lower river. (Has been completed.)
- Use Index of Hydrologic Alteration (IHA) or other methods to determine the frequency/duration of extreme flow events. (Being done as part of District minimum flows for the lower river.)
- Investigate existing FMRI juvenile/adult Charlotte Harbor fish data to determine potential influences/changes in freshwater inflows. (Has been done.)
- Determine whether submerged aquatic vegetation (SAV) should be monitored as part of the HBMP. (Currently not recommended.)

### 8.7 Summary and Recommendations

The primary objective of this Section was to review and summarize the overall effectiveness of the current key HBMP study elements, and consider potential program additions and/or deletions

in order to improve the overall ability of the HBMP design to cost-effectively address the specific critical goals articulated in the District's specific Water Use Permit conditions

Based on the analyses presented in this *Comprehensive Summary Report* and preceding HBMP documents, a series of possible changes to the existing overall HBMP design have been suggested and recommended. The following outlines the objectives, goals and expectations of each of these potential HBMP study element additions. These elements are ranked relative to the expected comparative strengths and importance of the derived information with regard to assessing the temporal and spatial magnitudes of the impacts relative to both natural and Facility related changes in freshwater inputs. It is recommended that all new HBMP components be implemented on an interim or trial test basis and reviewed at the end of the initial five-year period.

### Recommended Additions to the HBMP

- It is recommended that one or two additional continuous gages be established downstream of the existing USGS gage located at Peace River Heights (RK 26.7). The objective would be to obtain enhanced resolution of the relationships among freshwater flow, stage height and conductivity within the reach of the river characterized by the movement of the freshwater/saltwater interface at flows immediately above the Facility's 130 cfs withdrawal threshold.
- A new study element employing *in situ* fluorometer methodology is recommended to provide the spatial information necessary to accurately define the relative intensity and location of monthly chlorophyll *a* maxima along the lower river in order to better assess previously described seasonal interactions between freshwater flow and phytoplankton abundance.
- It is suggested than an initially limited probability-based sampling element be added to the existing overall HBMP monitoring program design. The generated data would be used to statistically describe and compare, using cumulative distribution functions, the spatial patterns of selected water quality parameters (salinity, color, nitrate+nitrite nitrogen, and *in situ* chlorophyll *a*) on both a seasonal and annual basis.

Two additional biological study elements are also suggested, depending on the availability of contributing District funds to further assess "health of the estuary" estuarine components in conjunction with the overall HBMP design.

- A limited benthic mollusk study is proposed (depending on the availability of contributing District funds) that would utilize established rapid field assessment methodologies to determine the extent and magnitude of the relationships between preceding seasonal periods of low and high freshwater inflows and the spatial distributions of benthic mollusks within the lower Peace River estuarine system. The resulting seasonal spatial mollusk distributional patterns would be combined with other physical/chemical/biological HBMP data to statistically analyze the responses to natural variations in freshwater flow.

- Preliminary research conducted by USF has indicated that reductions in chlorophyll *a* biomass and mysid numbers during periods of low freshwater inflow reduce the river's carrying capacities for a number of juvenile fishes. Corollary larval/juvenile studies of other southwest Florida estuaries have indicated that estuarine-dependent fishes exhibit broad salinity tolerances, and are distributed within estuarine systems based on food availability rather than distinct salinity preferences. It is suggested, dependent on availability of contributing District funds, that the plankton net sampling component of the larval fish/zooplankton community be reinstated.

### **Recommended HBMP Program Reductions**

- The HBMP has established an extensive long-term aerial database documenting the spatial distribution of lower Peace River vegetation extending back to 1976. It is recommended that the frequency of the aerial GIS-based vegetation monitoring be decreased from once every two years to a maintenance schedule where aerial photography is collected, analyzed and changes reported once every five years (or as needed following the occurrences of potential extreme events).
- The monitoring program includes a gage measuring only tide height near Boca Grande. Discussions with USGS staff have revealed the location of this gage is inappropriate for its intended use, and it is recommended that this gage be deleted from the array of HBMP continuous recorders.
- The first and last occurrences of indicator riparian plant species along the lower Peace River and the composition of long shore vegetation at fixed sampling sites have been surveyed at regular intervals since 1976. It is recommended that following 2004, no further routine monitoring be conducted with regard to these study elements.

## 9.0 Assessment of the Diversion Schedule

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The Authority's Peace River Facility is located adjacent to a side-branch of the Peace River in southwest DeSoto County (see [Figure 9.12](#)). Although the Facility has only been operated by the Authority since 1991, it has been operating and withdrawing water from the Peace River since 1980. The purpose of this section is to address specific Permit conditions, and provide answers to issues and questions raised by the Scientific Review Panel at the November 2002 meeting, regarding the efficacy of the existing withdrawal schedule. The 1996 Water Use Permit renewal specifically required that the Facility diversion schedule be evaluated in conjunction with the *Comprehensive Summary Reports* to determine if the existing withdrawal schedule has adequately provided protection to estuarine resources. The Permit also specifies that if analyses indicate that withdrawals have shown potential significant negative impacts, that proposed withdrawal schedule changes will be addressed to assure that future diversions provide a required additional level of safety.

This section reiterates that to date all analyses of long-term HBMP monitoring data collected between 1976-2002 have indicated that Facility diversion has not resulted in any observed physical or biological adverse impacts within the lower Peace River estuarine system. The statistical modeling results of the USGS continuous recorder information presented in [Section 5.0](#), combined with the results of previous HBMP data modeling efforts, indicate that the expected salinity changes resulting from both historic and future maximum withdrawals under the existing Permit constitute a small fraction of the normal range of salinity variations observed either due to the daily influences of tides or as a result of seasonal differences in freshwater inflows. The following topics are summarized in this section:

- The existing withdrawal schedule
- The existing low flow cutoff
- Projected Facility water use demands
- Recent and projected Facility expansions
- Potential modifications of the withdrawal schedule
- Potential adverse impacts

### 9.1 Permit Withdrawal Schedule

Since the initiation of withdrawals in 1980, the Facility has operated under several different District mandated withdrawal schedules. Initially, minimum flow criteria were established based on individual monthly historic long-term averages for USGS gaged Peace River flows at Arcadia. The initial withdrawal schedule was modified in 1988 in order to establish withdrawals based on ten percent of actual daily gaged flows rather than historic monthly long-term averages. A minimum flow based on Peace River flow at Arcadia gage was established under the revised 1988 withdrawal schedule of 100 cfs over the typically dry three month spring period, and 130 cfs during the remaining nine months of the year. A maximum daily withdrawal was set based on existing Facility capacity. This initial withdrawal schedule modification provided protection for river estuarine resources during periods of both seasonal and drought induced low river inflow,



as well as insured that Facility withdrawals mimicked natural patterns of seasonal freshwater inflow. During the most recent 1996 twenty-year renewal of the Facility's Water Use Permit, the minimum criteria of Peace River flow at Arcadia was increased to 130 cfs throughout the year, and the maximum daily withdrawal cap was set at 90 mgd (139 cfs).

## **9.2 Minimum Withdrawal Low Flow Cutoff**

The 1988 modification of Facility withdrawal schedule to ten percent of the preceding daily gaged Arcadia river flow also included a minimum low flow cutoff of 130 cfs for all but the driest months of the year. This establishment of a 130 cfs minimum Arcadia flow criteria by District staff in 1998 was based on plots of conductivity versus Peace River at Arcadia flow from HBMP data gathered at the upstream fixed monitoring sites located near the Facility's point of withdrawal.

Updated plots (using data through 2002) similar to those originally used to set the 130 cfs minimum are presented in Table 9.1. These figures show measured sub-surface and near-bottom conductivities versus the previous day Peace River at Arcadia flow (corrected for actual Facility withdrawals) using all HBMP monthly data collected between 1980 and 2002 at each of the four upstream fixed monitoring sites ([Figure 9.13](#)) located nearest the point of the Facility's intake structure (RK 29.8). Analogous plots are also provided for daily average surface and bottom conductivities versus withdrawal corrected for preceding day Arcadia Peace River flow during the five years of fifteen-minute interval data collected at the USGS continuous recorder. This recorder is located approximately three kilometers downstream of the point of withdrawal at RK 26.7. Additional plots are provided indicating the relative influences of average preceding 30-day average Peace River at Arcadia gaged flow on the spatial distributions of the four monitored "moving" isohaline locations.

The original basis of the established 130 cfs low flow cutoff was the determination that at approximately this rate there was an apparent inflection in the observed relationship between measured river conductivity and Arcadia gaged freshwater inflow at the monitoring sites located nearest the Facility's intake structure. In the figures presented in Table 9.1, a smoothed line has been statistically fitted to the observed data, and a vertical line has been added to indicate the established 130 cfs minimum cutoff. As these figures indicate, during periods of low flow, unusually high tides (especially those caused by sustained strong southerly winds) can result in high conductivities in this reach of the river and cause the observed variability in the relationships between conductivity and river flow at these sites.

The presented series of figures indicate that the observed inflection point in the relationship between conductivities and Arcadia gaged freshwater flows probably ranges between 80 and 150 cfs over the approximate seven kilometer reach of the river characterized by the five selected fixed sampling locations. At the lower end of this range it has been observed that measurable salinity can on occasion be present at the Facility intake structure. As such the existing 130 cfs minimum threshold for withdrawals represents the area immediately downstream of the facility withdrawal and was selected by District staff as a fairly conservative estimate to ensure minimal impacts to the Charlotte Harbor estuary. The HBMP data to date supports the minimum cutoff of 130 cfs as an appropriate and conservative withdrawal cutoff to protect the downstream estuary.

**Table 9.1**  
**Fixed Station Conductivity Versus Peace River at Arcadia Flow**

| River Location                                      | Sub-surface                 | Near-bottom                 |
|-----------------------------------------------------|-----------------------------|-----------------------------|
| <b>"Fixed" HBMP Monitoring Site</b>                 |                             |                             |
| River Kilometer 23.6                                | <a href="#">Figure 9.1</a>  | <a href="#">Figure 9.2</a>  |
| River Kilometer 25.9                                | <a href="#">Figure 9.3</a>  | <a href="#">Figure 9.4</a>  |
| River Kilometer 29.5                                | <a href="#">Figure 9.5</a>  | <a href="#">Figure 9.6</a>  |
| River Kilometer 30.4                                | <a href="#">Figure 9.7</a>  | <a href="#">Figure 9.8</a>  |
| <b>Continuous Recorder</b>                          |                             |                             |
| River Kilometer 26.7                                | <a href="#">Figure 9.9</a>  | <a href="#">Figure 9.10</a> |
| <b>"Moving" HBMP Isohaline Monitoring Locations</b> |                             |                             |
| 0 ppt Isohaline                                     | <a href="#">Figure 9.14</a> |                             |
| 0 ppt Isohaline                                     | <a href="#">Figure 9.15</a> |                             |
| 0 ppt Isohaline                                     | <a href="#">Figure 9.16</a> |                             |
| 0 ppt Isohaline                                     | <a href="#">Figure 9.17</a> |                             |

### 9.3 Projected Facility Water Supply Demands

In late 1994, in conjunction with preparation for the upcoming Permit renewal, the Authority contacted those public water supply utilities in Charlotte, Sarasota and Desoto counties that had expressed an interest in potentially receiving water and participating in future expansions of the Peace River Facility. These utilities were requested to supply updated water demand projections over the thirty-year planning period used in the Permit application subsequently submitted to the District. The projected total facility demands shown in Table 9.2 are based on demands provided by the utilities that were then adjusted using a peak month factor of 1.175 and a maximum day factor of 1.45 based on actual historical Facility pumping data to complete the table and provide maximum estimated demands. The current existing 20-year water use permit is for 3.27 mgd and runs until 2015.

The District has indicated to the Authority that there are currently only a few small agricultural permitted withdrawals along the upper and middle regions of the Peace River, and District staff does not know of any other significant pending or contemplated Water Use Permits to directly use the Peace River. However, there are a number of pending and future expansions of phosphate mining proposed within the Peace River watershed. The potential magnitude of hydrologic alterations to groundwater base flow and surface water runoff posed by both the expansion of mining and agriculture within the middle and lower regions of the river's watershed remains to be determined.

**Table 9.2**  
**Projected Facility Water Use Demands**

| Calendar Year | Total Demand Annual Average (mgd) | Total Demand Maximum Month (mgd) | Total Demand Peak Day (mgd) |
|---------------|-----------------------------------|----------------------------------|-----------------------------|
| 1994          | 8.2                               | 9.6                              | 11.8                        |
| 1995          | 8.9                               | 10.4                             | 12.8                        |
| 2000          | 14.7                              | 17.2                             | 21.8                        |
| 2005          | 16.2                              | 19.0                             | 24.0                        |
| 2010          | 18.6                              | 21.7                             | 27.5                        |
| 2015          | 32.7                              | 38.4                             | 50.7                        |
| 2020          | 38.5                              | 45.3                             | 60.1                        |
| 2025          | 44.2                              | 52.0                             | 69.1                        |

#### 9.4 Recent and Projected Facility Expansions

The recent expansion of the Facility became operational in December 2001. This expansion consisted of doubling the Facility’s previous existing treatment capacity from twelve million gallons per day to twenty-four million gallons per day, as well as adding twelve additional aquifer storage and recovery (ASR) wells to the system’s previous existing nine wells. A total of twenty-seven miles of new water transmission piping was also added in order to provide additional water to DeSoto and Charlotte counties, as well as Sarasota County’s Carlton Water Treatment Facility.

The Facility’s present capacity to treat and supply up to twenty-four million gallons per day (mgd) is equivalent to withdrawals from the river of 37.2 cubic feet per second (cfs). The Facility’s existing raw water river diversion station is comprised of four pumps having a combined maximum capacity of 44 mgd (68.0 cfs). In comparison, the long-term average annual daily total gaged river freshwater flow upstream of the Peace River Facility is approximately 840 mgd (1300 cfs). During periods of high river flow, raw river water is stored in an off-stream reservoir and any excess treated water is stored in the system’s twenty-one ASR wells. Conversely, when water is unavailable from the Peace River due to the established minimum 130 cfs cutoff, water can be pumped from the raw water reservoir to the Peace River Facility for treatment, and/or previously treated water can also be recovered from the ASR system to meet the water supply demands of the Authority’s service area.

In order to meet the region’s projected (Table 9.2) increased water demands, the Peace River/Manasota Regional Water Supply Authority has started planning for the next expansion of the Peace River Facility. This expansion is expected to consist of additional treatment capacity, as well as both additional ASR wells and another surface water reservoir to store excess untreated river water during the wet-season. The exact size of this planned expansion is still under

evaluation, however completion of this next expansion under the current Water Use Permit is currently envisioned for completion sometime during 2007-2008.

### 9.5 Potential Modifications of the Existing Withdrawal Schedule

The analyses previously presented in this and other HBMP summary reports have indicated that the existing withdrawal schedule, which combines a 130 cfs minimum Arcadia gaged flow prerequisite prior to any Facility withdrawals, with the requirement that diversions cannot exceed ten percent of the previous day's gaged flow, has been extremely effective in preventing Facility withdrawals from having any apparent significant adverse impacts as defined in [Section 6.0](#). In the future, the District and the Authority may wish to consider possible withdrawal schedule modifications available to allow additional withdrawals during high flow periods to meet future projected regional water demands.

### 9.6 Potential Facility Impacts

The results of the statistical analyses summarized in [Section 5.0](#) have indicated that the maximum salinity changes predicted within the lower Peace River downstream of the Facility under the current withdrawal schedule are of such a magnitude that they will be difficult or impossible to detect given the typical normal daily ranges of tidal and seasonal salinity variations observed along the lower river (see [Section 4.0](#)). The spatial salinity models previously presented in the *2000 Midterm Interpretive Report* indicated that since Facility withdrawals are set as a fixed percentage of flow, the predicted magnitude (less than 0.3 ppt) of salinity change due to withdrawals remained relatively constant once flows reach moderate levels. The models also showed that the area of the river potentially experiencing withdrawal induced salinity changes continues to shift further down river under increasing flows and proportionate withdrawals. The analyses presented in this and other HBMP reports have shown that the established withdrawal schedule that combines both a 130 cfs minimum Arcadia gaged flow prerequisite prior to any Facility withdrawals, and the requirement that diversions cannot exceed ten percent of the previous day's gaged flow, have been extremely effective in preventing Facility withdrawals from having any apparent significant adverse impacts.

### 9.7 Summary

The 1996 Water Use Permit renewal specifically required that the Facility diversion schedule be evaluated in conjunction with the *Comprehensive Summary Reports* to assess if the existing withdrawal schedule has and will continue to adequately protect the lower Peace River estuarine resources. The primary objectives of this section are to address both the specific Permit condition and provide additional answers to issues and questions raised by the Scientific Review Panel at the November 2002 meeting.

- The 130 cfs minimum flow criteria established by District staff in 1988 was based on plots of conductivity versus Peace River at Arcadia flow from HBMP data gathered at fixed monitoring sites located near the Facility's point of withdrawal. The 130 cfs minimum flow criteria was based on the observed inflection in the relationship between

measured river conductivity and Arcadia gaged freshwater inflow. Analogous updated plots are presented in this section using period-of-record HBMP data through 2002 (**Figure 9.11**). The presented series of figures indicate that the observed inflection point in the relationship between conductivities and Arcadia gaged freshwater flows ranges between 80 and 150 cfs over the approximate seven kilometer reach of the river characterized by the five selected HBMP fixed sampling locations. As such, the existing 130 cfs minimum threshold for withdrawals represents a fairly conservative estimate to ensure minimal impacts to the lower Peace River/upper Charlotte Harbor estuary during low flow periods.

- The recent Facility expansion became operational in December 2001. The Facility presently has the capacity to treat and supply up to 24 mgd and a maximum raw water river diversion capacity of 44 mgd. In order to future public demands the Authority has started planning for the next expansion of the Peace River Facility. Completion of the next Facility expansion under the current District Water Use Permit is currently envisioned for completion sometime during the 2007-2008 period.
- The results of the empirical modeling analyses presented in this *Comprehensive Summary Report* indicate that the maximum salinity changes predicted within the lower Peace River under the current permit withdrawal schedule are of such a magnitude that they will be extremely difficult to detect given the typical normal daily ranges of tidal and seasonal salinity variations.
- The existing withdrawal schedule elements, which combines a 130 cfs minimum Arcadia gaged flow, with the requirement that diversions cannot exceed ten percent of the previous day's gaged flow, have been and are expected to continue to be extremely effective in preventing Facility withdrawals from having any apparent adverse impacts on the lower Peace River estuarine system.

## 10.0 References

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# Appendix A – Overview of Statistical Methods

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## A.1 Time Series Analyses

The following summary is provided for those interested in a more comprehensive overview of the methods and statistical procedures that were used to test for long-term trends. The Seasonal Kendall Tau methodologies presented in Section IV were based on SAS code obtained from the EPA (1993) document “Methods for the Analysis of Lake Water Quality Trends.” In those instances requiring the analyses of more than fifty years of data, Seasonal Kendall Tau test were run directly from Fortran code obtained from USGS Menlo Park (JR Slack 1988).

Statistical test for significant trends in mean annual water quality conditions for the “fixed” Peace River sampling locations where data were available only for the periods 1976-1989 and 1996 through 2002, were analyzed for significant differences using methods developed by Coastal Environmental (1966) for the Florida Department of Environmental Protection using seasonally weighted yearly averages. Depending on the distribution of the sampling frequency, the procedure examines for either trends over the entire sampling period or differences between periods within the data record, depending upon the continuity and length of the data record.

## A.2 Objectives in Testing for Trends in Water Quality

Physical and chemical measurements of water quality vary both spatially and temporally. These changes are functions of complex interactions among numerous large and small scale processes at work within an estuarine system. On a large scale, changes in land use and associated point and non-point nutrient/pollutant loadings can often result in progressive changes (or trends) in water quality. Such changes may initially be evident in specific areas and eventually be detected through much of the system. However, unless dramatic, such patterns of change can often be obscured by the interactions of many other events. On a yearly basis, seasonal changes in physical influences, including solar radiation, temperature, and precipitation commonly result in distinct yearly cyclical patterns in many water quality measurements. Variations in water quality are also randomly influenced by a great many small-scale factors. Winds, tides and shoreline irregularities all interact with freshwater inflows to collectively cause turbulence and diffusion that can result in apparent random behavior with water quality parameters in both space and time.

In brief, the term "trends" is typically used to refer to progressive changes in the level (mean value) of a water quality variable caused by an external factor, while "seasonal" and shorter-term oscillating patterns are primarily caused by repeating natural processes. Additional "natural variability" can be used to summarize all other factors not explicitly identified. In addition, all environmental data includes some level of "measurement error" specifically inherent to the combined application of both field and laboratory methods.

The ability of being able to detect actual long-term changes (trends) in water quality from amid these sources of variation is dependent on: 1) the acquisition of uniform, standardized, time sequenced water quality data from a properly designed monitoring program; 2) the application of

appropriate statistical methods; and 3) a conceptual understanding of relevant water quality relationships (cause and effect). Researchers have proposed a number of parametric and nonparametric (distribution-free) statistical methods for statistically determining the presence of trends in water quality data. The goal of all such procedures is to be able to separate a pattern (trend) from the “noise” caused by repeating seasonal and/or associated other random “unexplained” components within the water quality data.

The analysis and determination of the presence and/or absence of long-term trends within the data associated with the Peace River Hydrobiological Monitoring Program (HBMP) is a key component to assessing the effectiveness of the overall goals prescribed by the Water Use Permit (WUP). It is important both to determine the potential influences of other long-term changes (rainfall/inflows), as well as assess potential biotic and abiotic responses within the Lower Peace River estuarine system. The ability to detect and quantify, or determine the lack of, progressive changes over time is key to providing the framework and basis for future management decisions.

### **A.3 Basic Statistical Concepts**

**Summary Statistics** - In order to characterize the various measurements contained within large data sets, the most effective method is usually to provide a few series of well-chosen statistics. In the selection of these descriptive statistics, it is important to understand their overall purpose. In general, summary statistics should provide as much information as possible to avoid potential misrepresentations or interpretations of the original data. The two most often used descriptive statistics to characterize data are measurements of central tendency and dispersion. Commonly used statistics of central tendency include the mean, median, mode, or geometric mean. Estimators of the spread, dispersion and scale of observations within the data include determination of the range, standard deviation, and interquartiles.

**Robustness, Resistance, and Influence** – “Robustness” is used to refer to a particular statistical procedure’s overall insensitivity to violations of its basic assumptions. The term “resistance” by comparison is used to refer to the method’s insensitivity to outliers; while the word “influence” is used to describe the effect of extreme observations on summary measures (statistics).

**Parametric versus Nonparametric Methods** – A basic assumption of most parametric statistical analyses is the assumption that the underlying distribution of the data in question is approximately normally distributed (or that it can be transformed to be so). The general overall robustness of parametric probability models is dependent on this underlying assumption and provides resistance to influential outliers. However, a great many types of measurements gathered in environmental data in general, and water quality characteristics in particular, often violate this underlying assumption that is key to the robustness and resistance of many of the most commonly applied parametric procedures. Therefore, unless the underlying normality of the data can be proven, nonparametric procedures are usually more appropriately used in assessing potential trends in water quality data. Such distribution-free nonparametric methods, as the name suggests, do not require an assumption concerning the underlying probability of the data. However, as with parametric procedures, an assumption of sequential independence is usually implicit. Thus, autocorrelation can be a serious problem for both nonparametric and parametric methods.

Kendall's Tau and the seasonal Kendall's Tau test is one of the widely used distribution-free methods to test for trends in data where normality cannot be assumed. These methods can be used to determine whether time series data are moving upward, downward, or remaining relatively level over time. This is accomplished by computing a statistic (Tau), based on the differences among all possible data pairs, thus representing the net direction of movement of the time series data. The number of positive differences minus the number of negative differences is then determined and this is used to determine the test statistic (the Mann-Kendall Tau). If the time series data is increasing (decreasing) over time, then the test statistic will be a large positive (negative) number. If the trend in the water quality data series over time is negligible, then the number of positive pairs and the number of negative pairs will be approximately equal, and the test statistic will be small in absolute value. The Tau estimator can thus be viewed as an estimate of the median slope from the set of slopes estimated for the lines connecting all possible pairs of data.

The Seasonal Kendall's Tau test incorporates a seasonal basis to the same form of analysis. When analyzing monthly data, each month is viewed as a "season." This method is directly applicable to data characterized by strong seasonal patterns.

**Hypothesis Testing** - In conventional statistical analysis, hypothesis testing for a trend is usually based on the point null hypothesis "that there is no trend," which can only be rejected on the basis of sufficient evidence. To test this hypothesis, the actual data are used to provide an estimate of a test statistic, and a table for the test statistic is consulted to estimate how unusual the observed value of the test statistic is if the null hypothesis is true. If the observed value of the test statistic is "very unusual," then there is a basis for rejecting the null hypothesis.

**A.4 Box and Whiskers Plots** - One of the most informative methods of looking for seasonal and spatial patterns with water quality data is through the production of a box and whiskers plot of the observations. Such plots display information on the sample median, dispersion, skew, relative size of the underlying data set, and statistical significance of the median. The procedures used in the box and whiskers plots presented in Section IV used the following methods:

1. All observations within the data set were ordered into spatial or temporal groupings.
2. The lowest and highest values for each group are represented as extreme values for each box as vertical "whiskers" plotted as vertical lines extending above and below each box.
3. The 25<sup>th</sup> and the 75<sup>th</sup> percentiles of observed values for each grouping were then calculated and these quartiles were used to define the upper and lower edges of the box.
4. The median value for each grouping is shown as a horizontal line at the center of the "notch," while the mean is depicted as a single round point.

5. The height of the notch in each box is determined based on the statistical significance of each group's median value. Thus, when boxes are compared among groups, if the notches do not overlap then the medians of those groups are statistically different at an alpha 0.05 level.
6. The height of the box is directly proportional to the amount of variability observed in the data collected within a group.
7. The width of the box is representative of the number of observations for each group (note: since most of the HBMP data is based on uniform monthly data collections the width of the boxes do not vary among groups).



# Tables

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- 1.0      Introduction**
- 2.0      Conceptual Model (no tables outside of main text)**
- 3.0      Summaries of Recent HBMP Reports and Primary Conclusions (no tables)**
- 4.0      Status and Trends of Hydrobiological Indicators in the Lower Peace River/Upper Charlotte Harbor Estuarine System**
- 5.0      Salinity/Flow /Withdrawal Relationships at Continuous Recorders**
- 6.0      Evaluation of the Presence or Absence of Adverse Impacts and Appropriate Indicators**
- 7.0      Controlled River Pump Test Design**
- 8.0      Proposed Monitoring Design Modifications to the Existing Long-term HBMP Elements**
- 9.0      Diversion Schedule Assessment (no tables outside of main text)**

**Table 1.1**  
**HBMP Fixed Sampling Locations**

| <b>USGS River Mile</b>                                                | <b>USGS Location Number</b> | <b>Previous EQL Station Number</b> | <b>Additional Sampling</b>           | <b>New River Kilometer designation based on Morphometric Study</b> |
|-----------------------------------------------------------------------|-----------------------------|------------------------------------|--------------------------------------|--------------------------------------------------------------------|
| <b>Current <i>In Situ</i> Water Column Profile Sampling Locations</b> |                             |                                    |                                      |                                                                    |
| CH6                                                                   | 265355082075500             | 9                                  | Water Quality                        | <b>-2.4</b>                                                        |
| RM3.95                                                                | 265640082033500             | 10                                 | Water Quality                        | <b>6.6</b>                                                         |
| RM4.88                                                                | 265724082024400             | 21                                 |                                      | <b>8.4</b>                                                         |
| RM6.25                                                                | 265727082012800             | 11                                 |                                      | <b>10.5</b>                                                        |
| RM8.61                                                                | 265711081595500             | Shell Creek 9 (92)                 |                                      | <b>12.7</b>                                                        |
| RM8.6B                                                                | 265819082003200             | 22                                 |                                      | <b>12.8</b>                                                        |
| RM10.2                                                                | 2297460                     | 12                                 | Water Quality/Tide Gage/Conductivity | <b>15.5</b>                                                        |
| RM11.2                                                                | 270022081591000             | 23                                 |                                      | <b>17.5</b>                                                        |
| RM 12.55                                                              | 270124081592500             | 13                                 |                                      | <b>20.1</b>                                                        |
| RM13.95                                                               | 270235081592400             | 24                                 |                                      | <b>21.9</b>                                                        |
| RM14.82                                                               | 270318081593100             | 14                                 | Water Quality                        | <b>23.6</b>                                                        |
| RM15.45                                                               | 270337081595800             | 25                                 |                                      | <b>24.7</b>                                                        |
| RM16.29                                                               | 270418082001600             | 15                                 |                                      | <b>25.9</b>                                                        |
| N/A                                                                   | 2297350                     | N/A                                | Tide Gage/ Conductivity              | <b>26.7</b>                                                        |
| RM18.25                                                               | 270451081595100             | 17                                 |                                      | <b>29.5</b>                                                        |
| RM18.95                                                               | 2297330                     | 18                                 | Water Quality                        | <b>30.4</b>                                                        |
| RM19.5                                                                | 270537081585800             | 19                                 |                                      | <b>32.3</b>                                                        |
| <b>Vegetation Transect Locations</b>                                  |                             |                                    |                                      |                                                                    |
| N/A                                                                   | N/A                         | I                                  |                                      | <b>15.6</b>                                                        |
| N/A                                                                   | N/A                         | II                                 |                                      | <b>22.3</b>                                                        |
| N/A                                                                   | N/A                         | III                                |                                      | <b>20.4</b>                                                        |
| <b>Previous EQL Water Column and Chemistry Sampling Sites</b>         |                             |                                    |                                      |                                                                    |
| N/A                                                                   | N/A                         | 16                                 |                                      | <b>27.1</b>                                                        |
| N/A                                                                   | N/A                         | 20                                 |                                      | <b>34.1</b>                                                        |

**Table 1.2**  
**HBMP Chemical Water Quality Parameters**

|                  |                            |
|------------------|----------------------------|
| Salinity         | Nitrate + Nitrite Nitrogen |
| Chloride         | Ammonia/Ammonium Nitrogen  |
| Color            | Total Kjeldahl Nitrogen    |
| Turbidity        | Total Nitrogen             |
| Alkalinity       | Ortho-Phosphorus           |
| Suspended Solids | Total Phosphorus           |
| Volatile Solids  | Inorganic Carbon           |
| Silica           | Total Organic Carbon       |
| Chlorophyll a    | Dissolved Organic Carbon   |

| <div> <div>Table 1.3</div> <div>Time Lines For Major HBMP Study Elements</div> </div> |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|---------------------------------------------------------------------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|                                                                                       | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 |
| Indicator Benthic Species                                                             |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sea Star                                                                              |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Upper Harbor Juvenile Fishes                                                          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Vegetation                                                                            |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Aerial Photography                                                                    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| First and Last                                                                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Transect Sites                                                                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Phytoplankton (Isohalines)                                                            |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Primary Production                                                                    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Species Identification                                                                |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Zooplankton (Isohalines)                                                              |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Physical Water Quality                                                                |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Lower /Middle Harbor                                                                  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Stations 1, 3, 5, 6                                                                   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| ● Stations 2, 4, 7                                                                    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Upper Harbor                                                                          |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| ● Station 9                                                                           |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Lower River                                                                           |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| ● Stations 10, 12, 14, 18                                                             |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| ● Stations 16, 20                                                                     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Stations 11, 13, 15, 17, 19                                                           |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Stations 21, 22, 23, 24, 25                                                           |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| ● Note: Includes Water Chemistry                                                      |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Continuous Recorders                                                                  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Benthic Invertebrates & Mollusc                                                       |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Larval Fish/Plankton                                                                  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

**Note:** The station locations used in this table refer to the historically used numerical identifications, since not all of the sites in the lower/upper harbor were sampled along the current river kilometer centerline. table 2.1 provides conversions to the currently used centerline identification system stations 9 through 25.

**Table 4.a**  
**Number of Days Each Year When Facility**  
**Withdrawals Exceeded 10 Percent Due to**  
**Subsequent Changes in “Provisional”**  
**Gaged Flow Estimates**

| <b>Year</b> | <b>Number of Days</b> |
|-------------|-----------------------|
| 1988        | 7                     |
| 1989        | 0                     |
| 1990        | 4                     |
| 1991        | 26                    |
| 1992        | 22                    |
| 1993        | 0                     |
| 1994        | 2                     |
| 1995        | 2                     |
| 1996        | 18                    |
| 1997        | 53                    |
| 1998        | 5                     |
| 1999        | 42                    |
| 2000        | 12                    |
| 2001        | 13                    |
| 2002        | 17                    |
| 2003        | 11                    |

**Table 4.2**  
**Statistical Summary Of Trend Analyses Of Gaged Long-term Peace River Watershed Rainfall**

| Rainfall Gaged<br>Time Period | Tau Statistic | P-Value Without<br>Serial Correlation | P-Value With<br>Serial Correlation | Slope Statistic |
|-------------------------------|---------------|---------------------------------------|------------------------------------|-----------------|
| <b>Bartow</b>                 |               |                                       |                                    |                 |
| 1932-2002                     | -0.04         | 0.088                                 | 0.116                              | -0.006          |
| 1976-2002                     | -0.02         | 0.632                                 | 0.659                              | -0.006          |
| <b>Arcadia</b>                |               |                                       |                                    |                 |
| 1932-2002                     | -0.04         | 0.082                                 | 0.179                              | -0.005          |
| 1976-2002                     | -0.04         | 0.368                                 | 0.517                              | -0.010          |
| <b>Punta Gorda</b>            |               |                                       |                                    |                 |
| 1932-2002                     | -0.01         | 0.787                                 | 0.813                              | -0.001          |
| 1976-2002                     | -0.03         | 0.514                                 | 0.565                              | -0.008          |

- Red denotes significance at the 0.05 level
- Blue denotes significance at the 0.10 level



**Table 4.5**  
**Statistical Summary Of Trend Analyses Of Gaged Long-term Mean Peace River Watershed Flows**

| Rainfall Gaged<br>Time Period            | Tau Statistic | P-Value Without<br>Serial Correlation | P-Value With<br>Serial Correlation | Slope Statistic |
|------------------------------------------|---------------|---------------------------------------|------------------------------------|-----------------|
| <b>Period of Record</b>                  |               |                                       |                                    |                 |
| Peace River at Arcadia 1932-2002         | -0.09         | 0.001                                 | 0.041                              | -2.279          |
| Horse Creek 1951-2002                    | -0.04         | 0.176                                 | 0.468                              | -0.127          |
| Joshua Creek 1951-2002                   | 0.14          | 0.001                                 | 0.010                              | 0.338           |
| Shell Creek 1966-2002                    | 0.06          | 0.065                                 | 0.315                              | 0.852           |
| <b>HBMP Period 1976-2002</b>             |               |                                       |                                    |                 |
| Peace River at Arcadia                   | -0.01         | 0.759                                 | 0.874                              | -0.841          |
| Horse Creek                              | 0.07          | 0.080                                 | 0.349                              | 0.482           |
| Joshua Creek                             | 0.18          | 0.001                                 | 0.015                              | 0.986           |
| Shell Creek                              | 0.09          | 0.024                                 | 0.246                              | 2.086           |
| Total Gaged Flow upstream of Facility    | 0.015         | 0.696                                 | 0.838                              | 1.158           |
| Total Gaged Flow upstream of US41 Bridge | 0.036         | 0.364                                 | 0.634                              | 3.629           |

- Red denotes significance at the 0.05 level
- Blue denotes significance at the 0.10 level

**Table 4.6**  
**Statistical Summary Of Trend Analyses Of Gaged Long-term Median Peace River Watershed Flows**

| Rainfall Gaged<br>Time Period            | Tau Statistic | P-Value Without<br>Serial Correlation | P-Value With<br>Serial Correlation | Slope Statistic |
|------------------------------------------|---------------|---------------------------------------|------------------------------------|-----------------|
| <b>Period of Record</b>                  |               |                                       |                                    |                 |
| Peace River at Arcadia 1932-2002         | -0.10         | 0.001                                 | 0.033                              | -2.00           |
| Horse Creek 1951-2002                    | -0.03         | 0.282                                 | 0.559                              | -0.069          |
| Joshua Creek 1951-2002                   | 0.22          | 0.001                                 | 0.001                              | 0.350           |
| Shell Creek 1966-2002                    | 0.07          | 0.048                                 | 0.284                              | 0.822           |
| <b>HBMP Period 1976-2002</b>             |               |                                       |                                    |                 |
| Peace River at Arcadia                   | -0.03         | 0.396                                 | 0.664                              | -1.643          |
| Horse Creek                              | 0.06          | 0.104                                 | 0.358                              | 0.286           |
| Joshua Creek                             | 0.25          | 0.001                                 | 0.002                              | 0.900           |
| Shell Creek                              | 0.08          | 0.038                                 | 0.289                              | 1.704           |
| Total Gaged Flow upstream of Facility    | -0.01         | 0.750                                 | 0.867                              | -0.679          |
| Total Gaged Flow upstream of US41 Bridge | 0.01          | 0.749                                 | 0.868                              | 1.293           |

- Red denotes significance at the 0.05 level
- Blue denotes significance at the 0.10 level

**Table 4.9**  
**Statistical Summary Of Trend Analyses Of Peace River Facility Withdrawals**

| Time Period                                | Tau Statistic | P-Value Without<br>Serial Correlation | P-Value With<br>Serial Correlation | Slope Statistic |
|--------------------------------------------|---------------|---------------------------------------|------------------------------------|-----------------|
| <b>Facility Withdrawals</b>                |               |                                       |                                    |                 |
| <b>1980-2002 (cfs)</b>                     | 0.32          | <b>0.001</b>                          | <b>0.001</b>                       | 0.509           |
| <b>1980-2002 (percent of Arcadia flow)</b> | 0.21          | <b>0.001</b>                          | <b>0.002</b>                       | 0.076           |

- Red denotes significance at the 0.05 level
- Blue denotes significance at the 0.10 level

**Table 4.12**  
**Trend Tests “Fixed” Station Water Quality (1976-1989 & 1996-2002)**

| River Kilometer<br>Parameter | Subsurface Values |               |                |                     | Near Bottom Values |               |                |                    |
|------------------------------|-------------------|---------------|----------------|---------------------|--------------------|---------------|----------------|--------------------|
|                              | Time Series       | Trend Test    | Diff.<br>Means | P Value<br>of Diff. | Bottom Value       | Trend Test    | Diff.<br>Means | P Value<br>of Diff |
| River Kilometer –2.4         |                   |               |                |                     |                    |               |                |                    |
| Salinity                     | Figure 4.5.16     | Figure 4.5.17 | 0.8            | 0.661               | Figure 4.5.18      | Figure 4.5.19 | 1.3            | 0.331              |
| Dissolved Oxygen             | Figure 4.5.20     | Figure 4.5.21 | -0.5           | 0.001               | Figure 4.5.22      | Figure 4.5.23 | -0.4           | 0.087              |
| Color                        | Figure 4.5.24     | Figure 4.5.25 | 5.9            | 0.468               | Figure 4.5.26      | Figure 4.5.27 | 8.7            | 0.157              |
| Turbidity                    | Figure 4.5.28     | Figure 4.5.29 | 1.0            | 0.453               | Figure 4.5.30      | Figure 4.5.31 | 0.4            | 0.834              |
| Nitrite + Nitrate            | Figure 4.5.32     | Figure 4.5.33 | 0.014          | 0.122               | Figure 4.5.34      | Figure 4.5.35 | 0.017          | 0.004              |
| Ammonia / Ammonium           | Figure 4.5.36     | Figure 4.5.37 | 0.027          | 0.001               | Figure 4.5.38      | Figure 4.5.39 | 0.026          | 0.74               |
| Total Kjeldahl Nitrogen      | Figure 4.5.40     | Figure 4.5.41 | -0.001         | 0.984               | Figure 4.5.42      | Figure 4.5.43 | 0.001          | 0.983              |
| Total Phosphorus             | Figure 4.5.44     | Figure 4.5.45 | -0.083         | 0.001               | Figure 4.5.46      | Figure 4.5.47 | -0.085         | 0.001              |
| Silica                       | Figure 4.5.48     | Figure 4.5.49 | 1.0            | 0.001               | Figure 4.5.50      | Figure 4.5.51 | 1.0            | 0.001              |
| Dissolved Organic Carbon     | Figure 4.5.52     | Figure 4.5.53 | -11.2          | 0.001               | Figure 4.5.54      | Figure 4.5.55 | -12.6          | 0.001              |
| Total Organic Carbon         | Figure 4.5.56     | Figure 4.5.57 | -12.8          | 0.001               | Figure 4.5.58      | Figure 4.5.59 | 13.1           | 0.001              |
| Chlorophyll <u>a</u>         | Figure 4.5.60     | Figure 4.5.61 | 0.4            | 0.890               | Figure 4.5.62      | Figure 4.5.63 | N/A            |                    |
| River Kilometer 6.6          |                   |               |                |                     |                    |               |                |                    |
| Salinity                     | Figure 4.5.64     | Figure 4.5.65 | -0.2           | 0.920               | Figure 4.5.66      | Figure 4.5.67 | 0.7            | 0.703              |
| Dissolved Oxygen             | Figure 4.5.68     | Figure 4.5.69 | -0.5           | 0.002               | Figure 4.5.70      | Figure 4.5.71 | -0.4           | 0.021              |
| Color                        | Figure 4.5.72     | Figure 4.5.73 | 10.2           | 0.443               | Figure 4.5.74      | Figure 4.5.75 | 8.5            | 0.373              |
| Turbidity                    | Figure 4.5.76     | Figure 4.5.77 | -0.7           | 0.152               | Figure 4.5.78      | Figure 4.5.79 | -3.5           | 0.001              |
| Nitrite + Nitrate            | Figure 4.5.80     | Figure 4.5.81 | -0.002         | 0.943               | Figure 4.5.82      | Figure 4.5.83 | 0.015          | 0.257              |
| Ammonia / Ammonium           | Figure 4.5.84     | Figure 4.5.85 | 0.031          | 0.020               | Figure 4.5.86      | Figure 4.5.87 | 0.048          | 0.004              |

**Table 4.12**  
**Trend Tests “Fixed” Station Water Quality (1976-1989 & 1996-2002)**

| River Kilometer<br>Parameter | Subsurface Values |                |                |                     | Near Bottom Values |                |                |                     |
|------------------------------|-------------------|----------------|----------------|---------------------|--------------------|----------------|----------------|---------------------|
|                              | Time Series       | Trend Test     | Diff.<br>Means | P Value<br>of Diff. | Bottom Value       | Trend Test     | Diff.<br>Means | P Value<br>of Diff. |
| Total Kjeldahl Nitrogen      | Figure 4.5.88     | Figure 4.5.89  | -0.040         | 0.612               | Figure 4.5.90      | Figure 4.5.91  | 0.025          | 0.703               |
| Total Phosphorus             | Figure 4.5.92     | Figure 4.5.93  | -0.198         | 0.001               | Figure 4.5.94      | Figure 4.5.95  | -0.217         | 0.001               |
| Silica                       | Figure 4.5.96     | Figure 4.5.97  | 1.2            | 0.001               | Figure 4.5.98      | Figure 4.5.99  | 1.1            | 0.001               |
| Dissolved Organic Carbon     | Figure 4.5.100    | Figure 4.5.101 | -12.8          | 0.001               | Figure 4.5.102     | Figure 4.5.103 | -12.1          | 0.001               |
| Total Organic Carbon         | Figure 4.5.104    | Figure 4.5.105 | -13.3          | 0.001               | Figure 4.5.106     | Figure 4.5.107 | -13.1          | 0.001               |
| Chlorophyll <u>a</u>         | Figure 4.5.108    | Figure 4.5.109 | -5.8           | 0.001               | Figure 4.5.110     | Figure 4.5.111 | N/A            |                     |
| River Kilometer 15.5         |                   |                |                |                     |                    |                |                |                     |
| Salinity                     | Figure 4.5.112    | Figure 4.5.113 | 1.3            | 0.347               | Figure 4.5.114     | Figure 4.5.115 | 1.8            | 0.222               |
| Dissolved Oxygen             | Figure 4.5.116    | Figure 4.5.117 | -0.5           | 0.008               | Figure 4.5.118     | Figure 4.5.119 | -0.6           | 0.001               |
| Color                        | Figure 4.5.120    | Figure 4.5.121 | 00.6           | 0.963               | Figure 4.5.122     | Figure 4.5.123 | 0.0            | 0.999               |
| Turbidity                    | Figure 4.5.124    | Figure 4.5.125 | -1.3           | 0.001               | Figure 4.5.126     | Figure 4.5.127 | -2.1           | 0.006               |
| Nitrite + Nitrate            | Figure 4.5.128    | Figure 4.5.129 | -0.037         | 0.216               | Figure 4.5.130     | Figure 4.5.131 | -0.036         | 0.193               |
| Ammonia / Ammonium           | Figure 4.5.132    | Figure 4.5.133 | 0.023          | 0.345               | Figure 4.5.134     | Figure 4.5.135 | 0.015          | 0.264               |
| Total Kjeldahl Nitrogen      | Figure 4.5.136    | Figure 4.5.137 | 0.100          | 0.294               | Figure 4.5.138     | Figure 4.5.139 | 0.033          | 0.473               |
| Total Phosphorus             | Figure 4.5.140    | Figure 4.5.141 | -0.525         | 0.001               | Figure 4.5.142     | Figure 4.5.143 | -0.540         | 0.001               |
| Silica                       | Figure 4.5.144    | Figure 4.5.145 | 1.7            | 0.001               | Figure 4.5.146     | Figure 4.5.147 | 1.6            | 0.001               |
| Dissolved Organic Carbon     | Figure 4.5.148    | Figure 4.5.149 | -11.4          | 0.001               | Figure 4.5.150     | Figure 4.5.151 | -8.7           | 0.001               |
| Total Organic Carbon         | Figure 4.5.152    | Figure 4.5.153 | -12.9          | 0.001               | Figure 4.5.154     | Figure 4.5.155 | -12.8          | 0.001               |
| Chlorophyll <u>a</u>         | Figure 4.5.156    | Figure 4.5.157 | -0.6           | 0.830               | Figure 4.5.158     | Figure 4.5.159 | N/A            |                     |
| River Kilometer 23.6         |                   |                |                |                     |                    |                |                |                     |
| Salinity                     | Figure 4.5.160    | Figure 4.5.161 | 0.6            | 0.290               | Figure 4.5.162     | Figure 4.5.163 | 0.7            | 0.328               |

**Table 4.12**  
**Trend Tests “Fixed” Station Water Quality (1976-1989 & 1996-2002)**

| River Kilometer<br>Parameter | Subsurface Values |                |                |                     | Near Bottom Values |                |                |                     |
|------------------------------|-------------------|----------------|----------------|---------------------|--------------------|----------------|----------------|---------------------|
|                              | Time Series       | Trend Test     | Diff.<br>Means | P Value<br>of Diff. | Bottom Value       | Trend Test     | Diff.<br>Means | P Value<br>of Diff. |
| Dissolved Oxygen             | Figure 4.5.164    | Figure 4.5.165 | -0.4           | 0.004               | Figure 4.5.166     | Figure 4.5.167 | -0.4           | 0.015               |
| Color                        | Figure 4.5.168    | Figure 4.5.169 | -1.6           | 0.898               | Figure 4.5.170     | Figure 4.5.171 | -0.6           | 0.962               |
| Turbidity                    | Figure 4.5.172    | Figure 4.5.173 | -1.3           | 0.001               | Figure 4.5.174     | Figure 4.5.175 | -1.7           | 0.001               |
| Nitrite + Nitrate            | Figure 4.5.176    | Figure 4.5.177 | -0.033         | 0.405               | Figure 4.5.178     | Figure 4.5.179 | -0.024         | 0.562               |
| Ammonia / Ammonium           | Figure 4.5.180    | Figure 4.5.181 | -0.007         | 0.254               | Figure 4.5.182     | Figure 4.5.183 | -0.007         | 0.228               |
| Total Kjeldahl Nitrogen      | Figure 4.5.184    | Figure 4.5.185 | -0.178         | 0.227               | Figure 4.5.186     | Figure 4.5.187 | -0.108         | 0.429               |
| Total Phosphorus             | Figure 4.5.188    | Figure 4.5.189 | -0.713         | 0.001               | Figure 4.5.190     | Figure 4.5.191 | -0.748         | 0.001               |
| Silica                       | Figure 4.5.192    | Figure 4.5.193 | 2.1            | 0.001               | Figure 4.5.194     | Figure 4.5.195 | 1.9            | 0.001               |
| Dissolved Organic Carbon     | Figure 4.5.196    | Figure 4.5.197 | -9.6           | 0.001               | Figure 4.5.198     | Figure 4.5.199 | -9.1           | 0.001               |
| Total Organic Carbon         | Figure 4.5.200    | Figure 4.5.201 | -11.0          | 0.001               | Figure 4.5.202     | Figure 4.5.203 | -10.4          | 0.001               |
| Chlorophyll <u>a</u>         | Figure 4.5.204    | Figure 4.5.205 | -2.8           | 0.204               | Figure 4.5.206     | Figure 4.5.207 | N/A            |                     |
| River Kilometer 30.4         |                   |                |                |                     |                    |                |                |                     |
| Salinity                     | Figure 4.5.208    | Figure 4.5.209 | 0.185          | 0.163               | Figure 4.5.210     | Figure 4.5.211 | 0.2            | 0.143               |
| Dissolved Oxygen             | Figure 4.5.212    | Figure 4.5.213 | -0.58          | 0.001               | Figure 4.5.214     | Figure 4.5.215 | -0.5           | 0.001               |
| Color                        | Figure 4.5.216    | Figure 4.5.217 | -3.8           | 0.773               | Figure 4.5.218     | Figure 4.5.219 | 0.7            | 0.954               |
| Turbidity                    | Figure 4.5.220    | Figure 4.5.221 | -1.79          | 0.001               | Figure 4.5.222     | Figure 4.5.223 | -2.1           | 0.001               |
| Nitrite + Nitrate            | Figure 4.5.224    | Figure 4.5.225 | -0.019         | 0.691               | Figure 4.5.226     | Figure 4.5.227 | -0.054         | 0.401               |
| Ammonia / Ammonium           | Figure 4.5.228    | Figure 4.5.229 | -0.006         | 0.389               | Figure 4.5.230     | Figure 4.5.231 | 0.004          | 0.575               |
| Total Kjeldahl Nitrogen      | Figure 4.5.232    | Figure 4.5.233 | -0.078         | 0.179               | Figure 4.5.234     | Figure 4.5.235 | -0.086         | 0.149               |
| Total Phosphorus             | Figure 4.5.236    | Figure 4.5.237 | -0.881         | 0.001               | Figure 4.5.238     | Figure 4.5.239 | -0.792         | 0.001               |
| Silica                       | Figure 4.5.240    | Figure 4.5.241 | 2.0            | 0.001               | Figure 4.5.242     | Figure 4.5.243 | 1.9            | 0.001               |



**Table 4.12**  
**Trend Tests “Fixed” Station Water Quality (1976-1989 & 1996-2002)**

| River Kilometer Parameter | Subsurface Values |                |             |                  | Near Bottom Values |                |             |                  |
|---------------------------|-------------------|----------------|-------------|------------------|--------------------|----------------|-------------|------------------|
|                           | Time Series       | Trend Test     | Diff. Means | P Value of Diff. | Bottom Value       | Trend Test     | Diff. Means | P Value of Diff. |
| Dissolved Organic Carbon  | Figure 4.5.244    | Figure 4.5.245 | -10.0       | 0.001            | Figure 4.5.246     | Figure 4.5.247 | -9.8        | 0.001            |
| Total Organic Carbon      | Figure 4.5.248    | Figure 4.5.249 | -11.5       | 0.001            | Figure 4.5.250     | Figure 4.5.251 | -10.8       | 0.001            |
| Chlorophyll <u>a</u>      | Figure 4.5.252    | Figure 4.5.253 | -4.1        | 0.040            | Figure 4.5.254     | Figure 4.5.255 | N/A         |                  |

- Red denotes significance at the 0.05 level
- Pink denotes significance at the 0.10 level

**Table 4.16****Correlation of Water Quality Parameters with Flow by Category at River Kilometer –2.2**

| <b>Water Quality Parameter</b> | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|--------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Salinity (ppt)</b>          |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.72246       | -0.49623          | -0.26007          | -0.26873           | -0.31549           | -0.31541            | -0.62716             |
| Probability                    | <.0001         | 0.0039            | 0.0921            | 0.0118             | 0.0062             | 0.0242              | <.0001               |
| Number of Observations         | 324            | 32                | 43                | 87                 | 74                 | 51                  | 37                   |
| <b>Dissolved Oxygen (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | 0.04977        | 0.04332           | 0.38373           | 0.24203            | -0.06358           | 0.14561             | -0.21152             |
| Probability                    | 0.3726         | 0.8139            | 0.0133            | 0.0239             | 0.5853             | 0.308               | 0.2156               |
| Number of Observations         | 323            | 32                | 41                | 87                 | 76                 | 51                  | 36                   |
| <b>Color (CPU)</b>             |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | 0.78832        | -0.03985          | 0.10461           | 0.12357            | 0.23734            | 0.37905             | 0.41612              |
| Probability                    | <.0001         | 0.8467            | 0.5378            | 0.2942             | 0.055              | 0.0207              | 0.0276               |
| Number of Observations         | 268            | 26                | 37                | 74                 | 66                 | 37                  | 28                   |
| <b>Turbidity (NTU)</b>         |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | 0.02281        | 0.13222           | -0.06804          | 0.03054            | -0.1118            | 0.3069              | 0.4482               |
| Probability                    | 0.7106         | 0.5197            | 0.689             | 0.7962             | 0.3753             | 0.0647              | 0.0168               |
| Number of Observations         | 267            | 26                | 37                | 74                 | 65                 | 37                  | 28                   |
| <b>Nitrite/Nitrate (mg/l)</b>  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | 0.22179        | -0.15665          | 0.22035           | 0.22484            | 0.26987            | 0.03495             | -0.00404             |
| Probability                    | 0.0003         | 0.4447            | 0.19              | 0.0541             | 0.0284             | 0.8373              | 0.9837               |
| Number of Observations         | 268            | 26                | 37                | 74                 | 66                 | 37                  | 28                   |
|                                |                |                   |                   |                    |                    |                     |                      |

**Table 4.16****Correlation of Water Quality Parameters with Flow by Category at River Kilometer –2.2**

| <b>Water Quality Parameter</b>        | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|---------------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Ammonia/Ammonium (mg/l)</b>        |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.4539         | -0.18868          | 0.56873           | 0.03708            | 0.24822            | -0.25531            | 0.28071              |
| Probability                           | <.0001         | 0.4127            | 0.0013            | 0.7861             | 0.0677             | 0.1898              | 0.1741               |
| Number of Observations                | 214            | 21                | 29                | 56                 | 55                 | 28                  | 25                   |
| <b>Total Kjeldahl Nitrogen (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.44737        | 0.3001            | 0.00945           | 0.20057            | -0.00854           | 0.09896             | 0.37502              |
| Probability                           | <.0001         | 0.1748            | 0.9627            | 0.1717             | 0.9536             | 0.6305              | 0.071                |
| Number of Observations                | 196            | 22                | 27                | 48                 | 49                 | 26                  | 24                   |
| <b>Total Phosphorus (mg/l)</b>        |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.54791        | 0.22393           | 0.13919           | 0.35097            | 0.01971            | 0.15912             | 0.24706              |
| Probability                           | <.0001         | 0.2819            | 0.4398            | 0.0036             | 0.8761             | 0.3469              | 0.205                |
| Number of Observations                | 255            | 25                | 33                | 67                 | 65                 | 37                  | 28                   |
| <b>Silica (mg/l)</b>                  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.40299        | -0.2802           | 0.14291           | -0.07159           | 0.14549            | 0.27522             | -0.10793             |
| Probability                           | <.0001         | 0.1656            | 0.3988            | 0.5444             | 0.2438             | 0.0992              | 0.5846               |
| Number of Observations                | 268            | 26                | 37                | 74                 | 66                 | 37                  | 28                   |
| <b>Total Organic Carbon (mg/l)</b>    |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.09402        | 0.29857           | 0.12538           | 0.13862            | 0.13266            | 0.09823             | -0.02471             |
| Probability                           | 0.1336         | 0.1471            | 0.4662            | 0.2524             | 0.3123             | 0.563               | 0.9007               |
| Number of Observations                | 256            | 25                | 36                | 70                 | 60                 | 37                  | 28                   |
|                                       |                |                   |                   |                    |                    |                     |                      |

**Table 4.16****Correlation of Water Quality Parameters with Flow by Category at River Kilometer –2.2**

| <b>Water Quality Parameter</b>         | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|----------------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Dissolved Organic Carbon (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | 0.16201        | 0.33901           | 0.35287           | 0.17269            | 0.16262            | 0.01227             | 0.07244              |
| Probability                            | 0.0251         | 0.1328            | 0.0836            | 0.2405             | 0.2695             | 0.9536              | 0.7366               |
| Number of Observations                 | 191            | 21                | 25                | 48                 | 48                 | 25                  | 24                   |
| <b>Chlorophyll a (ug/l)</b>            |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | 0.19504        | -0.21673          | 0.06884           | -0.02144           | 0.15338            | 0.224               | 0.22728              |
| Probability                            | 0.0015         | 0.2876            | 0.69              | 0.8582             | 0.2301             | 0.1826              | 0.2448               |
| Number of Observations                 | 262            | 26                | 36                | 72                 | 63                 | 37                  | 28                   |

**Table 4.17**  
**Correlation of Water Quality Parameters with Flow by Category at River Kilometer 6.6**

| <b>Water Quality Parameter</b> | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|--------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Salinity (ppt)</b>          |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.70013       | -0.43657          | -0.39982          | -0.34521           | -0.30993           | -0.47785            | -0.55007             |
| Probability                    | <.0001         | 0.0049            | 0.0059            | 0.0004             | 0.0044             | 0.0001              | 0.0003               |
| Number of Observations         | 366            | 40                | 46                | 100                | 83                 | 58                  | 39                   |
| <b>Dissolved Oxygen (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.25438       | -0.05461          | 0.27286           | 0.23007            | -0.08497           | -0.43047            | -0.24364             |
| Probability                    | <.0001         | 0.7413            | 0.0698            | 0.022              | 0.4394             | 0.0007              | 0.135                |
| Number of Observations         | 365            | 39                | 45                | 99                 | 85                 | 58                  | 39                   |
| <b>Color (CPU)</b>             |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | 0.81253        | -0.09913          | 0.07781           | 0.24412            | 0.31047            | 0.57837             | 0.39956              |
| Probability                    | <.0001         | 0.6158            | 0.6471            | 0.0361             | 0.0112             | 0.0002              | 0.0389               |
| Number of Observations         | 269            | 28                | 37                | 74                 | 66                 | 37                  | 27                   |
| <b>Turbidity (NTU)</b>         |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.0167        | 0.01835           | -0.01975          | 0.12781            | -0.08316           | 0.02671             | -0.00476             |
| Probability                    | 0.7852         | 0.9262            | 0.9076            | 0.2745             | 0.5101             | 0.8753              | 0.9812               |
| Number of Observations         | 269            | 28                | 37                | 75                 | 65                 | 37                  | 27                   |
| <b>Nitrite/Nitrate (mg/l)</b>  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | 0.14314        | -0.24089          | 0.35167           | 0.11473            | 0.19794            | 0.24152             | -0.03779             |
| Probability                    | 0.0188         | 0.2169            | 0.0328            | 0.3304             | 0.1111             | 0.1498              | 0.8515               |
| Number of Observations         | 269            | 28                | 37                | 74                 | 66                 | 37                  | 27                   |
|                                |                |                   |                   |                    |                    |                     |                      |

**Table 4.17**  
**Correlation of Water Quality Parameters with Flow by Category at River Kilometer 6.6**

| <b>Water Quality Parameter</b>        | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|---------------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Ammonia/Ammonium (mg/l)</b>        |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.16667        | -0.35104          | 0.02027           | -0.03831           | 0.2153             | 0.16541             | -0.09926             |
| Probability                           | 0.014          | 0.1092            | 0.9169            | 0.7772             | 0.111              | 0.4003              | 0.6369               |
| Number of Observations                | 217            | 22                | 29                | 57                 | 56                 | 28                  | 25                   |
| <b>Total Kjeldahl Nitrogen (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.29545        | 0.26815           | -0.10097          | 0.22241            | 0.15892            | 0.20742             | 0.06884              |
| Probability                           | <.0001         | 0.2161            | 0.6163            | 0.1206             | 0.2653             | 0.3093              | 0.7492               |
| Number of Observations                | 201            | 23                | 27                | 50                 | 51                 | 26                  | 24                   |
| <b>Total Phosphorus (mg/l)</b>        |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.41806        | 0.4261            | 0.10004           | 0.45455            | -0.08321           | -0.0124             | 0.31079              |
| Probability                           | <.0001         | 0.0238            | 0.5616            | <.0001             | 0.5065             | 0.9419              | 0.1146               |
| Number of Observations                | 266            | 28                | 36                | 72                 | 66                 | 37                  | 27                   |
| <b>Silica (mg/l)</b>                  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.42986        | -0.2247           | 0.2172            | 0.04189            | 0.25026            | 0.37956             | -0.19963             |
| Probability                           | <.0001         | 0.2503            | 0.1966            | 0.7212             | 0.0427             | 0.0205              | 0.3181               |
| Number of Observations                | 270            | 28                | 37                | 75                 | 66                 | 37                  | 27                   |
| <b>Total Organic Carbon (mg/l)</b>    |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.1798         | 0.39729           | 0.15145           | 0.15488            | 0.06733            | 0.02896             | -0.09834             |
| Probability                           | 0.004          | 0.0402            | 0.3851            | 0.2005             | 0.6124             | 0.8649              | 0.6327               |
| Number of Observations                | 254            | 27                | 35                | 70                 | 59                 | 37                  | 26                   |
|                                       |                |                   |                   |                    |                    |                     |                      |



**Table 4.17**  
**Correlation of Water Quality Parameters with Flow by Category at River Kilometer 6.6**

| <b>Water Quality Parameter</b>         | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|----------------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Dissolved Organic Carbon (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | 0.24851        | 0.34999           | 0.29269           | 0.20807            | 0.13903            | 0.00429             | -0.08988             |
| Probability                            | 0.0005         | 0.1103            | 0.1557            | 0.1559             | 0.346              | 0.9837              | 0.6762               |
| Number of Observations                 | 192            | 22                | 25                | 48                 | 48                 | 25                  | 24                   |
| <b>Chlorophyll a (ug/l)</b>            |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | -0.00312       | -0.35928          | 0.00907           | 0.0838             | 0.15009            | -0.10706            | -0.35662             |
| Probability                            | 0.9598         | 0.0604            | 0.9581            | 0.4809             | 0.2403             | 0.5283              | 0.0679               |
| Number of Observations                 | 264            | 28                | 36                | 73                 | 63                 | 37                  | 27                   |

**Table 4.18****Correlation of Water Quality Parameters with Flow by Category at River Kilometer 15.5**

| <b>Water Quality Parameter</b> | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|--------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Salinity (ppt)</b>          |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.44929       | -0.49067          | -0.55228          | -0.42568           | -0.15299           | -0.39591            | -0.20604             |
| Probability                    | <.0001         | 0.0018            | 0.0002            | <.0001             | 0.1727             | 0.0049              | 0.2212               |
| Number of Observations         | 332            | 38                | 41                | 86                 | 81                 | 49                  | 37                   |
| <b>Dissolved Oxygen (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.30874       | 0.18482           | 0.32771           | 0.02304            | -0.10415           | -0.47157            | -0.17344             |
| Probability                    | <.0001         | 0.2666            | 0.039             | 0.8342             | 0.3518             | 0.0006              | 0.3046               |
| Number of Observations         | 331            | 38                | 40                | 85                 | 82                 | 49                  | 37                   |
| <b>Color (CPU)</b>             |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | 0.69179        | -0.00565          | 0.00644           | 0.19723            | 0.325              | 0.41701             | 0.12899              |
| Probability                    | <.0001         | 0.9781            | 0.9712            | 0.1183             | 0.0083             | 0.0141              | 0.53                 |
| Number of Observations         | 249            | 26                | 34                | 64                 | 65                 | 34                  | 26                   |
| <b>Turbidity (NTU)</b>         |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.0812        | -0.0261           | -0.2506           | -0.01105           | -0.01437           | -0.22182            | -0.04792             |
| Probability                    | 0.2025         | 0.8993            | 0.1529            | 0.9309             | 0.9103             | 0.2074              | 0.8162               |
| Number of Observations         | 248            | 26                | 34                | 64                 | 64                 | 34                  | 26                   |
| <b>Nitrite/Nitrate (mg/l)</b>  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | 0.10185        | -0.08051          | 0.30413           | 0.28506            | 0.07089            | -0.16293            | -0.44529             |
| Probability                    | 0.1089         | 0.6958            | 0.0803            | 0.0224             | 0.5747             | 0.3572              | 0.0226               |
| Number of Observations         | 249            | 26                | 34                | 64                 | 65                 | 34                  | 26                   |
|                                |                |                   |                   |                    |                    |                     |                      |

**Table 4.18****Correlation of Water Quality Parameters with Flow by Category at River Kilometer 15.5**

| <b>Water Quality Parameter</b>        | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|---------------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Ammonia/Ammonium (mg/l)</b>        |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.0349         | -0.0192           | 0.07567           | -0.09253           | 0.14213            | -0.01205            | 0.14745              |
| Probability                           | 0.6075         | 0.9307            | 0.6964            | 0.4936             | 0.2916             | 0.9515              | 0.4818               |
| Number of Observations                | 219            | 23                | 29                | 57                 | 57                 | 28                  | 25                   |
| <b>Total Kjeldahl Nitrogen (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.11913        | 0.09276           | -0.21904          | -0.11597           | 0.05947            | 0.04756             | -0.16834             |
| Probability                           | 0.0921         | 0.6738            | 0.2723            | 0.4226             | 0.6754             | 0.8214              | 0.4317               |
| Number of Observations                | 201            | 23                | 27                | 50                 | 52                 | 25                  | 24                   |
| <b>Total Phosphorus (mg/l)</b>        |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | -0.01585       | 0.39525           | 0.11932           | 0.2573             | -0.25697           | -0.14207            | 0.04757              |
| Probability                           | 0.8042         | 0.0457            | 0.5084            | 0.0418             | 0.0388             | 0.4229              | 0.8175               |
| Number of Observations                | 247            | 26                | 33                | 63                 | 65                 | 34                  | 26                   |
| <b>Silica (mg/l)</b>                  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.22787        | -0.32506          | 0.13865           | 0.06845            | 0.24294            | 0.24981             | -0.30392             |
| Probability                           | 0.0003         | 0.1052            | 0.4342            | 0.591              | 0.0512             | 0.1542              | 0.1312               |
| Number of Observations                | 249            | 26                | 34                | 64                 | 65                 | 34                  | 26                   |
| <b>Total Organic Carbon (mg/l)</b>    |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.16979        | 0.32687           | 0.31147           | 0.17208            | 0.07381            | -0.02353            | -0.20469             |
| Probability                           | 0.0093         | 0.1107            | 0.0777            | 0.1925             | 0.5819             | 0.8949              | 0.3264               |
| Number of Observations                | 234            | 25                | 33                | 59                 | 58                 | 34                  | 25                   |
|                                       |                |                   |                   |                    |                    |                     |                      |

**Table 4.18****Correlation of Water Quality Parameters with Flow by Category at River Kilometer 15.5**

| <b>Water Quality Parameter</b>         | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|----------------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Dissolved Organic Carbon (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | 0.23517        | 0.19536           | 0.21862           | 0.21541            | 0.2033             | 0.01006             | -0.19899             |
| Probability                            | 0.0009         | 0.3836            | 0.2833            | 0.1372             | 0.1658             | 0.9611              | 0.3512               |
| Number of Observations                 | 195            | 22                | 26                | 49                 | 48                 | 26                  | 24                   |
| <b>Chlorophyll a (ug/l)</b>            |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | -0.22342       | -0.1438           | -0.28073          | 0.09883            | -0.09646           | -0.32844            | -0.29482             |
| Probability                            | 0.0004         | 0.4834            | 0.1135            | 0.4447             | 0.4558             | 0.0579              | 0.1437               |
| Number of Observations                 | 243            | 26                | 33                | 62                 | 62                 | 34                  | 26                   |

**Table 4.19****Correlation of Water Quality Parameters with Flow by Category at River Kilometer 23.6**

| <b>Water Quality Parameter</b> | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|--------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Salinity (ppt)</b>          |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.24202       | -0.53664          | -0.45987          | -0.36721           | -0.13363           | -0.1351             | -0.08061             |
| Probability                    | <.0001         | 0.0004            | 0.0028            | 0.0005             | 0.2373             | 0.3547              | 0.6353               |
| Number of Observations         | 330            | 39                | 40                | 85                 | 80                 | 49                  | 37                   |
| <b>Dissolved Oxygen (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.26982       | 0.04907           | 0.34468           | 0.12296            | -0.2101            | -0.37377            | -0.18578             |
| Probability                    | <.0001         | 0.7699            | 0.0316            | 0.2652             | 0.0598             | 0.0082              | 0.2709               |
| Number of Observations         | 328            | 38                | 39                | 84                 | 81                 | 49                  | 37                   |
| <b>Color (CPU)</b>             |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | 0.66609        | -0.15074          | -0.10369          | 0.27639            | 0.36529            | 0.35819             | 0.06917              |
| Probability                    | <.0001         | 0.4529            | 0.5722            | 0.0271             | 0.003              | 0.0375              | 0.737                |
| Number of Observations         | 247            | 27                | 32                | 64                 | 64                 | 34                  | 26                   |
| <b>Turbidity (NTU)</b>         |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.06334       | 0.03146           | -0.31675          | 0.07835            | -0.01397           | 0.014               | -0.18191             |
| Probability                    | 0.3225         | 0.8762            | 0.0773            | 0.5383             | 0.9135             | 0.9374              | 0.3738               |
| Number of Observations         | 246            | 27                | 32                | 64                 | 63                 | 34                  | 26                   |
| <b>Nitrite/Nitrate (mg/l)</b>  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.12069       | 0.24669           | 0.25615           | 0.20656            | -0.1522            | -0.30211            | -0.38728             |
| Probability                    | 0.0582         | 0.2148            | 0.157             | 0.1015             | 0.2299             | 0.0825              | 0.0506               |
| Number of Observations         | 247            | 27                | 32                | 64                 | 64                 | 34                  | 26                   |
|                                |                |                   |                   |                    |                    |                     |                      |

**Table 4.19****Correlation of Water Quality Parameters with Flow by Category at River Kilometer 23.6**

| <b>Water Quality Parameter</b>        | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|---------------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Ammonia/Ammonium (mg/l)</b>        |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.1575         | -0.0524           | 0.10572           | 0.25831            | -0.03917           | -0.05007            | 0.28177              |
| Probability                           | 0.0197         | 0.8079            | 0.5852            | 0.0524             | 0.7744             | 0.8003              | 0.1724               |
| Number of Observations                | 219            | 24                | 29                | 57                 | 56                 | 28                  | 25                   |
| <b>Total Kjeldahl Nitrogen (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | -0.00518       | -0.05643          | -0.05978          | 0.30891            | -0.21133           | 0.28695             | -0.56623             |
| Probability                           | 0.9417         | 0.7934            | 0.7671            | 0.0308             | 0.1288             | 0.1643              | 0.0039               |
| Number of Observations                | 202            | 24                | 27                | 49                 | 53                 | 25                  | 24                   |
| <b>Total Phosphorus (mg/l)</b>        |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | -0.19405       | 0.32268           | 0.00782           | 0.15799            | -0.27699           | -0.20914            | -0.0755              |
| Probability                           | 0.0023         | 0.1007            | 0.9667            | 0.2162             | 0.0267             | 0.2352              | 0.7139               |
| Number of Observations                | 245            | 27                | 31                | 63                 | 64                 | 34                  | 26                   |
| <b>Silica (mg/l)</b>                  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.13305        | -0.23117          | -0.16254          | -0.01793           | 0.16844            | 0.16111             | -0.29924             |
| Probability                           | 0.037          | 0.246             | 0.3741            | 0.8891             | 0.1834             | 0.3627              | 0.1375               |
| Number of Observations                | 246            | 27                | 32                | 63                 | 64                 | 34                  | 26                   |
| <b>Total Organic Carbon (mg/l)</b>    |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.21319        | 0.26702           | 0.154             | 0.18051            | 0.27664            | 0.07957             | -0.25348             |
| Probability                           | 0.0011         | 0.1873            | 0.4082            | 0.1675             | 0.039              | 0.6547              | 0.2215               |
| Number of Observations                | 232            | 26                | 31                | 60                 | 56                 | 34                  | 25                   |
|                                       |                |                   |                   |                    |                    |                     |                      |

**Table 4.19****Correlation of Water Quality Parameters with Flow by Category at River Kilometer 23.6**

| <b>Water Quality Parameter</b>         | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|----------------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Dissolved Organic Carbon (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | 0.24199        | 0.15941           | 0.16582           | 0.20819            | 0.31186            | 0.08004             | -0.24563             |
| Probability                            | 0.0007         | 0.4675            | 0.4182            | 0.1511             | 0.0328             | 0.6975              | 0.2473               |
| Number of Observations                 | 195            | 23                | 26                | 49                 | 47                 | 26                  | 24                   |
| <b>Chlorophyll a (ug/l)</b>            |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | -0.18965       | 0.10574           | -0.17168          | -0.04076           | -0.10415           | -0.16494            | -0.15718             |
| Probability                            | 0.0031         | 0.5996            | 0.3558            | 0.7531             | 0.4244             | 0.3512              | 0.4432               |
| Number of Observations                 | 241            | 27                | 31                | 62                 | 61                 | 34                  | 26                   |



**Table 4.20****Correlation of Water Quality Parameters with Flow by Category at River Kilometer 30.4**

| <b>Water Quality Parameter</b> | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|--------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Salinity (ppt)</b>          |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.14359       | -0.60137          | -0.22114          | -0.10247           | -0.19547           | -0.10492            | -0.02425             |
| Probability                    | 0.009          | <.0001            | 0.1703            | 0.3478             | 0.0823             | 0.4731              | 0.8867               |
| Number of Observations         | 330            | 38                | 40                | 86                 | 80                 | 49                  | 37                   |
| <b>Dissolved Oxygen (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.35609       | 0.09927           | 0.40142           | 0.14426            | -0.09914           | -0.42073            | -0.18424             |
| Probability                    | <.0001         | 0.5532            | 0.0103            | 0.1905             | 0.3786             | 0.0026              | 0.275                |
| Number of Observations         | 329            | 38                | 40                | 84                 | 81                 | 49                  | 37                   |
| <b>Color (CPU)</b>             |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | 0.64277        | -0.23264          | -0.02193          | 0.41153            | 0.35863            | 0.28398             | 0.01477              |
| Probability                    | <.0001         | 0.2429            | 0.902             | 0.0002             | 0.0029             | 0.072               | 0.9382               |
| Number of Observations         | 275            | 27                | 34                | 76                 | 67                 | 41                  | 30                   |
| <b>Turbidity (NTU)</b>         |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.01086       | 0.06221           | -0.33748          | 0.13828            | 0.06631            | -0.07082            | -0.25765             |
| Probability                    | 0.8582         | 0.7579            | 0.0548            | 0.2336             | 0.5968             | 0.6599              | 0.1693               |
| Number of Observations         | 273            | 27                | 33                | 76                 | 66                 | 41                  | 30                   |
| <b>Nitrite/Nitrate (mg/l)</b>  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.26088       | 0.25318           | 0.24504           | 0.09545            | -0.20281           | -0.34083            | -0.45309             |
| Probability                    | <.0001         | 0.2026            | 0.1693            | 0.4121             | 0.0998             | 0.0292              | 0.0119               |
| Number of Observations         | 274            | 27                | 33                | 76                 | 67                 | 41                  | 30                   |
|                                |                |                   |                   |                    |                    |                     |                      |

**Table 4.20**

**Correlation of Water Quality Parameters with Flow by Category at River Kilometer 30.4**

| <b>Water Quality Parameter</b>        | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|---------------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Ammonia/Ammonium (mg/l)</b>        |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.11059        | -0.10628          | 0.11907           | 0.1699             | 0.06288            | 0.17878             | 0.34921              |
| Probability                           | 0.0995         | 0.6293            | 0.5462            | 0.1943             | 0.6422             | 0.3723              | 0.0685               |
| Number of Observations                | 223            | 23                | 28                | 60                 | 57                 | 27                  | 28                   |
| <b>Total Kjeldahl Nitrogen (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.25229        | -0.08283          | -0.27854          | 0.29845            | 0.001              | 0.29054             | -0.11951             |
| Probability                           | 0.0002         | 0.7071            | 0.1595            | 0.03               | 0.9944             | 0.1589              | 0.5527               |
| Number of Observations                | 207            | 23                | 27                | 53                 | 52                 | 25                  | 27                   |
| <b>Total Phosphorus (mg/l)</b>        |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | -0.25425       | 0.36959           | -0.14628          | 0.11581            | -0.23253           | -0.19621            | -0.16576             |
| Probability                           | <.0001         | 0.0578            | 0.4166            | 0.3224             | 0.0583             | 0.2189              | 0.3901               |
| Number of Observations                | 272            | 27                | 33                | 75                 | 67                 | 41                  | 29                   |
| <b>Silica (mg/l)</b>                  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.13107        | -0.34961          | -0.07731          | 0.09725            | 0.14706            | 0.16398             | -0.33192             |
| Probability                           | 0.0298         | 0.0738            | 0.6639            | 0.4033             | 0.235              | 0.3056              | 0.0731               |
| Number of Observations                | 275            | 27                | 34                | 76                 | 67                 | 41                  | 30                   |
| <b>Total Organic Carbon (mg/l)</b>    |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)           | 0.27233        | 0.28981           | 0.13289           | 0.20759            | 0.20327            | 0.02232             | -0.2098              |
| Probability                           | <.0001         | 0.151             | 0.461             | 0.0824             | 0.1161             | 0.8898              | 0.2747               |
| Number of Observations                | 261            | 26                | 33                | 71                 | 61                 | 41                  | 29                   |
|                                       |                |                   |                   |                    |                    |                     |                      |

**Table 4.20****Correlation of Water Quality Parameters with Flow by Category at River Kilometer 30.4**

| <b>Water Quality Parameter</b>         | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|----------------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Dissolved Organic Carbon (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | 0.292          | 0.15581           | 0.03466           | 0.21865            | 0.25233            | 0.02397             | -0.19025             |
| Probability                            | <.0001         | 0.4887            | 0.8665            | 0.1232             | 0.0771             | 0.9095              | 0.3419               |
| Number of Observations                 | 201            | 22                | 26                | 51                 | 50                 | 25                  | 27                   |
| <b>Chlorophyll a (ug/l)</b>            |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | -0.12315       | -0.31207          | -0.07871          | 0.05227            | -0.1554            | -0.08789            | -0.29795             |
| Probability                            | 0.0432         | 0.113             | 0.6633            | 0.6583             | 0.2201             | 0.5848              | 0.1035               |
| Number of Observations                 | 270            | 27                | 33                | 74                 | 64                 | 41                  | 31                   |

**Table 4.21**  
**Correlation of Water Quality Parameters – River Kilometer –2.2**

| Water Quality Parameter                | Salinity | Dissolved Oxygen | Color   | Turbidity | Nitrite + Nitrate Nitrogen | Ammonia / Ammonium | Total Kjeldahl Nitrogen | Total Phosphorus | Silica   | Total Organic Carbon | Dissolved Organic Carbon |
|----------------------------------------|----------|------------------|---------|-----------|----------------------------|--------------------|-------------------------|------------------|----------|----------------------|--------------------------|
| <b>Dissolved Oxygen (mg/l)</b>         | 319      |                  |         |           |                            |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | -0.11816 |                  |         |           |                            |                    |                         |                  |          |                      |                          |
| Probability                            | 0.0349   |                  |         |           |                            |                    |                         |                  |          |                      |                          |
| <b>Color (CPU)</b>                     | 252      | 252              |         |           |                            |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | -0.78651 | -0.01747         |         |           |                            |                    |                         |                  |          |                      |                          |
| Probability                            | <.0001   | 0.7826           |         |           |                            |                    |                         |                  |          |                      |                          |
| <b>Turbidity (NTU)</b>                 | 251      | 251              | 267     |           |                            |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | 0.09764  | 0.03972          | 0.01867 |           |                            |                    |                         |                  |          |                      |                          |
| Probability                            | 0.1229   | 0.5311           | 0.7614  |           |                            |                    |                         |                  |          |                      |                          |
| <b>Nitrite/Nitrate (mg/l)</b>          | 252      | 252              | 268     | 267       |                            |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | -0.51124 | -0.05426         | 0.19783 | -0.04546  |                            |                    |                         |                  |          |                      |                          |
| Probability                            | <.0001   | 0.3911           | 0.0011  | 0.4594    |                            |                    |                         |                  |          |                      |                          |
| <b>Ammonia/Ammonium (mg/l)</b>         | 206      | 205              | 214     | 213       | 214                        |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | -0.42891 | -0.13205         | 0.55936 | -0.03164  | 0.5665                     |                    |                         |                  |          |                      |                          |
| Probability                            | <.0001   | 0.0591           | <.0001  | 0.6461    | <.0001                     |                    |                         |                  |          |                      |                          |
| <b>Total Kjeldahl Nitrogen (mg/l)</b>  | 190      | 188              | 196     | 195       | 196                        | 195                |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | -0.57089 | 0.02028          | 0.63554 | 0.06163   | 0.22169                    | 0.39695            |                         |                  |          |                      |                          |
| Probability                            | <.0001   | 0.7824           | <.0001  | 0.3921    | 0.0018                     | <.0001             |                         |                  |          |                      |                          |
| <b>Total Phosphorus (mg/l)</b>         | 240      | 240              | 255     | 254       | 255                        | 211                | 194                     |                  |          |                      |                          |
| Correlation Coefficient (R)            | -0.64038 | 0.06918          | 0.6832  | -0.04473  | 0.09409                    | 0.34287            | 0.54058                 |                  |          |                      |                          |
| Probability                            | <.0001   | 0.2858           | <.0001  | 0.4779    | 0.134                      | <.0001             | <.0001                  |                  |          |                      |                          |
| <b>Silica (mg/l)</b>                   | 252      | 252              | 268     | 267       | 268                        | 214                | 196                     | 255              |          |                      |                          |
| Correlation Coefficient (R)            | -0.53194 | -0.20964         | 0.53722 | -0.04524  | 0.18995                    | 0.39283            | 0.42685                 | 0.3272           |          |                      |                          |
| Probability                            | <.0001   | 0.0008           | <.0001  | 0.4617    | 0.0018                     | <.0001             | <.0001                  | <.0001           |          |                      |                          |
| <b>Total Organic Carbon (mg/l)</b>     | 243      | 243              | 256     | 255       | 256                        | 203                | 186                     | 244              | 256      |                      |                          |
| Correlation Coefficient (R)            | -0.21332 | 0.02083          | 0.1418  | -0.07785  | -0.01733                   | 0.02093            | 0.18699                 | 0.32805          | -0.05152 |                      |                          |
| Probability                            | 0.0008   | 0.7467           | 0.0233  | 0.2154    | 0.7826                     | 0.7669             | 0.0106                  | <.0001           | 0.4117   |                      |                          |
| <b>Dissolved Organic Carbon (mg/l)</b> | 185      | 184              | 191     | 190       | 191                        | 190                | 181                     | 188              | 191      | 191                  |                          |
| Correlation Coefficient (R)            | -0.31838 | -0.04059         | 0.25945 | -0.07957  | 0.00245                    | 0.0287             | 0.22785                 | 0.4162           | -0.0275  | 0.89949              |                          |
| Probability                            | <.0001   | 0.5843           | 0.0003  | 0.2752    | 0.9732                     | 0.6943             | 0.002                   | <.0001           | 0.7057   | <.0001               |                          |
| <b>Chlorophyll a (ug/l)</b>            | 246      | 247              | 262     | 261       | 262                        | 208                | 190                     | 250              | 262      | 250                  | 185                      |
| Correlation Coefficient (R)            | -0.37834 | 0.1128           | 0.33172 | 0.09837   | 0.00191                    | 0.04519            | 0.56844                 | 0.29331          | 0.26585  | 0.09727              | 0.13276                  |
| Probability                            | <.0001   | 0.0768           | <.0001  | 0.1129    | 0.9755                     | 0.5169             | <.0001                  | <.0001           | <.0001   | 0.125                | 0.0716                   |

**Table 4.22**  
**Correlation of Water Quality Parameters – River Kilometer 6.6**

| Water Quality Parameter                | SAL      | DO       | COLOR    | TURB     | N23     | NH34    | TKN     | TP      | SI      | TOC     | DOC     |
|----------------------------------------|----------|----------|----------|----------|---------|---------|---------|---------|---------|---------|---------|
| <b>Dissolved Oxygen (mg/l)</b>         | 362      |          |          |          |         |         |         |         |         |         |         |
| Correlation Coefficient (R)            | 0.18812  |          |          |          |         |         |         |         |         |         |         |
| Probability                            | 0.0003   |          |          |          |         |         |         |         |         |         |         |
| <b>Color (CPU)</b>                     | 257      | 256      |          |          |         |         |         |         |         |         |         |
| Correlation Coefficient (R)            | -0.83943 | -0.28951 |          |          |         |         |         |         |         |         |         |
| Probability                            | <.0001   | <.0001   |          |          |         |         |         |         |         |         |         |
| <b>Turbidity (NTU)</b>                 | 257      | 256      | 268      |          |         |         |         |         |         |         |         |
| Correlation Coefficient (R)            | 0.09849  | 0.04507  | -0.05586 |          |         |         |         |         |         |         |         |
| Probability                            | 0.1152   | 0.4727   | 0.3623   |          |         |         |         |         |         |         |         |
| <b>Nitrite/Nitrate (mg/l)</b>          | 257      | 256      | 268      | 268      |         |         |         |         |         |         |         |
| Correlation Coefficient (R)            | -0.57733 | -0.1418  | 0.16255  | -0.01083 |         |         |         |         |         |         |         |
| Probability                            | <.0001   | 0.0233   | 0.0077   | 0.8599   |         |         |         |         |         |         |         |
| <b>Ammonia/Ammonium (mg/l)</b>         | 210      | 209      | 217      | 216      | 217     |         |         |         |         |         |         |
| Correlation Coefficient (R)            | -0.25072 | -0.23888 | 0.29758  | -0.07091 | 0.15694 |         |         |         |         |         |         |
| Probability                            | 0.0002   | 0.0005   | <.0001   | 0.2995   | 0.0207  |         |         |         |         |         |         |
| <b>Total Kjeldahl Nitrogen (mg/l)</b>  | 196      | 194      | 201      | 200      | 201     | 200     |         |         |         |         |         |
| Correlation Coefficient (R)            | -0.39089 | -0.16998 | 0.44182  | 0.04246  | 0.06504 | 0.30175 |         |         |         |         |         |
| Probability                            | <.0001   | 0.0178   | <.0001   | 0.5506   | 0.359   | <.0001  |         |         |         |         |         |
| <b>Total Phosphorus (mg/l)</b>         | 254      | 253      | 265      | 265      | 266     | 214     | 199     |         |         |         |         |
| Correlation Coefficient (R)            | -0.49776 | -0.00518 | 0.51855  | 0.22466  | 0.02739 | 0.14906 | 0.28148 |         |         |         |         |
| Probability                            | <.0001   | 0.9346   | <.0001   | 0.0002   | 0.6565  | 0.0293  | <.0001  |         |         |         |         |
| <b>Silica (mg/l)</b>                   | 258      | 257      | 269      | 269      | 269     | 217     | 201     | 266     |         |         |         |
| Correlation Coefficient (R)            | -0.66603 | -0.28131 | 0.66416  | -0.14145 | 0.12564 | 0.27826 | 0.32744 | 0.23645 |         |         |         |
| Probability                            | <.0001   | <.0001   | <.0001   | 0.0203   | 0.0395  | <.0001  | <.0001  | <.0001  |         |         |         |
| <b>Total Organic Carbon (mg/l)</b>     | 243      | 242      | 253      | 253      | 253     | 201     | 187     | 250     | 254     |         |         |
| Correlation Coefficient (R)            | -0.27203 | -0.08937 | 0.25831  | 0.07595  | 0.05343 | 0.07433 | 0.19245 | 0.41752 | 0.08062 |         |         |
| Probability                            | <.0001   | 0.1658   | <.0001   | 0.2287   | 0.3974  | 0.2943  | 0.0083  | <.0001  | 0.2003  |         |         |
| <b>Dissolved Organic Carbon (mg/l)</b> | 186      | 185      | 192      | 191      | 191     | 190     | 183     | 188     | 192     | 192     |         |
| Correlation Coefficient (R)            | -0.35524 | -0.15418 | 0.34935  | 0.04352  | 0.05762 | 0.04438 | 0.366   | 0.48982 | 0.10077 | 0.96937 |         |
| Probability                            | <.0001   | 0.0361   | <.0001   | 0.55     | 0.4285  | 0.5432  | <.0001  | <.0001  | 0.1643  | <.0001  |         |
| <b>Chlorophyll a (ug/l)</b>            | 252      | 252      | 263      | 263      | 263     | 211     | 195     | 260     | 264     | 248     | 186     |
| Correlation Coefficient (R)            | -0.16329 | 0.08444  | 0.14239  | 0.12209  | 0.01992 | 0.04833 | 0.18169 | 0.27914 | 0.12192 | 0.2093  | 0.16283 |
| Probability                            | 0.0094   | 0.1815   | 0.0209   | 0.0479   | 0.7478  | 0.485   | 0.011   | <.0001  | 0.0478  | 0.0009  | 0.0264  |



Table 4.23  
Correlation of Water Quality Parameters – River Kilometer 15.5

| Water Quality Parameter                | SAL      | DO       | COLOR    | TURB     | N23      | NH34     | TKN     | TP       | SI       | TOC      | DOC      |
|----------------------------------------|----------|----------|----------|----------|----------|----------|---------|----------|----------|----------|----------|
| <b>Dissolved Oxygen (mg/l)</b>         | 329      |          |          |          |          |          |         |          |          |          |          |
| Correlation Coefficient (R)            | 0.24292  |          |          |          |          |          |         |          |          |          |          |
| Probability                            | <.0001   |          |          |          |          |          |         |          |          |          |          |
| <b>Color (CPU)</b>                     | 237      | 237      |          |          |          |          |         |          |          |          |          |
| Correlation Coefficient (R)            | -0.68497 | -0.49439 |          |          |          |          |         |          |          |          |          |
| Probability                            | <.0001   | <.0001   |          |          |          |          |         |          |          |          |          |
| <b>Turbidity (NTU)</b>                 | 236      | 236      | 248      |          |          |          |         |          |          |          |          |
| Correlation Coefficient (R)            | -0.01295 | 0.25807  | -0.08913 |          |          |          |         |          |          |          |          |
| Probability                            | 0.8431   | <.0001   | 0.1617   |          |          |          |         |          |          |          |          |
| <b>Nitrite/Nitrate (mg/l)</b>          | 237      | 237      | 249      | 248      |          |          |         |          |          |          |          |
| Correlation Coefficient (R)            | -0.49662 | -0.0981  | 0.27424  | 0.01444  |          |          |         |          |          |          |          |
| Probability                            | <.0001   | 0.1321   | <.0001   | 0.8211   |          |          |         |          |          |          |          |
| <b>Ammonia/Ammonium (mg/l)</b>         | 212      | 211      | 219      | 218      | 219      |          |         |          |          |          |          |
| Correlation Coefficient (R)            | -0.02711 | 0.17357  | 0.10595  | 0.45086  | 0.06635  |          |         |          |          |          |          |
| Probability                            | 0.6947   | 0.0116   | 0.118    | <.0001   | 0.3284   |          |         |          |          |          |          |
| <b>Total Kjeldahl Nitrogen (mg/l)</b>  | 196      | 194      | 201      | 200      | 201      | 201      |         |          |          |          |          |
| Correlation Coefficient (R)            | -0.16483 | 0.10935  | 0.33535  | 0.40287  | 0.04102  | 0.81153  |         |          |          |          |          |
| Probability                            | 0.021    | 0.1291   | <.0001   | <.0001   | 0.5632   | <.0001   |         |          |          |          |          |
| <b>Total Phosphorus (mg/l)</b>         | 235      | 235      | 247      | 246      | 247      | 217      | 200     |          |          |          |          |
| Correlation Coefficient (R)            | -0.1502  | 0.1469   | 0.039    | 0.22638  | 0.09863  | 0.04937  | 0.09914 |          |          |          |          |
| Probability                            | 0.0213   | 0.0243   | 0.5418   | 0.0003   | 0.1221   | 0.4694   | 0.1625  |          |          |          |          |
| <b>Silica (mg/l)</b>                   | 237      | 237      | 249      | 248      | 249      | 219      | 201     | 247      |          |          |          |
| Correlation Coefficient (R)            | -0.50144 | -0.32452 | 0.53715  | -0.07434 | 0.32101  | 0.14759  | 0.27151 | -0.17728 |          |          |          |
| Probability                            | <.0001   | <.0001   | <.0001   | 0.2434   | <.0001   | 0.029    | <.0001  | 0.0052   |          |          |          |
| <b>Total Organic Carbon (mg/l)</b>     | 223      | 223      | 234      | 233      | 234      | 204      | 188     | 232      | 234      |          |          |
| Correlation Coefficient (R)            | -0.40198 | -0.12902 | 0.45007  | 0.02888  | 0.23059  | -0.003   | 0.14244 | 0.35886  | 0.06115  |          |          |
| Probability                            | <.0001   | 0.0544   | <.0001   | 0.661    | 0.0004   | 0.966    | 0.0512  | <.0001   | 0.3517   |          |          |
| <b>Dissolved Organic Carbon (mg/l)</b> | 189      | 188      | 195      | 194      | 195      | 195      | 185     | 193      | 195      | 195      |          |
| Correlation Coefficient (R)            | -0.47462 | -0.2104  | 0.54123  | 0.04783  | 0.28951  | -0.00044 | 0.1272  | 0.31166  | 0.1142   | 0.97308  |          |
| Probability                            | <.0001   | 0.0038   | <.0001   | 0.5078   | <.0001   | 0.9951   | 0.0845  | <.0001   | 0.1119   | <.0001   |          |
| <b>Chlorophyll a (ug/l)</b>            | 231      | 232      | 243      | 242      | 243      | 213      | 195     | 241      | 243      | 228      | 190      |
| Correlation Coefficient (R)            | 0.15655  | 0.26492  | -0.20561 | 0.18861  | -0.19785 | -0.10624 | 0.00987 | 0.03465  | -0.07511 | -0.08177 | -0.11646 |
| Probability                            | 0.0173   | <.0001   | 0.0013   | 0.0032   | 0.0019   | 0.1222   | 0.891   | 0.5925   | 0.2435   | 0.2187   | 0.1096   |

**Table 4.24**  
**Correlation of Water Quality Parameters – River Kilometer 23.6**

| Water Quality Parameter                | SAL      | DO       | COLOR    | TURB     | N23      | NH34     | TKN      | TP       | SI       | TOC      | DOC      |
|----------------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| <b>Dissolved Oxygen (mg/l)</b>         | 326      |          |          |          |          |          |          |          |          |          |          |
| Correlation Coefficient (R)            | 0.00465  |          |          |          |          |          |          |          |          |          |          |
| Probability                            | 0.9334   |          |          |          |          |          |          |          |          |          |          |
| <b>Color (CPU)</b>                     | 236      | 235      |          |          |          |          |          |          |          |          |          |
| Correlation Coefficient (R)            | -0.38616 | -0.47219 |          |          |          |          |          |          |          |          |          |
| Probability                            | <.0001   | <.0001   |          |          |          |          |          |          |          |          |          |
| <b>Turbidity (NTU)</b>                 | 235      | 234      | 246      |          |          |          |          |          |          |          |          |
| Correlation Coefficient (R)            | -0.05256 | 0.17257  | -0.09977 |          |          |          |          |          |          |          |          |
| Probability                            | 0.4226   | 0.0082   | 0.1186   |          |          |          |          |          |          |          |          |
| <b>Nitrite/Nitrate (mg/l)</b>          | 236      | 235      | 247      | 246      |          |          |          |          |          |          |          |
| Correlation Coefficient (R)            | -0.39022 | 0.1575   | -0.06272 | -0.04518 |          |          |          |          |          |          |          |
| Probability                            | <.0001   | 0.0157   | 0.3263   | 0.4806   |          |          |          |          |          |          |          |
| <b>Ammonia/Ammonium (mg/l)</b>         | 212      | 210      | 219      | 218      | 219      |          |          |          |          |          |          |
| Correlation Coefficient (R)            | -0.0806  | -0.1842  | 0.23405  | -0.09697 | 0.19562  |          |          |          |          |          |          |
| Probability                            | 0.2426   | 0.0074   | 0.0005   | 0.1536   | 0.0037   |          |          |          |          |          |          |
| <b>Total Kjeldahl Nitrogen (mg/l)</b>  | 197      | 194      | 202      | 201      | 202      | 202      |          |          |          |          |          |
| Correlation Coefficient (R)            | -0.07532 | 0.14687  | 0.05419  | 0.22283  | 0.05005  | -0.04562 |          |          |          |          |          |
| Probability                            | 0.2928   | 0.041    | 0.4437   | 0.0015   | 0.4794   | 0.5191   |          |          |          |          |          |
| <b>Total Phosphorus (mg/l)</b>         | 234      | 233      | 245      | 244      | 245      | 217      | 201      |          |          |          |          |
| Correlation Coefficient (R)            | -0.04139 | 0.24736  | -0.23643 | 0.16728  | 0.13232  | 0.01127  | -0.05829 |          |          |          |          |
| Probability                            | 0.5287   | 0.0001   | 0.0002   | 0.0088   | 0.0385   | 0.8689   | 0.4111   |          |          |          |          |
| <b>Silica (mg/l)</b>                   | 235      | 234      | 246      | 245      | 246      | 218      | 201      | 244      |          |          |          |
| Correlation Coefficient (R)            | -0.31487 | -0.33459 | 0.40751  | -0.07664 | 0.14721  | 0.1045   | 0.02946  | -0.28514 |          |          |          |
| Probability                            | <.0001   | <.0001   | <.0001   | 0.232    | 0.0209   | 0.124    | 0.6781   | <.0001   |          |          |          |
| <b>Total Organic Carbon (mg/l)</b>     | 222      | 221      | 232      | 231      | 232      | 204      | 189      | 230      | 231      |          |          |
| Correlation Coefficient (R)            | -0.28801 | -0.21817 | 0.54353  | 0.16287  | 0.00066  | 0.20149  | -0.08245 | 0.11259  | 0.07134  |          |          |
| Probability                            | <.0001   | 0.0011   | <.0001   | 0.0132   | 0.992    | 0.0039   | 0.2594   | 0.0884   | 0.2802   |          |          |
| <b>Dissolved Organic Carbon (mg/l)</b> | 189      | 187      | 195      | 194      | 195      | 195      | 187      | 193      | 194      | 195      |          |
| Correlation Coefficient (R)            | -0.31195 | -0.29007 | 0.61753  | 0.13041  | 0.02281  | 0.21132  | -0.02359 | 0.10652  | 0.09389  | 0.97407  |          |
| Probability                            | <.0001   | <.0001   | <.0001   | 0.0699   | 0.7516   | 0.003    | 0.7486   | 0.1404   | 0.1929   | <.0001   |          |
| <b>Chlorophyll a (ug/l)</b>            | 230      | 230      | 241      | 240      | 241      | 213      | 196      | 239      | 240      | 226      | 189      |
| Correlation Coefficient (R)            | 0.18223  | 0.32691  | -0.24039 | 0.5907   | -0.25932 | -0.21579 | 0.08782  | 0.19508  | -0.15956 | -0.05091 | -0.09048 |
| Probability                            | 0.0056   | <.0001   | 0.0002   | <.0001   | <.0001   | 0.0015   | 0.2209   | 0.0025   | 0.0133   | 0.4463   | 0.2156   |



**Table 4.25**  
**Correlation of Water Quality Parameters – River Kilometer 30.4**

| Water Quality Parameter                | SAL      | DO       | COLOR    | TURB     | N23      | NH34     | TKN      | TP       | SI       | TOC     | DOC      |
|----------------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|---------|----------|
| <b>Dissolved Oxygen (mg/l)</b>         | 327      |          |          |          |          |          |          |          |          |         |          |
| Correlation Coefficient (R)            | -0.065   |          |          |          |          |          |          |          |          |         |          |
| Probability                            | 0.2411   |          |          |          |          |          |          |          |          |         |          |
| <b>Color (CPU)</b>                     | 235      | 235      |          |          |          |          |          |          |          |         |          |
| Correlation Coefficient (R)            | -0.22815 | -0.55647 |          |          |          |          |          |          |          |         |          |
| Probability                            | 0.0004   | <.0001   |          |          |          |          |          |          |          |         |          |
| <b>Turbidity (NTU)</b>                 | 233      | 233      | 273      |          |          |          |          |          |          |         |          |
| Correlation Coefficient (R)            | -0.08353 | 0.22183  | 0.02743  |          |          |          |          |          |          |         |          |
| Probability                            | 0.2039   | 0.0006   | 0.6518   |          |          |          |          |          |          |         |          |
| <b>Nitrite/Nitrate (mg/l)</b>          | 235      | 235      | 273      | 271      |          |          |          |          |          |         |          |
| Correlation Coefficient (R)            | -0.14434 | 0.21907  | -0.20883 | -0.14603 |          |          |          |          |          |         |          |
| Probability                            | 0.0269   | 0.0007   | 0.0005   | 0.0161   |          |          |          |          |          |         |          |
| <b>Ammonia/Ammonium (mg/l)</b>         | 213      | 212      | 222      | 220      | 223      |          |          |          |          |         |          |
| Correlation Coefficient (R)            | 0.01538  | -0.28691 | 0.13253  | -0.16063 | 0.18393  |          |          |          |          |         |          |
| Probability                            | 0.8234   | <.0001   | 0.0486   | 0.0171   | 0.0059   |          |          |          |          |         |          |
| <b>Total Kjeldahl Nitrogen (mg/l)</b>  | 199      | 197      | 206      | 204      | 207      | 207      |          |          |          |         |          |
| Correlation Coefficient (R)            | -0.10247 | -0.11195 | 0.46563  | 0.71979  | -0.24927 | -0.02753 |          |          |          |         |          |
| Probability                            | 0.1498   | 0.1173   | <.0001   | <.0001   | 0.0003   | 0.6938   |          |          |          |         |          |
| <b>Total Phosphorus (mg/l)</b>         | 233      | 233      | 271      | 269      | 271      | 221      | 206      |          |          |         |          |
| Correlation Coefficient (R)            | -0.01761 | 0.18278  | -0.32892 | -0.04134 | 0.16565  | 0.10734  | -0.07187 |          |          |         |          |
| Probability                            | 0.7892   | 0.0051   | <.0001   | 0.4996   | 0.0063   | 0.1116   | 0.3047   |          |          |         |          |
| <b>Silica (mg/l)</b>                   | 235      | 235      | 274      | 272      | 274      | 223      | 207      | 272      |          |         |          |
| Correlation Coefficient (R)            | -0.15557 | -0.20836 | 0.43677  | 0.09745  | 0.0768   | 0.04385  | 0.29209  | -0.27569 |          |         |          |
| Probability                            | 0.017    | 0.0013   | <.0001   | 0.1088   | 0.205    | 0.5148   | <.0001   | <.0001   |          |         |          |
| <b>Total Organic Carbon (mg/l)</b>     | 221      | 222      | 261      | 259      | 259      | 208      | 193      | 257      | 260      |         |          |
| Correlation Coefficient (R)            | -0.20587 | -0.1885  | 0.59639  | 0.27972  | -0.12041 | 0.08017  | 0.50399  | -0.00216 | 0.08332  |         |          |
| Probability                            | 0.0021   | 0.0048   | <.0001   | <.0001   | 0.0529   | 0.2497   | <.0001   | 0.9725   | 0.1804   |         |          |
| <b>Dissolved Organic Carbon (mg/l)</b> | 191      | 191      | 201      | 199      | 200      | 200      | 191      | 198      | 200      | 201     |          |
| Correlation Coefficient (R)            | -0.19024 | -0.28199 | 0.62741  | 0.17394  | -0.0781  | 0.13948  | 0.39516  | 0.07382  | 0.08088  | 0.96388 |          |
| Probability                            | 0.0084   | <.0001   | <.0001   | 0.014    | 0.2716   | 0.0489   | <.0001   | 0.3013   | 0.2549   | <.0001  |          |
| <b>Chlorophyll a (ug/l)</b>            | 229      | 229      | 269      | 267      | 268      | 217      | 201      | 266      | 269      | 255     | 195      |
| Correlation Coefficient (R)            | 0.09193  | 0.33704  | -0.17265 | 0.7902   | -0.19554 | -0.25447 | 0.53748  | -0.00679 | -0.07051 | 0.10328 | -0.03028 |
| Probability                            | 0.1656   | <.0001   | 0.0045   | <.0001   | 0.0013   | 0.0002   | <.0001   | 0.9123   | 0.2491   | 0.0999  | 0.6743   |

**Table 4.37**

**Correlation of Water Quality Parameters with Flow by Category – 0 ppt Isohaline**

| <b>Water Quality Parameter</b>  | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|---------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Isohaline Location (kml)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)     | -0.58626       | -0.58931          | -0.10004          | -0.36940           | -0.17802           | -0.23793            | -0.59420             |
| Probability                     | <.0001         | 0.0031            | 0.6125            | 0.0043             | 0.1495             | 0.1623              | 0.0017               |
| Number of Observations          | 237            | 23                | 28                | 58                 | 67                 | 36                  | 25                   |
| <b>Color (CPU)</b>              |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)     | 0.51491        | -0.09987          | 0.32146           | 0.4493             | 0.11937            | 0.43458             | -0.33688             |
| Probability                     | <.0001         | 0.6503            | 0.0953            | 0.0004             | 0.336              | 0.0081              | 0.0996               |
| Number of Observations          | 237            | 23                | 28                | 58                 | 67                 | 36                  | 25                   |
| <b>Turbidity (NTU)</b>          |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)     | -0.00084       | 0.2402            | -0.09808          | 0.21751            | 0.244              | -0.4015             | -0.60145             |
| Probability                     | 0.9917         | 0.3531            | 0.6986            | 0.2025             | 0.1194             | 0.0712              | 0.0039               |
| Number of Observations          | 155            | 17                | 18                | 36                 | 42                 | 21                  | 21                   |
| <b>Nitrite/Nitrate (mg/l)</b>   |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)     | -0.17394       | 0.52852           | 0.24777           | 0.07003            | -0.14073           | -0.21924            | -0.22962             |
| Probability                     | 0.0074         | 0.0095            | 0.2037            | 0.6014             | 0.2597             | 0.1989              | 0.2695               |
| Number of Observations          | 236            | 23                | 28                | 58                 | 66                 | 36                  | 25                   |
| <b>Ammonia/Ammonium (mg/l)</b>  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)     | 0.03162        | 0.03204           | -0.14115          | 0.24431            | -0.24018           | 0.01                | -0.04229             |
| Probability                     | 0.6289         | 0.8846            | 0.4737            | 0.0646             | 0.0521             | 0.9538              | 0.8409               |
| Number of Observations          | 236            | 23                | 28                | 58                 | 66                 | 36                  | 25                   |
|                                 |                |                   |                   |                    |                    |                     |                      |

**Table 4.37**

**Correlation of Water Quality Parameters with Flow by Category – 0 ppt Isohaline**

| <b>Water Quality Parameter</b>         | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|----------------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Total Kjeldahl Nitrogen (mg/l)</b>  |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | 0.21038        | -0.17778          | 0.18262           | 0.18278            | 0.02341            | 0.02532             | -0.23522             |
| Probability                            | 0.0011         | 0.4171            | 0.3523            | 0.1697             | 0.8509             | 0.8835              | 0.2577               |
| Number of Observations                 | 237            | 23                | 28                | 58                 | 67                 | 36                  | 25                   |
| <b>Total Phosphorus (mg/l)</b>         |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | -0.26985       | 0.16983           | -0.44286          | -0.01553           | 0.05393            | -0.13               | -0.09302             |
| Probability                            | <.0001         | 0.4385            | 0.0183            | 0.9079             | 0.6647             | 0.4498              | 0.6583               |
| Number of Observations                 | 237            | 23                | 28                | 58                 | 67                 | 36                  | 25                   |
| <b>Silica (mg/l)</b>                   |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | 0.20634        | 0.28021           | 0.13426           | 0.17383            | -0.07205           | 0.48609             | -0.19755             |
| Probability                            | 0.0014         | 0.1953            | 0.5044            | 0.1919             | 0.5623             | 0.0026              | 0.3439               |
| Number of Observations                 | 236            | 23                | 27                | 58                 | 67                 | 36                  | 25                   |
| <b>Total Organic Carbon (mg/l)</b>     |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | 0.40599        | -0.11892          | 0.35681           | -0.00469           | 0.04534            | 0.05796             | -0.13349             |
| Probability                            | <.0001         | 0.6494            | 0.1337            | 0.978              | 0.7728             | 0.8029              | 0.564                |
| Number of Observations                 | 158            | 17                | 19                | 37                 | 43                 | 21                  | 21                   |
| <b>Dissolved Organic Carbon (mg/l)</b> |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)            | 0.42556        | -0.08311          | 0.24664           | 0.10968            | -0.04609           | 0.09882             | -0.17666             |
| Probability                            | <.0001         | 0.7511            | 0.3087            | 0.5181             | 0.7692             | 0.67                | 0.4437               |
| Number of Observations                 | 158            | 17                | 19                | 37                 | 43                 | 21                  | 21                   |
|                                        |                |                   |                   |                    |                    |                     |                      |

**Table 4.37**

**Correlation of Water Quality Parameters with Flow by Category – 0 ppt Isohaline**

| <b>Water Quality Parameter</b> | <b>Overall</b> | <b>&lt;90 cfs</b> | <b>90-160 cfs</b> | <b>160-360 cfs</b> | <b>360-920 cfs</b> | <b>920-2100 cfs</b> | <b>&gt; 2100 cfs</b> |
|--------------------------------|----------------|-------------------|-------------------|--------------------|--------------------|---------------------|----------------------|
| <b>Chlorophyll a (ug/l)</b>    |                |                   |                   |                    |                    |                     |                      |
| Correlation Coefficient (R)    | -0.07829       | 0.18194           | -0.27084          | 0.15211            | 0.128              | -0.18378            | -0.2744              |
| Probability                    | 0.2328         | 0.406             | 0.1633            | 0.2543             | 0.3057             | 0.2906              | 0.1944               |
| Number of Observations         | 234            | 23                | 28                | 58                 | 66                 | 35                  | 24                   |

**Table 4.38**  
**Correlation of Water Quality Parameters with Flow by Category – 6 ppt Isohaline**

| Water Quality Parameter         | Overall  | <90 cfs  | 90-160 cfs | 160-360 cfs | 360-920 cfs | 920-2100 cfs | > 2100 cfs |
|---------------------------------|----------|----------|------------|-------------|-------------|--------------|------------|
| <b>Isohaline Location (kml)</b> |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | -0.67375 | -0.58918 | -0.42977   | -0.36355    | -0.13034    | -0.41191     | -0.448928  |
| Probability                     | <.0001   | 0.0039   | 0.0225     | 0.0054      | 0.2931      | 0.0126       | 0.0096     |
| Number of Observations          | 237      | 22       | 28         | 57          | 67          | 36           | 27         |
| <b>Color (CPU)</b>              |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | 0.51493  | -0.27527 | 0.39456    | 0.22434     | 0.03999     | 0.44822      | -0.35116   |
| Probability                     | <.0001   | 0.215    | 0.0377     | 0.0934      | 0.748       | 0.0061       | 0.0725     |
| Number of Observations          | 237      | 22       | 28         | 57          | 67          | 36           | 27         |
| <b>Turbidity (NTU)</b>          |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | -0.18146 | 0.19273  | -0.00041   | 0.0238      | 0.03669     | -0.18368     | -0.52326   |
| Probability                     | 0.0238   | 0.4745   | 0.9987     | 0.892       | 0.8175      | 0.4255       | 0.0104     |
| Number of Observations          | 155      | 16       | 18         | 35          | 42          | 21           | 23         |
| <b>Nitrite/Nitrate (mg/l)</b>   |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | -0.09207 | 0.33599  | -0.07494   | 0.17919     | -0.04653    | -0.27984     | -0.42688   |
| Probability                     | 0.1577   | 0.1263   | 0.7047     | 0.1823      | 0.7085      | 0.0983       | 0.0264     |
| Number of Observations          | 237      | 22       | 28         | 57          | 67          | 36           | 27         |
| <b>Ammonia/Ammonium (mg/l)</b>  |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | 0.33542  | -0.17132 | 0.11824    | 0.21571     | 0.08152     | 0.50793      | 0.31772    |
| Probability                     | <.0001   | 0.4459   | 0.549      | 0.1071      | 0.5152      | 0.0016       | 0.1063     |
| Number of Observations          | 236      | 22       | 28         | 57          | 66          | 36           | 27         |
|                                 |          |          |            |             |             |              |            |

**Table 4.38**  
**Correlation of Water Quality Parameters with Flow by Category – 6 ppt Isohaline**

| Water Quality Parameter                | Overall  | <90 cfs  | 90-160 cfs | 160-360 cfs | 360-920 cfs | 920-2100 cfs | > 2100 cfs |
|----------------------------------------|----------|----------|------------|-------------|-------------|--------------|------------|
| <b>Total Kjeldahl Nitrogen (mg/l)</b>  |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | 0.07958  | -0.2247  | 0.30702    | 0.06422     | -0.04107    | -0.01037     | -0.2394    |
| Probability                            | 0.2223   | 0.3147   | 0.112      | 0.6351      | 0.7414      | 0.9521       | 0.2291     |
| Number of Observations                 | 237      | 22       | 28         | 57          | 67          | 36           | 27         |
| <b>Total Phosphorus (mg/l)</b>         |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | -0.33378 | 0.01888  | -0.47212   | -0.17506    | 0.10851     | -0.04265     | -0.22951   |
| Probability                            | <.0001   | 0.9335   | 0.0112     | 0.1928      | 0.3821      | 0.8049       | 0.2495     |
| Number of Observations                 | 237      | 22       | 28         | 57          | 67          | 36           | 27         |
| <b>Silica (mg/l)</b>                   |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | 0.21639  | 0.12467  | 0.05505    | 0.09752     | 0.08322     | 0.51479      | -0.18416   |
| Probability                            | 0.0008   | 0.5804   | 0.7851     | 0.4705      | 0.5032      | 0.0013       | 0.3578     |
| Number of Observations                 | 236      | 22       | 27         | 57          | 67          | 36           | 27         |
| <b>Total Organic Carbon (mg/l)</b>     |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | 0.32445  | -0.54166 | 0.28811    | -0.11532    | 0.05404     | -0.08053     | -0.23279   |
| Probability                            | <.0001   | 0.0302   | 0.2316     | 0.503       | 0.7307      | 0.7286       | 0.2851     |
| Number of Observations                 | 158      | 16       | 19         | 36          | 43          | 21           | 23         |
| <b>Dissolved Organic Carbon (mg/l)</b> |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | 0.37008  | -0.32771 | 0.22731    | 0.099       | -0.07783    | -0.04823     | -0.20217   |
| Probability                            | <.0001   | 0.2153   | 0.3493     | 0.5657      | 0.6198      | 0.8355       | 0.3549     |
| Number of Observations                 | 158      | 16       | 19         | 36          | 43          | 21           | 23         |
|                                        |          |          |            |             |             |              |            |

**Table 4.38**

**Correlation of Water Quality Parameters with Flow by Category – 6 ppt Isohaline**

| Water Quality Parameter     | Overall | <90 cfs  | 90-160 cfs | 160-360 cfs | 360-920 cfs | 920-2100 cfs | > 2100 cfs |
|-----------------------------|---------|----------|------------|-------------|-------------|--------------|------------|
| <b>Chlorophyll a (ug/l)</b> |         |          |            |             |             |              |            |
| Correlation Coefficient (R) | -0.0376 | -0.19457 | 0.03561    | 0.02473     | 0.14806     | -0.11634     | -0.05034   |
| Probability                 | 0.5671  | 0.3856   | 0.8572     | 0.8551      | 0.2355      | 0.5057       | 0.807      |
| Number of Observations      | 234     | 22       | 28         | 57          | 66          | 35           | 26         |



**Table 4.39**

**Correlation of Water Quality Parameters with Flow by Category – 12 ppt Isohaline**

| Water Quality Parameter         | Overall  | <90 cfs  | 90-160 cfs | 160-360 cfs | 360-920 cfs | 920-2100 cfs | > 2100 cfs |
|---------------------------------|----------|----------|------------|-------------|-------------|--------------|------------|
| <b>Isohaline Location (kml)</b> |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | -0.77803 | -0.60761 | -0.54319   | -0.34301    | -0.03909    | -0.35962     | -0.63839   |
| Probability                     | <.0001   | 0.0027   | 0.0028     | 0.0097      | 0.7516      | 0.0312       | 0.0006     |
| Number of Observations          | 235      | 22       | 28         | 56          | 68          | 36           | 25         |
| <b>Color (CPU)</b>              |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | 0.48894  | -0.23031 | 0.15157    | 0.15244     | 0.10033     | 0.32554      | -0.04559   |
| Probability                     | <.0001   | 0.3025   | 0.4413     | 0.262       | 0.4156      | 0.0527       | 0.8287     |
| Number of Observations          | 235      | 22       | 28         | 56          | 68          | 36           | 25         |
| <b>Turbidity (NTU)</b>          |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | -0.07889 | 0.09289  | -0.08042   | 0.0552      | -0.1173     | 0.01855      | 0.12969    |
| Probability                     | 0.3324   | 0.7322   | 0.7511     | 0.7565      | 0.4538      | 0.9364       | 0.5753     |
| Number of Observations          | 153      | 16       | 18         | 34          | 43          | 21           | 21         |
| <b>Nitrite/Nitrate (mg/l)</b>   |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | -0.06365 | 0.0742   | 0.22507    | 0.26977     | -0.03614    | -0.1331      | -0.40835   |
| Probability                     | 0.3313   | 0.7428   | 0.2495     | 0.0444      | 0.7699      | 0.439        | 0.0427     |
| Number of Observations          | 235      | 22       | 28         | 56          | 68          | 36           | 25         |
| <b>Ammonia/Ammonium (mg/l)</b>  |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | 0.25748  | -0.01869 | 0.18816    | 0.21903     | -0.03118    | 0.20428      | 0.22126    |
| Probability                     | <.0001   | 0.9342   | 0.3376     | 0.1048      | 0.8022      | 0.2321       | 0.2878     |
| Number of Observations          | 234      | 22       | 28         | 56          | 67          | 36           | 25         |
|                                 |          |          |            |             |             |              |            |

**Table 4.39**

**Correlation of Water Quality Parameters with Flow by Category – 12 ppt Isohaline**

| Water Quality Parameter                | Overall  | <90 cfs  | 90-160 cfs | 160-360 cfs | 360-920 cfs | 920-2100 cfs | > 2100 cfs |
|----------------------------------------|----------|----------|------------|-------------|-------------|--------------|------------|
| <b>Total Kjeldahl Nitrogen (mg/l)</b>  |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | 0.03675  | -0.17741 | -0.15292   | -0.08649    | -0.06646    | 0.05793      | -0.28164   |
| Probability                            | 0.5751   | 0.4296   | 0.4372     | 0.5262      | 0.5902      | 0.7372       | 0.1726     |
| Number of Observations                 | 235      | 22       | 28         | 56          | 68          | 36           | 25         |
| <b>Total Phosphorus (mg/l)</b>         |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | -0.36685 | -0.0161  | -0.38736   | -0.10864    | 0.0793      | 0.20324      | -0.30087   |
| Probability                            | <.0001   | 0.9433   | 0.0417     | 0.4254      | 0.5203      | 0.2345       | 0.1439     |
| Number of Observations                 | 235      | 22       | 28         | 56          | 68          | 36           | 25         |
| <b>Silica (mg/l)</b>                   |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | 0.17145  | 0.01099  | 0.11633    | 0.00384     | 0.1398      | 0.45384      | -0.20235   |
| Probability                            | 0.0087   | 0.9613   | 0.5634     | 0.9776      | 0.2555      | 0.0062       | 0.332      |
| Number of Observations                 | 233      | 22       | 27         | 56          | 68          | 35           | 25         |
| <b>Total Organic Carbon (mg/l)</b>     |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | 0.16637  | -0.51489 | 0.20157    | -0.30856    | 0.04489     | -0.07325     | -0.12023   |
| Probability                            | 0.0379   | 0.0413   | 0.4079     | 0.0713      | 0.7723      | 0.7524       | 0.6037     |
| Number of Observations                 | 156      | 16       | 19         | 35          | 44          | 21           | 21         |
| <b>Dissolved Organic Carbon (mg/l)</b> |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | 0.2036   | -0.56028 | 0.24001    | -0.28945    | -0.02738    | -0.06559     | -0.14903   |
| Probability                            | 0.0108   | 0.024    | 0.3223     | 0.0917      | 0.86        | 0.7776       | 0.5191     |
| Number of Observations                 | 156      | 16       | 19         | 35          | 44          | 21           | 21         |
|                                        |          |          |            |             |             |              |            |

**Table 4.39**

**Correlation of Water Quality Parameters with Flow by Category – 12 ppt Isohaline**

| Water Quality Parameter     | Overall | <90 cfs | 90-160 cfs | 160-360 cfs | 360-920 cfs | 920-2100 cfs | > 2100 cfs |
|-----------------------------|---------|---------|------------|-------------|-------------|--------------|------------|
| <b>Chlorophyll a (ug/l)</b> |         |         |            |             |             |              |            |
| Correlation Coefficient (R) | 0.06291 | 0.14983 | -0.21065   | 0.01554     | 0.17899     | -0.01052     | -0.00713   |
| Probability                 | 0.3401  | 0.5057  | 0.282      | 0.9095      | 0.1473      | 0.9522       | 0.9736     |
| Number of Observations      | 232     | 22      | 28         | 56          | 67          | 35           | 24         |

**Table 4.40**

**Correlation of Water Quality Parameters with Flow by Category – 20 ppt Isohaline**

| Water Quality Parameter         | Overall  | <90 cfs  | 90-160 cfs | 160-360 cfs | 360-920 cfs | 920-2100 cfs | > 2100 cfs |
|---------------------------------|----------|----------|------------|-------------|-------------|--------------|------------|
| <b>Isohaline Location (kml)</b> |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | -0.72511 | -0.62726 | -0.35729   | -0.37483    | -0.13944    | -0.34815     | -0.55049   |
| Probability                     | <.0001   | 0.0018   | 0.0620     | 0.00044     | 0.2567      | 0.0375       | 0.0044     |
| Number of Observations          | 235      | 22       | 28         | 56          | 68          | 36           | 25         |
| <b>Color (CPU)</b>              |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | 0.35081  | -0.34177 | 0.16448    | 0.04379     | 0.00883     | 0.58912      | 0.12308    |
| Probability                     | <.0001   | 0.1195   | 0.4029     | 0.7486      | 0.943       | 0.0002       | 0.5578     |
| Number of Observations          | 235      | 22       | 28         | 56          | 68          | 36           | 25         |
| <b>Turbidity (NTU)</b>          |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | -0.01205 | -0.01556 | 0.11969    | 0.00649     | -0.15017    | -0.36375     | 0.15565    |
| Probability                     | 0.8825   | 0.9544   | 0.6362     | 0.971       | 0.3365      | 0.105        | 0.5005     |
| Number of Observations          | 153      | 16       | 18         | 34          | 43          | 21           | 21         |
| <b>Nitrite/Nitrate (mg/l)</b>   |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | -0.02202 | 0.29911  | 0.23791    | 0.23143     | -0.05802    | -0.25918     | -0.06537   |
| Probability                     | 0.737    | 0.1763   | 0.2228     | 0.0861      | 0.6384      | 0.1269       | 0.7562     |
| Number of Observations          | 235      | 22       | 28         | 56          | 68          | 36           | 25         |
| <b>Ammonia/Ammonium (mg/l)</b>  |          |          |            |             |             |              |            |
| Correlation Coefficient (R)     | 0.05145  | 0.21825  | 0.43597    | 0.19758     | -0.13296    | -0.15594     | 0.19666    |
| Probability                     | 0.4334   | 0.3292   | 0.0204     | 0.1444      | 0.2834      | 0.3638       | 0.3461     |
| Number of Observations          | 234      | 22       | 28         | 56          | 67          | 36           | 25         |
|                                 |          |          |            |             |             |              |            |

**Table 4.40**

**Correlation of Water Quality Parameters with Flow by Category – 20 ppt Isohaline**

| Water Quality Parameter                | Overall  | <90 cfs  | 90-160 cfs | 160-360 cfs | 360-920 cfs | 920-2100 cfs | > 2100 cfs |
|----------------------------------------|----------|----------|------------|-------------|-------------|--------------|------------|
| <b>Total Kjeldahl Nitrogen (mg/l)</b>  |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | -0.01906 | -0.42989 | -0.12501   | -0.12788    | 0.11997     | 0.2682       | -0.13279   |
| Probability                            | 0.7713   | 0.0458   | 0.5262     | 0.3476      | 0.3298      | 0.1138       | 0.5269     |
| Number of Observations                 | 235      | 22       | 28         | 56          | 68          | 36           | 25         |
| <b>Total Phosphorus (mg/l)</b>         |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | -0.32031 | -0.1151  | -0.37452   | -0.03555    | 0.03061     | 0.3132       | -0.15161   |
| Probability                            | <.0001   | 0.61     | 0.0496     | 0.7947      | 0.8043      | 0.0629       | 0.4694     |
| Number of Observations                 | 235      | 22       | 28         | 56          | 68          | 36           | 25         |
| <b>Silica (mg/l)</b>                   |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | 0.09753  | -0.05561 | 0.09195    | 0.03216     | 0.11363     | 0.47113      | -0.20975   |
| Probability                            | 0.1369   | 0.8058   | 0.6483     | 0.814       | 0.3562      | 0.0037       | 0.3143     |
| Number of Observations                 | 234      | 22       | 27         | 56          | 68          | 36           | 25         |
| <b>Total Organic Carbon (mg/l)</b>     |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | 0.02773  | -0.5851  | 0.17855    | -0.3239     | -0.02258    | -0.10841     | -0.09791   |
| Probability                            | 0.7312   | 0.0173   | 0.4646     | 0.0577      | 0.8843      | 0.64         | 0.6729     |
| Number of Observations                 | 156      | 16       | 19         | 35          | 44          | 21           | 21         |
| <b>Dissolved Organic Carbon (mg/l)</b> |          |          |            |             |             |              |            |
| Correlation Coefficient (R)            | 0.02301  | -0.45494 | 0.34083    | -0.25647    | -0.05751    | -0.1039      | -0.13027   |
| Probability                            | 0.7756   | 0.0766   | 0.1533     | 0.137       | 0.7108      | 0.654        | 0.5735     |
| Number of Observations                 | 156      | 16       | 19         | 35          | 44          | 21           | 21         |
|                                        |          |          |            |             |             |              |            |

**Table 4.40**

**Correlation of Water Quality Parameters with Flow by Category – 20 ppt Isohaline**

| Water Quality Parameter     | Overall | <90 cfs  | 90-160 cfs | 160-360 cfs | 360-920 cfs | 920-2100 cfs | > 2100 cfs |
|-----------------------------|---------|----------|------------|-------------|-------------|--------------|------------|
| <b>Chlorophyll a (ug/l)</b> |         |          |            |             |             |              |            |
| Correlation Coefficient (R) | 0.03245 | -0.47212 | 0.00044    | -0.05852    | 0.09412     | 0.50736      | 0.06652    |
| Probability                 | 0.6229  | 0.0265   | 0.9982     | 0.6683      | 0.4487      | 0.0019       | 0.7575     |
| Number of Observations      | 232     | 22       | 28         | 56          | 67          | 35           | 24         |

**Table 4.41**  
**Correlation of Water Quality Parameters – 0 ppt Isohaline**

| Water Quality Parameter                | River Kilometer | Color    | Turbidity | Nitrite + Nitrate Nitrogen | Ammonia / Ammonium | Total Kjeldahl Nitrogen | Total Phosphorus | Silica  | Total Organic Carbon | Dissolved Organic Carbon |
|----------------------------------------|-----------------|----------|-----------|----------------------------|--------------------|-------------------------|------------------|---------|----------------------|--------------------------|
| <b>Color (CPU)</b>                     | 237             |          |           |                            |                    |                         |                  |         |                      |                          |
| Correlation Coefficient (R)            | -0.57425        |          |           |                            |                    |                         |                  |         |                      |                          |
| Probability                            | <.0001          |          |           |                            |                    |                         |                  |         |                      |                          |
| <b>Turbidity (NTU)</b>                 | 155             | 155      |           |                            |                    |                         |                  |         |                      |                          |
| Correlation Coefficient (R)            | -0.31443        | 0.05783  |           |                            |                    |                         |                  |         |                      |                          |
| Probability                            | <.0001          | 0.4748   |           |                            |                    |                         |                  |         |                      |                          |
| <b>Nitrite/Nitrate (mg/L)</b>          | 236             | 236      | 154       |                            |                    |                         |                  |         |                      |                          |
| Correlation Coefficient (R)            | 0.09748         | -0.09023 | -0.12984  |                            |                    |                         |                  |         |                      |                          |
| Probability                            | 0.1354          | 0.1671   | 0.1085    |                            |                    |                         |                  |         |                      |                          |
| <b>Ammonia/Ammonium (mg/L)</b>         | 236             | 236      | 155       | 235                        |                    |                         |                  |         |                      |                          |
| Correlation Coefficient (R)            | -0.09083        | 0.11841  | -0.03301  | 0.13833                    |                    |                         |                  |         |                      |                          |
| Probability                            | 0.1643          | 0.0694   | 0.6835    | 0.0341                     |                    |                         |                  |         |                      |                          |
| <b>Total Kjeldahl Nitrogen (mg/L)</b>  | 237             | 237      | 155       | 236                        | 236                |                         |                  |         |                      |                          |
| Correlation Coefficient (R)            | -0.23905        | 0.40675  | 0.22222   | 0.16861                    | 0.12709            |                         |                  |         |                      |                          |
| Probability                            | 0.0002          | <.0001   | 0.0055    | 0.0095                     | 0.0512             |                         |                  |         |                      |                          |
| <b>Total Phosphorus (mg/L)</b>         | 237             | 237      | 155       | 236                        | 236                | 237                     |                  |         |                      |                          |
| Correlation Coefficient (R)            | 0.2359          | -0.24586 | 0.07812   | -0.09214                   | 0.08516            | -0.1091                 |                  |         |                      |                          |
| Probability                            | 0.0002          | 0.0001   | 0.334     | 0.1583                     | 0.1923             | 0.0938                  |                  |         |                      |                          |
| <b>Silica (mg/L)</b>                   | 236             | 236      | 154       | 235                        | 235                | 236                     | 236              |         |                      |                          |
| Correlation Coefficient (R)            | -0.34324        | 0.54121  | 0.11852   | 0.12558                    | 0.03268            | 0.33515                 | -0.11341         |         |                      |                          |
| Probability                            | <.0001          | <.0001   | 0.1432    | 0.0546                     | 0.6182             | <.0001                  | 0.0821           |         |                      |                          |
| <b>Total Organic Carbon (mg/L)</b>     | 158             | 158      | 155       | 157                        | 158                | 158                     | 158              | 157     |                      |                          |
| Correlation Coefficient (R)            | -0.51692        | 0.60514  | 0.0948    | -0.06326                   | 0.02917            | 0.32356                 | -0.10166         | 0.31775 |                      |                          |
| Probability                            | <.0001          | <.0001   | 0.2407    | 0.4313                     | 0.716              | <.0001                  | 0.2037           | <.0001  |                      |                          |
| <b>Dissolved Organic Carbon (mg/L)</b> | 158             | 158      | 155       | 157                        | 158                | 158                     | 158              | 157     | 158                  |                          |
| Correlation Coefficient (R)            | -0.51306        | 0.47932  | 0.14583   | -0.07488                   | 0.00793            | 0.37302                 | -0.08            | 0.32521 | 0.78604              |                          |
| Probability                            | <.0001          | <.0001   | 0.0702    | 0.3513                     | 0.9213             | <.0001                  | 0.3177           | <.0001  | <.0001               |                          |
| <b>Chlorophyll a (ug/L)</b>            | 234             | 234      | 153       | 233                        | 233                | 234                     | 234              | 233     | 156                  | 156                      |
| Correlation Coefficient (R)            | -0.08404        | -0.02113 | 0.55439   | -0.27094                   | -0.11483           | 0.14464                 | 0.17003          | 0.05277 | -0.06875             | 0.11382                  |
| Probability                            | 0.2002          | 0.7478   | <.0001    | <.0001                     | 0.0802             | 0.0269                  | 0.0092           | 0.4228  | 0.3938               | 0.1571                   |



**Table 4.42**  
**Correlation of Water Quality Parameters – 6 ppt Isohaline**

| Water Quality Parameter                | River Kilometer | Color    | Turbidity | Nitrite + Nitrate Nitrogen | Ammonia / Ammonium | Total Kjeldahl Nitrogen | Total Phosphorus | Silica   | Total Organic Carbon | Dissolved Organic Carbon |
|----------------------------------------|-----------------|----------|-----------|----------------------------|--------------------|-------------------------|------------------|----------|----------------------|--------------------------|
| <b>Color (CPU)</b>                     | 237             |          |           |                            |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | -0.60576        |          |           |                            |                    |                         |                  |          |                      |                          |
| Probability                            | <.0001          |          |           |                            |                    |                         |                  |          |                      |                          |
| <b>Turbidity (NTU)</b>                 | 155             | 155      |           |                            |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | 0.0964          | 0.04365  |           |                            |                    |                         |                  |          |                      |                          |
| Probability                            | 0.2328          | 0.5897   |           |                            |                    |                         |                  |          |                      |                          |
| <b>Nitrite/Nitrate (mg/L)</b>          | 237             | 237      | 155       |                            |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | 0.01801         | -0.10088 | 0.02823   |                            |                    |                         |                  |          |                      |                          |
| Probability                            | 0.7827          | 0.1214   | 0.7273    |                            |                    |                         |                  |          |                      |                          |
| <b>Ammonia/Ammonium (mg/L)</b>         | 236             | 236      | 155       | 236                        |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | -0.35884        | 0.27899  | -0.12933  | 0.15992                    |                    |                         |                  |          |                      |                          |
| Probability                            | <.0001          | <.0001   | 0.1087    | 0.0139                     |                    |                         |                  |          |                      |                          |
| <b>Total Kjeldahl Nitrogen (mg/L)</b>  | 237             | 237      | 155       | 237                        | 236                |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | -0.1407         | 0.16766  | 0.44267   | -0.07157                   | 0.16751            |                         |                  |          |                      |                          |
| Probability                            | 0.0304          | 0.0097   | <.0001    | 0.2725                     | 0.0099             |                         |                  |          |                      |                          |
| <b>Total Phosphorus (mg/L)</b>         | 237             | 237      | 155       | 237                        | 236                | 237                     |                  |          |                      |                          |
| Correlation Coefficient (R)            | 0.56905         | -0.34483 | 0.334     | 0.02274                    | -0.05047           | -0.09865                |                  |          |                      |                          |
| Probability                            | <.0001          | <.0001   | <.0001    | 0.7276                     | 0.4403             | 0.1299                  |                  |          |                      |                          |
| <b>Silica (mg/L)</b>                   | 236             | 236      | 154       | 236                        | 235                | 236                     | 236              |          |                      |                          |
| Correlation Coefficient (R)            | -0.29445        | 0.52586  | 0.01387   | 0.17137                    | 0.25039            | 0.01744                 | -0.17426         |          |                      |                          |
| Probability                            | <.0001          | <.0001   | 0.8644    | 0.0083                     | 0.0001             | 0.7898                  | 0.0073           |          |                      |                          |
| <b>Total Organic Carbon (mg/L)</b>     | 158             | 158      | 155       | 158                        | 158                | 158                     | 158              | 157      |                      |                          |
| Correlation Coefficient (R)            | -0.38662        | 0.50535  | -0.01933  | -0.08144                   | 0.22615            | 0.32319                 | -0.1525          | 0.18363  |                      |                          |
| Probability                            | <.0001          | <.0001   | 0.8113    | 0.309                      | 0.0043             | <.0001                  | 0.0558           | 0.0213   |                      |                          |
| <b>Dissolved Organic Carbon (mg/L)</b> | 158             | 158      | 155       | 158                        | 158                | 158                     | 158              | 157      | 158                  |                          |
| Correlation Coefficient (R)            | -0.43402        | 0.41152  | -0.00122  | -0.09773                   | 0.24292            | 0.39906                 | -0.20062         | 0.12799  | 0.77041              |                          |
| Probability                            | <.0001          | <.0001   | 0.9879    | 0.2218                     | 0.0021             | <.0001                  | 0.0115           | 0.1102   | <.0001               |                          |
| <b>Chlorophyll a (ug/L)</b>            | 234             | 234      | 153       | 234                        | 233                | 234                     | 234              | 233      | 156                  | 156                      |
| Correlation Coefficient (R)            | -0.01591        | 0.11272  | 0.60668   | -0.2102                    | -0.17527           | 0.26174                 | 0.13882          | -0.00337 | 0.02244              | 0.09146                  |
| Probability                            | 0.8087          | 0.0853   | <.0001    | 0.0012                     | 0.0073             | <.0001                  | 0.0338           | 0.9592   | 0.7809               | 0.2561                   |

**Table 4.43**  
**Correlation of Water Quality Parameters – 12 ppt Isohaline**

| Water Quality Parameter                | River Kilometer | Color    | Turbidity | Nitrite + Nitrate Nitrogen | Ammonia / Ammonium | Total Kjeldahl Nitrogen | Total Phosphorus | Silica  | Total Organic Carbon | Dissolved Organic Carbon |
|----------------------------------------|-----------------|----------|-----------|----------------------------|--------------------|-------------------------|------------------|---------|----------------------|--------------------------|
| <b>Color (CPU)</b>                     | 235             |          |           |                            |                    |                         |                  |         |                      |                          |
| Correlation Coefficient (R)            | -0.52748        |          |           |                            |                    |                         |                  |         |                      |                          |
| Probability                            | <.0001          |          |           |                            |                    |                         |                  |         |                      |                          |
| <b>Turbidity (NTU)</b>                 | 153             | 153      |           |                            |                    |                         |                  |         |                      |                          |
| Correlation Coefficient (R)            | 0.07577         | 0.09296  |           |                            |                    |                         |                  |         |                      |                          |
| Probability                            | 0.3519          | 0.2531   |           |                            |                    |                         |                  |         |                      |                          |
| <b>Nitrite/Nitrate (mg/L)</b>          | 235             | 235      | 153       |                            |                    |                         |                  |         |                      |                          |
| Correlation Coefficient (R)            | 0.06172         | 0.05952  | -0.06092  |                            |                    |                         |                  |         |                      |                          |
| Probability                            | 0.3462          | 0.3637   | 0.4545    |                            |                    |                         |                  |         |                      |                          |
| <b>Ammonia/Ammonium (mg/L)</b>         | 234             | 234      | 153       | 234                        |                    |                         |                  |         |                      |                          |
| Correlation Coefficient (R)            | -0.21954        | 0.2473   | -0.1246   | 0.16577                    |                    |                         |                  |         |                      |                          |
| Probability                            | 0.0007          | 0.0001   | 0.1249    | 0.0111                     |                    |                         |                  |         |                      |                          |
| <b>Total Kjeldahl Nitrogen (mg/L)</b>  | 235             | 235      | 153       | 235                        | 234                |                         |                  |         |                      |                          |
| Correlation Coefficient (R)            | -0.08229        | 0.2809   | 0.75644   | -0.04205                   | 0.14071            |                         |                  |         |                      |                          |
| <b>Total Phosphorus (mg/L)</b>         | 235             | 235      | 153       | 235                        | 234                | 235                     |                  |         |                      |                          |
| Correlation Coefficient (R)            | 0.5148          | -0.17275 | 0.2829    | -0.04244                   | 0.00147            | 0.18668                 |                  |         |                      |                          |
| Probability                            | <.0001          | 0.008    | 0.0004    | 0.5173                     | 0.9821             | 0.0041                  |                  |         |                      |                          |
| <b>Silica (mg/L)</b>                   | 233             | 233      | 151       | 233                        | 232                | 233                     | 233              |         |                      |                          |
| Correlation Coefficient (R)            | -0.14024        | 0.54961  | 0.07451   | 0.25593                    | 0.3405             | 0.21432                 | 0.00969          |         |                      |                          |
| Probability                            | 0.0324          | <.0001   | 0.3632    | <.0001                     | <.0001             | 0.001                   | 0.883            |         |                      |                          |
| <b>Total Organic Carbon (mg/L)</b>     | 156             | 156      | 153       | 156                        | 156                | 156                     | 156              | 154     |                      |                          |
| Correlation Coefficient (R)            | -0.26338        | 0.25977  | 0.0942    | -0.09379                   | 0.03619            | 0.12964                 | -0.10729         | 0.06688 |                      |                          |
| Probability                            | 0.0009          | 0.0011   | 0.2468    | 0.2442                     | 0.6537             | 0.1067                  | 0.1825           | 0.4099  |                      |                          |
| <b>Dissolved Organic Carbon (mg/L)</b> | 156             | 156      | 153       | 156                        | 156                | 156                     | 156              | 154     | 156                  |                          |
| Correlation Coefficient (R)            | -0.29399        | 0.27092  | 0.09823   | -0.09786                   | 0.05337            | 0.16776                 | -0.09604         | 0.0804  | 0.91369              |                          |
| Probability                            | 0.0002          | 0.0006   | 0.2271    | 0.2242                     | 0.5082             | 0.0363                  | 0.233            | 0.3216  | <.0001               |                          |
| <b>Chlorophyll a (ug/L)</b>            | 232             | 232      | 151       | 232                        | 231                | 232                     | 232              | 230     | 154                  | 154                      |
| Correlation Coefficient (R)            | -0.0514         | 0.25613  | 0.37175   | -0.08804                   | -0.06955           | 0.24593                 | 0.14338          | 0.15121 | 0.11688              | 0.12288                  |
| Probability                            | 0.4358          | <.0001   | <.0001    | 0.1814                     | 0.2925             | 0.0002                  | 0.029            | 0.0218  | 0.1489               | 0.129                    |

**Table 4.44**  
**Correlation of Water Quality Parameters – 20 ppt Isohaline**

| Water Quality Parameter                | River Kilometer | Color    | Turbidity | Nitrite + Nitrate Nitrogen | Ammonia / Ammonium | Total Kjeldahl Nitrogen | Total Phosphorus | Silica   | Total Organic Carbon | Dissolved Organic Carbon |
|----------------------------------------|-----------------|----------|-----------|----------------------------|--------------------|-------------------------|------------------|----------|----------------------|--------------------------|
| <b>Color (CPU)</b>                     | 235             |          |           |                            |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | -0.33262        |          |           |                            |                    |                         |                  |          |                      |                          |
| Probability                            | <.0001          |          |           |                            |                    |                         |                  |          |                      |                          |
| <b>Turbidity (NTU)</b>                 | 153             | 153      |           |                            |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | 0.13014         | 0.07068  |           |                            |                    |                         |                  |          |                      |                          |
| Probability                            | 0.1088          | 0.3853   |           |                            |                    |                         |                  |          |                      |                          |
| <b>Nitrite/Nitrate (mg/L)</b>          | 235             | 235      | 153       |                            |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | 0.10993         | 0.04579  | 0.08913   |                            |                    |                         |                  |          |                      |                          |
| Probability                            | 0.0927          | 0.4848   | 0.2733    |                            |                    |                         |                  |          |                      |                          |
| <b>Ammonia/Ammonium (mg/L)</b>         | 234             | 234      | 153       | 234                        |                    |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | -0.00966        | 0.2595   | -0.00318  | 0.33273                    |                    |                         |                  |          |                      |                          |
| Probability                            | 0.8832          | <.0001   | 0.9689    | <.0001                     |                    |                         |                  |          |                      |                          |
| <b>Total Kjeldahl Nitrogen (mg/L)</b>  | 235             | 235      | 153       | 235                        | 234                |                         |                  |          |                      |                          |
| Correlation Coefficient (R)            | 0.04704         | 0.26945  | 0.33419   | -0.01083                   | 0.12349            |                         |                  |          |                      |                          |
| Probability                            | 0.4729          | <.0001   | <.0001    | 0.8688                     | 0.0593             |                         |                  |          |                      |                          |
| <b>Total Phosphorus (mg/L)</b>         | 235             | 235      | 153       | 235                        | 234                | 235                     |                  |          |                      |                          |
| Correlation Coefficient (R)            | 0.5276          | -0.00772 | 0.23059   | 0.25906                    | 0.05068            | 0.17377                 |                  |          |                      |                          |
| Probability                            | <.0001          | 0.9063   | 0.0041    | <.0001                     | 0.4403             | 0.0076                  |                  |          |                      |                          |
| <b>Silica (mg/L)</b>                   | 234             | 234      | 152       | 234                        | 233                | 234                     | 234              |          |                      |                          |
| Correlation Coefficient (R)            | -0.07942        | 0.44225  | 0.07355   | 0.25976                    | 0.21922            | 0.18022                 | 0.12846          |          |                      |                          |
| Probability                            | 0.2262          | <.0001   | 0.3678    | <.0001                     | 0.0008             | 0.0057                  | 0.0497           |          |                      |                          |
| <b>Total Organic Carbon (mg/L)</b>     | 156             | 156      | 153       | 156                        | 156                | 156                     | 156              | 155      |                      |                          |
| Correlation Coefficient (R)            | -0.0915         | 0.15309  | 0.27421   | -0.04303                   | 0.12252            | 0.13096                 | 0.02736          | -0.05712 |                      |                          |
| Probability                            | 0.2559          | 0.0564   | 0.0006    | 0.5937                     | 0.1276             | 0.1032                  | 0.7346           | 0.4802   |                      |                          |
| <b>Dissolved Organic Carbon (mg/L)</b> | 156             | 156      | 153       | 156                        | 156                | 156                     | 156              | 155      | 156                  |                          |
| Correlation Coefficient (R)            | -0.05889        | 0.11409  | 0.31931   | -0.02251                   | 0.10195            | 0.15559                 | 0.06026          | -0.05204 | 0.91373              |                          |
| Probability                            | 0.4652          | 0.1562   | <.0001    | 0.7803                     | 0.2054             | 0.0524                  | 0.4549           | 0.5202   | <.0001               |                          |
| <b>Chlorophyll a (ug/L)</b>            | 232             | 232      | 151       | 232                        | 231                | 232                     | 232              | 231      | 154                  | 154                      |
| Correlation Coefficient (R)            | -0.00989        | 0.28984  | 0.45631   | -0.00772                   | 0.01408            | 0.59746                 | 0.18527          | 0.20513  | 0.10648              | 0.08477                  |
| Probability                            | 0.8809          | <.0001   | <.0001    | 0.9069                     | 0.8315             | <.0001                  | 0.0046           | 0.0017   | 0.1887               | 0.2959                   |

**Table 4.48**  
**Site 1 Growing On Land**

| Species Name                 | Common Name                | 1983 | 1984 | 1985 | 1987 | 1991 | 1993 | 1997 | 1998 | 2000 | 2002 |
|------------------------------|----------------------------|------|------|------|------|------|------|------|------|------|------|
| <i>Axonopus affinis</i>      | Carpetgrass                | X    |      |      |      |      |      |      |      |      |      |
| <i>Ficus aurea</i>           | Strangler fig              | X    | X    |      |      |      |      |      |      |      |      |
| <i>Hypericum setosum</i>     | Hairy St. John's wort      | X    | X    | X    |      |      |      |      |      |      |      |
| <i>Panicum ciliatum</i>      | Fringed panic grass        | X    | X    | X    |      |      |      |      |      |      |      |
| <i>Solidago microcephala</i> | Slender flat-top goldenrod | X    | X    | X    |      |      |      |      |      |      |      |
| <i>Juncus coriaceous</i>     | Leathery rush              | X    |      | X    |      |      |      |      |      |      |      |
| <i>Phytolacca americana</i>  | Pokeweed                   | X    |      | X    |      |      |      |      |      |      |      |
| <i>Aristida stricta</i>      | Wiregrass                  | X    |      | X    | X    | X    |      |      |      |      |      |
| <i>Galactia elliotii</i>     | Elliot's milk pea          | X    | X    | X    |      | X    |      |      |      |      |      |
| <i>Bumelia celastrina</i>    | Safron plum                | X    | X    |      | X    | X    |      |      |      |      |      |
| <i>Foresteria segregata</i>  | Florida privit             | X    | X    | X    | X    | X    |      |      |      |      |      |
| <i>Myrica cerifera</i>       | Wax myrtle                 | X    | X    | X    | X    | X    |      |      |      |      |      |
| <i>Pteridium aquilinum</i>   | Lacy bracken               | X    | X    | X    | X    | X    |      |      |      |      |      |
| <i>Chloris glauca</i>        | Saltmarsh fingergrass      | X    |      | X    | X    | X    | X    |      |      |      |      |
| <i>Opuntia compressa</i>     | Tuna cactus                | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Panicum chamaelonche</i>  | Panic grass                | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Quercus geminata</i>      | Sand live oak              | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Tillandsia recurvata</i>  | Ballmoss                   | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Tillandsia usneoides</i>  | Spanish moss               | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Amorpha fruticosa</i>     | Dull-leaf indigo           | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Vitis rotundifolia</i>    | Muscadine grape            | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Ximenia americana</i>     | Tallowwood                 | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Laguncularia racemosa</i> | White mangrove             | X    | X    | X    | X    | X    | X    |      |      |      |      |

**Table 4.48**  
**Site 1 Growing On Land**

| Species Name                          | Common Name            | 1983 | 1984 | 1985 | 1987 | 1991 | 1993 | 1997 | 1998 | 2000 | 2002 |
|---------------------------------------|------------------------|------|------|------|------|------|------|------|------|------|------|
| <i>Rhizophora mangle</i>              | Red mangrove           | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Erythrina herbacea</i>             | Coral bean             | X    | X    | X    | X    | X    | X    | X    |      |      |      |
| <i>Rhus copallina</i>                 | Winged sumac           | X    | X    | X    | X    | X    | X    | X    | X    | X    |      |
| <i>Toxicodendron radicans</i>         | Poison Ivy             | X    | X    | X    | X    | X    | X    | X    | X    |      | X    |
| <i>Bumelia reclinata</i>              | Shrubby buckthorn      | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Callicarpa americana</i>           | Beauty berry           | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Dalbergia ecastophyllum</i>        | Coin vine              | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Quercus virginiana</i>             | Live oak               | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Sabal palmetto</i>                 | Sabal palm             | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Schinus terebinthifolius</i>       | Brazilian pepper       | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Serenoa repens</i>                 | Saw palmetto           | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Yucca aliofolia</i>                | Spanish bayonet        | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Myrsine guianensis</i>             | Myrsine                | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Zamia integrifolia (palustris)</i> | Coontie                | X    | X    | X    | X    | X    | X    | X    | X    |      |      |
| <i>Samolus parviflorus</i>            | Water pimpernel        | X    | X    | X    | X    | X    |      |      |      | X    | X    |
| <i>Tillandsia utriculata</i>          | Giant air plant        |      | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Parthenocissus quinquefolia</i>    | Virginia creeper       |      | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Commelina erecta</i>               | Dayflower              |      | X    |      |      |      |      |      |      |      |      |
| <i>Crotalaria maritima</i>            | Rabbit bells           |      | X    |      |      |      |      |      |      |      |      |
| <i>Fimbristylis castanea</i>          | Saltmarsh fimbristylis |      | X    |      |      |      |      |      |      |      |      |
| <i>Caesalpinia crista</i>             | Dwarf poinciana        |      | X    |      |      |      |      |      |      |      |      |
| <i>Sesbania punicea</i>               | Rattlebox              |      | X    | X    |      |      |      |      |      |      |      |
| <i>Andropogon glomeratus</i>          | Bushy bluestem         |      | X    | X    |      |      |      |      |      |      |      |

**Table 4.48**  
**Site 1 Growing On Land**

| Species Name                   | Common Name         | 1983      | 1984      | 1985      | 1987      | 1991      | 1993      | 1997      | 1998      | 2000      | 2002      |
|--------------------------------|---------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| <i>Panicum virgatum</i>        | Switchgrass         |           |           | X         |           |           |           |           |           |           |           |
| <i>Tillandsia circinata</i>    | Twisted airplant    |           |           | X         | X         | X         |           |           |           |           |           |
| <i>Phlebodium aureum</i>       | Golden polypody     |           |           | X         | X         | X         |           |           |           |           |           |
| <i>Canavalia rosea</i>         | June bean           |           |           |           | X         |           | X         |           |           |           |           |
| <i>Wedelia trilobata</i>       | Creeping wedelia    |           |           |           | X         |           | X         |           |           |           |           |
| <i>Veronia gigantea</i>        | Giant ironweed      |           |           |           | X         | X         | X         |           |           |           |           |
| <i>Vigna luteola</i>           | Cow pea             |           |           |           | X         | X         | X         |           |           |           |           |
| <i>Lycium carolinianum</i>     | Christmas berry     |           |           |           |           | X         |           |           |           |           |           |
| <i>Randia aculeata</i>         | White indigo berry  |           |           |           |           |           | X         |           |           |           |           |
| <i>Sporobolus poiretii</i>     | Smutgrass           |           |           |           |           |           | X         |           |           |           |           |
| <i>Opuntia stricta</i>         | Prickly pear        |           |           |           |           |           |           | X         |           |           |           |
| <i>Stenotaphrum secundatum</i> | St. Augustine grass |           |           |           |           |           |           | X         | X         | X         | X         |
| <i>Tillandsia fasciculata</i>  | Cardinal airpine    |           |           |           |           |           |           | X         | X         |           |           |
| <b>Total Number of Species</b> |                     | <b>38</b> | <b>41</b> | <b>42</b> | <b>38</b> | <b>38</b> | <b>32</b> | <b>16</b> | <b>14</b> | <b>12</b> | <b>12</b> |

**Table 4.49**  
**Site 1 Growing in Water (shoreline and transect)**

| Species Name                       | Common Name         | 1983 | 1984 | 1985 | 1987 | 1991 | 1993 | 1997 | 1998 | 2000 | 2002 |
|------------------------------------|---------------------|------|------|------|------|------|------|------|------|------|------|
| <i>Panicum hemitomom</i>           | Maidencane          | X    |      |      |      |      |      |      |      |      |      |
| <i>Alternanthera philoxeroides</i> | Alligator weed      | X    | X    |      |      |      |      |      |      |      |      |
| <i>Colocassia esculentum</i>       | Wild taro           | X    | X    |      |      |      |      |      |      |      |      |
| <i>Annona glabra</i>               | Pond apple          | X    |      | X    |      |      |      |      |      |      |      |
| <i>Eleocharis albida</i>           | Saltmarsh spikerush | X    | X    | X    |      |      |      |      |      |      |      |
| <i>Panicum purpurescens</i>        | Paragrass           | X    | X    | X    |      |      |      |      |      |      |      |
| <i>Pluchea purpurascens</i>        | Camphorweed         | X    | X    | X    | X    |      |      |      |      |      |      |
| <i>Scleria triglomerata</i>        | Whipgrass           | X    | X    |      | X    | X    |      |      |      |      |      |
| <i>Cyperus distinctus</i>          | Flatsedge           | X    | X    | X    | X    | X    |      |      |      |      |      |
| <i>Carex lupulina</i>              | Hopsedge            | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Solidago stricta</i>            | Slim goldenrod      | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Conocarpus erecta</i>           | Buttonwood          | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Distichlis spicata</i>          | Saltgrass           | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Iva frutescens</i>              | Big-leaf sumpweed   | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Bacopa monnieri</i>             | Water hyssop        | X    | X    | X    |      | X    | X    |      |      |      |      |
| <i>Blechnum serrulatum</i>         | Swamp fern          | X    | X    | X    | X    |      | X    |      |      |      |      |
| <i>Acrostichum danaeifolium</i>    | Giant leather fern  | X    | X    | X    | X    | X    | X    | X    | X    |      | X    |
| <i>Dalbergia ecastophyllum</i>     | Coin vine           | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Laguncularia racemosa</i>       | White mangrove      | X    | X    |      | X    | X    | X    | X    | X    | X    | X    |
| <i>Stenotaphrum secundatum</i>     | St. Augustine grass | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Rhizophora mangle</i>           | Red mangrove        | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Juncus roemerianus</i>          | Black needlerush    | X    | X    | X    | X    | X    | X    |      | X    |      | X    |



**Table 4.49**  
**Site 1 Growing in Water (shoreline and transect)**

| Species Name                    | Common Name      | 1983      | 1984      | 1985      | 1987      | 1991      | 1993      | 1997      | 1998      | 2000     | 2002      |
|---------------------------------|------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|-----------|
| <i>Scirpus validus</i>          | Giant bulrush    | X         | X         | X         | X         | X         | X         | X         | X         | X        |           |
| <i>Spartina bakerii</i>         | Sand cordgrass   | X         | X         | X         | X         |           | X         |           |           |          |           |
| <i>Amaranthus australis</i>     | Waterhemp        | X         |           |           |           |           | X         |           |           |          |           |
| <i>Sesuvium portulacastrum</i>  | Sea purslane     |           |           | X         |           |           | X         |           |           |          |           |
| <i>Cladium jamaicensis</i>      | Sawgrass         |           |           |           | X         | X         | X         |           |           |          |           |
| <i>Serenoa repens</i>           | Saw palmetto     |           |           |           |           | X         |           | X         | X         |          | X         |
| <i>Schinus teribinthifolius</i> | Brazilian pepper |           |           |           |           | X         | X         | X         | X         | X        | X         |
| <i>Ambrosia artemisiifolia</i>  | ragweed          |           |           |           |           |           | X         |           |           |          |           |
| <i>Vigna luteola</i>            | cow pea          |           |           |           |           |           | X         |           |           |          |           |
| <i>Myrsine guiansis</i>         | Myrsine          |           |           |           |           |           |           | X         | X         | X        | X         |
| <i>Quercus virginiana</i>       | Live oak         |           |           |           |           |           |           | X         | X         |          | X         |
| <i>Eleocharis baldwinnii</i>    | Spikerush        |           |           |           |           |           |           | X         |           |          |           |
| <i>Eleocharis geniculata</i>    | Spikerush        |           |           |           |           |           |           |           | X         |          |           |
| <i>Samolus parviflorus</i>      | Water Pimpernel  |           |           |           |           |           |           |           | X         |          | X         |
| <b>Total Number of Species</b>  |                  | <b>25</b> | <b>22</b> | <b>20</b> | <b>18</b> | <b>18</b> | <b>21</b> | <b>11</b> | <b>13</b> | <b>7</b> | <b>11</b> |

**Table 4.50**  
**Transition Site I Upstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline  |           |           |           |           |           |           |           |           |           |       |        |        |        |        |        |
|-----------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-------|--------|--------|--------|--------|--------|
| Year / Species                    | 0-1m      | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m      | 6-7m      | 7-8m      | 8-9m      | 9-10m | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <b>1997</b>                       |           |           |           |           |           |           |           |           |           |       |        |        |        |        |        |
| <b>Upland Species</b>             |           |           |           |           |           |           |           |           |           |       |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    |           | 2         | 2         | 2         |           |           |           |           |           |       |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>   | 95        | 95        | 95        | 90        | 65        | 5         |           |           |           |       |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 1         |           |           |           |           |           |           |           |           |       |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>96</b> | <b>97</b> | <b>97</b> | <b>92</b> | <b>65</b> | <b>5</b>  |           |           |           |       |        |        |        |        |        |
| <b>Wetland Species</b>            |           |           |           |           |           |           |           |           |           |       |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |           |           |           | 5         | 30        | 80        | 70        | 30        | 5         |       |        |        |        |        |        |
| <i>Scirpus validus</i>            |           |           |           |           | 1         | 3         | 2         |           | 8         |       |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> |           |           |           | <b>5</b>  | <b>31</b> | <b>83</b> | <b>72</b> | <b>30</b> | <b>13</b> |       |        |        |        |        |        |
| <b>1998</b>                       |           |           |           |           |           |           |           |           |           |       |        |        |        |        |        |
| <b>Upland Species</b>             |           |           |           |           |           |           |           |           |           |       |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    | 2         | 2         |           | 2         | 15        |           |           |           |           |       |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>   | 80        | 80        | 95        | 80        | 50        |           |           |           |           |       |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 10        | 1         |           |           |           |           |           |           |           |       |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>92</b> | <b>83</b> | <b>95</b> | <b>82</b> | <b>75</b> |           |           |           |           |       |        |        |        |        |        |
| <b>Wetland Species</b>            |           |           |           |           |           |           |           |           |           |       |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |           | 1         |           | 20        | 50        | 90        | 70        | 30        | 10        |       |        |        |        |        |        |
| <i>Scirpus validus</i>            |           |           |           |           | 1         |           |           |           |           |       |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> |           | <b>1</b>  |           | <b>20</b> | <b>51</b> | <b>90</b> | <b>70</b> | <b>30</b> | <b>10</b> |       |        |        |        |        |        |

**Table 4.50**  
**Transition Site I Upstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline  |            |           |            |            |           |           |           |      |      |       |        |        |        |        |        |
|-----------------------------------|------------|-----------|------------|------------|-----------|-----------|-----------|------|------|-------|--------|--------|--------|--------|--------|
| Year / Species                    | 0-1m       | 1-2m      | 2-3m       | 3-4m       | 4-5m      | 5-6m      | 6-7m      | 7-8m | 8-9m | 9-10m | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <b>2000</b>                       |            |           |            |            |           |           |           |      |      |       |        |        |        |        |        |
| <b>Upland Species</b>             |            |           |            |            |           |           |           |      |      |       |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    |            | 10        |            |            |           | 15        |           |      |      |       |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>   | 85         | 55        | 80         | 65         | 30        | 10        |           |      |      |       |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 2          |           |            |            |           |           |           |      |      |       |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>87</b>  | <b>65</b> | <b>80</b>  | <b>65</b>  | <b>30</b> | <b>25</b> |           |      |      |       |        |        |        |        |        |
| <b>Wetland Species</b>            |            |           |            |            |           |           |           |      |      |       |        |        |        |        |        |
| <i>Laguncularia racemosa</i>      |            |           | 15         |            |           |           |           |      |      |       |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |            |           |            | 2          | 75        | 20        | 30        |      |      |       |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> |            |           | <b>15</b>  | <b>2</b>   | <b>75</b> | <b>20</b> | <b>30</b> |      |      |       |        |        |        |        |        |
| <b>2002</b>                       |            |           |            |            |           |           |           |      |      |       |        |        |        |        |        |
| <b>Upland Species</b>             |            |           |            |            |           |           |           |      |      |       |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    | 15         |           | 30         | 25         | 25        |           |           |      |      |       |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>   | 90         | 90        | 90         | 85         | 40        |           |           |      |      |       |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 20         |           |            |            |           |           |           |      |      |       |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>125</b> | <b>90</b> | <b>120</b> | <b>110</b> | <b>65</b> |           |           |      |      |       |        |        |        |        |        |
| <b>Wetland Species</b>            |            |           |            |            |           |           |           |      |      |       |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |            |           |            |            | 70        | 85        | 60        |      |      |       |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> |            |           |            |            | <b>70</b> | <b>85</b> | <b>60</b> |      |      |       |        |        |        |        |        |

**Table 4.51**  
**Transition Site I Upstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline  |           |           |           |           |           |           |           |           |           |          |        |        |        |        |        |
|-----------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|--------|--------|--------|--------|--------|
| Year / Species                    | 0-1m      | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m      | 6-7m      | 7-8m      | 8-9m      | 9-10m    | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <b>1997</b>                       |           |           |           |           |           |           |           |           |           |          |        |        |        |        |        |
| <b>Upland Species</b>             |           |           |           |           |           |           |           |           |           |          |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    |           | 2         |           | 5         | 10        | 2         |           |           |           |          |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>   | 95        | 95        | 80        | 85        | 10        | 3         |           |           |           |          |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 1         | 1         |           |           |           |           |           |           |           |          |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>96</b> | <b>98</b> | <b>80</b> | <b>85</b> | <b>20</b> | <b>5</b>  |           |           |           |          |        |        |        |        |        |
| <b>Wetland Species</b>            |           |           |           |           |           |           |           |           |           |          |        |        |        |        |        |
| <i>Laguncularia racemosa</i>      |           | 4         | 3         |           |           |           |           |           |           |          |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |           |           |           | 7         | 75        | 85        | 90        | 90        | 25        |          |        |        |        |        |        |
| <i>Scirpus validus</i>            |           |           |           |           |           |           |           |           |           | 1        |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> |           | <b>4</b>  | <b>3</b>  | <b>7</b>  | <b>75</b> | <b>85</b> | <b>90</b> | <b>90</b> | <b>25</b> | <b>1</b> |        |        |        |        |        |
| <b>1998</b>                       |           |           |           |           |           |           |           |           |           |          |        |        |        |        |        |
| <b>Upland Species</b>             |           |           |           |           |           |           |           |           |           |          |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    | 2         | 2         |           | 2         | 15        |           |           |           |           |          |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>   | 80        | 80        | 95        | 80        | 50        |           |           |           |           |          |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 10        | 1         |           |           |           |           |           |           |           |          |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>92</b> | <b>83</b> | <b>95</b> | <b>82</b> | <b>75</b> |           |           |           |           |          |        |        |        |        |        |
| <b>Wetland Species</b>            |           |           |           |           |           |           |           |           |           |          |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |           | 1         |           | 20        | 50        | 90        | 70        | 30        | 10        |          |        |        |        |        |        |

**Table 4.51**  
**Transition Site I Upstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline  |           |           |           |            |           |           |           |          |      |       |        |        |        |        |        |
|-----------------------------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|----------|------|-------|--------|--------|--------|--------|--------|
| Year / Species                    | 0-1m      | 1-2m      | 2-3m      | 3-4m       | 4-5m      | 5-6m      | 6-7m      | 7-8m     | 8-9m | 9-10m | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <i>Scirpus validus</i>            |           |           |           |            | 1         |           |           |          |      |       |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> |           | 1         |           | 20         | 51        | 90        | 70        | 30       | 10   |       |        |        |        |        |        |
| <b>2000</b>                       |           |           |           |            |           |           |           |          |      |       |        |        |        |        |        |
| <b>Upland Species</b>             |           |           |           |            |           |           |           |          |      |       |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    |           |           | 2         |            | 2         | 5         |           |          |      |       |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>   | 65        | 65        | 90        | 80         | 65        |           |           |          |      |       |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 10        |           |           |            |           |           |           |          |      |       |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>75</b> | <b>65</b> | <b>92</b> | <b>80</b>  | <b>67</b> | <b>5</b>  |           |          |      |       |        |        |        |        |        |
| <b>Wetland Species</b>            |           |           |           |            |           |           |           |          |      |       |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |           |           |           |            | 60        | 20        | 30        |          |      |       |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> |           |           |           |            | <b>60</b> | <b>20</b> | <b>30</b> |          |      |       |        |        |        |        |        |
| <b>2002</b>                       |           |           |           |            |           |           |           |          |      |       |        |        |        |        |        |
| <b>Upland Species</b>             |           |           |           |            |           |           |           |          |      |       |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    | 10        |           | 5         | 30         | 2         |           |           |          |      |       |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>   | 80        | 80        | 80        | 70         |           |           |           |          |      |       |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    |           | 1         |           |            |           |           |           |          |      |       |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>90</b> | <b>81</b> | <b>85</b> | <b>100</b> | <b>2</b>  |           |           |          |      |       |        |        |        |        |        |
| <b>Wetland Species</b>            |           |           |           |            |           |           |           |          |      |       |        |        |        |        |        |
| <i>Juncus roemarianus</i>         |           |           |           |            |           |           |           | 4        |      |       |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |           |           |           |            | 70        | 60        |           |          |      |       |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> |           |           |           |            | <b>70</b> | <b>60</b> |           | <b>4</b> |      |       |        |        |        |        |        |

**Table 4.52**  
**Transition Site I Downstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline  |           |           |           |           |           |           |           |           |           |            |        |        |        |        |        |
|-----------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|--------|--------|--------|--------|--------|
| Year / Species                    | 0-1m      | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m      | 6-7m      | 7-8m      | 8-9m      | 9-10m      | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <b>1997</b>                       |           |           |           |           |           |           |           |           |           |            |        |        |        |        |        |
| <b>Upland Species</b>             |           |           |           |           |           |           |           |           |           |            |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    | 20        | 5         | 10        | 3         |           |           |           |           |           |            |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>   | 1         |           |           |           |           |           |           |           |           |            |        |        |        |        |        |
| <i>Serenoa repens</i>             | 2         |           |           |           |           |           |           |           |           |            |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 2         |           | 1         |           |           |           |           |           |           |            |        |        |        |        |        |
| <i>Quercus virginiana</i>         | 70        | 90        | 10        |           |           |           |           |           |           |            |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>95</b> | <b>95</b> | <b>21</b> | <b>3</b>  |           |           |           |           |           |            |        |        |        |        |        |
| <b>Wetland Species</b>            |           |           |           |           |           |           |           |           |           |            |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>   | 15        | 5         | 10        |           |           |           |           |           |           |            |        |        |        |        |        |
| <i>Laguncularia racemosa</i>      |           | 1         | 15        | 75        |           | 25        | 3         |           |           |            |        |        |        |        |        |
| <i>Myrsine guianensis</i>         | 10        | 5         |           |           | 75        |           |           |           |           |            |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |           |           |           | 5         | 20        | 70        | 88        | 95        | 90        | 65         |        |        |        |        |        |
| <i>Scirpus validus</i>            |           |           |           |           | 2         |           |           |           | 1         | 40         |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> | <b>10</b> | <b>6</b>  | <b>15</b> | <b>80</b> | <b>98</b> | <b>95</b> | <b>91</b> | <b>95</b> | <b>91</b> | <b>105</b> |        |        |        |        |        |
| <b>1998</b>                       |           |           |           |           |           |           |           |           |           |            |        |        |        |        |        |
| <b>Upland Species</b>             |           |           |           |           |           |           |           |           |           |            |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    | 15        | 5         | 10        |           |           |           |           |           |           |            |        |        |        |        |        |
| <i>Serenoa repens</i>             | 10        |           |           |           |           |           |           |           |           |            |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 4         | 5         |           |           |           |           |           |           |           |            |        |        |        |        |        |

**Table 4.52**  
**Transition Site I Downstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline  |           |           |           |            |            |           |           |           |           |           |        |        |        |        |        |
|-----------------------------------|-----------|-----------|-----------|------------|------------|-----------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|
| Year / Species                    | 0-1m      | 1-2m      | 2-3m      | 3-4m       | 4-5m       | 5-6m      | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <i>Quercus virginiana</i>         | 70        | 80        |           |            |            |           |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>99</b> | <b>90</b> | <b>10</b> |            |            |           |           |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>            |           |           |           |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>   |           |           |           | 10         |            |           |           |           |           |           |        |        |        |        |        |
| <i>Juncus roemarianus</i>         |           |           |           | 4          |            |           |           |           |           |           |        |        |        |        |        |
| <i>Laguncularia racemes</i>       |           |           | 20        | 75         | 30         |           |           |           |           |           |        |        |        |        |        |
| <i>Myrsine guiansis</i>           | 10        | 3         |           |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |           |           |           | 25         | 65         | 70        | 80        | 95        | 80        | 65        |        |        |        |        |        |
| <i>Samolus parviflorus</i>        |           |           |           | 15         |            |           |           |           |           |           |        |        |        |        |        |
| <i>Scirpus validus</i>            |           |           |           |            |            |           |           |           |           | 1         |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> | <b>10</b> | <b>3</b>  | <b>20</b> | <b>105</b> | <b>105</b> | <b>70</b> | <b>80</b> | <b>95</b> | <b>80</b> | <b>66</b> |        |        |        |        |        |
| <b>2000</b>                       |           |           |           |            |            |           |           |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>             |           |           |           |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    | 2         |           |           |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Serenoa repens</i>             | 5         |           |           |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 20        | 1         |           |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Quercus virginiana</i>         | 60        | 70        |           |            |            |           |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>87</b> | <b>71</b> |           |            |            |           |           |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>            |           |           |           |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>   |           |           |           |            | 15         |           |           |           |           |           |        |        |        |        |        |
| <i>Juncus roemarianus</i>         |           |           |           |            | 8          |           |           |           |           |           |        |        |        |        |        |



**Table 4.52**  
**Transition Site I Downstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline  |            |            |           |            |            |            |           |           |           |           |        |        |        |        |        |
|-----------------------------------|------------|------------|-----------|------------|------------|------------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|
| Year / Species                    | 0-1m       | 1-2m       | 2-3m      | 3-4m       | 4-5m       | 5-6m       | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <i>Laguncularia racemosa</i>      |            |            | 30        | 75         | 60         |            |           |           |           |           |        |        |        |        |        |
| <i>Myrsine guianensis</i>         | 5          | 5          |           |            |            |            |           |           |           |           |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |            | 2          |           | 30         | 40         | 80         | 65        | 70        | 75        | 55        |        |        |        |        |        |
| <i>Scirpus validus</i>            |            |            |           |            |            |            |           |           |           | 5         |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> | <b>5</b>   | <b>7</b>   | <b>30</b> | <b>105</b> | <b>123</b> | <b>80</b>  | <b>65</b> | <b>70</b> | <b>75</b> | <b>60</b> |        |        |        |        |        |
| <b>2002</b>                       |            |            |           |            |            |            |           |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>             |            |            |           |            |            |            |           |           |           |           |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    |            | 10         |           |            |            |            |           |           |           |           |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 70         | 60         | 20        |            |            |            |           |           |           |           |        |        |        |        |        |
| <i>Quercus virginiana</i>         | 30         | 70         |           |            |            |            |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>100</b> | <b>140</b> | <b>20</b> |            |            |            |           |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>            |            |            |           |            |            |            |           |           |           |           |        |        |        |        |        |
| <i>Laguncularia racemosa</i>      |            |            | 20        | 50         | 75         | 30         |           |           |           |           |        |        |        |        |        |
| <i>Myrsine guianensis</i>         | 25         | 10         |           |            |            |            |           |           |           |           |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |            |            |           | 30         | 10         | 85         | 90        | 75        | 80        | 60        |        |        |        |        |        |
| <i>Samolus parviflorus</i>        |            |            |           | 10         | 30         |            |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> | <b>25</b>  | <b>10</b>  | <b>20</b> | <b>90</b>  | <b>115</b> | <b>115</b> | <b>90</b> | <b>75</b> | <b>80</b> | <b>60</b> |        |        |        |        |        |

**Table 4.53**  
**Transition Site I Downstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline  |            |           |           |           |           |           |           |            |           |            |        |        |        |        |        |
|-----------------------------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|------------|-----------|------------|--------|--------|--------|--------|--------|
| Year / Species                    | 0-1m       | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m      | 6-7m      | 7-8m       | 8-9m      | 9-10m      | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <b>1997</b>                       |            |           |           |           |           |           |           |            |           |            |        |        |        |        |        |
| <b>Upland Species</b>             |            |           |           |           |           |           |           |            |           |            |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    | 5          |           | 15        | 5         |           |           |           |            |           |            |        |        |        |        |        |
| <i>Quercus virginiana</i>         | 80         | 80        | 30        |           |           |           |           |            |           |            |        |        |        |        |        |
| <i>Serenoa repens</i>             | 30         | 2         |           |           |           |           |           |            |           |            |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 10         | 10        |           |           |           |           |           |            |           |            |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>125</b> | <b>92</b> | <b>45</b> | <b>5</b>  |           |           |           |            |           |            |        |        |        |        |        |
| <b>Wetland Species</b>            |            |           |           |           |           |           |           |            |           |            |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>   |            |           |           |           | 1         |           | 2         |            |           |            |        |        |        |        |        |
| <i>Laguncularia racemosa</i>      |            |           | 20        | 20        | 70        | 5         |           |            |           |            |        |        |        |        |        |
| <i>Myrsine guianensis</i>         | 1          | 2         |           |           |           |           |           |            |           |            |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |            |           | 2         | 2         | 20        | 90        | 90        | 100        | 85        | 70         |        |        |        |        |        |
| <i>Scirpus validus</i>            |            |           |           |           |           |           |           |            | 1         | 45         |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> | <b>1</b>   | <b>2</b>  | <b>22</b> | <b>22</b> | <b>91</b> | <b>95</b> | <b>92</b> | <b>100</b> | <b>86</b> | <b>115</b> |        |        |        |        |        |
| <b>1998</b>                       |            |           |           |           |           |           |           |            |           |            |        |        |        |        |        |
| <b>Upland Species</b>             |            |           |           |           |           |           |           |            |           |            |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    | 7          |           | 5         |           |           |           |           |            |           |            |        |        |        |        |        |
| <i>Quercus virginiana</i>         | 80         | 70        | 30        |           |           |           |           |            |           |            |        |        |        |        |        |
| <i>Serenoa repens</i>             | 30         |           |           |           |           |           |           |            |           |            |        |        |        |        |        |
| <i>Stenotaphrum secundatum</i>    | 20         | 15        |           |           |           |           |           |            |           |            |        |        |        |        |        |

**Table 4.53**  
**Transition Site I Downstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline  |            |           |           |           |            |            |           |           |           |           |           |           |           |        |        |
|-----------------------------------|------------|-----------|-----------|-----------|------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|--------|
| Year / Species                    | 0-1m       | 1-2m      | 2-3m      | 3-4m      | 4-5m       | 5-6m       | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m    | 11-12m    | 12-13m    | 13-14m | 14-15m |
| <b>% Coverage Upland Species</b>  | <b>137</b> | <b>85</b> | <b>35</b> |           |            |            |           |           |           |           |           |           |           |        |        |
| <b>Wetland Species</b>            |            |           |           |           |            |            |           |           |           |           |           |           |           |        |        |
| <i>Languncularia racemosa</i>     |            |           | 10        | 30        | 70         | 25         | 15        |           |           |           |           |           |           |        |        |
| <i>Rhizophora mangle</i>          |            |           | 1         | 2         | 20         | 70         | 80        | 70        | 80        | 70        |           |           |           |        |        |
| <b>% Coverage Wetland Species</b> |            |           | <b>11</b> | <b>32</b> | <b>90</b>  | <b>95</b>  | <b>95</b> | <b>70</b> | <b>80</b> | <b>70</b> |           |           |           |        |        |
| <b>2000</b>                       |            |           |           |           |            |            |           |           |           |           |           |           |           |        |        |
| <b>Upland Species</b>             |            |           |           |           |            |            |           |           |           |           |           |           |           |        |        |
| <i>Dalbergia ecastophyllum</i>    | 3          |           |           |           |            |            |           |           |           |           |           |           |           |        |        |
| <i>Quercus virginiana</i>         | 80         | 60        | 20        |           |            |            |           |           |           |           |           |           |           |        |        |
| <i>Serenoa repens</i>             | 30         |           |           |           |            |            |           |           |           |           |           |           |           |        |        |
| <i>Stentotaphrum secundatum</i>   | 20         | 2         |           |           |            |            |           |           |           |           |           |           |           |        |        |
| <b>% Coverage Upland Species</b>  | <b>133</b> | <b>62</b> | <b>20</b> |           |            |            |           |           |           |           |           |           |           |        |        |
| <b>Wetland Species</b>            |            |           |           |           |            |            |           |           |           |           |           |           |           |        |        |
| <i>Laguncularia racemosa</i>      |            |           | 10        | 60        | 80         | 45         |           |           |           |           |           |           |           |        |        |
| <i>Rhizophora mangle</i>          |            | 2         |           |           | 20         | 70         | 80        | 60        | 65        | 55        |           |           |           |        |        |
| <i>Scirpus validus</i>            |            |           |           |           |            |            |           |           |           | 2         | 15        | 15        | 10        |        |        |
| <b>% Coverage Wetland Species</b> |            | <b>2</b>  | <b>10</b> | <b>60</b> | <b>100</b> | <b>115</b> | <b>80</b> | <b>60</b> | <b>65</b> | <b>57</b> | <b>15</b> | <b>15</b> | <b>10</b> |        |        |
| <b>2002</b>                       |            |           |           |           |            |            |           |           |           |           |           |           |           |        |        |
| <b>Upland Species</b>             |            |           |           |           |            |            |           |           |           |           |           |           |           |        |        |
| <i>Quercus virginiana</i>         | 45         | 25        | 20        |           |            |            |           |           |           |           |           |           |           |        |        |
| <i>Serenoa repens</i>             | 30         |           |           |           |            |            |           |           |           |           |           |           |           |        |        |

**Table 4.53**  
**Transition Site I Downstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline  |            |           |           |           |           |            |           |           |           |           |        |        |        |        |        |
|-----------------------------------|------------|-----------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|
| Year / Species                    | 0-1m       | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m       | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <i>Stenotaphrum secundatum</i>    | 60         | 30        | 25        | 5         |           |            |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>135</b> | <b>55</b> | <b>45</b> | <b>5</b>  |           |            |           |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>            |            |           |           |           |           |            |           |           |           |           |        |        |        |        |        |
| <i>Laguncularia racemosa</i>      |            |           |           | 60        | 75        | 60         |           |           |           |           |        |        |        |        |        |
| <i>Rhizophora mangle</i>          |            |           | 20        |           | 4         | 70         | 75        | 60        | 80        | 40        |        |        |        |        |        |
| <i>Samolus parviflorus</i>        |            |           |           | 10        | 2         |            |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> |            |           | <b>20</b> | <b>70</b> | <b>81</b> | <b>130</b> | <b>75</b> | <b>60</b> | <b>80</b> | <b>40</b> |        |        |        |        |        |

**Table 4.54**  
**Site II Growing on Land**

| Species Name              | Common Name           | 1983 | 1984 | 1985 | 1987 | 1991 | 1993 | 1997 | 1998 | 2000 | 2002 |
|---------------------------|-----------------------|------|------|------|------|------|------|------|------|------|------|
| Yucca aloifolia           | Spanish bayonet       | X    |      |      |      |      |      |      |      |      |      |
| Roystonea regia           | Royal palm            | X    |      |      |      |      |      |      |      |      |      |
| Psidium guajava           | Guava                 | X    | X    |      |      |      |      |      |      |      |      |
| Encyclia tampensis        | Butterfly orchid      | X    | X    |      | X    |      |      |      |      |      |      |
| Phytolacca americana      | Poke weed             | X    |      | X    | X    |      |      |      |      |      |      |
| Panicum ciliatum          | Roughhair witchgrass  | X    | X    |      |      | X    |      |      |      |      |      |
| Zanthoxylum fagara        | Wild lime             | X    | X    | X    | X    | X    |      |      |      |      |      |
| Chloris glauca            | Saltmarsh fingergrass | X    |      | X    | X    | X    |      |      |      |      |      |
| Andropogon glomeratus     | Bushy bluestem        | X    |      | X    | X    | X    |      |      |      |      |      |
| Tillandsia usneoides      | Spanish moss          | X    | X    | X    | X    | X    |      |      |      |      |      |
| Tillandsia fasciculata    | Cardinal airpine      | X    | X    | X    | X    |      | X    |      |      |      |      |
| Ampelopsis arborea        | Pepper vine           | X    | X    | X    | X    | X    | X    |      |      |      |      |
| Cephalanthus occidentalis | Button bush           | X    | X    | X    | X    | X    | X    |      |      |      |      |
| Quercus virginiana        | Live oak              | X    | X    | X    | X    | X    | X    |      |      |      |      |
| Sabal palmetto            | Cabbage palm          | X    | X    | X    | X    | X    | X    |      |      |      |      |
| Tillandsia utriculata     | Giant airplant        | X    | X    | X    | X    | X    | X    |      |      |      |      |
| Urena lobata              | Caesar weed           | X    | X    | X    | X    | X    | X    |      |      |      |      |
| Vigna luteola             | Cow pea               | X    | X    | X    | X    | X    | X    |      |      |      |      |
| Vitis rotundifolia        | Muscadine             | X    | X    | X    | X    | X    | X    |      |      |      |      |
| Ximenia americana         | Tallow wood           | X    | X    | X    | X    | X    | X    |      |      |      |      |
| Bumelia reclinatorum      | Buckthorn             | X    | X    | X    | X    | X    | X    |      | X    | X    | X    |
| Ipomoea alba              | Moon flower           | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| Myrica cerifera           | Wax myrtle            | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |

**Table 4.54**  
**Site II Growing on Land**

| Species Name                | Common Name          | 1983 | 1984 | 1985 | 1987 | 1991 | 1993 | 1997 | 1998 | 2000 | 2002 |
|-----------------------------|----------------------|------|------|------|------|------|------|------|------|------|------|
| Schinus terebinthifolius    | Brazilian pepper     | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| Myrsine guianensis          | Myrsine              | X    | X    | X    |      | X    | X    | X    | X    | X    | X    |
| Persea palustris            | Swamp Bay            | X    | X    | X    | X    | X    | X    | X    | X    |      | X    |
| Toxicodendron radicans      | Poinson ivy          | X    | X    | X    | X    | X    | X    |      | X    | X    | X    |
| Parthenocissus quinquefolia | Virginia creeper     | X    | X    | X    | X    | X    | X    |      | X    | X    | X    |
| Psychotria sp.              | Wild coffee          | X    | X    | X    | X    | X    | X    |      | X    |      | X    |
| Smilax bona-nox             | Catbriar             | X    | X    |      |      | X    |      |      | X    | X    |      |
| Mikania scandens            | Climbing hempweed    |      | X    | X    | X    | X    | X    |      |      |      |      |
| Tillandsia recurvata        | Ball moss            |      | X    | X    | X    | X    | X    |      |      |      |      |
| Oplismenus setarius         | Armed grass          |      | X    | X    | X    | X    |      |      |      |      |      |
| Callicarpa americana        | Beauty berry         |      | X    | X    |      |      | X    |      |      |      |      |
| Itea virginica              | Virginia sweet spire |      | X    |      |      |      |      |      |      |      |      |
| Cornus foemina              | Swamp dogwood        |      | X    |      |      |      |      |      |      |      |      |
| Panicum maximum             | Guinea grass         |      | X    |      |      |      |      |      |      |      |      |
| Sabatia calycina            | Coastal rosegiant    |      | X    |      |      |      |      |      |      |      |      |
| Canovalia rosea             | June bean            |      |      | X    |      |      |      |      |      |      |      |
| Baccharis halimifolia       | Saltbush             |      |      | X    |      | X    | X    |      |      |      |      |
| Veronia gigantia            | Giant ironweed       |      |      |      | X    | X    | X    |      |      |      |      |
| Galactia elliotii           | Elliot's milk pea    |      |      |      |      | X    | X    |      |      |      |      |
| Galactia macreei            | Milk pea             |      |      |      |      | X    |      |      |      |      |      |
| Ipomoea trichocarpa         | Morning glory        |      |      |      |      | X    |      |      |      |      |      |
| Lythrum alatum              | Loosestrife          |      |      |      |      | X    |      |      |      |      |      |
| Psychotria undata           | Shiny wild coffee    |      |      |      |      | X    |      |      |      |      |      |

**Table 4.54**  
**Site II Growing on Land**

| Species Name                   | Common Name          | 1983      | 1984      | 1985      | 1987      | 1991      | 1993      | 1997     | 1998      | 2000      | 2002      |
|--------------------------------|----------------------|-----------|-----------|-----------|-----------|-----------|-----------|----------|-----------|-----------|-----------|
| Smilax laurifolia              | Bamboo vine          |           |           |           |           |           | X         |          |           |           |           |
| Panicum chamaleonce            | Panic grass          |           |           |           |           |           | X         |          |           |           |           |
| Panicum jorii                  | Variable panic grass |           |           |           |           |           | X         |          |           |           |           |
| Rhizophora mangle              | Red mangrove         |           |           |           |           |           |           | X        |           |           |           |
| Conocarpus erecta              | Buttonwood           |           |           |           |           |           |           | X        | X         | X         | X         |
| Pontedaria cordata             | Pickeralweed         |           |           |           |           |           |           |          | X         |           | X         |
| Panicum gymnocarpum            | Savanna panicum      |           |           |           |           |           |           |          | X         |           |           |
| Colocasia esculenta            | Taro                 |           |           |           |           |           |           |          | X         | X         | X         |
| Dalbergia ecastophyllum        | Coin vine            |           |           |           |           |           |           |          | X         | X         | X         |
| Acer rubrum                    | Red maple            |           |           |           |           |           |           |          |           | X         | X         |
| Acrostichum danaeifolium       | Giant leather fern   |           |           |           |           |           |           |          |           | X         | X         |
| Cladium jamaicensis            | Saw grass            |           |           |           |           |           |           |          |           |           | X         |
| Rumex verticillatus            | Swamp dock           |           |           |           |           |           |           |          |           |           | X         |
| Typha spp.                     | Cattail              |           |           |           |           |           |           |          |           |           | X         |
| Annona glabra                  | Pond apple           |           |           |           |           |           |           |          |           |           | X         |
| <b>Total Number of Species</b> |                      | <b>30</b> | <b>33</b> | <b>30</b> | <b>28</b> | <b>34</b> | <b>28</b> | <b>7</b> | <b>15</b> | <b>13</b> | <b>19</b> |



**Table 4.55**  
**Site II Growing in Water (shoreline and transects)**

| Species Name                       | Common Name            | 1983 | 1984 | 1985 | 1987 | 1991 | 1993 | 1997 | 1998 | 2000 | 2002 |
|------------------------------------|------------------------|------|------|------|------|------|------|------|------|------|------|
| <i>Ptilimnium capillaceum</i>      | Mock bishop weed       | X    | X    |      |      |      |      |      |      |      |      |
| <i>Ceratopteris pteridoides</i>    | Water horn fern        | X    | X    |      |      |      |      |      |      |      |      |
| <i>Tripsacum dactyloides</i>       | Eastern gama grass     | X    | X    |      |      |      |      |      |      |      |      |
| <i>Senecio glabellus</i>           | Ragwort                | X    | X    | X    |      |      |      |      |      |      |      |
| <i>Boehmeria cylindrica</i>        | Button hemp            | X    | X    |      | X    |      |      |      |      |      |      |
| <i>Ludwigia repens</i>             | Marsh purslane         | X    | X    |      | X    |      |      |      |      |      |      |
| <i>Sambucus simpsonii</i>          | Southern elderberry    | X    | X    | X    | X    |      |      |      |      |      |      |
| <i>Cicuta mexicana</i>             | Water hemlock          | X    | X    | X    | X    |      |      |      |      |      |      |
| <i>Cyperus distinctus</i>          | Flatsedge              | X    | X    | X    | X    | X    |      |      |      |      |      |
| <i>Spartina bakerii</i>            | Sand cordgrass         | X    | X    |      | X    | X    |      |      |      |      |      |
| <i>Baccharis halimifolia</i>       | Saltbush               | X    | X    |      | X    | X    |      |      |      |      |      |
| <i>Sagittaria lancifolia</i>       | Lance leaved arrowhead | X    | X    |      | X    | X    | X    |      |      |      |      |
| <i>Iris hexagonia</i>              | Iris                   | X    | X    | X    | X    |      | X    |      |      |      |      |
| <i>Polygonum hydropiperoides</i>   | Swamp knotweed         | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Pontederia lanceolata</i>       | Pickerelweed           | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Solidago stricta</i>            | Slim goldenrod         | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Alternanthera philoxeroides</i> | Alligator weed         | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Acer rubrum</i>                 | Red maple              | X    | X    | X    | X    | X    | X    |      |      |      |      |
| <i>Toxicodendron radicans</i>      | Poison ivy             | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Acrostichum danaeifolium</i>    | Giant leather fern     | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Caladium jamaicensis</i>        | Saw grass              | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |
| <i>Scirpus validus</i>             | Giant bulrush          | X    | X    | X    | X    | X    | X    | X    | X    | X    | X    |

**Table 4.55**  
**Site II Growing in Water (shoreline and transects)**

| Species Name                   | Common Name            | 1983 | 1984 | 1985 | 1987 | 1991 | 1993 | 1997 | 1998 | 2000 | 2002 |
|--------------------------------|------------------------|------|------|------|------|------|------|------|------|------|------|
| <i>Annona glabra</i>           | Pond apple             | X    | X    | X    | X    | X    | X    |      |      | X    | X    |
| <i>Samolus parviflorus</i>     | Water spangles         | X    | X    | X    | X    | X    | X    |      |      |      | X    |
| <i>Pluchea purpurascens</i>    | Camporweed             | X    | X    | X    | X    | X    | X    |      |      |      | X    |
| <i>Eichhinornia crassipes</i>  | Water-hyacinth         | X    | X    | X    | X    |      |      |      | X    |      |      |
| <i>Rumex verticillatus</i>     | Swamp dock             | X    | X    |      | X    |      |      | X    | X    | X    |      |
| <i>Typha domingensis</i>       | Cattail                | X    | X    |      |      |      | X    | X    | X    |      | X    |
| <i>Colocasia esculentum</i>    | Taro                   | X    | X    |      | X    |      |      |      | X    | X    | X    |
| <i>Echinochloa crusgalli</i>   | Barnyard grass         |      | X    |      |      |      |      |      |      |      |      |
| <i>Eleocharis albid</i>        | Saltmarsh spikerush    |      | X    | X    |      |      |      |      |      |      |      |
| <i>Bacopa monnieri</i>         | Water hyssop           |      |      | X    |      |      |      |      |      |      |      |
| <i>Panicum purpurescens</i>    | Para grass             |      |      | X    |      |      |      |      |      |      |      |
| <i>Amaranthus australis</i>    | Southern amaranth      |      |      |      |      | X    | X    |      |      |      |      |
| <i>Pontederia cordata</i>      | Pickereelweed          |      |      |      |      | X    |      | X    | X    | X    | X    |
| <i>Rhizophora mangle</i>       | Red mangrove           |      |      |      |      | X    | X    | X    | X    | X    |      |
| <i>Dalbergia ecastophyllum</i> | Coin vine              |      |      |      |      |      | X    | X    | X    | X    | X    |
| <i>Crinum americanum</i>       | Swamp lily             |      |      |      |      |      | X    |      |      |      | X    |
| <i>Ludwigia octovalvis</i>     | Shrubby water primrose |      |      |      |      |      | X    |      |      |      |      |
| <i>Sagittaria subulata</i>     | Owl-leaf arrowhead     |      |      |      |      |      | X    |      |      |      |      |
| <i>Ammannia teres</i>          | Scarlet ammannia       |      |      |      |      |      | X    |      |      |      |      |
| <i>Sclaria triglomerata</i>    | Whip grass             |      |      |      |      |      | X    |      |      |      |      |
| <i>Serenoa repens</i>          | Saw palmetto           |      |      |      |      |      |      | X    |      |      |      |
| <i>Dioscorea bulbifera</i>     | Wild yam               |      |      |      |      |      |      | X    |      |      |      |
| <i>Panicum gymnocarpum</i>     | Savannah panicum       |      |      |      |      |      |      | X    | X    |      |      |

**Table 4.55**  
**Site II Growing in Water (shoreline and transects)**

| Species Name                       | Common Name         | 1983      | 1984      | 1985      | 1987      | 1991      | 1993      | 1997      | 1998      | 2000      | 2002      |
|------------------------------------|---------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| <i>Myrica cerifera</i>             | Wax myrtle          |           |           |           |           |           |           | X         | X         | X         |           |
| <i>Schinus teribinthifolius</i>    | Brazilian pepper    |           |           |           |           |           |           | X         | X         | X         |           |
| <i>Persea palustris</i>            | Swamp bay           |           |           |           |           |           |           | X         | X         | X         | X         |
| <i>Mikania scandens</i>            | Climbing hempweed   |           |           |           |           |           |           | X         | X         | X         | X         |
| <i>Ficus aurea</i>                 | Strangler fig       |           |           |           |           |           |           | X         | X         |           | X         |
| <i>Polygonum punctatum</i>         | Smartweed           |           |           |           |           |           |           | X         |           |           | X         |
| <i>Ipomoea alba</i>                | Moon flower         |           |           |           |           |           |           | X         | X         |           |           |
| <i>Psychotria sp.</i>              | Wild coffee         |           |           |           |           |           |           |           | X         |           |           |
| <i>Parthenocissus quinquefoila</i> | Virginia creeper    |           |           |           |           |           |           |           | X         | X         | X         |
| <i>Rumex crispus</i>               | Curly dock          |           |           |           |           |           |           |           | X         | X         | X         |
| <i>Pistia stratiotes</i>           | Water lettuce       |           |           |           |           |           |           |           | X         |           | X         |
| <i>Myrsine guianensis</i>          | Myrsine             |           |           |           |           |           |           |           | X         | X         |           |
| <i>Atriplex spp.</i>               | Saltbush            |           |           |           |           |           |           |           |           |           | X         |
| <i>Sambucus canadensis</i>         | American elder      |           |           |           |           |           |           |           |           |           | X         |
| <i>Eupatorium capillifolium</i>    | Dog fennel          |           |           |           |           |           |           |           |           |           | X         |
| <i>Diodia virginiana</i>           | Virginia buttonwood |           |           |           |           |           |           |           |           |           | X         |
| <b>Total Number of Species</b>     |                     | <b>29</b> | <b>31</b> | <b>21</b> | <b>24</b> | <b>19</b> | <b>23</b> | <b>19</b> | <b>23</b> | <b>17</b> | <b>23</b> |

**Table 4.56**  
**Transition Site II Upstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline  |            |            |            |            |            |           |           |           |           |           |        |        |        |        |        |
|-----------------------------------|------------|------------|------------|------------|------------|-----------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|
| Year / Species                    | 0-1m       | 1-2m       | 2-3m       | 3-4m       | 4-5m       | 5-6m      | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <b>1997</b>                       |            |            |            |            |            |           |           |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>             |            |            |            |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    |            |            | 25         | 5          | 20         | 50        |           |           |           |           |        |        |        |        |        |
| <i>Persea palustris</i>           |            | 25         | 75         | 65         | 75         |           |           |           |           |           |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>   | 20         | 15         |            |            | 10         |           |           |           |           |           |        |        |        |        |        |
| <i>Toxicodendron radicans</i>     | 20         | 15         | 5          |            |            |           |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>40</b>  | <b>55</b>  | <b>105</b> | <b>70</b>  | <b>105</b> | <b>50</b> |           |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>            |            |            |            |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>   | 50         |            |            |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Scirpus validus</i>            |            |            |            |            | 20         | 35        | 95        | 98        | 98        | 35        |        |        |        |        |        |
| <b>% Coverage Wetland Species</b> | <b>50</b>  |            |            |            | <b>20</b>  | <b>35</b> | <b>95</b> | <b>98</b> | <b>98</b> | <b>35</b> |        |        |        |        |        |
| <b>1998</b>                       |            |            |            |            |            |           |           |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>             |            |            |            |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>    |            | 5          | 10         | 10         | 25         | 65        | 1         |           |           |           |        |        |        |        |        |
| <i>Persea palustris</i>           |            | 20         | 40         | 55         | 80         |           |           |           |           |           |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>   | 80         | 80         | 60         | 40         |            |           |           |           |           |           |        |        |        |        |        |
| <i>Toxicodendron radicans</i>     | 20         | 5          |            |            |            |           |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b>  | <b>100</b> | <b>110</b> | <b>110</b> | <b>105</b> | <b>105</b> | <b>65</b> | <b>1</b>  |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>            |            |            |            |            |            |           |           |           |           |           |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>   | 25         | 30         |            |            |            |           |           |           |           |           |        |        |        |        |        |

**Table 4.56**  
**Transition Site II Upstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline  |            |            |            |            |            |            |            |           |           |           |           |           |           |        |        |
|-----------------------------------|------------|------------|------------|------------|------------|------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|--------|--------|
| Year / Species                    | 0-1m       | 1-2m       | 2-3m       | 3-4m       | 4-5m       | 5-6m       | 6-7m       | 7-8m      | 8-9m      | 9-10m     | 10-11m    | 11-12m    | 12-13m    | 13-14m | 14-15m |
| <i>Myrsine guianensis</i>         | 15         |            |            |            |            |            |            |           |           |           |           |           |           |        |        |
| <i>Scirpus validus</i>            |            |            |            | 5          | 20         | 40         | 95         | 75        | 45        | 2         | 15        | 85        |           |        |        |
| <b>% Coverage Wetland Species</b> | <b>40</b>  | <b>30</b>  |            | <b>5</b>   | <b>20</b>  | <b>40</b>  | <b>95</b>  | <b>75</b> | <b>45</b> | <b>2</b>  | <b>15</b> | <b>85</b> |           |        |        |
| <b>2000</b>                       |            |            |            |            |            |            |            |           |           |           |           |           |           |        |        |
| <b>Upland Species</b>             |            |            |            |            |            |            |            |           |           |           |           |           |           |        |        |
| <i>Dalbergia ecastophyllum</i>    |            | 5          | 25         | 10         | 10         | 15         |            |           |           |           |           |           |           |        |        |
| <i>Persea palustris</i>           | 30         | 40         | 20         | 10         | 75         | 30         |            |           |           |           |           |           |           |        |        |
| <i>Schinus terebinthifolius</i>   | 80         | 80         | 90         | 70         | 75         | 50         | 5          |           |           |           |           |           |           |        |        |
| <i>Toxicodendron radicans</i>     | 10         | 2          |            |            |            |            |            |           |           |           |           |           |           |        |        |
| <b>% Coverage Upland Species</b>  | <b>120</b> | <b>127</b> | <b>135</b> | <b>90</b>  | <b>155</b> | <b>95</b>  | <b>5</b>   |           |           |           |           |           |           |        |        |
| <b>Wetland Species</b>            |            |            |            |            |            |            |            |           |           |           |           |           |           |        |        |
| <i>Acrostichum danaeifolium</i>   | 25         | 20         |            |            |            |            |            |           |           |           |           |           |           |        |        |
| <i>Myrsine guianensis</i>         | 10         |            |            |            |            |            |            |           |           |           |           |           |           |        |        |
| <i>Scirpus validus</i>            |            |            |            |            |            | 1          | 40         | 75        | 70        | 30        | 20        | 20        | 70        |        |        |
| <b>% Coverage Wetland Species</b> | <b>35</b>  | <b>20</b>  |            |            |            | <b>1</b>   | <b>40</b>  | <b>75</b> | <b>70</b> | <b>30</b> | <b>20</b> | <b>20</b> | <b>70</b> |        |        |
| <b>2002</b>                       |            |            |            |            |            |            |            |           |           |           |           |           |           |        |        |
| <b>Upland Species</b>             |            |            |            |            |            |            |            |           |           |           |           |           |           |        |        |
| <i>Dalbergia ecastophyllum</i>    |            |            | 15         | 20         | 15         |            | 15         |           |           |           |           |           |           |        |        |
| <i>Persea palustris</i>           | 10         | 45         | 65         |            |            |            |            |           |           |           |           |           |           |        |        |
| <i>Schinus terebinthifolius</i>   | 95         | 95         | 95         | 98         | 100        | 90         | 90         |           |           |           |           |           |           |        |        |
| <b>% Coverage Upland Species</b>  | <b>105</b> | <b>140</b> | <b>175</b> | <b>118</b> | <b>115</b> | <b>150</b> | <b>105</b> |           |           |           |           |           |           |        |        |

**Table 4.56**  
**Transition Site II Upstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline  |           |           |          |      |      |      |           |           |           |           |           |           |           |           |        |
|-----------------------------------|-----------|-----------|----------|------|------|------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|
| Year / Species                    | 0-1m      | 1-2m      | 2-3m     | 3-4m | 4-5m | 5-6m | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m    | 11-12m    | 12-13m    | 13-14m    | 14-15m |
| <b>Wetland Species</b>            |           |           |          |      |      |      |           |           |           |           |           |           |           |           |        |
| <i>Acrostichum danaeifolium</i>   | 10        | 10        | 5        |      |      |      |           |           |           |           |           |           |           |           |        |
| <i>Rhizophora mangle</i>          |           |           |          |      |      |      | 10        |           |           |           |           |           |           |           |        |
| <i>Scirpus validus</i>            |           |           |          |      |      |      |           | 25        | 50        | 50        | 65        | 70        | 80        | 80        |        |
| <b>% Coverage Wetland Species</b> | <b>10</b> | <b>10</b> | <b>5</b> |      |      |      | <b>10</b> | <b>25</b> | <b>50</b> | <b>50</b> | <b>65</b> | <b>70</b> | <b>80</b> | <b>80</b> |        |

**Table 4.57**  
**Transition Site II Upstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline   |            |            |            |           |           |           |           |           |           |           |        |        |        |        |        |
|------------------------------------|------------|------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|
| Year / Species                     | 0-1m       | 1-2m       | 2-3m       | 3-4m      | 4-5m      | 5-6m      | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <b>1997</b>                        |            |            |            |           |           |           |           |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>              |            |            |            |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>     |            |            | 20         | 5         | 2         |           |           |           |           |           |        |        |        |        |        |
| <i>Persea palustris</i>            |            | 30         | 65         |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>    | 75         | 30         | 10         |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Toxicodendron radicans</i>      | 20         | 30         | 10         |           |           |           |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b>   | <b>95</b>  | <b>90</b>  | <b>105</b> | <b>5</b>  | <b>2</b>  |           |           |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>             |            |            |            |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Ficus aurea</i>                 | 20         |            |            |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Rhizophora mangle</i>           |            |            |            |           |           | 2         | 5         |           |           |           |        |        |        |        |        |
| <i>Scirpus validus</i>             |            |            |            | 5         | 65        | 75        | 75        | 98        | 98        | 20        |        |        |        |        |        |
| <b>% Coverage Wetland Species</b>  | <b>20</b>  |            |            | <b>5</b>  | <b>65</b> | <b>79</b> | <b>80</b> | <b>98</b> | <b>98</b> | <b>20</b> |        |        |        |        |        |
| <b>1998</b>                        |            |            |            |           |           |           |           |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>              |            |            |            |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>     |            | 5          | 20         | 7         | 10        | 5         |           |           |           |           |        |        |        |        |        |
| <i>Parthenocissus quinquefolia</i> |            |            | 5          |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Persea plustris</i>             |            | 20         | 65         | 8         | 45        |           |           |           |           |           |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>    | 75         | 85         | 15         |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Toxicodendron radicans</i>      | 30         | 25         | 1          |           |           |           |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b>   | <b>105</b> | <b>135</b> | <b>106</b> | <b>15</b> | <b>55</b> | <b>5</b>  |           |           |           |           |        |        |        |        |        |



**Table 4.57**  
**Transition Site II Upstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline   |           |            |            |            |           |           |           |           |           |           |           |           |           |        |        |
|------------------------------------|-----------|------------|------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|--------|
| Year / Species                     | 0-1m      | 1-2m       | 2-3m       | 3-4m       | 4-5m      | 5-6m      | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m    | 11-12m    | 12-13m    | 13-14m | 14-15m |
| <b>Wetland Species</b>             |           |            |            |            |           |           |           |           |           |           |           |           |           |        |        |
| <i>Colocasia esculentum</i>        |           |            | 5          |            |           |           |           |           |           |           |           |           |           |        |        |
| <i>Ficus aurea</i>                 | 20        |            |            |            |           |           |           |           |           |           |           |           |           |        |        |
| <i>Rhizophora mangle</i>           |           |            |            |            |           | 20        | 5         |           |           |           |           |           |           |        |        |
| <i>Scirpus validus</i>             |           |            |            | 7          | 65        | 65        | 75        | 75        | 40        | 15        | 20        | 85        |           |        |        |
| <b>% Coverage Wetland Species</b>  | <b>20</b> |            | <b>5</b>   | <b>7</b>   | <b>65</b> | <b>85</b> | <b>80</b> | <b>75</b> | <b>40</b> | <b>15</b> | <b>12</b> | <b>85</b> |           |        |        |
| <b>2000</b>                        |           |            |            |            |           |           |           |           |           |           |           |           |           |        |        |
| <b>Upland Species</b>              |           |            |            |            |           |           |           |           |           |           |           |           |           |        |        |
| <i>Bumelia reclinata</i>           | 10        |            |            |            |           |           |           |           |           |           |           |           |           |        |        |
| <i>Dalbergia ecastophyllum</i>     |           | 5          | 5          | 3          | 1         | 3         | 15        | 5         |           |           |           |           |           |        |        |
| <i>Parthenocissus quinquefolia</i> |           |            |            |            |           | 10        |           |           |           |           |           |           |           |        |        |
| <i>Persea palustris</i>            |           | 35         | 65         | 60         | 95        | 40        |           |           |           |           |           |           |           |        |        |
| <i>Schinus terebinthifolius</i>    | 75        | 60         | 50         | 80         |           |           |           |           |           |           |           |           |           |        |        |
| <i>Toxicodendron radicans</i>      | 10        | 5          |            |            |           |           |           |           |           |           |           |           |           |        |        |
| <b>% Coverage Upland Species</b>   | <b>95</b> | <b>110</b> | <b>119</b> | <b>143</b> | <b>96</b> | <b>53</b> | <b>15</b> | <b>5</b>  |           |           |           |           |           |        |        |
| <b>Wetland Species</b>             |           |            |            |            |           |           |           |           |           |           |           |           |           |        |        |
| <i>Annona glabra</i>               | 20        |            |            |            |           |           |           |           |           |           |           |           |           |        |        |
| <i>Rhizophora mangle</i>           |           |            |            |            | 15        | 50        |           |           |           |           |           |           |           |        |        |
| <b>Scirpus validus</b>             |           |            |            | 45         | 1         | 25        | 60        | 70        | 30        | 10        | 20        | 20        | 70        |        |        |
| <b>% Coverage Wetland Species</b>  | <b>20</b> |            |            | <b>45</b>  | <b>16</b> | <b>75</b> | <b>60</b> | <b>70</b> | <b>30</b> | <b>10</b> | <b>20</b> | <b>20</b> | <b>70</b> |        |        |
|                                    |           |            |            |            |           |           |           |           |           |           |           |           |           |        |        |

**Table 4.57**  
**Transition Site II Upstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline  |            |            |            |            |            |            |           |           |           |           |           |           |           |           |           |
|-----------------------------------|------------|------------|------------|------------|------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Year / Species                    | 0-1m       | 1-2m       | 2-3m       | 3-4m       | 4-5m       | 5-6m       | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m    | 11-12m    | 12-13m    | 13-14m    | 14-15m    |
| 2002                              |            |            |            |            |            |            |           |           |           |           |           |           |           |           |           |
| <b>Upland Species</b>             |            |            |            |            |            |            |           |           |           |           |           |           |           |           |           |
| <i>Dalbergia ecastophyllum</i>    |            | 10         | 5          |            | 5          |            |           |           |           |           |           |           |           |           |           |
| <i>Persea palustris</i>           | 20         | 25         | 10         | 10         | 10         | 30         |           |           |           |           |           |           |           |           |           |
| <i>Schinus terebinthifolius</i>   | 90         | 95         | 95         | 95         | 99         | 90         |           |           |           |           |           |           |           |           |           |
| <b>% Coverage Upland Species</b>  | <b>110</b> | <b>130</b> | <b>110</b> | <b>105</b> | <b>114</b> | <b>120</b> |           |           |           |           |           |           |           |           |           |
| <b>Wetland Species</b>            |            |            |            |            |            |            |           |           |           |           |           |           |           |           |           |
| <i>Rhizophora mangle</i>          |            |            |            |            |            | 4          | 70        | 50        |           |           |           |           |           |           |           |
| <i>Scirpus validus</i>            |            |            |            |            |            |            | 2         | 15        | 45        | 25        | 50        | 70        | 85        | 85        | 50        |
| <b>% Coverage Wetland Species</b> |            |            |            |            |            | <b>4</b>   | <b>72</b> | <b>65</b> | <b>45</b> | <b>25</b> | <b>50</b> | <b>70</b> | <b>85</b> | <b>85</b> | <b>50</b> |

**Table 4.58**  
**Transition Site II Downstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline |            |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
|----------------------------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Year / Species                   | 0-1m       | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m      | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m | 15-16m | 16-17m | 17-18m | 18-19m |
| <b>1997</b>                      |            |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>            |            |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>   | 2          | 5         |           |           | 2         |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Dioscorea bulbifera</i>       | 2          |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Panicum gymnocarpum</i>       |            |           | 35        | 10        | 1         |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Ipomoea alba</i>              |            | 2         | 5         |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Serenoa repens</i>            | 7          | 10        |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Upland Species</b> | <b>11</b>  | <b>17</b> | <b>40</b> | <b>10</b> | <b>3</b>  |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>Wetland Species</b>           |            |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>  | 50         | 10        |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Cladium jamaicensis</i>       |            | 10        | 3         |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Persea palustris</i>          | 50         |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Polygonum punctatum</i>       |            |           |           | 75        | 95        | 25        |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Rumex verticillatus</i>       |            |           | 2         |           | 2         |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Scirpus validus</i>           |            |           |           |           |           |           | 3         | 15        | 50        | 95        |        |        |        |        |        |        |        |        |        |
| <i>Typha domingensis</i>         |            |           |           |           |           | 2         | 10        | 5         | 2         | 2         |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Wetland</b>        | <b>100</b> | <b>20</b> | <b>5</b>  | <b>75</b> | <b>97</b> | <b>27</b> | <b>13</b> | <b>20</b> | <b>52</b> | <b>97</b> |        |        |        |        |        |        |        |        |        |
| <b>1998</b>                      |            |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>            |            |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>   | 2          | 50        | 50        | 10        | 2         | 1         |           |           |           |           |        |        |        |        |        |        |        |        |        |

**Table 4.58**  
**Transition Site II Downstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline   |            |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
|------------------------------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Year / Species                     | 0-1m       | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m      | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m | 15-16m | 16-17m | 17-18m | 18-19m |
| <i>Panicum gymnocarpum</i>         |            | 15        | 65        | 65        | 20        | 2         | 1         |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Ipomoea alba</i>                |            |           | 2         |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Toxicodendron radicans</i>      | 15         |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Upland Species</b>   | <b>19</b>  | <b>20</b> | <b>67</b> | <b>65</b> | <b>20</b> | <b>2</b>  | <b>1</b>  |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>Wetland Species</b>             |            |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>    | 50         |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Cladium jamaicensis</i>         | 5          | 2         | 5         |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Colocasia esculentum</i>        | 2          | 3         |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Eichhornia crassipes</i>        |            |           |           |           |           |           |           |           | 2         | 1         |        |        |        |        |        |        |        |        |        |
| <i>Mikania scandens</i>            |            |           |           | 30        | 80        | 75        | 25        | 45        | 5         |           |        |        |        |        |        |        |        |        |        |
| <i>Parthenocissus quinquefolia</i> | 2          |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Persea palustris</i>            | 50         | 10        |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Pistia stratiotes</i>           |            |           |           |           |           |           |           |           |           | 2         |        |        |        |        |        |        |        |        |        |
| <i>Rumex verticillatus</i>         |            | 2         | 10        | 2         |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Scirpus validus</i>             |            |           |           |           |           | 2         | 10        | 50        | 60        | 60        |        |        |        |        |        |        |        |        |        |
| <i>Typha domingensis</i>           |            |           | 10        | 5         | 2         | 1         | 1         |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>      | <b>109</b> | <b>17</b> | <b>25</b> | <b>37</b> | <b>82</b> | <b>78</b> | <b>36</b> | <b>95</b> | <b>67</b> | <b>62</b> |        |        |        |        |        |        |        |        |        |
| <b>2000</b>                        |            |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>              |            |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Panicum gymnocarpum</i>         |            | 1         | 2         | 2         | 3         |           | 1         |           |           |           |        |        |        |        |        |        |        |        |        |

**Table 4.58**  
**Transition Site II Downstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline |            |           |           |           |           |          |           |           |           |           |           |           |           |           |           |           |           |           |        |
|----------------------------------|------------|-----------|-----------|-----------|-----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|
| Year / Species                   | 0-1m       | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m     | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m    | 11-12m    | 12-13m    | 13-14m    | 14-15m    | 15-16m    | 16-17m    | 17-18m    | 18-19m |
| <i>Toxicodendron radicans</i>    | 20         |           |           |           |           |          |           |           |           |           |           |           |           |           |           |           |           |           |        |
| <b>% Coverage Upland Species</b> | <b>20</b>  | <b>1</b>  | <b>2</b>  | <b>2</b>  | <b>3</b>  |          | <b>1</b>  |           |           |           |           |           |           |           |           |           |           |           |        |
| <b>Wetland Species</b>           |            |           |           |           |           |          |           |           |           |           |           |           |           |           |           |           |           |           |        |
| <i>Acrostichum danaeifolium</i>  | 25         |           |           |           |           |          |           |           |           |           |           |           |           |           |           |           |           |           |        |
| <i>Annona glabra</i>             | 30         | 20        |           |           |           |          |           |           |           |           |           |           |           |           |           |           |           |           |        |
| <i>Colocasia esculentum</i>      |            | 1         |           | 4         |           | 2        | 2         |           |           |           |           |           |           |           |           |           |           |           |        |
| <i>Mikania scandens</i>          |            |           | 5         | 20        | 10        | 2        | 5         | 30        | 2         |           | 5         | 5         |           |           |           |           |           |           |        |
| <i>Persea palustris</i>          | 50         | 35        |           |           |           |          |           |           |           |           |           |           |           |           |           |           |           |           |        |
| <i>Polygonum</i>                 |            |           | 2         |           | 5         | 1        | 25        |           | 2         | 2         |           |           |           |           |           |           |           |           |        |
| <i>Rumex verticillatus</i>       |            |           | 2         | 20        | 10        |          |           |           |           |           |           |           |           |           |           |           |           |           |        |
| <i>Sambucus canadensis</i>       |            |           | 1         | 2         | 15        | 2        | 1         |           |           |           |           |           |           |           |           |           |           |           |        |
| <i>Scirpus validus</i>           |            |           |           |           |           |          | 2         | 4         | 60        | 60        | 5         | 30        | 70        | 70        | 80        | 80        | 80        | 80        |        |
| <i>Typha domingensis</i>         |            |           | 10        |           |           |          |           |           |           |           |           |           |           |           |           |           |           |           |        |
| <b>% Coverage Wetland Sp.</b>    | <b>105</b> | <b>66</b> | <b>18</b> | <b>46</b> | <b>40</b> | <b>7</b> | <b>35</b> | <b>34</b> | <b>64</b> | <b>63</b> | <b>10</b> | <b>35</b> | <b>70</b> | <b>70</b> | <b>80</b> | <b>80</b> | <b>80</b> | <b>80</b> |        |
| <b>2002</b>                      |            |           |           |           |           |          |           |           |           |           |           |           |           |           |           |           |           |           |        |
| <b>Upland Species</b>            |            |           |           |           |           |          |           |           |           |           |           |           |           |           |           |           |           |           |        |
| <i>Atriplex spp.</i>             |            |           |           |           |           |          |           |           |           | 10        | 10        |           | 5         |           |           |           |           |           |        |
| <i>Eupatorium capillifolium</i>  |            |           |           |           |           |          |           |           |           |           |           |           | 5         |           |           |           |           |           |        |
| <i>Pluchea spp.</i>              |            |           | 40        | 40        |           |          |           | 10        | 10        | 30        |           | 25        |           |           |           |           |           |           |        |
| <i>Schinus terebinthifolius</i>  | 75         |           |           |           |           |          |           |           |           |           |           |           |           |           |           |           |           |           |        |

**Table 4.58**  
**Transition Site II Downstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline  |            |            |           |           |           |           |            |           |           |           |           |           |           |           |           |           |           |           |           |
|-----------------------------------|------------|------------|-----------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Year / Species                    | 0-1m       | 1-2m       | 2-3m      | 3-4m      | 4-5m      | 5-6m      | 6-7m       | 7-8m      | 8-9m      | 9-10m     | 10-11m    | 11-12m    | 12-13m    | 13-14m    | 14-15m    | 15-16m    | 16-17m    | 17-18m    | 18-19m    |
| <i>Toxicodendron radicans</i>     | 2          |            |           |           |           |           |            |           |           |           |           |           |           |           |           |           |           |           |           |
| <b>% Coverage Upland Species</b>  | <b>77</b>  |            | <b>40</b> | <b>40</b> |           |           |            | <b>10</b> | <b>10</b> | <b>40</b> | <b>10</b> | <b>25</b> | <b>10</b> |           |           |           |           |           |           |
| <b>Wetland Species</b>            |            |            |           |           |           |           |            |           |           |           |           |           |           |           |           |           |           |           |           |
| <i>Acrostichum danaeifolium</i>   | 60         | 50         | 10        |           |           |           |            |           |           |           |           |           |           |           |           |           |           |           |           |
| <i>Annona glabra</i>              | 40         | 70         | 5         |           |           |           |            |           |           |           |           |           |           |           |           |           |           |           |           |
| <i>Cladium jamaicense</i>         |            | 1          | 5         |           |           |           |            |           |           |           |           |           |           |           |           |           |           |           |           |
| <i>Diodia virginiana</i>          |            |            |           |           |           |           |            |           | 10        | 20        | 10        |           |           |           |           |           |           |           |           |
| <i>Ipomoea glabra</i>             | 5          |            |           |           |           |           |            |           |           |           |           |           |           |           |           |           |           |           |           |
| <i>Mikania scandens</i>           |            |            |           |           |           |           |            |           |           | 2         | 3         |           |           |           |           |           |           |           |           |
| <i>Parthenocisus quinquefolia</i> | 5          |            |           |           |           |           |            |           |           |           |           |           |           |           |           |           |           |           |           |
| <i>Polygonum punctatum</i>        |            |            |           |           | 15        | 1         | 15         | 20        | 4         |           |           |           |           |           |           |           |           |           |           |
| <i>Rhizophora mangle</i>          |            | 1          |           |           |           |           |            |           |           |           |           |           |           |           |           |           |           |           |           |
| <i>Rumex verticillatus</i>        |            |            |           |           |           |           |            |           | 2         | 20        | 20        | 15        |           | 4         |           |           |           |           |           |
| <i>Samolus parviflorus</i>        |            |            | 40        | 60        | 30        |           |            |           |           | 10        |           |           |           |           |           |           |           |           |           |
| <i>Scirpus validus</i>            |            |            |           |           |           | 40        | 80         | 45        |           | 10        | 10        | 20        | 70        | 15        | 80        | 95        | 85        | 80        | 70        |
| <i>Typha spp.</i>                 |            |            |           | 10        | 15        | 5         | 10         | 10        | 25        | 10        | 4         |           |           | 5         |           |           |           |           |           |
| <b>% Coverage Wetland Sp.</b>     | <b>110</b> | <b>122</b> | <b>60</b> | <b>70</b> | <b>60</b> | <b>46</b> | <b>105</b> | <b>75</b> | <b>41</b> | <b>72</b> | <b>47</b> | <b>35</b> | <b>70</b> | <b>24</b> | <b>80</b> | <b>95</b> | <b>85</b> | <b>80</b> | <b>70</b> |

**Table 4.59**  
**Transition Site II Downstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline |           |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
|----------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Year / Species                   | 0-1m      | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m      | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m | 15-16m | 16-17m | 17-18m | 18-19m |
| <b>1997</b>                      |           |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>            |           |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Panicum gymnocarpum</i>       |           | 10        | 35        | 60        | 5         | 2         |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Ipomoea alba</i>              |           | 15        | 10        |           |           |           | 2         | 5         | 5         |           |        |        |        |        |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>  | 2         |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Serenoa repens</i>            | 1         |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Upland Species</b> | <b>3</b>  | <b>25</b> | <b>45</b> | <b>60</b> | <b>5</b>  | <b>2</b>  | <b>2</b>  | <b>5</b>  | <b>5</b>  |           |        |        |        |        |        |        |        |        |        |
| <b>Wetland Species</b>           |           |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>  | 75        | 75        | 5         |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Persea palustris</i>          | 20        |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Polygonum punctatum</i>       |           |           |           | 3         | 75        | 20        |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Rhizophora mangle</i>         |           |           |           |           |           |           |           |           | 2         |           |        |        |        |        |        |        |        |        |        |
| <i>Scirpus validus</i>           |           |           |           |           |           |           | 10        | 5         | 45        | 95        |        |        |        |        |        |        |        |        |        |
| <i>Typha domingensis</i>         |           |           |           |           |           | 20        | 10        | 30        | 20        |           |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Wetland</b>        | <b>95</b> | <b>75</b> | <b>5</b>  | <b>3</b>  | <b>76</b> | <b>40</b> | <b>21</b> | <b>35</b> | <b>67</b> | <b>95</b> |        |        |        |        |        |        |        |        |        |
| <b>1998</b>                      |           |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>            |           |           |           |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Panicum gymnocarpum</i>       |           | 2         | 50        | 50        | 10        | 2         | 1         |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Ipomoea alba</i>              | 4         | 10        | 10        |           |           |           |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Upland Species</b> | <b>4</b>  | <b>12</b> | <b>60</b> | <b>50</b> | <b>10</b> | <b>2</b>  | <b>1</b>  |           |           |           |        |        |        |        |        |        |        |        |        |



**Table 4.59**  
**Transition Site II Downstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline   |            |           |           |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
|------------------------------------|------------|-----------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Year / Species                     | 0-1m       | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m       | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m | 15-16m | 16-17m | 17-18m | 18-19m |
| <b>Wetland Species</b>             |            |           |           |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>    | 80         | 75        |           |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Cladium jamaicensis</i>         | 3          | 1         |           |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Mikania scandens</i>            |            |           |           | 15        | 35        | 90         | 80        | 60        | 5         |           |        |        |        |        |        |        |        |        |        |
| <i>Parthenocissus quinquefolia</i> | 1          |           |           |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Persea palustris</i>            | 45         |           |           |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Pontederia cordata</i>          |            |           |           | 1         | 25        | 25         |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Rhizophora mangle</i>           |            |           |           |           |           |            |           | 2         | 1         |           |        |        |        |        |        |        |        |        |        |
| <i>Rumex crispus</i>               |            | 1         | 10        | 15        |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Rumex verticillatus</i>         | 1          | 1         |           |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Scirpus validus</i>             |            |           |           |           |           |            | 5         | 25        | 70        | 65        |        |        |        |        |        |        |        |        |        |
| <i>Typha domingensis</i>           | 1          | 7         | 4         | 5         | 3         | 1          |           | 5         | 20        |           |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>      | <b>131</b> | <b>85</b> | <b>14</b> | <b>36</b> | <b>63</b> | <b>120</b> | <b>85</b> | <b>92</b> | <b>96</b> | <b>65</b> |        |        |        |        |        |        |        |        |        |
| <b>2000</b>                        |            |           |           |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>              |            |           |           |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Panicum gymocarpum</i>          |            |           |           | 5         |           |            | 1         |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Upland Species</b>   |            |           |           | <b>5</b>  |           |            | <b>1</b>  |           |           |           |        |        |        |        |        |        |        |        |        |
| <b>Wetland Species</b>             |            |           |           |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>    | 90         | 80        | 50        |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |
| <i>Bumelia reclinata</i>           |            | 5         |           |           |           |            |           |           |           |           |        |        |        |        |        |        |        |        |        |

**Table 4.59**  
**Transition Site II Downstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline |            |      |           |           |           |            |            |            |           |           |           |           |           |           |           |           |           |           |        |
|----------------------------------|------------|------|-----------|-----------|-----------|------------|------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|
| Year / Species                   | 0-1m       | 1-2m | 2-3m      | 3-4m      | 4-5m      | 5-6m       | 6-7m       | 7-8m       | 8-9m      | 9-10m     | 10-11m    | 11-12m    | 12-13m    | 13-14m    | 14-15m    | 15-16m    | 16-17m    | 17-18m    | 18-19m |
| <i>Cladium jamaicensis</i>       |            | 1    | 3         |           |           |            |            |            |           |           |           |           |           |           |           |           |           |           |        |
| <i>Colocasia esculentum</i>      |            |      | 4         | 20        | 20        | 2          |            |            |           |           |           |           |           |           |           |           |           |           |        |
| <i>Mikania scandens</i>          |            |      | 10        |           |           | 10         | 30         | 25         | 20        |           | 75        | 40        |           |           |           |           |           |           |        |
| <i>Persea palustris</i>          | 45         |      |           |           |           |            |            |            |           |           |           |           |           |           |           |           |           |           |        |
| <i>Polygonum punctatum</i>       |            |      |           |           | 15        | 60         | 25         | 60         | 40        | 10        |           |           |           |           |           |           |           |           |        |
| <i>Pontederia cordata</i>        |            |      |           | 3         |           | 25         |            |            |           |           |           |           |           |           |           |           |           |           |        |
| <i>Rhizophora mangle</i>         |            |      |           |           |           |            |            |            | 1         |           |           |           |           |           |           |           |           |           |        |
| <i>Rumex crispus</i>             |            |      | 3         |           |           |            | 30         |            |           |           |           |           |           |           |           |           |           |           |        |
| <i>Rumex verticillatus</i>       |            |      |           |           |           |            |            | 15         | 15        | 1         |           |           |           |           |           |           |           |           |        |
| <i>Sambucus canadensis</i>       |            |      | 2         | 20        | 10        | 5          |            |            |           |           |           |           |           |           |           |           |           |           |        |
| <i>Scirpus validus</i>           |            |      |           |           |           |            | 10         |            |           | 65        | 5         | 40        | 70        | 70        | 80        | 80        | 80        | 80        |        |
| <i>Cuscuta spp.</i>              |            |      |           |           |           | 20         | 40         |            |           |           |           |           |           |           |           |           |           |           |        |
| <b>% Coverage Wetland Sp.</b>    | <b>135</b> |      | <b>86</b> | <b>43</b> | <b>45</b> | <b>122</b> | <b>135</b> | <b>100</b> | <b>76</b> | <b>76</b> | <b>80</b> | <b>80</b> | <b>70</b> | <b>70</b> | <b>80</b> | <b>80</b> | <b>80</b> | <b>80</b> |        |
| <b>2002</b>                      |            |      |           |           |           |            |            |            |           |           |           |           |           |           |           |           |           |           |        |
| <b>Upland Species</b>            |            |      |           |           |           |            |            |            |           |           |           |           |           |           |           |           |           |           |        |
| <i>Atriplex spp.</i>             |            |      |           |           |           |            |            |            |           | 2         | 5         | 30        |           |           |           |           |           |           |        |
| <i>Eupatorium capillifolium</i>  |            |      |           |           |           |            |            |            |           |           |           |           | 10        | 5         |           |           |           |           |        |
| <i>Pluchea spp.</i>              |            |      |           | 60        | 60        | 10         |            |            |           | 10        |           |           |           |           |           |           |           |           |        |
| <i>Schinus terebinthifolius</i>  | 25         |      | 20        | 10        |           |            |            |            |           |           |           |           |           |           |           |           |           |           |        |
| <b>% Coverage Upland Species</b> | <b>25</b>  |      | <b>20</b> | <b>70</b> | <b>60</b> | <b>10</b>  |            |            |           | <b>12</b> | <b>5</b>  | <b>30</b> | <b>10</b> | <b>5</b>  |           |           |           |           |        |

**Table 4.59**  
**Transition Site II Downstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline |            |            |            |           |           |           |            |           |           |           |           |          |           |           |           |           |           |           |           |
|----------------------------------|------------|------------|------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Year / Species                   | 0-1m       | 1-2m       | 2-3m       | 3-4m      | 4-5m      | 5-6m      | 6-7m       | 7-8m      | 8-9m      | 9-10m     | 10-11m    | 11-12m   | 12-13m    | 13-14m    | 14-15m    | 15-16m    | 16-17m    | 17-18m    | 18-19m    |
| <b>Wetland Species</b>           |            |            |            |           |           |           |            |           |           |           |           |          |           |           |           |           |           |           |           |
| <i>Acrostichum danaeifolium</i>  | 30         | 95         | 98         | 5         |           |           |            |           |           |           |           |          |           |           |           |           |           |           |           |
| <i>Annona glabra</i>             | 20         | 25         |            |           |           |           |            |           |           |           |           |          |           |           |           |           |           |           |           |
| <i>Cladium jamaicensis</i>       |            |            | 5          | 2         |           |           |            |           |           |           |           |          |           |           |           |           |           |           |           |
| <i>Colocasia esculentum</i>      |            |            |            |           | 3         |           |            |           |           |           |           |          |           |           |           |           |           |           |           |
| <i>Diodia virginiana</i>         |            |            |            |           |           |           |            |           |           | 2         |           |          |           |           |           |           |           |           |           |
| <i>Persea palustris</i>          | 75         | 45         |            |           |           |           |            |           |           |           |           |          |           |           |           |           |           |           |           |
| <i>Polygonum punctatum</i>       |            |            |            |           | 25        | 50        | 70         | 40        | 15        | 5         |           |          |           |           |           |           |           |           |           |
| <i>Pontederia cordata</i>        |            |            |            |           |           | 25        |            |           |           |           |           |          |           |           |           |           |           |           |           |
| <i>Rhizophora mangle</i>         |            |            |            |           |           |           | 5          | 2         |           |           |           |          |           |           |           |           |           |           |           |
| <i>Rumex crispus</i>             |            |            |            |           |           |           |            |           |           |           | 25        |          |           |           |           |           |           |           |           |
| <i>Rumex verticillatus</i>       |            |            |            |           |           |           | 5          | 5         |           | 2         | 5         |          | 20        |           |           |           |           |           |           |
| <i>Sambucus canadensis</i>       |            |            |            |           |           |           |            |           |           |           |           | 5        |           |           |           |           |           |           |           |
| <i>Samolus parviflorus</i>       |            |            |            | 5         |           |           |            |           |           | 10        |           |          |           |           |           |           |           |           |           |
| <i>Scirpus validus</i>           |            |            |            |           |           |           | 30         | 45        | 50        | 60        | 5         | 2        |           | 15        | 70        | 80        | 70        | 90        | 50        |
| <i>Typha spp.</i>                |            |            |            | 5         | 10        | 20        | 25         | 4         | 5         |           | 5         |          |           |           |           |           |           |           |           |
| <b>% Coverage Wetland Sp.</b>    | <b>125</b> | <b>165</b> | <b>103</b> | <b>17</b> | <b>38</b> | <b>95</b> | <b>135</b> | <b>96</b> | <b>70</b> | <b>69</b> | <b>40</b> | <b>7</b> | <b>20</b> | <b>15</b> | <b>70</b> | <b>80</b> | <b>70</b> | <b>90</b> | <b>50</b> |

**Table 4.60**  
**Site III Growing on Land**

| <b>Species</b>                  | <b>Common Name</b>  | <b>1997</b> | <b>1998</b> | <b>2000</b> | <b>2002</b> |
|---------------------------------|---------------------|-------------|-------------|-------------|-------------|
| <i>Psychotria undata</i>        | Shining wild coffee | X           |             |             |             |
| <i>Acrostichum danaeifolium</i> | Giant leather fern  | X           |             |             |             |
| <i>Cladium jamaicensis</i>      | Saw grass           | X           |             |             |             |
| <i>Myrsine guianensis</i>       | Myrsine             | X           |             |             |             |
| <i>Persea palustris</i>         | Swamp Bay           | X           |             |             |             |
| <i>Vitis rotundifolia</i>       | Muscadine grape     | X           | X           |             |             |
| <i>Quercus virginiana</i>       | Live oak            | X           | X           | X           | X           |
| <i>Schinus terebinthifolius</i> | Brazilian pepper    | X           | X           | X           | X           |
| <i>Toxicodendron radicans</i>   | Poison ivy          | X           | X           | X           | X           |
| <i>Yucca aloifolia</i>          | Spanish bayonet     | X           | X           | X           | X           |
| <i>Zanthoxylum fagara</i>       | Wild lime           | X           | X           | X           | X           |
| <i>Blechnum serrulatum</i>      | Swamp fern          | X           | X           | X           | X           |
| <i>Myrsine guianensis</i>       | Myrsine             |             | X           | X           | X           |
| <i>Smilax bona-nex</i>          | Catbriar            |             | X           | X           | X           |
| <i>Psychotria nervosa</i>       | Wild coffee         |             | X           | X           | X           |
| <i>Persea palustris</i>         | Swamp bay           |             | X           | X           | X           |
| <i>Zamia integrifolia</i>       | Coontie             |             | X           |             |             |
| <b>Total Number of Species</b>  |                     | <b>12</b>   | <b>12</b>   | <b>10</b>   | <b>10</b>   |

**Table 4.61**  
**Site III Growing in Water (shoreline and transects)**

| <b>Species Name</b>                | <b>Common Name</b> | <b>1997</b> | <b>1998</b> | <b>2000</b> | <b>2002</b> |
|------------------------------------|--------------------|-------------|-------------|-------------|-------------|
| <i>Quercus laurifolia</i>          | Laurel oak         | X           |             |             |             |
| <i>Psidium gjava</i>               | Guava              | X           |             |             |             |
| <i>Callicarpa americana</i>        | Beauty berry       | X           |             |             |             |
| <i>Acrostichum danaeifolium</i>    | Giant leather fern | X           |             |             | X           |
| <i>Persea palustris</i>            | Swamp bay          | X           |             |             | X           |
| <i>Erythrina herbacea</i>          | Coral bean         | X           | X           |             |             |
| <i>Eugenia axillaris</i>           | White stopper      | X           | X           |             |             |
| <i>Ipomoea alba</i>                | Moon flower        | X           | X           |             |             |
| <i>Psychotria nervosa</i>          | Wild coffee        | X           | X           |             | X           |
| <i>Blechnum serrulatum</i>         | Swamp fern         | X           | X           | X           | X           |
| <i>Juncus roemerianus</i>          | Black needlerush   | X           | X           | X           | X           |
| <i>Myrsine guianensis</i>          | Myrsine            | X           | X           | X           | X           |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper   | X           | X           | X           | X           |
| <i>Quercus virginiana</i>          | Live oak           | X           | X           | X           | X           |
| <i>Scirpus validus</i>             | Giant bulrush      | X           | X           | X           | X           |
| <i>Schinus terebinthifolius</i>    | Brazilian pepper   | X           | X           | X           | X           |
| <i>Smilax noca-nox</i>             | Catbrier           | X           | X           | X           | X           |
| <i>Toxicodendron radicans</i>      | Poison ivy         | X           | X           | X           | X           |
| <i>Zamia integrifolia</i>          | Coontie            | X           | X           | X           | X           |
| <i>Zanthoxylum fagara</i>          | Wild lime          | X           | X           |             | X           |
| <i>Bumelia reclinata</i>           | Shrubby Buckthorn  |             | X           | X           | X           |
| <i>Colocasia esculenta</i>         | Taro               |             | X           |             |             |
| <i>Ludwigia repens</i>             | Red ludwigia       |             | X           |             |             |
| <i>Dalbergia ecastophyllum</i>     | Coin vine          |             | X           |             | X           |
| <i>Rhizophora mangle</i>           | Red mangrove       |             |             |             | X           |
| <i>Spartina bakeri</i>             | Cordgrass          |             |             |             | X           |
| <b>Total Species</b>               |                    | <b>20</b>   | <b>19</b>   | <b>11</b>   | <b>18</b>   |

**Table 4.62**  
**Transition Site III Upstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline   |           |            |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
|------------------------------------|-----------|------------|-----------|-----------|-----------|-----------|------------|------------|------------|------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Year / Species                     | 0-1m      | 1-2m       | 2-3m      | 3-4m      | 4-5m      | 5-6m      | 6-7m       | 7-8m       | 8-9m       | 9-10m      | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m | 15-16m | 16-17m | 17-18m | 18-19m |
| <b>1997</b>                        |           |            |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>              |           |            |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Parthenocussus quinquefolia</i> |           | 2          | 5         |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Psidium guajava</i>             | 20        |            | 3         |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Quercus virginiana</i>          | 20        | 50         | 1         |           | 20        |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>    |           |            | 2         | 85        |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Smilax bona-nox</i>             | 5         |            |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Toxicodendron radicans</i>      | 10        | 10         |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Zamia integrifolia</i>          | 5         |            |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Zanthoxylum fagara</i>          | 20        | 40         |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Upland Species</b>   | <b>80</b> | <b>100</b> | <b>11</b> | <b>85</b> | <b>20</b> |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <b>Wetland Species</b>             |           |            |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Blechnum serrulatum</i>         | 3         |            |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Juncus roemerianus</i>          |           | 5          |           | 10        | 20        | 5         |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Persea palustris</i>            | 7         |            |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Quercus laurifolia</i>          | 20        |            |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |
| <i>Scirpus validus</i>             |           |            |           |           |           | 80        | 100        | 100        | 100        | 100        |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>      | <b>30</b> | <b>5</b>   |           | <b>10</b> | <b>20</b> | <b>85</b> | <b>100</b> | <b>100</b> | <b>100</b> | <b>100</b> |        |        |        |        |        |        |        |        |        |
|                                    |           |            |           |           |           |           |            |            |            |            |        |        |        |        |        |        |        |        |        |

**Table 4.62**  
**Transition Site III Upstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline   |           |            |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
|------------------------------------|-----------|------------|-----------|-----------|-----------|-----------|-----------|-----------|------------|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Year / Species                     | 0-1m      | 1-2m       | 2-3m      | 3-4m      | 4-5m      | 5-6m      | 6-7m      | 7-8m      | 8-9m       | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m | 15-16m | 16-17m | 17-18m | 18-19m |
| <b>1998</b>                        |           |            |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>              |           |            |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Bumelia reclinata</i>           | 20        | 1          |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Parthenocissus quinquefolia</i> |           | 10         |           | 8         |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Quercus virginiana</i>          | 40        | 50         | 80        | 85        | 2         |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Smilax bona-nox</i>             | 2         |            |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Toxicodendron radicans</i>      | 10        | 5          |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Zamia integrifolia</i>          | 5         |            |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Zanthoxylum fagara</i>          | 20        | 40         |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Upland Species</b>   | <b>97</b> | <b>106</b> | <b>80</b> | <b>85</b> | <b>2</b>  |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <b>Wetland Species</b>             |           |            |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Blechnum serrulatum</i>         | 10        |            |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Juncus roemerianus</i>          |           | 2          |           |           |           | 10        | 5         | 10        |            |           |        |        |        |        |        |        |        |        |        |
| <i>Myrsine guianensis</i>          | 3         |            |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Scirpus validus</i>             |           |            | 1         |           | 10        | 50        | 75        | 80        | 100        | 95        |        |        |        |        |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>      | <b>13</b> | <b>2</b>   | <b>1</b>  |           | <b>20</b> | <b>55</b> | <b>85</b> | <b>80</b> | <b>100</b> | <b>95</b> |        |        |        |        |        |        |        |        |        |
| <b>2000</b>                        |           |            |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>              |           |            |           |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Bumelia reclinata</i>           | 45        | 1          | 15        |           |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |
| <i>Parthenocissus quinquefolia</i> |           | 1          | 2         | 10        |           |           |           |           |            |           |        |        |        |        |        |        |        |        |        |



**Table 4.62**  
**Transition Site III Upstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline |            |           |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
|----------------------------------|------------|-----------|-----------|-----------|-----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|
| Year / Species                   | 0-1m       | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m     | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m    | 11-12m    | 12-13m    | 13-14m    | 14-15m | 15-16m | 16-17m | 17-18m | 18-19m |
| <i>Quercus virginiana</i>        | 25         | 25        | 50        | 60        | 30        |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Smilax bona-nox</i>           | 10         |           |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Toxicodendron radicans</i>    |            | 5         |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Zamia integrifolia</i>        | 3          |           |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Zanthoxylum fagara</i>        | 25         | 40        |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b> | <b>108</b> | <b>72</b> | <b>67</b> | <b>70</b> | <b>30</b> |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>           |            |           |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Blechnum serrulatum</i>       | 2          |           |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Myrsine guianensis</i>        | 5          |           |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Scirpus validus</i>           |            |           |           |           |           | 4        | 15        | 50        | 20        | 25        | 50        | 50        | 65        | 65        |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>    | <b>7</b>   |           |           |           |           | <b>4</b> | <b>15</b> | <b>50</b> | <b>20</b> | <b>25</b> | <b>50</b> | <b>50</b> | <b>65</b> | <b>65</b> |        |        |        |        |        |
| <b>2002</b>                      |            |           |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>            |            |           |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Bumelia reclinata</i>         | 70         | 35        |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>   | 15         |           |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Persea palustris</i>          |            | 30        |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Quercus virginiana</i>        | 30         | 10        | 40        | 75        | 25        |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b> | <b>115</b> | <b>75</b> | <b>40</b> | <b>75</b> | <b>25</b> |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>           |            |           |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |
| <i>Myrsine guianensis</i>        | 2          |           |           |           |           |          |           |           |           |           |           |           |           |           |        |        |        |        |        |

**Table 4.62**  
**Transition Site III Upstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
|----------------------------------|------|------|------|------|------|------|------|------|------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Year / Species                   | 0-1m | 1-2m | 2-3m | 3-4m | 4-5m | 5-6m | 6-7m | 7-8m | 8-9m | 9-10m | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m | 15-16m | 16-17m | 17-18m | 18-19m |
| <i>Juncus roemarianus</i>        |      |      |      |      |      |      | 10   |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Scirpus validus</i>           |      |      |      |      |      |      | 15   | 20   | 20   | 10    | 2      | 5      | 5      | 20     | 10     |        |        |        |        |
| % Coverage Wetland Sp.           | 2    |      |      |      |      |      | 25   | 20   | 20   | 10    | 2      | 5      | 5      | 20     | 10     |        |        |        |        |

**Table 4.63**  
**Transition Site III Upstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
|----------------------------------|------|------|------|------|------|------|------|------|------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Year / Species                   | 0-1m | 1-2m | 2-3m | 3-4m | 4-5m | 5-6m | 6-7m | 7-8m | 8-9m | 9-10m | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m | 15-16m | 16-17m | 17-18m | 18-19m |
| <b>1997</b>                      |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>            |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <b>Psidium guajava</b>           | 2    |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Psidium guajava</i>           | 4    | 10   | 10   |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Quercus virginiana</i>        |      | 20   | 80   | 70   | 30   |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Smilax bona-nox</i>           | 2    |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Toxicodendron radicans</i>    |      | 5    | 5    |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Zanthoxylum fagara</i>        |      | 10   |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| % Coverage Upland Sp.            | 8    | 45   | 95   | 70   | 30   |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <b>Wetland Species</b>           |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Blechnum serrulatun</i>       | 20   |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Juncus roemerianus</i>        |      |      | 5    | 7    | 50   | 10   |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Persea palustris</i>          | 20   |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Quercus laurifolia</i>        | 30   |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Scirpus validus</i>           |      |      |      |      |      | 80   | 100  | 100  | 100  | 100   |        |        |        |        |        |        |        |        |        |
| % Coverage WetlandSp.            | 70   |      | 5    | 7    | 50   | 90   | 100  | 100  | 100  | 100   |        |        |        |        |        |        |        |        |        |
| <b>1998</b>                      |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>            |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <b>Bumelia reclinata</b>         | 4    | 15   | 10   |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Ipomoea alba</i>              | 2    |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Quercus virginiana</i>        | 50   | 20   | 80   | 60   |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |

**Table 4.63**  
**Transition Site III Upstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
|----------------------------------|------|------|------|------|------|------|------|------|------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Year / Species                   | 0-1m | 1-2m | 2-3m | 3-4m | 4-5m | 5-6m | 6-7m | 7-8m | 8-9m | 9-10m | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m | 15-16m | 16-17m | 17-18m | 18-19m |
| <i>Schinus terebinthifolius</i>  |      |      | 5    |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Smilax bona-nox</i>           | 2    | 15   | 2    |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Toxicodendron radicans</i>    |      | 5    |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| % Coverage Upland Sp.            | 56   | 55   | 92   | 60   | 30   |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <b>Wetland Species</b>           |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Blechnum serrulatum</i>       | 20   |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Juncus roemerianus</i>        |      |      | 5    | 7    | 25   | 5    | 5    |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Ludwigia repens</i>           |      |      |      |      | 1    |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Myrsine guianensis</i>        | 5    |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Scirpus validus</i>           |      |      |      |      | 10   | 40   | 60   | 80   | 100  | 95    |        |        |        |        |        |        |        |        |        |
| % Coverage Wetland Sp.           | 25   |      | 5    | 7    | 35   | 45   | 65   | 80   | 100  | 95    |        |        |        |        |        |        |        |        |        |
| <b>2000</b>                      |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <b>Upland Species</b>            |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Bumelia reclinata</i>         | 20   | 15   | 25   |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Quercus virginiana</i>        | 50   | 20   | 20   | 60   | 20   |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>  | 10   | 15   | 65   | 25   | 20   |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Smilax bona-nox</i>           |      | 15   | 10   | 15   |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Toxicodendron radicans</i>    |      | 5    |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| % Coverage Upland Sp.            | 70   | 70   | 120  | 100  | 40   |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <b>Wetland Species</b>           |      |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |
| <i>Blechnum serrulatum</i>       | 5    |      |      |      |      |      |      |      |      |       |        |        |        |        |        |        |        |        |        |

**Table 4.63**  
**Transition Site III Upstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline |            |            |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
|----------------------------------|------------|------------|------------|------------|-----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|
| Year / Species                   | 0-1m       | 1-2m       | 2-3m       | 3-4m       | 4-5m      | 5-6m     | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m    | 11-12m    | 12-13m    | 13-14m    | 14-15m    | 15-16m | 16-17m | 17-18m | 18-19m |
| <i>Myrsine guiansis</i>          | 5          |            |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <i>Parthenocissus quinifolia</i> |            | 2          |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <b>Scirpus validus</b>           |            |            |            |            |           | 5        | 3         | 5         | 20        | 25        | 50        | 50        | 65        | 65        | 65        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>    | <b>10</b>  | <b>2</b>   |            |            |           | <b>5</b> | <b>3</b>  | <b>5</b>  | <b>20</b> | <b>25</b> | <b>50</b> | <b>50</b> | <b>65</b> | <b>65</b> | <b>65</b> |        |        |        |        |
| <b>2002</b>                      |            |            |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <b>Upland Species</b>            |            |            |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <i>Bumelia reclinata</i>         | 40         | 40         |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <i>Dalbergia ecastophyllum</i>   | 15         |            |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <i>Persea palustris</i>          |            | 15         |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <i>Quercus Virginiana</i>        | 60         | 30         | 40         | 25         | 30        |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <i>Schinus Terebinthifolius</i>  |            |            | 75         | 95         | 60        |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <i>Smilax bona-nox</i>           |            | 15         | 15         |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <i>Zamia pumila</i>              | 10         |            |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <b>% Coverage Upland Sp.</b>     | <b>125</b> | <b>100</b> | <b>130</b> | <b>120</b> | <b>90</b> |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <b>Wetland Species</b>           |            |            |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <i>Blechnum serrulatum</i>       | 2          |            |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <i>Myrsine guiansis</i>          | 4          |            |            |            |           |          |           |           |           |           |           |           |           |           |           |        |        |        |        |
| <i>Juncus roemarianus</i>        |            |            |            |            |           |          | 15        | 5         |           |           |           |           |           |           |           |        |        |        |        |
| <i>Scirpus validus</i>           |            |            |            |            |           | 2        | 5         | 25        | 25        | 8         | 3         | 8         | 15        | 20        | 8         |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>    | <b>6</b>   |            |            |            |           | <b>2</b> | <b>20</b> | <b>30</b> | <b>25</b> | <b>8</b>  | <b>3</b>  | <b>8</b>  | <b>15</b> | <b>20</b> | <b>8</b>  |        |        |        |        |

**Table 4.64**  
**Transition Site III Downstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline   |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
|------------------------------------|-----------|-----------|-----------|-----------|-----------|----------|----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|
| Year / Species                     | 0-1m      | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m     | 6-7m     | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <b>1997</b>                        |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>              |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Erythrina herbacea</i>          | 2         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Persea palustris</i>            | 3         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Parthenocissus quinquefolia</i> |           | 3         |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Quercus virginiana</i>          | 5         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>    | 5         | 18        | 20        | 20        |           |          |          |           |           |           |        |        |        |        |        |
| <i>Smilax bona-nox</i>             | 5         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Toxicodendron radicans</i>      | 2         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Sp.</b>       | <b>22</b> | <b>21</b> | <b>20</b> | <b>20</b> |           |          |          |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>             |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>    | 3         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Blechnum serrulatum</i>         |           | 5         | 3         |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Juncus roemerianus</i>          | 80        | 75        | 85        | 90        | 25        |          |          |           |           |           |        |        |        |        |        |
| <i>Psychotria nervosa</i>          | 2         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Scirpus validus</i>             |           |           |           |           | 1         | 2        | 2        | 50        | 65        | 15        |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>      | <b>85</b> | <b>80</b> | <b>88</b> | <b>90</b> | <b>26</b> | <b>2</b> | <b>2</b> | <b>50</b> | <b>65</b> | <b>15</b> |        |        |        |        |        |
| <b>1998</b>                        |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>              |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Ipomoea alba</i>                | 5         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Parthenocissus quinquefolia</i> |           | 5         |           |           |           |          |          |           |           |           |        |        |        |        |        |

**Table 4.64**  
**Transition Site III Downstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline |           |           |           |           |           |          |          |          |          |          |        |        |        |        |        |
|----------------------------------|-----------|-----------|-----------|-----------|-----------|----------|----------|----------|----------|----------|--------|--------|--------|--------|--------|
| Year / Species                   | 0-1m      | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m     | 6-7m     | 7-8m     | 8-9m     | 9-10m    | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <i>Schinus terebinthifolius</i>  | 5         | 2         | 15        | 15        |           |          |          |          |          |          |        |        |        |        |        |
| <i>Smilax bona-nox</i>           | 5         |           |           |           |           |          |          |          |          |          |        |        |        |        |        |
| <i>Toxicodendron radicans</i>    | 25        | 1         |           |           |           |          |          |          |          |          |        |        |        |        |        |
| <b>% Coverage Upland Sp.</b>     | <b>35</b> | <b>8</b>  | <b>15</b> | <b>15</b> |           |          |          |          |          |          |        |        |        |        |        |
| <b>Wetland Species</b>           |           |           |           |           |           |          |          |          |          |          |        |        |        |        |        |
| <i>Blechnum serrulatum</i>       | 10        | 15        | 3         |           |           |          |          |          |          |          |        |        |        |        |        |
| <i>Colocasia esculentum</i>      |           |           | 1         |           |           |          |          |          |          |          |        |        |        |        |        |
| <i>Juncus roemerianus</i>        | 65        | 50        | 25        | 10        | 30        | 1        |          |          |          |          |        |        |        |        |        |
| <i>Myrsine guianensis</i>        | 15        |           |           |           |           |          |          |          |          |          |        |        |        |        |        |
| <i>Psychotria nervosa</i>        | 2         |           |           |           |           |          |          |          |          |          |        |        |        |        |        |
| <i>Scirpus validus</i>           |           |           |           |           | 1         | 2        | 2        | 7        | 3        | 2        |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>    | <b>92</b> | <b>65</b> | <b>29</b> | <b>10</b> | <b>31</b> | <b>3</b> | <b>2</b> | <b>7</b> | <b>3</b> | <b>2</b> |        |        |        |        |        |
| <b>2000</b>                      |           |           |           |           |           |          |          |          |          |          |        |        |        |        |        |
| <b>Upland Species</b>            |           |           |           |           |           |          |          |          |          |          |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>  | 25        | 15        | 20        | 20        | 10        |          |          |          |          |          |        |        |        |        |        |
| <i>Smilax bona-nox</i>           | 2         |           |           |           |           |          |          |          |          |          |        |        |        |        |        |
| <i>Toxicodendron radicans</i>    | 4         | 2         |           |           |           |          |          |          |          |          |        |        |        |        |        |
| <b>% Coverage Upland Sp.</b>     | <b>31</b> | <b>17</b> | <b>20</b> | <b>20</b> | <b>10</b> |          |          |          |          |          |        |        |        |        |        |
| <b>Wetland Species</b>           |           |           |           |           |           |          |          |          |          |          |        |        |        |        |        |
| <i>Blechnum serrulatum</i>       | 30        | 7         | 2         |           |           |          |          |          |          |          |        |        |        |        |        |
| <i>Juncus roemarianus</i>        | 45        | 20        | 2         | 15        | 50        |          |          |          |          |          |        |        |        |        |        |

**Table 4.64**  
**Transition Site III Downstream Belt Transect – Upstream Side**

| Percent Waterward from Shoreline |           |           |           |           |           |          |          |           |           |       |        |        |        |        |        |
|----------------------------------|-----------|-----------|-----------|-----------|-----------|----------|----------|-----------|-----------|-------|--------|--------|--------|--------|--------|
| Year / Species                   | 0-1m      | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m     | 6-7m     | 7-8m      | 8-9m      | 9-10m | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <i>Myrsine guiansis</i>          | 10        | 5         |           |           |           |          |          |           |           |       |        |        |        |        |        |
| <i>Psychotria nervosa</i>        | 5         |           |           |           |           |          |          |           |           |       |        |        |        |        |        |
| <i>Scirpus validus</i>           |           |           |           |           |           | 2        | 3        | 8         | 10        |       |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>    | <b>90</b> | <b>33</b> | <b>4</b>  | <b>15</b> | <b>50</b> | <b>2</b> | <b>3</b> | <b>8</b>  | <b>10</b> |       |        |        |        |        |        |
| <b>2002</b>                      |           |           |           |           |           |          |          |           |           |       |        |        |        |        |        |
| <b>Upland Species</b>            |           |           |           |           |           |          |          |           |           |       |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>  | 10        | 50        | 60        | 30        | 1         |          |          |           |           |       |        |        |        |        |        |
| <i>Smilax bona-nox</i>           | 15        | 5         |           |           |           |          |          |           |           |       |        |        |        |        |        |
| <i>Toxicodendron radicans</i>    | 8         |           |           |           |           |          |          |           |           |       |        |        |        |        |        |
| <b>% Coverage Upland Sp.</b>     | <b>33</b> | <b>55</b> | <b>60</b> | <b>30</b> | <b>1</b>  |          |          |           |           |       |        |        |        |        |        |
| <b>Wetland Species</b>           |           |           |           |           |           |          |          |           |           |       |        |        |        |        |        |
| <i>Blechnum serrulatum</i>       | 20        |           |           |           |           |          |          |           |           |       |        |        |        |        |        |
| <i>Juncus roemerianus</i>        | 40        | 50        |           | 45        | 8         |          |          |           |           |       |        |        |        |        |        |
| <i>Myrsine guiansis</i>          | 8         |           |           |           |           |          |          |           |           |       |        |        |        |        |        |
| <i>Scirpus validus</i>           |           |           |           |           |           | 2        | 4        | 20        |           |       |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>    | <b>68</b> | <b>50</b> |           | <b>45</b> | <b>8</b>  | <b>2</b> | <b>4</b> | <b>20</b> |           |       |        |        |        |        |        |



**Table 4.65**  
**Transition Site III Downstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline   |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
|------------------------------------|-----------|-----------|-----------|-----------|-----------|----------|----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|
| Year / Species                     | 0-1m      | 1-2m      | 2-3m      | 3-4m      | 4-5m      | 5-6m     | 6-7m     | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <b>1997</b>                        |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>              |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Erythrina herbacea</i>          | 2         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Persea palustris</i>            | 3         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Parthenocissus quinquefolia</i> |           | 3         |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Quercus virginiana</i>          | 5         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>    | 5         | 18        | 20        | 20        |           |          |          |           |           |           |        |        |        |        |        |
| <i>Smilax bona-nox</i>             | 5         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Toxicodendron radicans</i>      | 2         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b>   | <b>22</b> | <b>21</b> | <b>20</b> | <b>20</b> |           |          |          |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>             |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Acrostichum danaeifolium</i>    | 3         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Blechnum serrulatum</i>         |           | 5         | 3         |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Juncus roemerianus</i>          | 80        | 75        | 85        | 90        | 25        |          |          |           |           |           |        |        |        |        |        |
| <i>Psychotria nervosa</i>          | 2         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Scirpus validus</i>             |           |           |           |           | 1         | 2        | 2        | 50        | 65        | 15        |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>      | <b>85</b> | <b>80</b> | <b>88</b> | <b>90</b> | <b>26</b> | <b>2</b> | <b>2</b> | <b>50</b> | <b>65</b> | <b>15</b> |        |        |        |        |        |
| <b>1998</b>                        |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>              |           |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Ipomoea alba</i>                | 3         |           |           |           |           |          |          |           |           |           |        |        |        |        |        |
| <i>Parthenocissus quinquefolia</i> | 5         |           | 5         |           |           |          |          |           |           |           |        |        |        |        |        |

**Table 4.65**  
**Transition Site III Downstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline |           |           |           |           |          |           |           |           |           |           |        |        |        |        |        |
|----------------------------------|-----------|-----------|-----------|-----------|----------|-----------|-----------|-----------|-----------|-----------|--------|--------|--------|--------|--------|
| Year / Species                   | 0-1m      | 1-2m      | 2-3m      | 3-4m      | 4-5m     | 5-6m      | 6-7m      | 7-8m      | 8-9m      | 9-10m     | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <i>Quercus virginiana</i>        | 30        | 15        |           |           |          |           |           |           |           |           |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>  | 30        | 30        | 40        | 15        | 3        |           |           |           |           |           |        |        |        |        |        |
| <i>Smilax bona-nox</i>           | 5         | 2         |           |           |          |           |           |           |           |           |        |        |        |        |        |
| <i>Toxicodendron radicans</i>    | 3         |           |           |           |          |           |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b> | <b>76</b> | <b>47</b> | <b>45</b> | <b>15</b> | <b>3</b> |           |           |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>           |           |           |           |           |          |           |           |           |           |           |        |        |        |        |        |
| <i>Blechnum serrulatum</i>       | 2         |           | 2         |           |          |           |           |           |           |           |        |        |        |        |        |
| <i>Juncus roemerianus</i>        | 75        | 20        | 20        | 80        | 1        |           |           |           |           |           |        |        |        |        |        |
| <i>Scirpus validus</i>           |           |           |           |           | 3        | 10        | 25        | 60        | 75        | 20        |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>    | <b>77</b> | <b>20</b> | <b>22</b> | <b>80</b> | <b>4</b> | <b>10</b> | <b>25</b> | <b>60</b> | <b>75</b> | <b>20</b> |        |        |        |        |        |
| <b>2000</b>                      |           |           |           |           |          |           |           |           |           |           |        |        |        |        |        |
| <b>Upland Species</b>            |           |           |           |           |          |           |           |           |           |           |        |        |        |        |        |
| <i>Quercus virginiana</i>        | 30        | 15        |           |           |          |           |           |           |           |           |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>  | 25        | 15        | 15        | 7         | 3        |           |           |           |           |           |        |        |        |        |        |
| <i>Smilax bona-nox</i>           | 2         | 15        |           |           |          |           |           |           |           |           |        |        |        |        |        |
| <i>Toxicodendron radicans</i>    | 5         |           |           |           |          |           |           |           |           |           |        |        |        |        |        |
| <i>Vitis rotundifolia</i>        | 3         | 45        | 15        | 7         | 3        |           |           |           |           |           |        |        |        |        |        |
| <b>% Coverage Upland Species</b> | <b>65</b> | <b>90</b> | <b>30</b> | <b>14</b> | <b>6</b> |           |           |           |           |           |        |        |        |        |        |
| <b>Wetland Species</b>           |           |           |           |           |          |           |           |           |           |           |        |        |        |        |        |
| <i>Achrostichum danaeifolium</i> |           | 2         |           |           |          |           |           |           |           |           |        |        |        |        |        |
| <i>Blechnum serrulatum</i>       | 5         |           |           |           |          |           |           |           |           |           |        |        |        |        |        |

**Table 4.65**  
**Transition Site III Downstream Belt Transect – Downstream Side**

| Percent Waterward from Shoreline   |           |           |          |           |           |          |           |           |           |       |        |        |        |        |        |
|------------------------------------|-----------|-----------|----------|-----------|-----------|----------|-----------|-----------|-----------|-------|--------|--------|--------|--------|--------|
| Year / Species                     | 0-1m      | 1-2m      | 2-3m     | 3-4m      | 4-5m      | 5-6m     | 6-7m      | 7-8m      | 8-9m      | 9-10m | 10-11m | 11-12m | 12-13m | 13-14m | 14-15m |
| <i>Juncus roemarianus</i>          | 20        | 20        |          | 10        | 30        |          |           |           |           |       |        |        |        |        |        |
| <i>Myrsine guiansis</i>            | 5         | 2         |          |           |           |          |           |           |           |       |        |        |        |        |        |
| <i>Psychotria nervosa</i>          | 5         | 2         |          |           |           |          |           |           |           |       |        |        |        |        |        |
| <i>Rhizophora mangle</i>           |           |           |          |           | 1         |          |           |           |           |       |        |        |        |        |        |
| <i>Scirpus validus</i>             |           |           |          |           |           |          | 3         | 10        | 30        |       |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>      | <b>40</b> | <b>26</b> |          | <b>10</b> | <b>31</b> |          | <b>3</b>  | <b>10</b> | <b>30</b> |       |        |        |        |        |        |
| <b>2002</b>                        |           |           |          |           |           |          |           |           |           |       |        |        |        |        |        |
| <b>Upland Species</b>              |           |           |          |           |           |          |           |           |           |       |        |        |        |        |        |
| <i>Parthenocissus quinquefolia</i> | 10        |           |          |           |           |          |           |           |           |       |        |        |        |        |        |
| <i>Quercus virginiana</i>          | 15        |           |          |           |           |          |           |           |           |       |        |        |        |        |        |
| <i>Schinus terebinthifolius</i>    | 25        | 10        | 1        |           |           |          |           |           |           |       |        |        |        |        |        |
| <i>Smilax bona-nox</i>             | 10        |           |          |           |           |          |           |           |           |       |        |        |        |        |        |
| <i>Toxicodendron radicans</i>      | 7         |           |          |           |           |          |           |           |           |       |        |        |        |        |        |
| <b>% Coverage Upland Species</b>   | <b>67</b> | <b>10</b> | <b>1</b> |           |           |          |           |           |           |       |        |        |        |        |        |
| <b>Wetland Species</b>             |           |           |          |           |           |          |           |           |           |       |        |        |        |        |        |
| <i>Blechnum serrulatum</i>         | 20        |           |          |           |           |          |           |           |           |       |        |        |        |        |        |
| <i>Juncus roemerianus</i>          |           | 10        |          | 30        | 1         |          |           |           |           |       |        |        |        |        |        |
| <i>Rhizophora mangle</i>           |           |           |          | 2         |           |          |           |           |           |       |        |        |        |        |        |
| <i>Scirpus validus</i>             |           |           |          |           |           | 5        | 10        | 15        |           |       |        |        |        |        |        |
| <b>% Coverage Wetland Sp.</b>      | <b>20</b> | <b>10</b> |          | <b>32</b> | <b>1</b>  | <b>5</b> | <b>10</b> | <b>15</b> |           |       |        |        |        |        |        |

**Table 5.7**  
**Summary of Lower Peace River Estuary Salinity / Isohaline Models**

| <b>Study</b>                           | <b>Year</b>            | <b>Descriptions</b>                                                                                                                                                                                                                                                                                                                                                                     | <b>Summary of Potential Impacts of Withdrawals</b>                                                                                                                                         |
|----------------------------------------|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| University of Miami                    | 1975                   | Statistical models were developed from monthly salinity data collected between 1973-1974 at fixed sampling locations along the lower Peace River, and Arcadia gaged flows.                                                                                                                                                                                                              | Potential increase of 1.3 to 3.2 ppt with 30 mgd withdrawals during flows of 100 cfs                                                                                                       |
| Environmental Quality Laboratory       | 1982, 1984, 1989, 1996 | Statistical models were developed of surface and bottom salinities at HBMP long-term fixed monitoring sites in the lower river and upper Charlotte Harbor based on monthly data and daily gaged freshwater inflows and withdrawals. Additional models were used to indicate the spatial variability of both freshwater interface and isohalines in relation to inflows and withdrawals. | Less than 0.5 ppt change under 1988 revised withdrawal schedule, and isohaline movement less than 0.4 kilometers                                                                           |
| 2000 HBMP Midterm Interpretive Report  | 2002                   | Long-term monthly HBMP fixed station and moving isohaline data were combined to develop statistical models of the spatial salinity relationships in the lower Peace River with daily gaged inflows and withdrawals.                                                                                                                                                                     | Less than 0.5 ppt change under the 1996 revised permit withdrawals schedule                                                                                                                |
| Janicki Environmental                  | 2003                   | Updated long-term monthly HBMP fixed station and moving isohaline data were used to develop predictive models of salinity water column profile and relative isohaline relationships in the lower Peace River with daily gaged inflows and withdrawals.                                                                                                                                  | Average potential increases of 0.1 to 0.3 ppt in salinity and upstream movement of 0.1 to 0.3 kilometers of the isohalines under 1996 withdrawal schedule                                  |
| 2003 HBMP Comprehensive Summary Report | 2004                   | Statistical models were developed using hourly averaged subsurface and near bottom salinities collected at 15-minute intervals between 1997 and 2002 at river kilometers 15.5 and 26.7 with corresponding stage level and daily gaged inflows and Facility withdrawals.                                                                                                                 | Increases in salinities at each site under 1996 permit conditions predicted to be less than 0.4 ppt (actual predicted increases have exceeded this approximately ten percent of the time). |

**Table 6.1**

**HBMP Indicators Related to Resource Management Goals in the Lower Peace River and Upper Charlotte Harbor (D=Direct Indicators; R=Related Indicators)**

| Resource/HBMP Component    | Habitats | Sport & Commercial Species | Nursery Function | Fish Food Sources | Nutrient Dynamics | Organic Matter | Salinity | Dissolved Oxygen | Wildlife |
|----------------------------|----------|----------------------------|------------------|-------------------|-------------------|----------------|----------|------------------|----------|
| Freshwater Inflow          | -        | -                          | -                | -                 | R                 | R              | R        | R                | -        |
| Vegetation Mapping         | D        | -                          | R                | -                 | -                 | -              | -        | -                | R        |
| Morphometric Mapping       | D        | -                          | R                | -                 | -                 | -              | -        | -                | R        |
| Salinity Measurements      | R        | R                          | R                | R                 | -                 | -              | D        | -                | R        |
| Water Quality              | R        | R                          | -                | -                 | D                 | D              | -        | D                | R        |
| FIM Fishes & Invertebrates | -        | D                          | D                | -                 | -                 | -              | R        | R                | D        |
| USF Fish Nursery Study     | R        | D                          | D                | D                 | -                 | -              | R        | R                | -        |
| MML Benthic Study          | R        | R                          | D                | D                 | -                 | R              | R        | R                | R        |

**Table 7.3**  
**Chemistry Results of Ion Study**

| Sampling Location<br>(Three Replicate Samples) | Method 200.7 (mg/L) |      |      |      |       | Method 300.0 (mg/L) |      |     | Method<br>370.10<br>(mg/L) |
|------------------------------------------------|---------------------|------|------|------|-------|---------------------|------|-----|----------------------------|
|                                                | Fe                  | Mg   | Ca   | Na   | Mn    | F-                  | Cl-  | SO4 | Silica                     |
| <b>Freshwater Sources</b>                      |                     |      |      |      |       |                     |      |     |                            |
| Peace River at Arcadia                         | 0.203               | 18.1 | 38.3 | 22.7 | 0.012 | 0.955               | 25.3 | 100 | 5.47                       |
| Peace River at Arcadia                         | 0.206               | 18.7 | 40.2 | 23.7 | 0.012 | 0.958               | 25.5 | 100 | 5.45                       |
| Peace River at Arcadia                         | 0.215               | 18.8 | 40.1 | 23.4 | 0.012 | 0.915               | 25.2 | 100 | 5.53                       |
|                                                |                     |      |      |      |       |                     |      |     |                            |
| Joshua Creek Highway 17                        | 0.555               | 23.9 | 72.0 | 53.7 | 0.025 | 0.395               | 151  | 134 | 5.36                       |
| Joshua Creek Highway 17                        | 0.304               | 25.0 | 75.4 | 55.3 | 0.020 | 0.441               | 150  | 123 | 5.40                       |
| Joshua Creek Highway 17                        | 0.284               | 24.7 | 74.0 | 54.7 | 0.018 | 0.367               | 151  | 124 | 5.43                       |
|                                                |                     |      |      |      |       |                     |      |     |                            |
| Horse Creek at Kings Highway                   | 0.581               | 14.8 | 41.0 | 10.6 | 0.034 | 0.383               | 26.9 | 99  | 5.68                       |
| Horse Creek at Kings Highway                   | 0.244               | 14.7 | 40.4 | 10.6 | 0.015 | 0.438               | 28.1 | 103 | 5.60                       |
| Horse Creek at Kings Highway                   | 0.276               | 15.1 | 41.6 | 10.6 | 0.017 | 0.392               | 27.8 | 106 | 5.77                       |
|                                                |                     |      |      |      |       |                     |      |     |                            |
| <b>High Tide</b>                               |                     |      |      |      |       |                     |      |     |                            |
| Upstream Facility - High Tide                  | 0.221               | 18.5 | 43.4 | 23.9 | 0.015 | 0.782               | 41.7 | 99  | 5.75                       |
| Upstream Facility - High Tide                  | 0.215               | 18.2 | 42.1 | 23.3 | 0.014 | 0.761               | 41.6 | 101 | 5.58                       |
| Upstream Facility - High Tide                  | 0.233               | 18.8 | 43.2 | 23.8 | 0.015 | 0.739               | 42.0 | 101 | 5.72                       |
|                                                |                     |      |      |      |       |                     |      |     |                            |
| Downstream Facility - High Tide                | 0.227               | 19.9 | 45.4 | 25.1 | 0.015 | 0.782               | 42.9 | 102 | 5.73                       |
| Downstream Facility - High Tide                | 0.221               | 19.0 | 43.4 | 24.1 | 0.015 | 0.716               | 42.6 | 102 | 5.71                       |
| Downstream Facility - High Tide                | 0.223               | 19.0 | 43.8 | 24.6 | 0.015 | 0.717               | 42.5 | 101 | 5.74                       |
|                                                |                     |      |      |      |       |                     |      |     |                            |

**Table 7.3**  
**Chemistry Results of Ion Study**

| Sampling Location<br>(Three Replicate Samples) | Method 200.7 (mg/L) |      |      |      |       | Method 300.0 (mg/L) |      |      | Method<br>370.10<br>(mg/L) |
|------------------------------------------------|---------------------|------|------|------|-------|---------------------|------|------|----------------------------|
|                                                | Fe                  | Mg   | Ca   | Na   | Mn    | F-                  | Cl-  | SO4  | Silica                     |
| Upstream Interface - High Tide                 | 0.211               | 19.2 | 42.0 | 28.3 | 0.014 | 0.790               | 54.4 | 98.0 | 5.54                       |
| Upstream Interface - High Tide                 | 0.210               | 19.1 | 42.3 | 28.4 | 0.014 | 0.665               | 53.5 | 99   | 3.62                       |
| Upstream Interface - High Tide                 | 1.240*              | 19.3 | 41.8 | 28.3 | 0.017 | 0.726               | 53.7 | 100  | 5.60                       |
|                                                |                     |      |      |      |       |                     |      |      |                            |
| Downstream Interface - High Tide               | 0.207               | 21.5 | 41.3 | 47.7 | 0.014 | 0.742               | 97.5 | 101  | 5.57                       |
| Downstream Interface - High Tide               | 0.210               | 22.3 | 43.0 | 49.6 | 0.014 | 0.721               | 98.5 | 98   | 5.66                       |
| Downstream Interface - High Tide               | 0.211               | 22.8 | 42.9 | 50.1 | 0.014 | 0.683               | 101  | 105  | 4.74                       |
| <b>Low Tide</b>                                |                     |      |      |      |       |                     |      |      |                            |
| Upstream Facility - Low Tide                   | 0.213               | 19.0 | 44.1 | 25.6 | 0.013 | 0.745               | 43.2 | 101  | 5.77                       |
| Upstream Facility - Low Tide                   | 0.212               | 19.2 | 43.5 | 25.2 | 0.013 | 0.742               | 43.1 | 100  | 5.77                       |
| Upstream Facility - Low Tide                   | 0.213               | 19.2 | 43.3 | 25.1 | 0.013 | 0.709               | 43.4 | 101  | 6.28                       |
|                                                |                     |      |      |      |       |                     |      |      |                            |
| Downstream Facility - Low Tide                 | 0.221               | 19.4 | 44.7 | 25.3 | 0.014 | 0.772               | 41.9 | 102  | 5.65                       |
| Downstream Facility - Low Tide                 | 0.214               | 18.9 | 43.2 | 24.2 | 0.014 | 0.782               | 42.4 | 102  | 5.69                       |
| Downstream Facility - Low Tide                 | 0.215               | 19.1 | 43.9 | 24.8 | 0.014 | 0.723               | 42.1 | 100  | 5.76                       |
|                                                |                     |      |      |      |       |                     |      |      |                            |
| Upstream Interface - Low Tide                  | 0.235               | 18.8 | 42.2 | 26.5 | 0.015 | 0.771               | 49.5 | 100  | 5.56                       |
| Upstream Interface - Low Tide                  | 0.245               | 19.0 | 41.9 | 26.5 | 0.015 | 0.715               | 49.9 | 101  | 5.68                       |
| Upstream Interface - Low Tide                  | 0.254               | 19.1 | 42.4 | 27.0 | 0.015 | 0.662               | 49.0 | 98   | 5.70                       |
|                                                |                     |      |      |      |       |                     |      |      |                            |

**Table 7.3**  
**Chemistry Results of Ion Study**

| Sampling Location<br>(Three Replicate Samples) | Method 200.7 (mg/L) |      |      |      |       | Method 300.0 (mg/L) |     |     | Method<br>370.10<br>(mg/L) |
|------------------------------------------------|---------------------|------|------|------|-------|---------------------|-----|-----|----------------------------|
|                                                | Fe                  | Mg   | Ca   | Na   | Mn    | F-                  | Cl- | SO4 | Silica                     |
| Downstream Interface - Low Tide                | 0.259               | 25.3 | 42.8 | 72.5 | 0.014 | 0.687               | 153 | 102 | 5.57                       |
| Downstream Interface - Low Tide                | 0.243               | 24.4 | 42.2 | 65.9 | 0.014 | 0.723               | 148 | 106 | 5.68                       |
| Downstream Interface - Low Tide                | 0.244               | 25.2 | 42.9 | 71.4 | 0.014 | 0.752               | 133 | 100 | 5.64                       |

\* Denotes apparent abnormally high value



**Table 8.1**  
**Revised HBMP Water Chemistry Parameters**

| <b>Parameter</b>                          | <b>Method</b>                 | <b>Detection Limit</b> |
|-------------------------------------------|-------------------------------|------------------------|
| Color                                     | EPA 110.2                     | 1.0 Co_Pt Units        |
| Chloride                                  | EPA 325.2                     | 0.4 mg/l               |
| Total Suspended Solids                    | EPA 160.2                     | 0.8 mg/l               |
| Volatile Suspended Solids                 | EPA 160.4                     | 0.8 mg/l               |
| NO <sub>2</sub> +NO <sub>3</sub> Nitrogen | EPA 353.2                     | 0.002 mg/l             |
| NH <sub>3</sub> +NH <sub>4</sub> Nitrogen | EPA 350.1                     | 0.01 mg/l              |
| Total Kjeldahl                            | EPA 351.2                     | 0.1 mg/l               |
| Orthophosphorus                           | EPA 365.2                     | 0.002 mg/l             |
| Silica                                    | EPA 370.1                     | 0.05 mg/l              |
| Iron                                      | EPA 236.1                     | 0.04 mg/l              |
| Chlorophyll a                             | Spectrophotometric SM10200H.2 | 2.0 ug/l               |

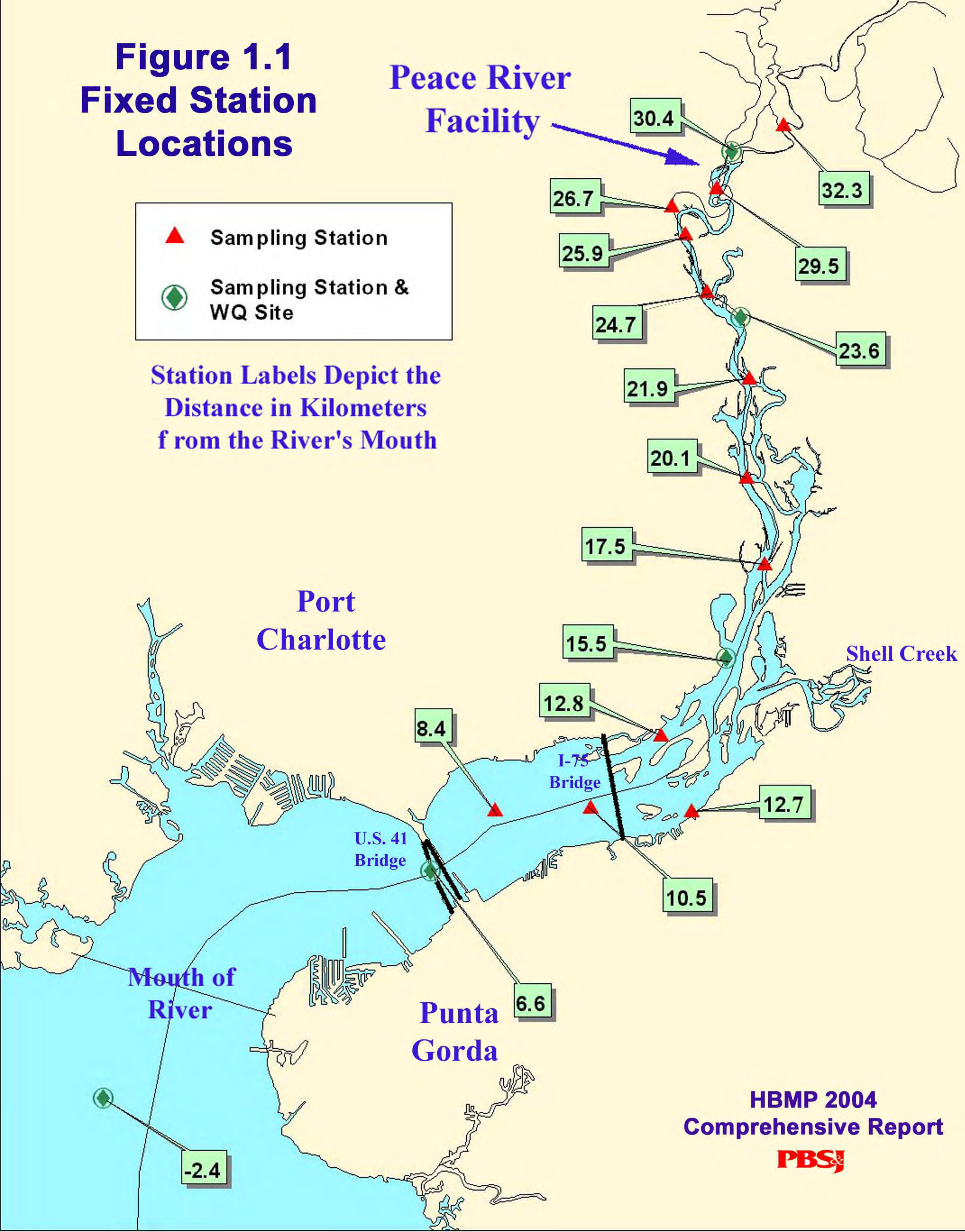
# Figures

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- 1.0 Introduction
- 2.0 Conceptual Model
- 3.0 Summaries of Recent HBMP Reports and Primary Conclusions (no figures)
- 4.0 Status and Trends of Hydrobiological Indicators in the Lower Peace River/Upper Charlotte Harbor Estuarine System
- 5.0 Salinity/Flow /Withdrawal Relationships at Continuous Recorders
- 6.0 Evaluation of the Presence or Absence of Adverse Impacts and Appropriate Indicators
- 7.0 Controlled River Pump Test Design
- 8.0 Proposed Monitoring Design Modifications to the Existing Long-term HBMP Elements
- 9.0 Diversion Schedule Assessment



**Figure 1.1  
Fixed Station  
Locations**





**PEACE RIVER  
REGIONAL WATER  
SUPPLY FACILITY**

Horse Creek

## **Figure 1.2**

### **Vegetation Transect Locations**

**Site II**  
(22.3 km)

**Site III**  
(20.4 km)

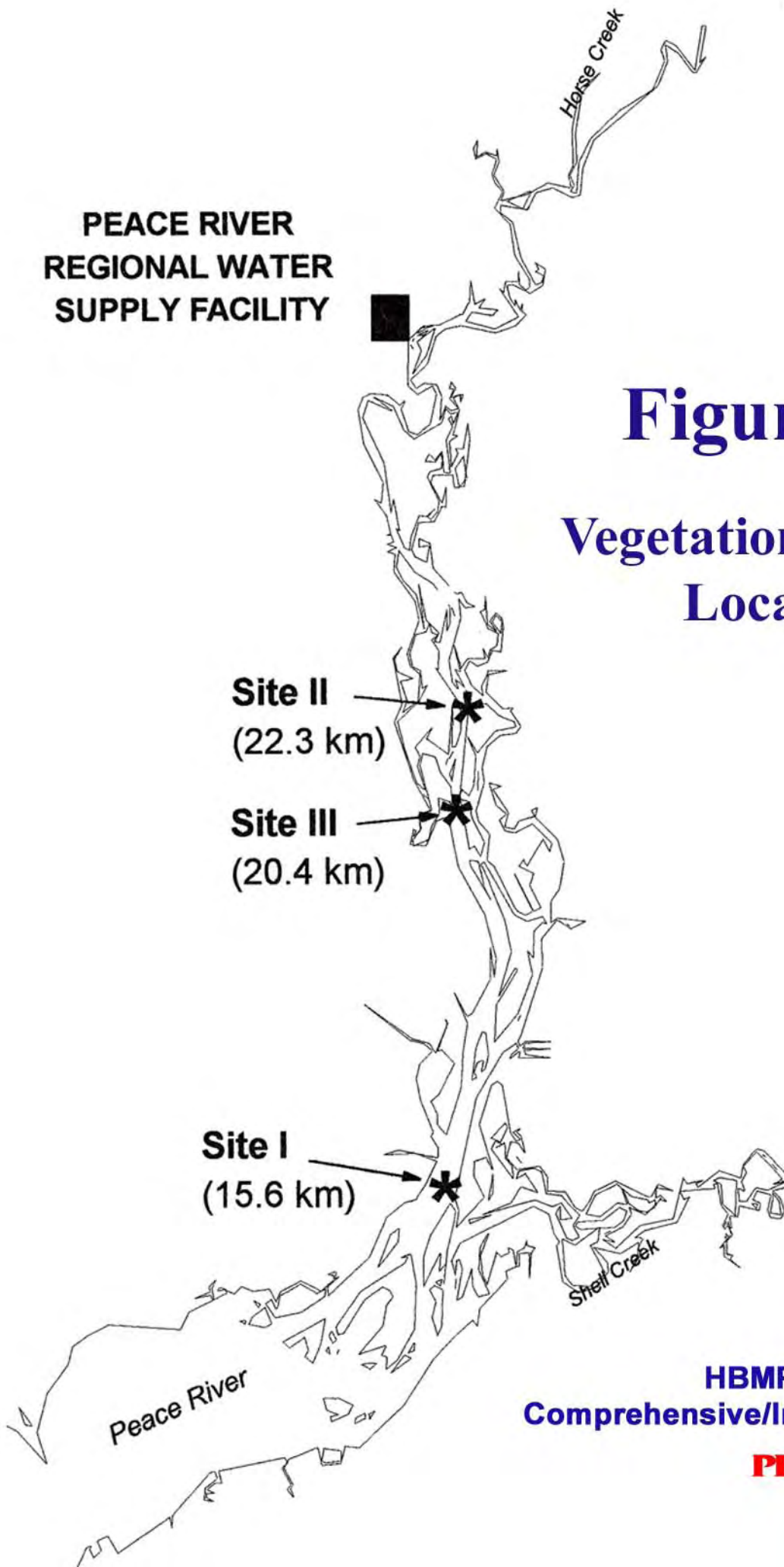
**Site I**  
(15.6 km)

Shell Creek

Peace River

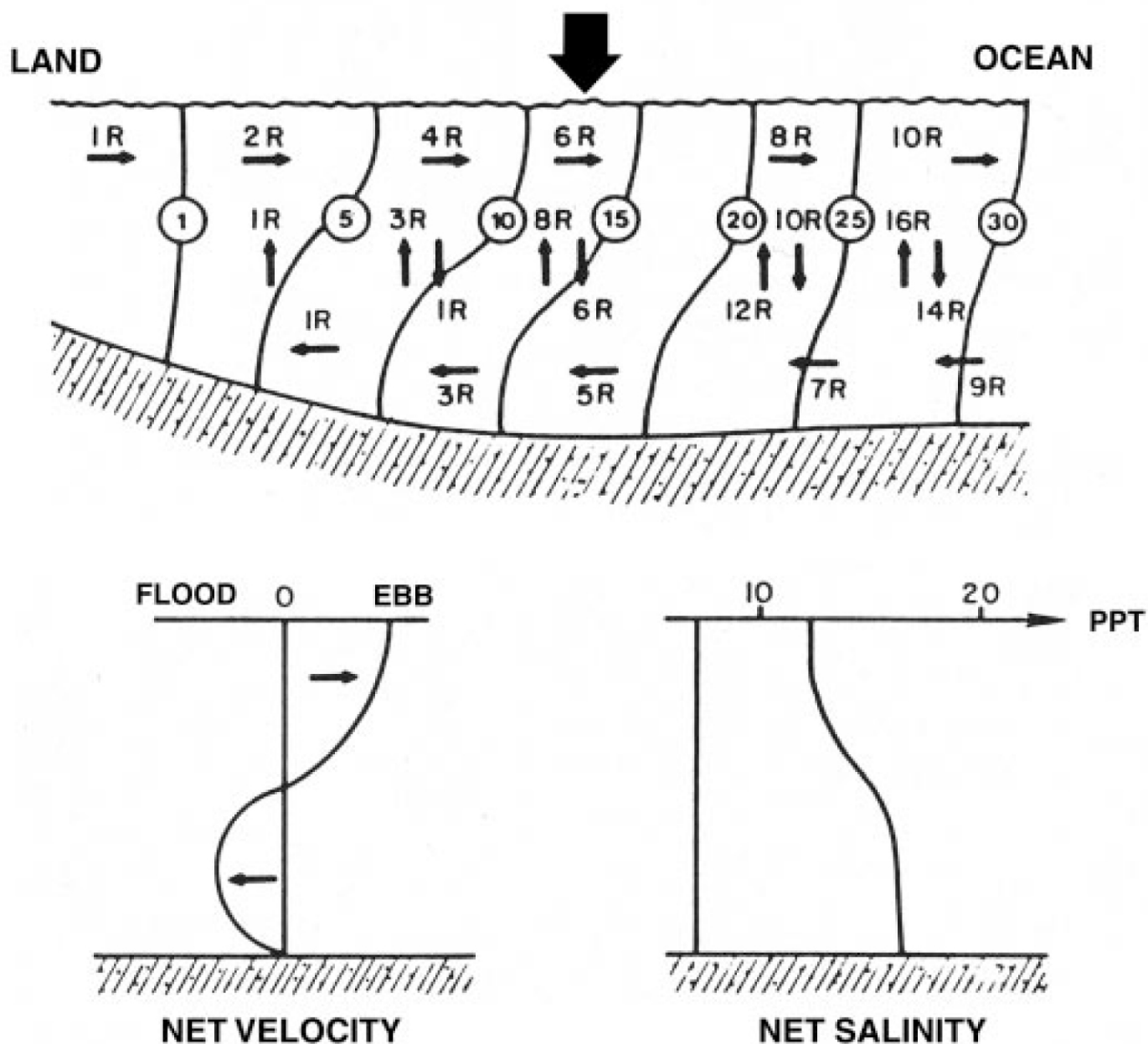
**HBMP 2004  
Comprehensive/Intrepretive Report**

**PBS**



## Figure 2.1

### Schematic Representation of the Net Circulation in the Mixing Zone of a Partially-Mixed Estuary



Horizontal and vertical water volume exchanges are expressed in units of river flow R. Isoleths of salinity (isohalines) in ppt are superimposed in the circulation, indicating the change of net salinity profiles (and stratification) from the tidal riverzone to the nearshore zone (Dryer 1979).

**Figure 2.2**  
**Mixing diagram for conservative variabls (a),**  
**and for variables for which the estuary is a source (b) or a sink (c)**

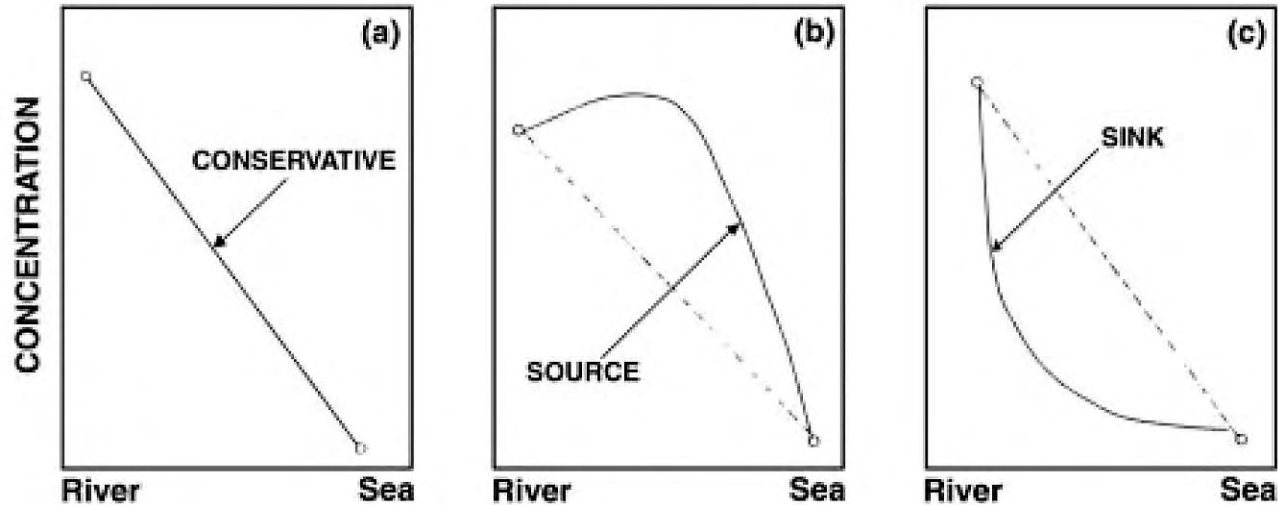


**Figure 2.3**  
**Picture Model of an Estuarine Food Web**

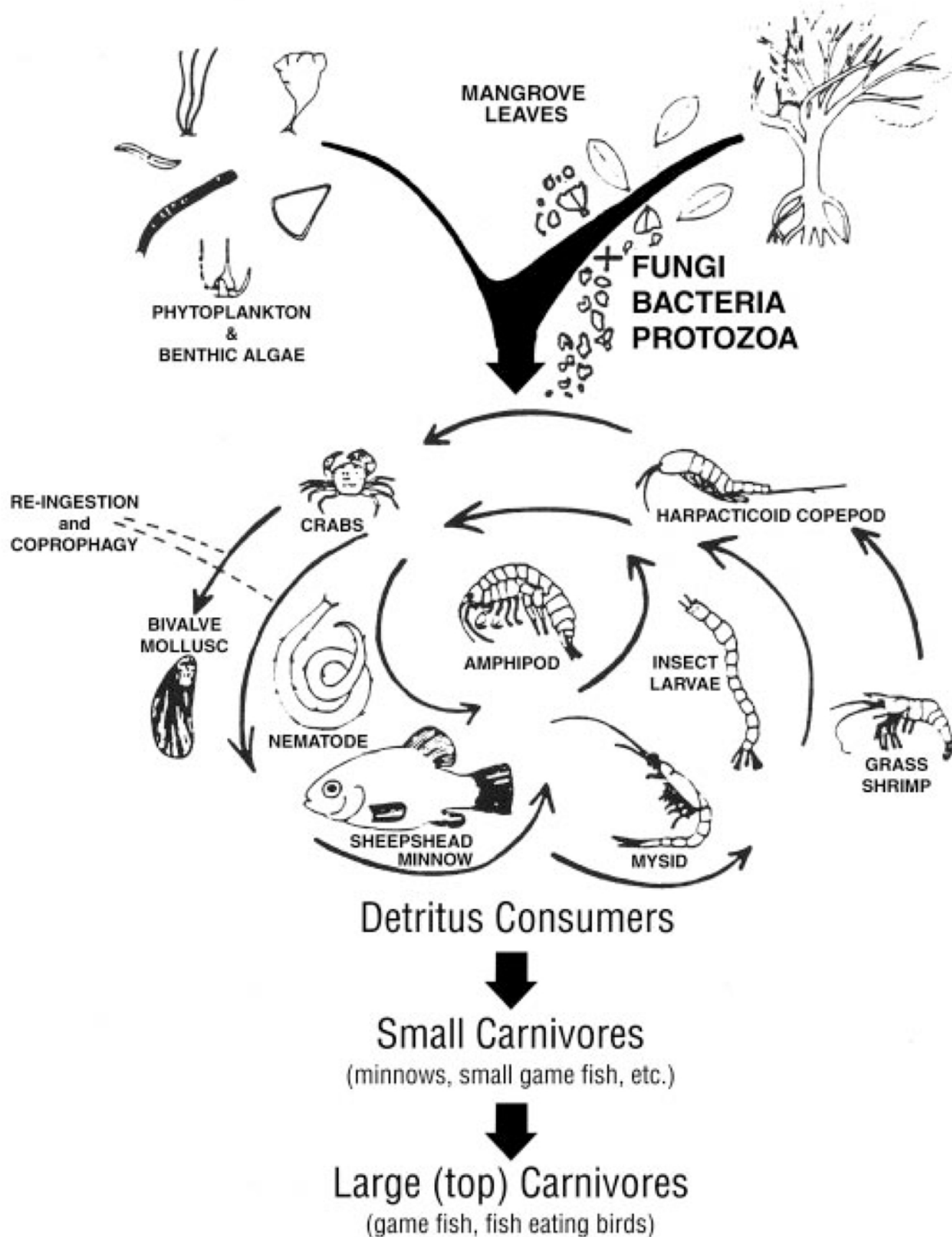
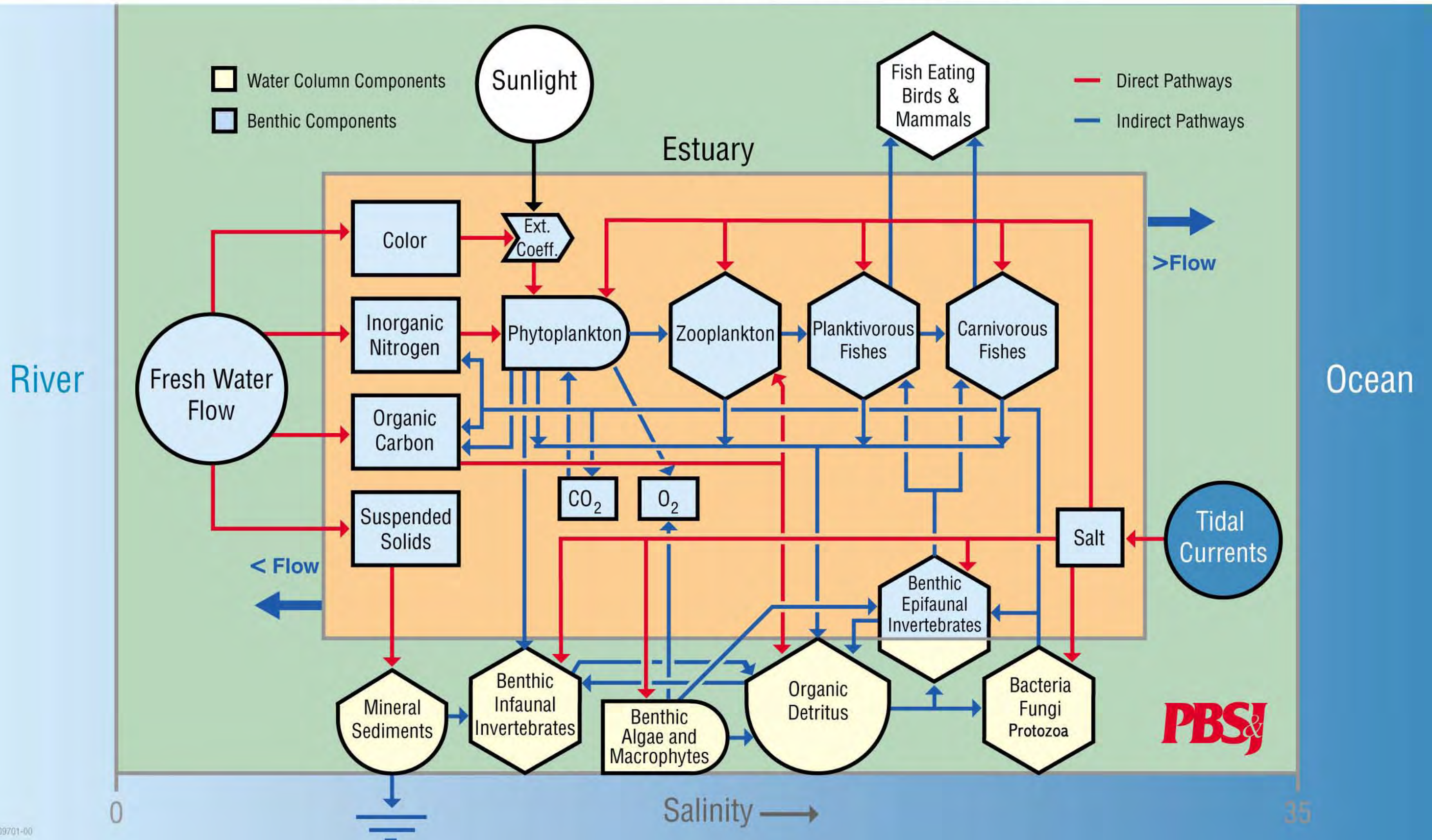




**Figure 2.4**  
**Conceptual Model of the Peace River Estuarine System**





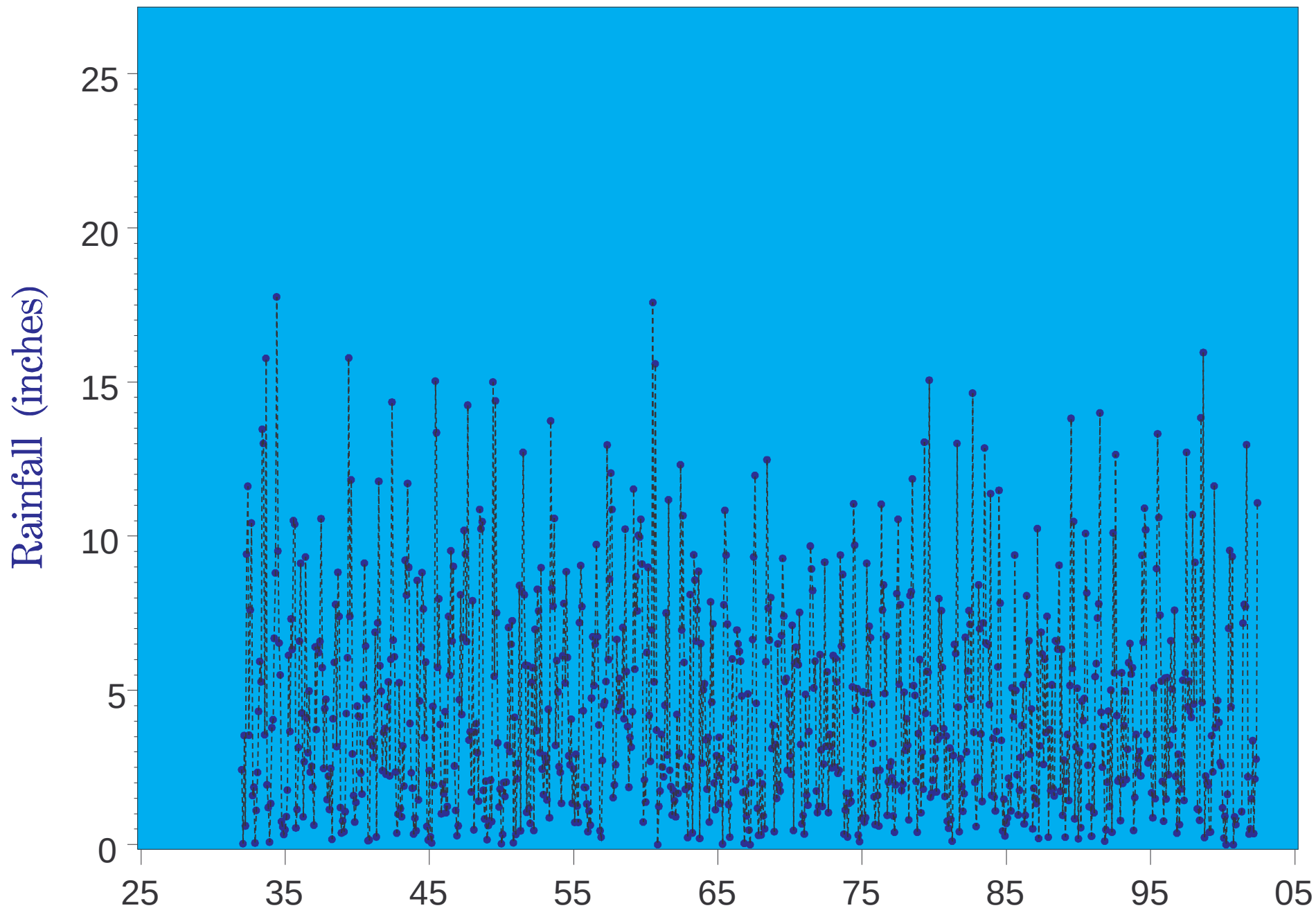


Figure 4.1.1 Total monthly rainfall at long-term Bartow gage (1932-2002)

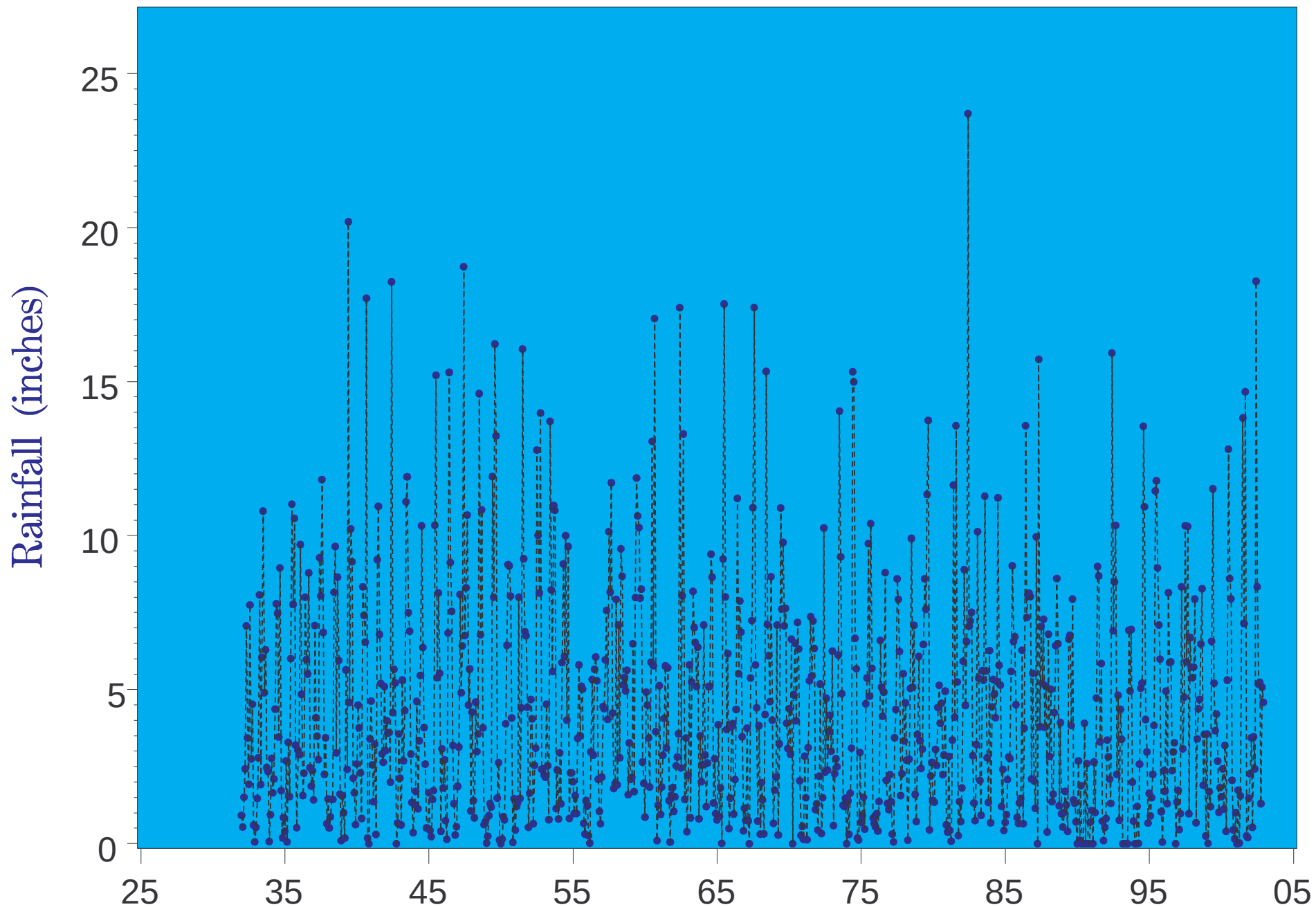


Figure 4.1.2 Total monthly rainfall at long-term Arcadia gage (1932-2002)

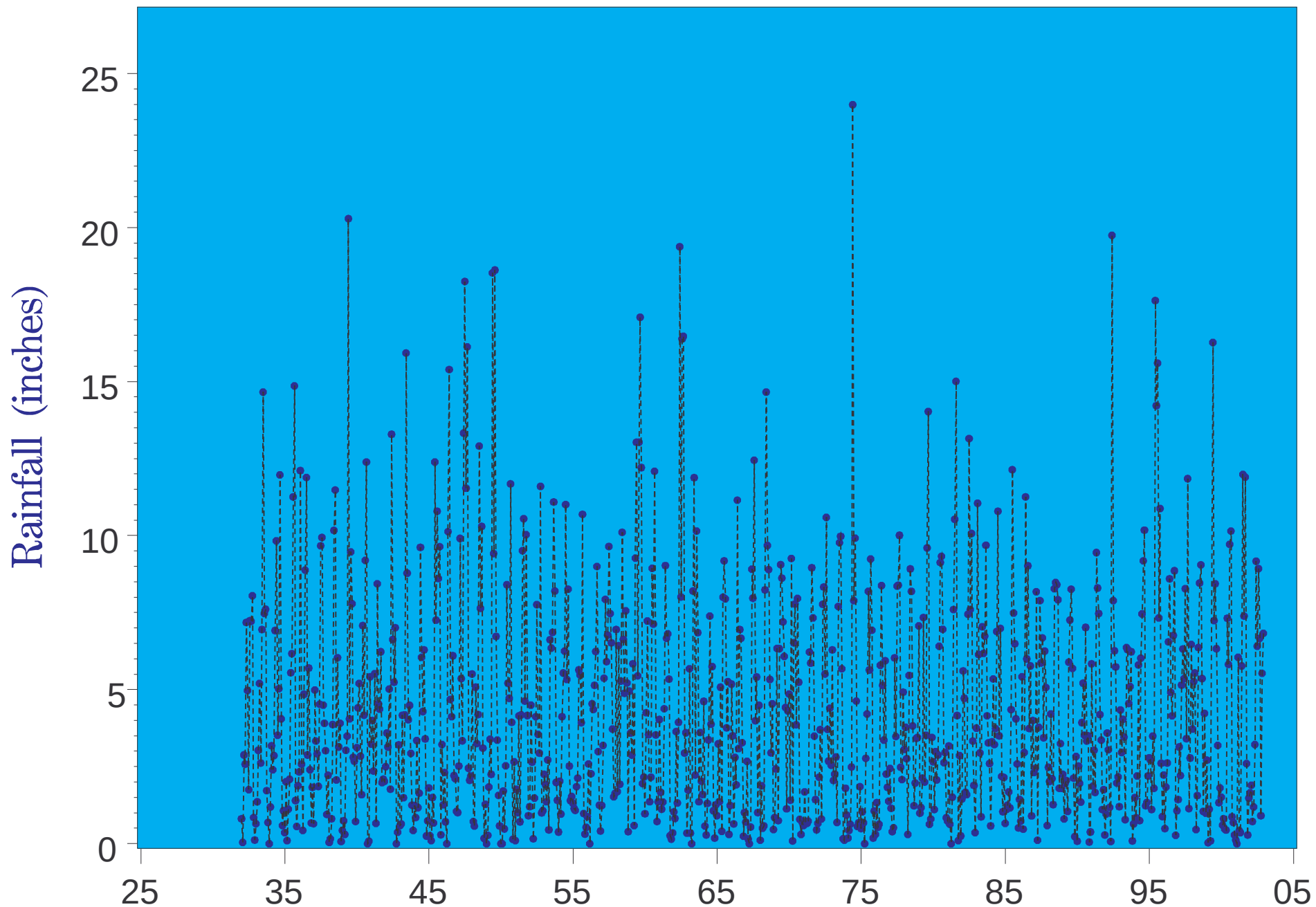


Figure 4.1.3 Total monthly rainfall at long-term Punta Gorda gage (1932-2002)

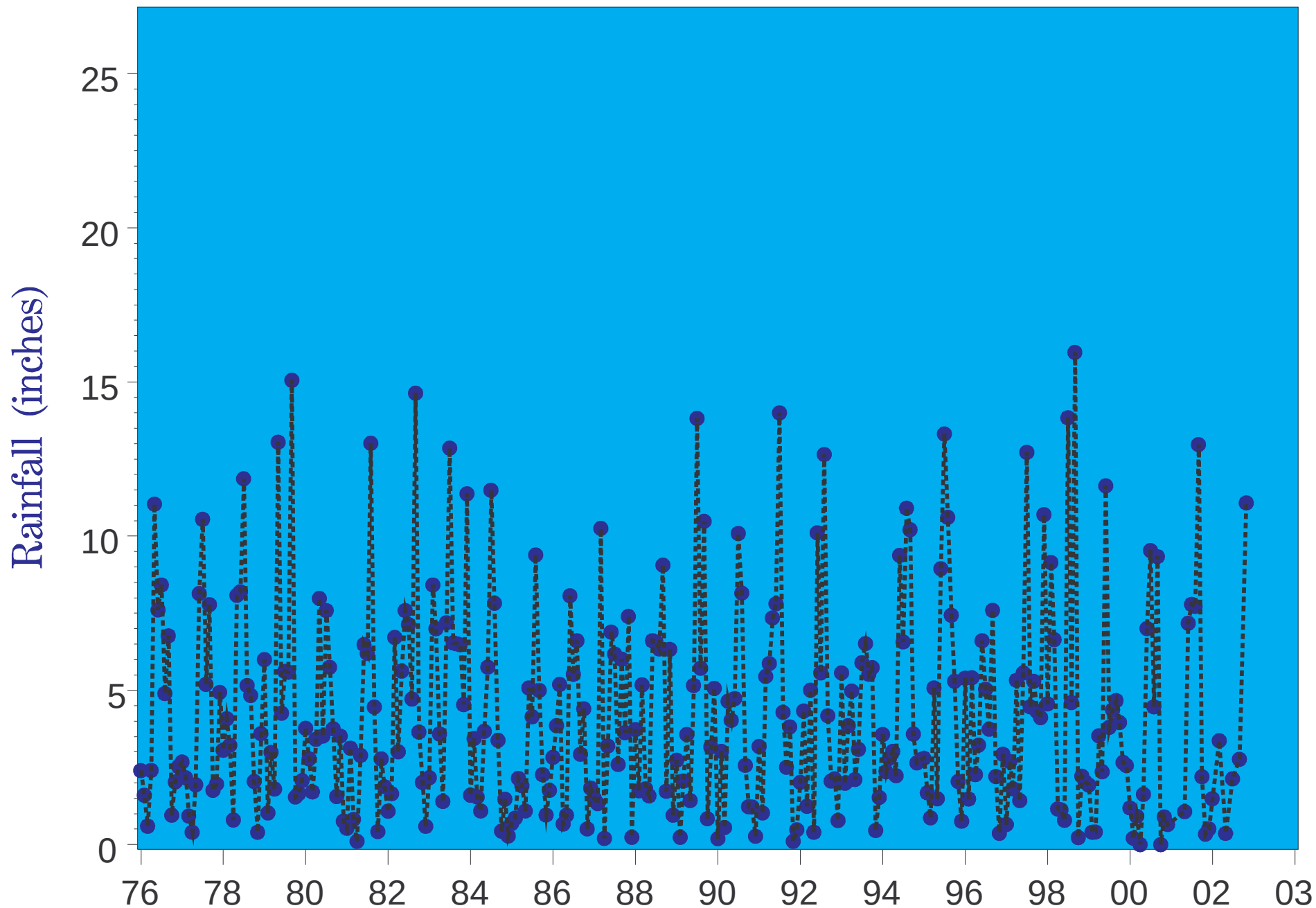


Figure 4.1.4 Total monthly rainfall at long-term Bartow gage (1976-2002)

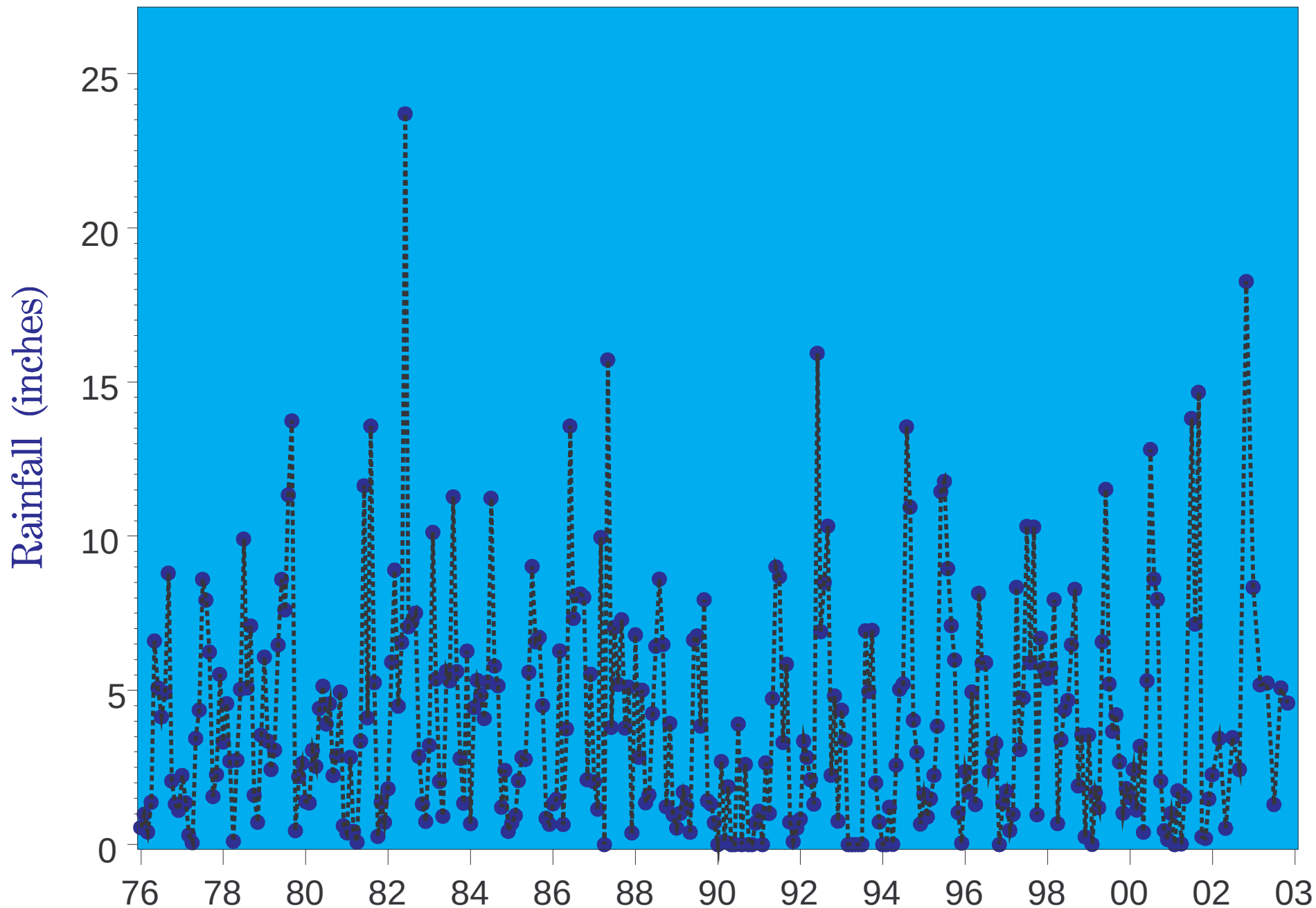


Figure 4.1.5 Total monthly rainfall at long-term Arcadia gage (1976-2002)

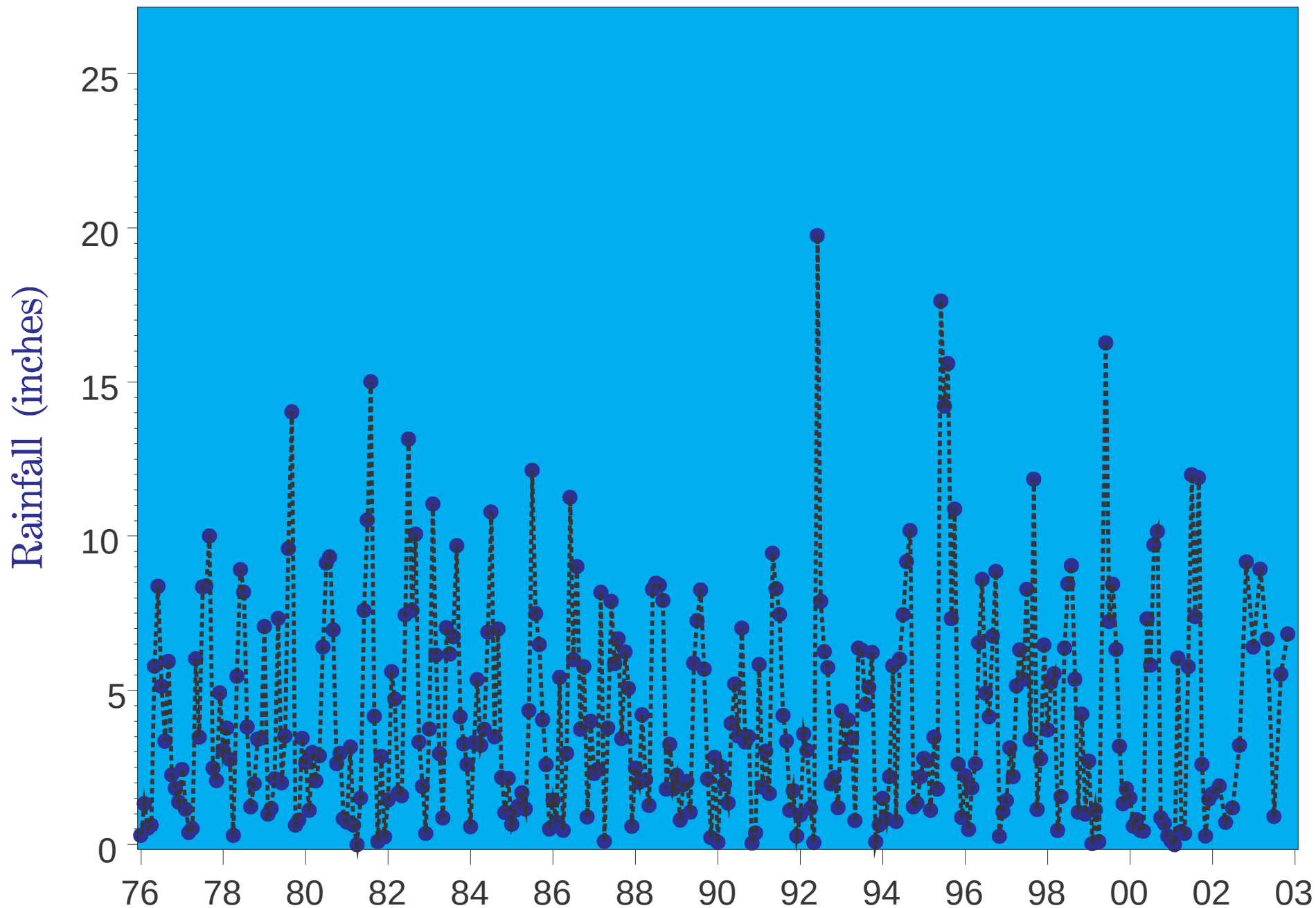


Figure 4.1.6 Total monthly rainfall at long-term Punta Gorda gage (1976-2002)

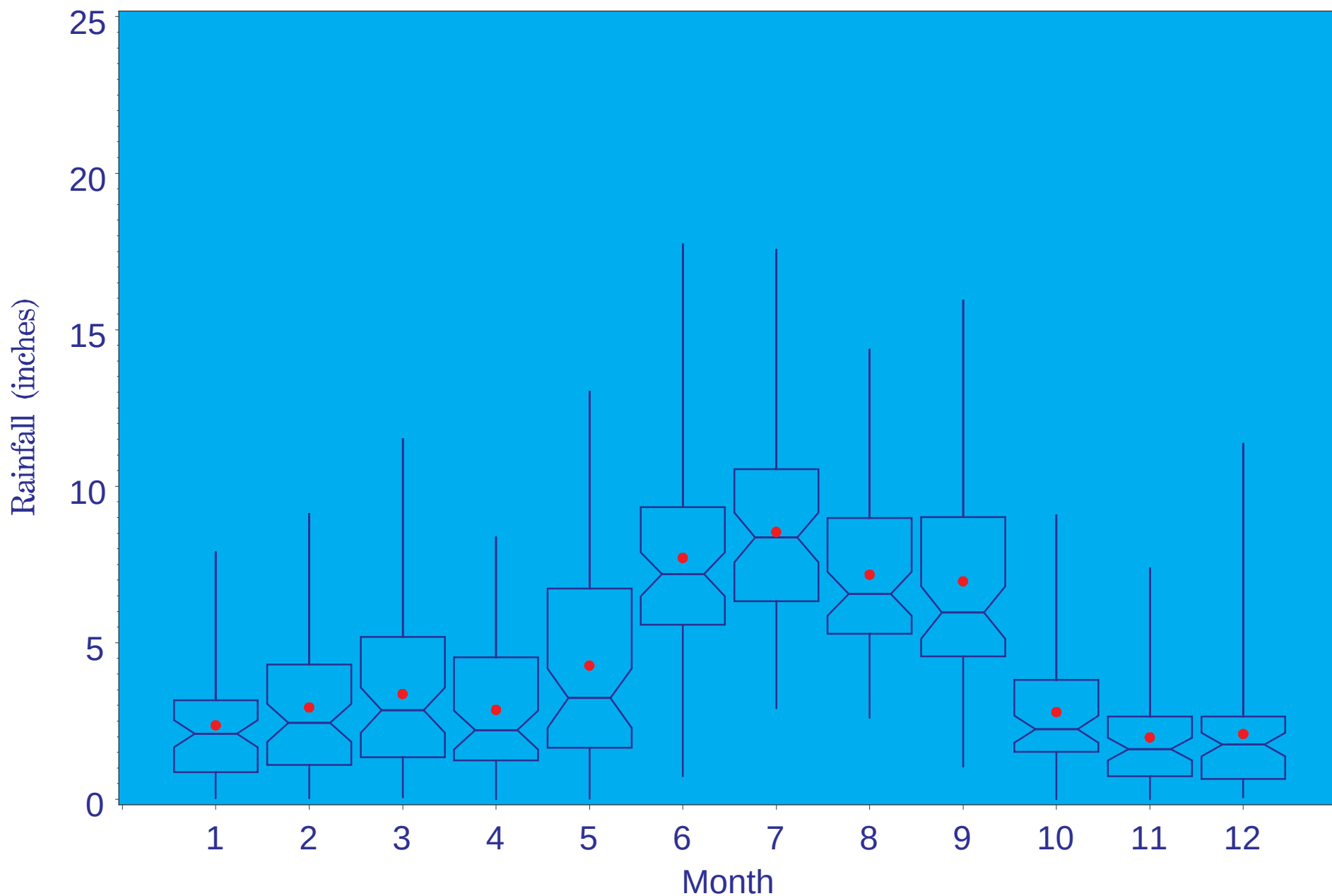


Figure 4.1.7 Mean monthly boxplots of total rainfall at Bartow (1932-2002)



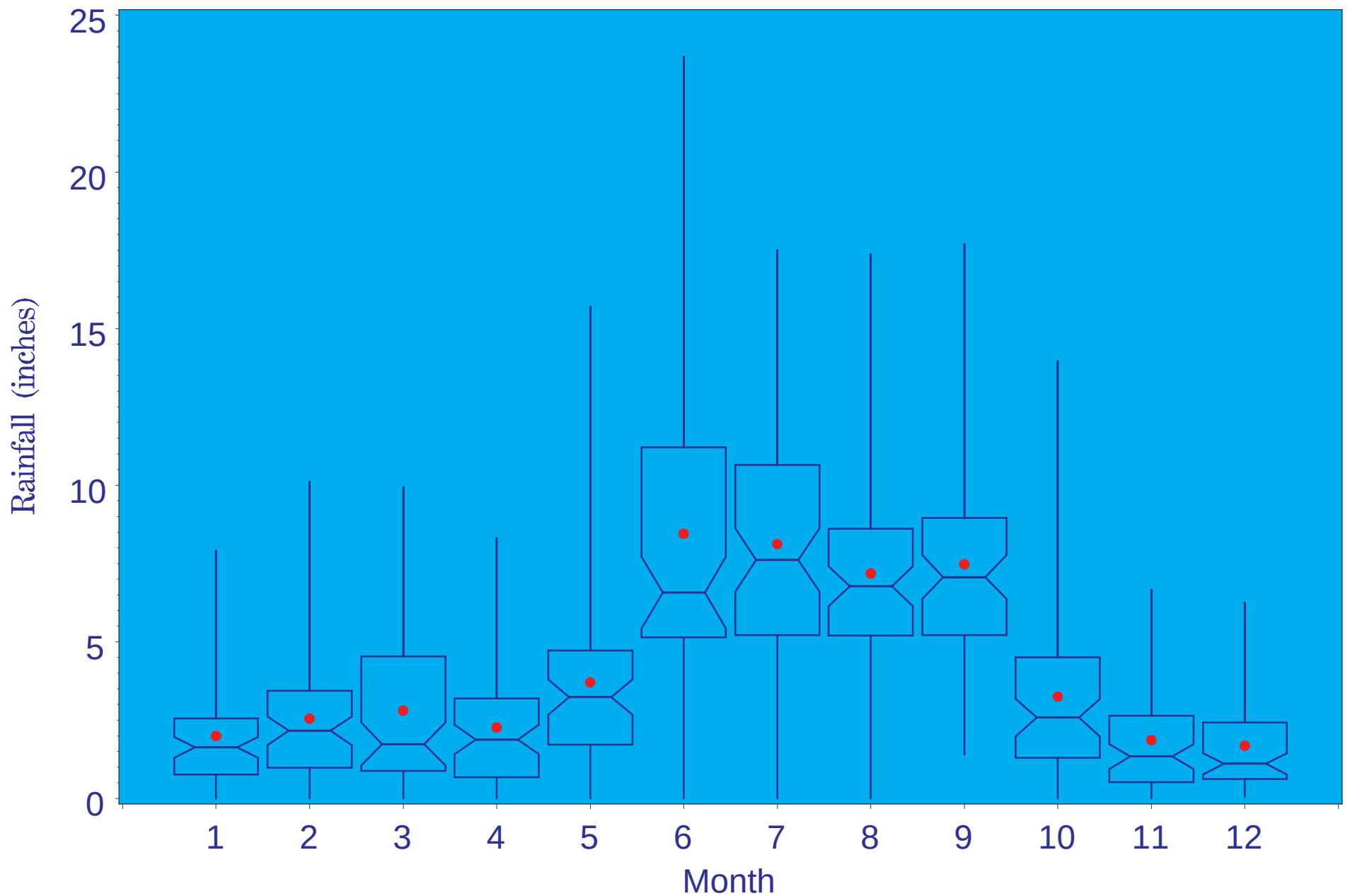


Figure 4.1.8 Mean monthly boxplots of total rainfall at Arcadia (1932-2002)

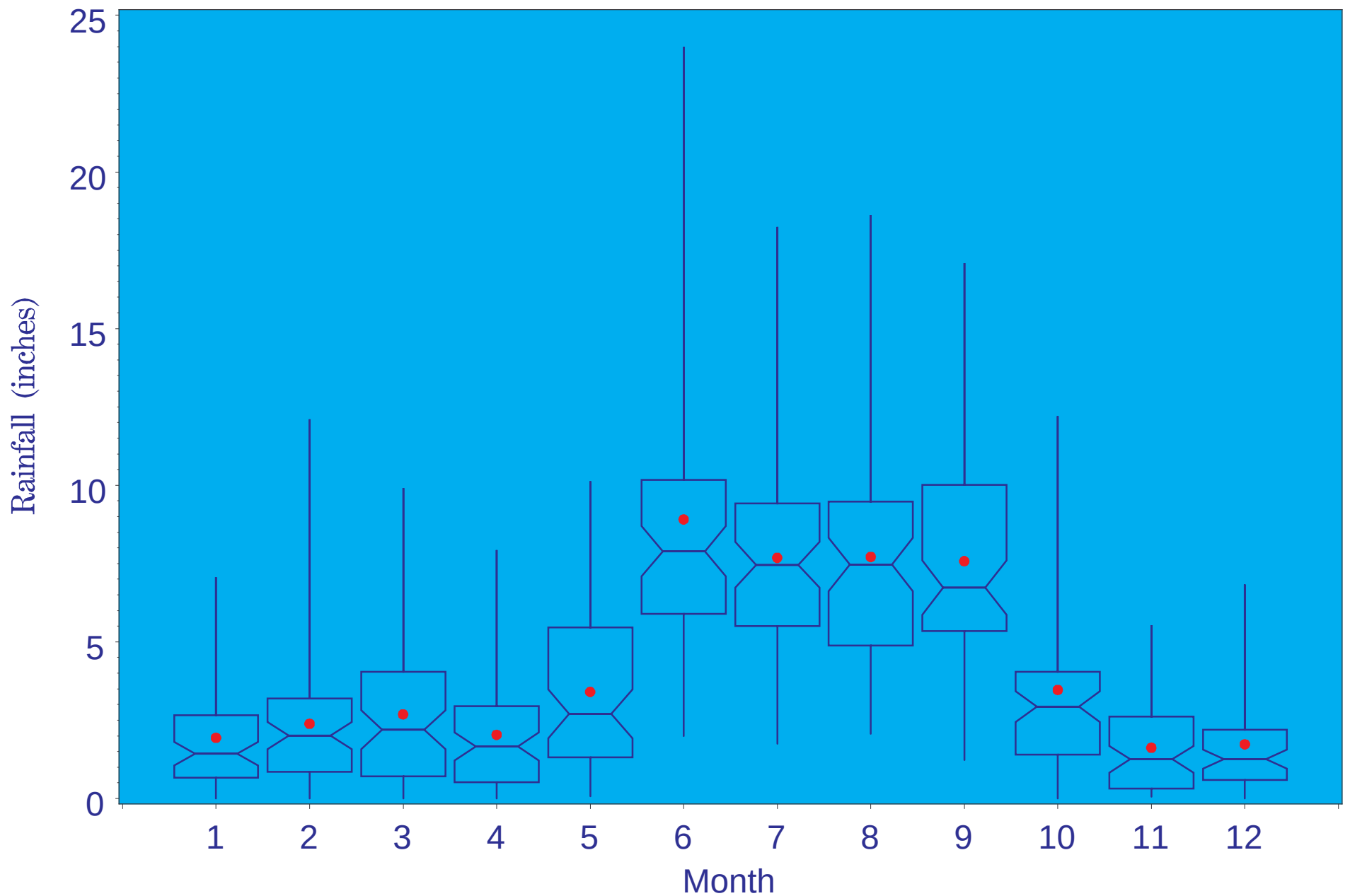


Figure 4.1.9 Mean monthly boxplots of total rainfall at Punta Gorda (1932-2002)

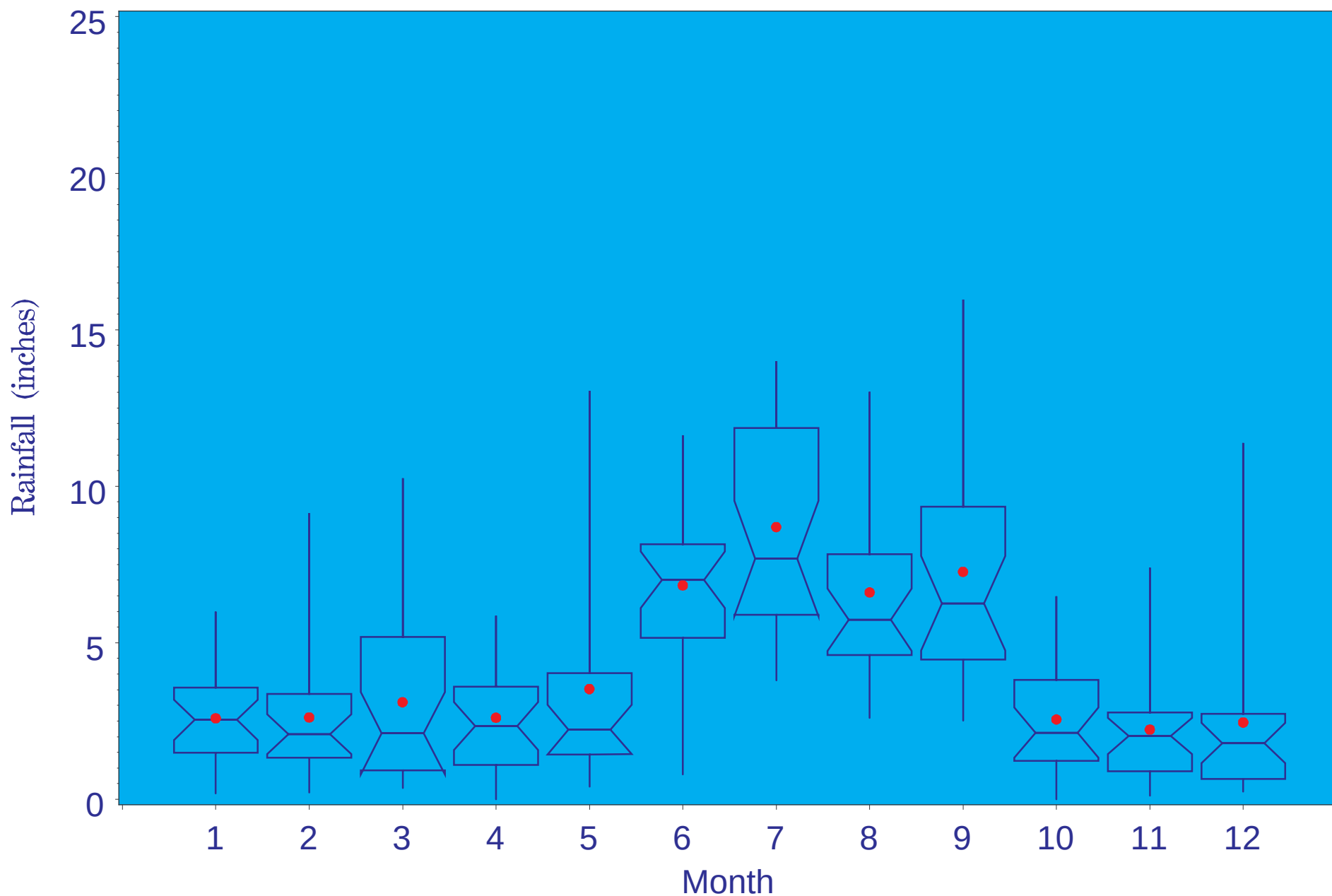


Figure 4.1.10 Mean monthly boxplots of total rainfall at Bartow (1976-2002)

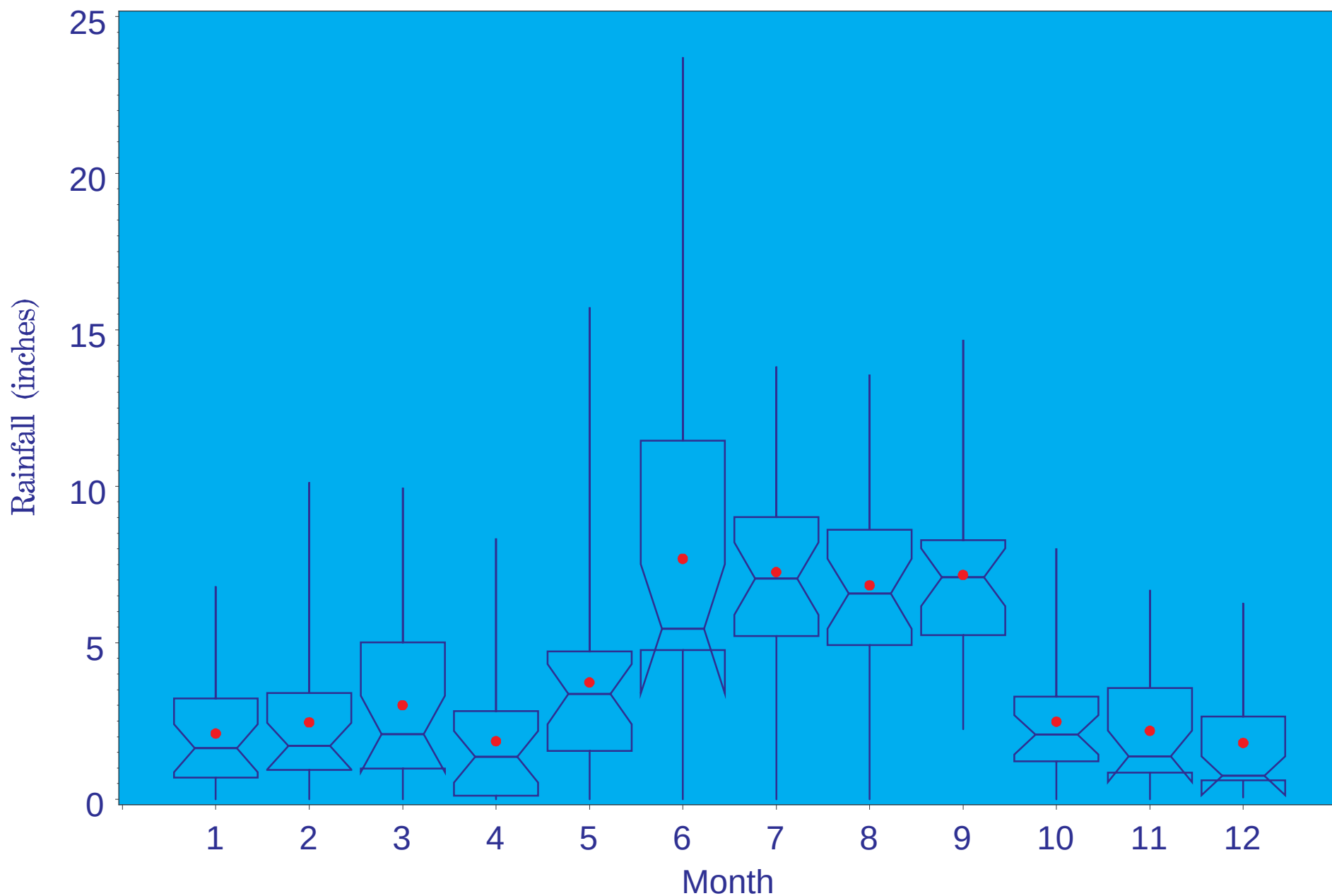


Figure 4.1.11 Mean monthly boxplots of total rainfall at Arcadia (1976-2002)

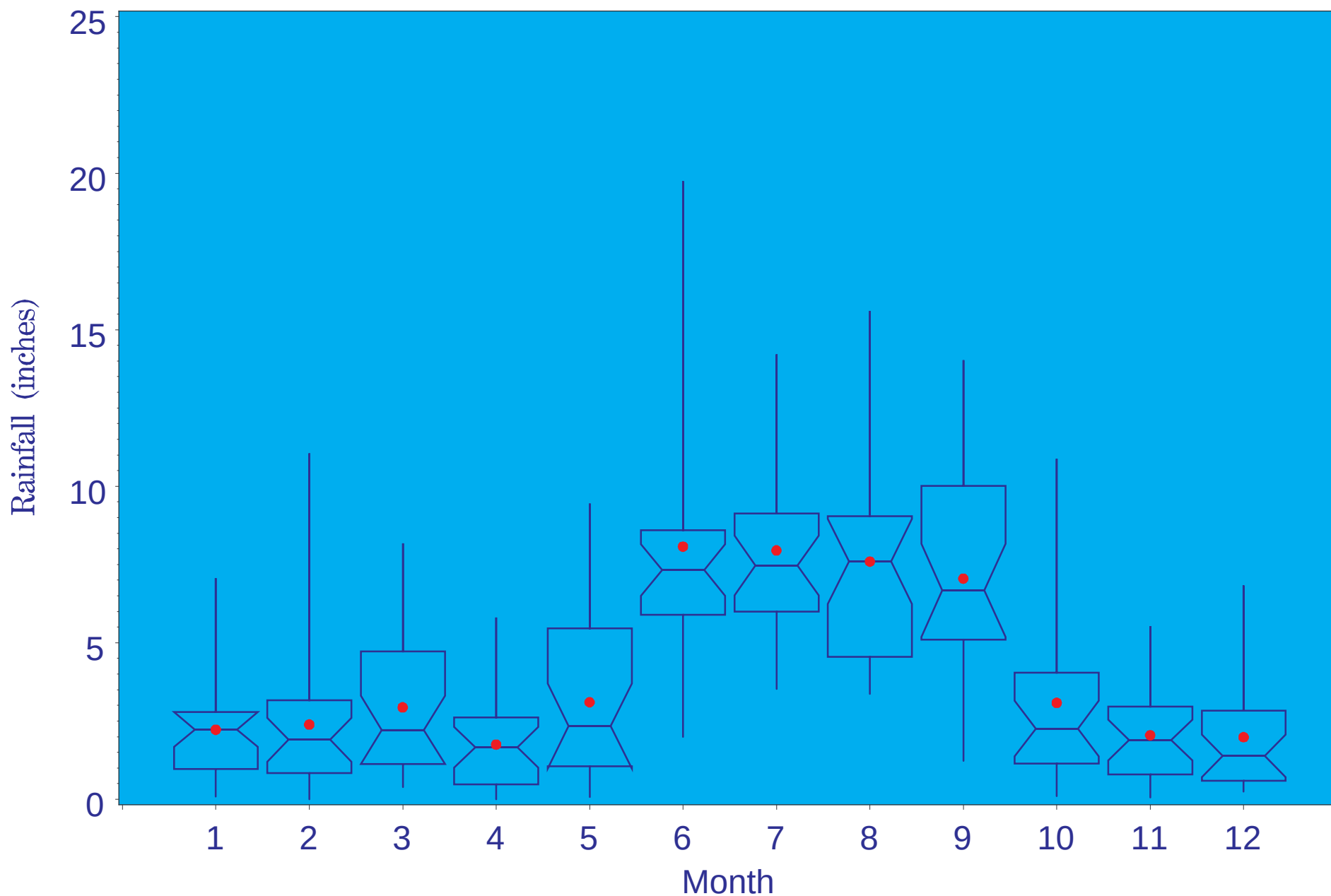


Figure 4.1.12 Mean monthly boxplots of total rainfall at Punta Gorda (1976-2002)

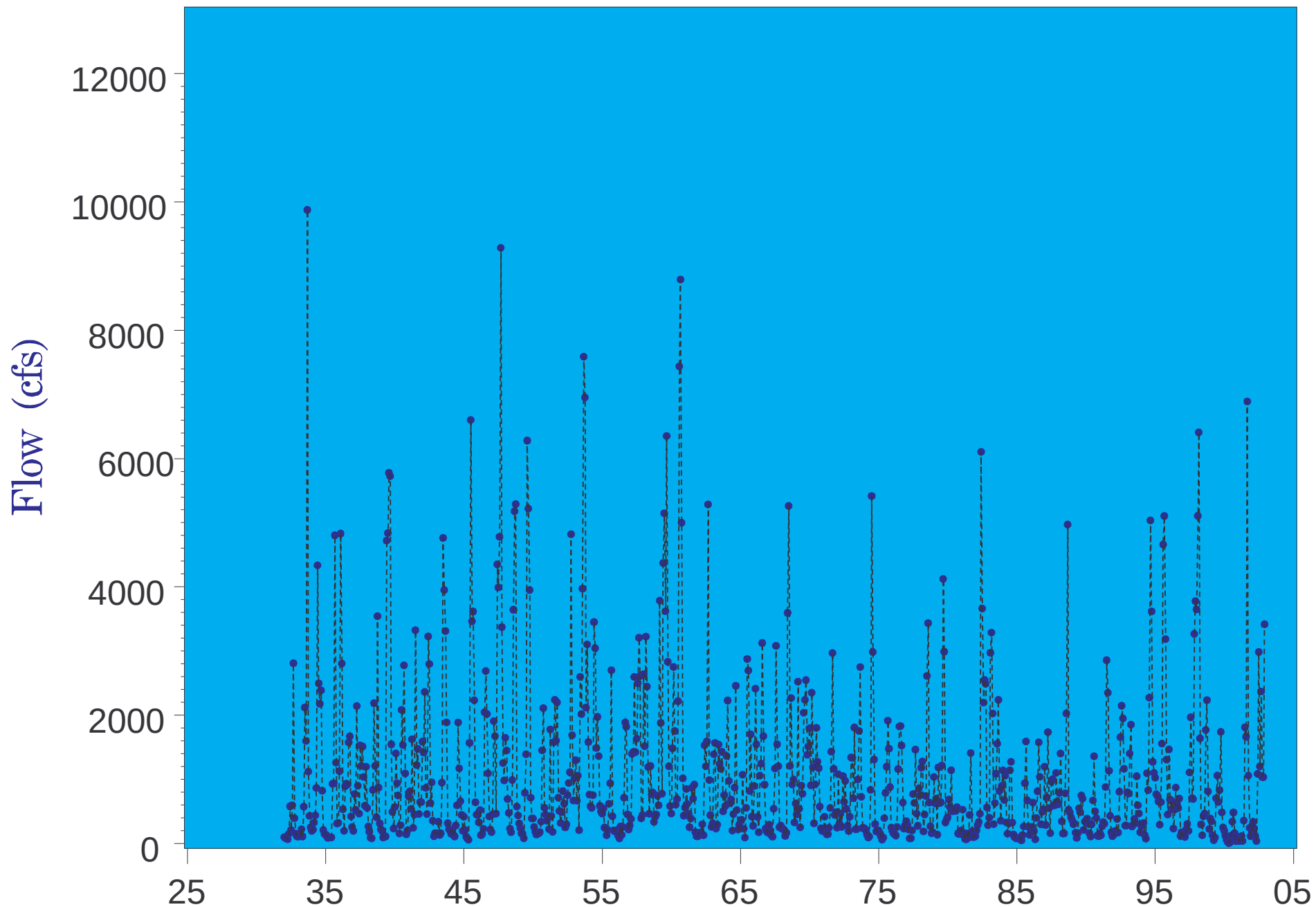


Figure 4.2.1 Monthly mean flow at long-term Peace River Arcadia gage (1932-2002)

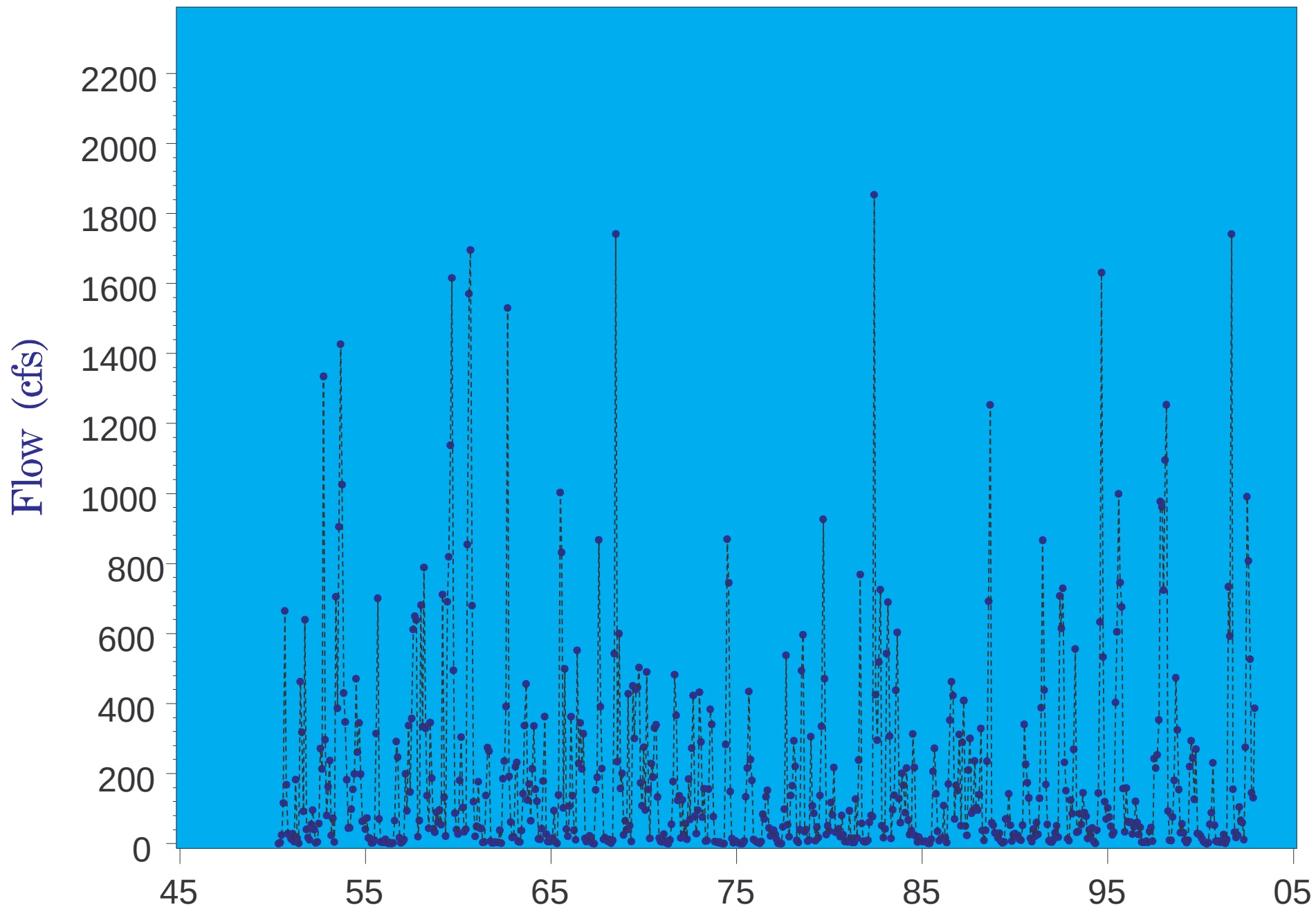


Figure 4.2.2 Monthly mean flow at long-term Horse Creek gage (1951-2002)



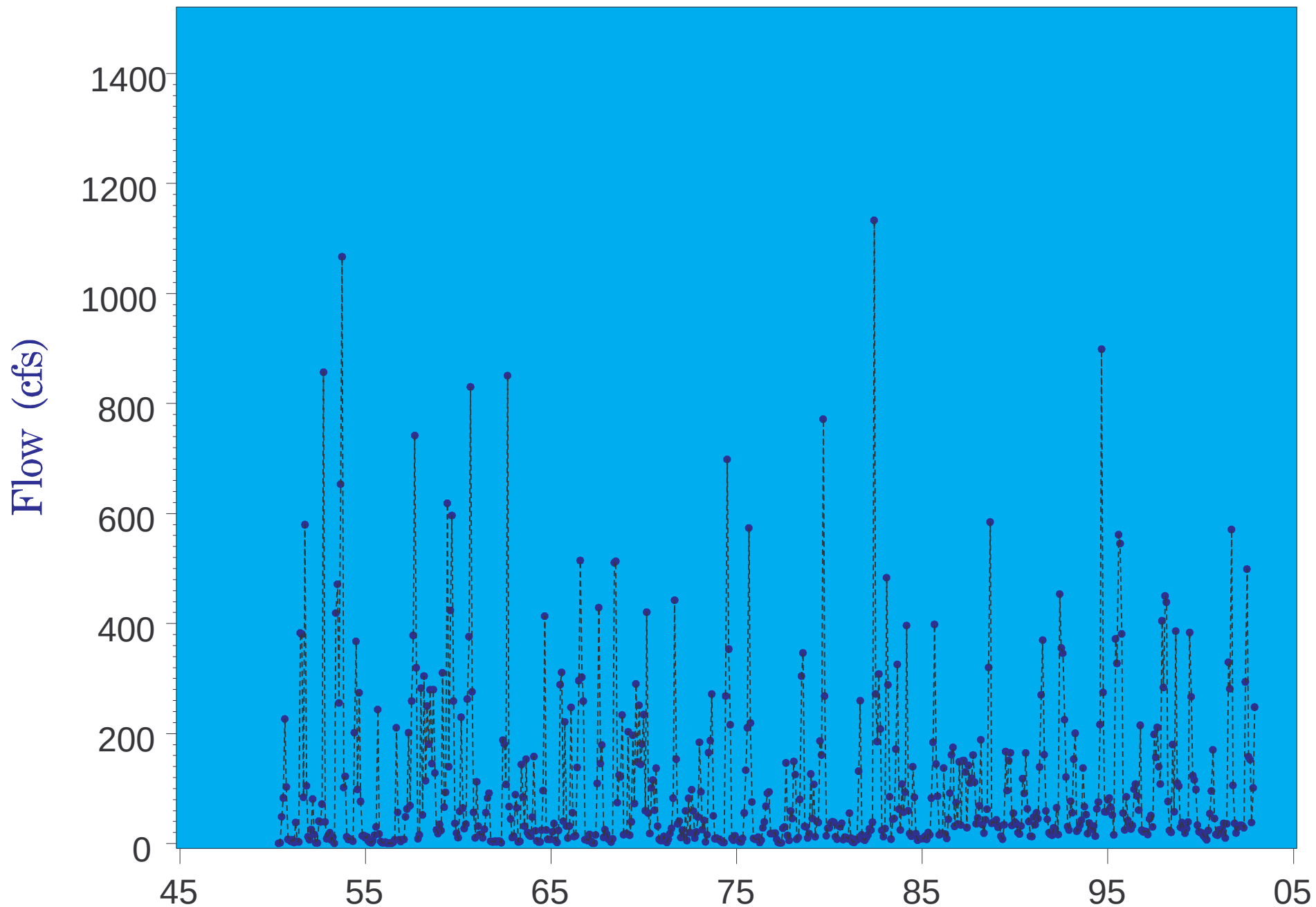


Figure 4.2.3 Monthly mean flow at long-term Joshua Creek gage (1951-2002)

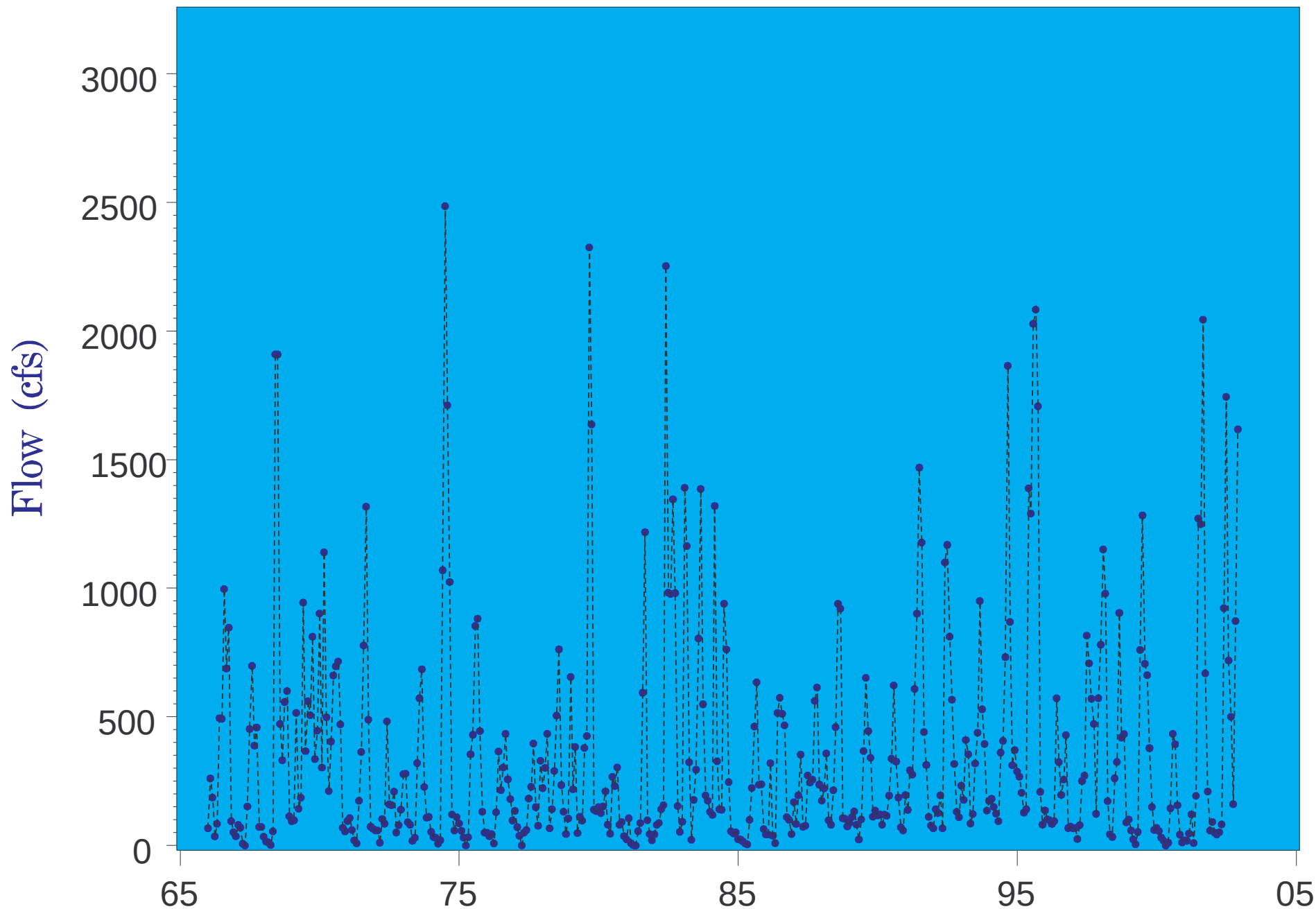


Figure 4.2.4 Monthly mean flow at long-term Shell Creek gage (1966-2002)

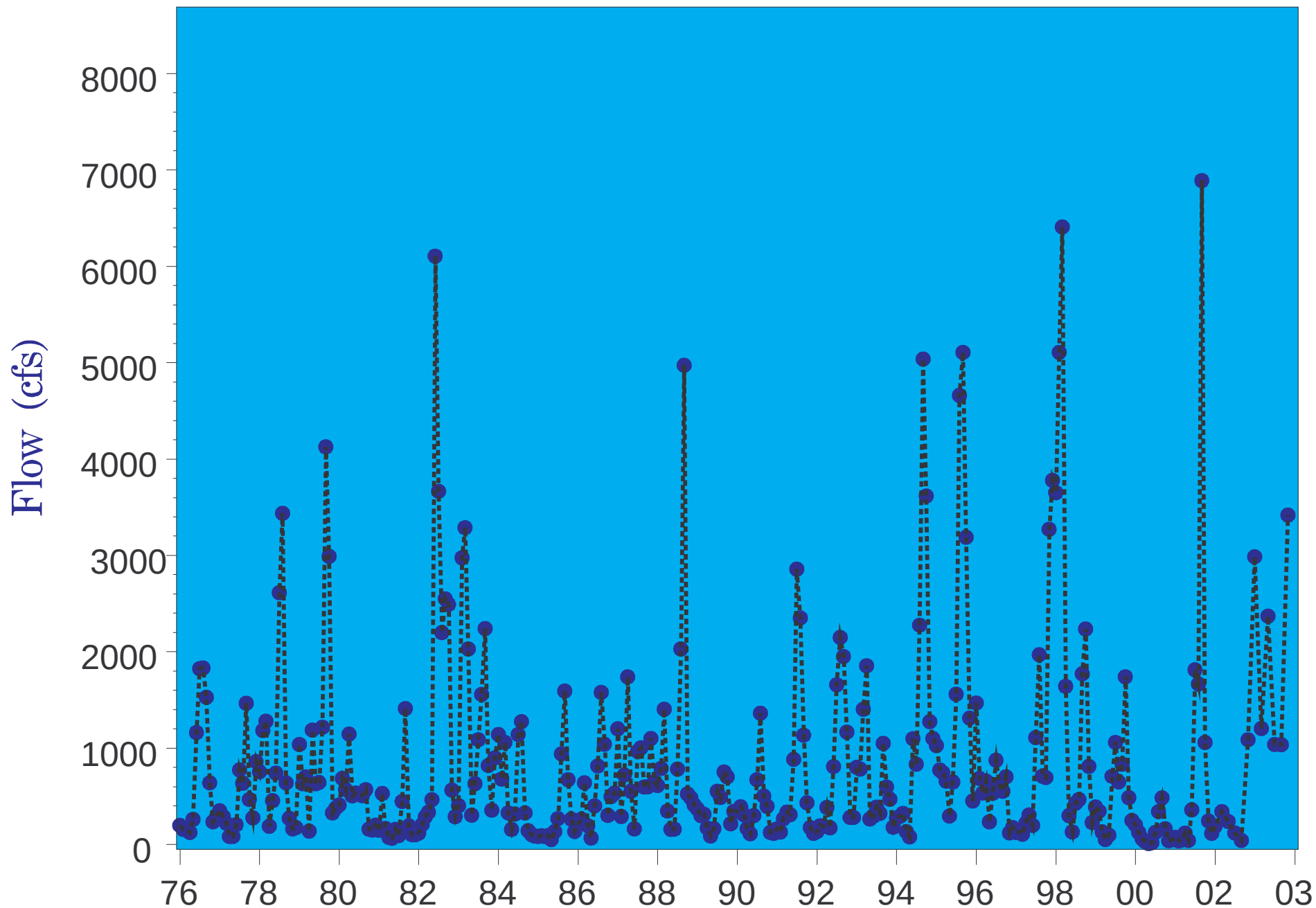


Figure 4.2.5 Monthly mean flow at long-term Peace River Arcadia gage (1976-2002)

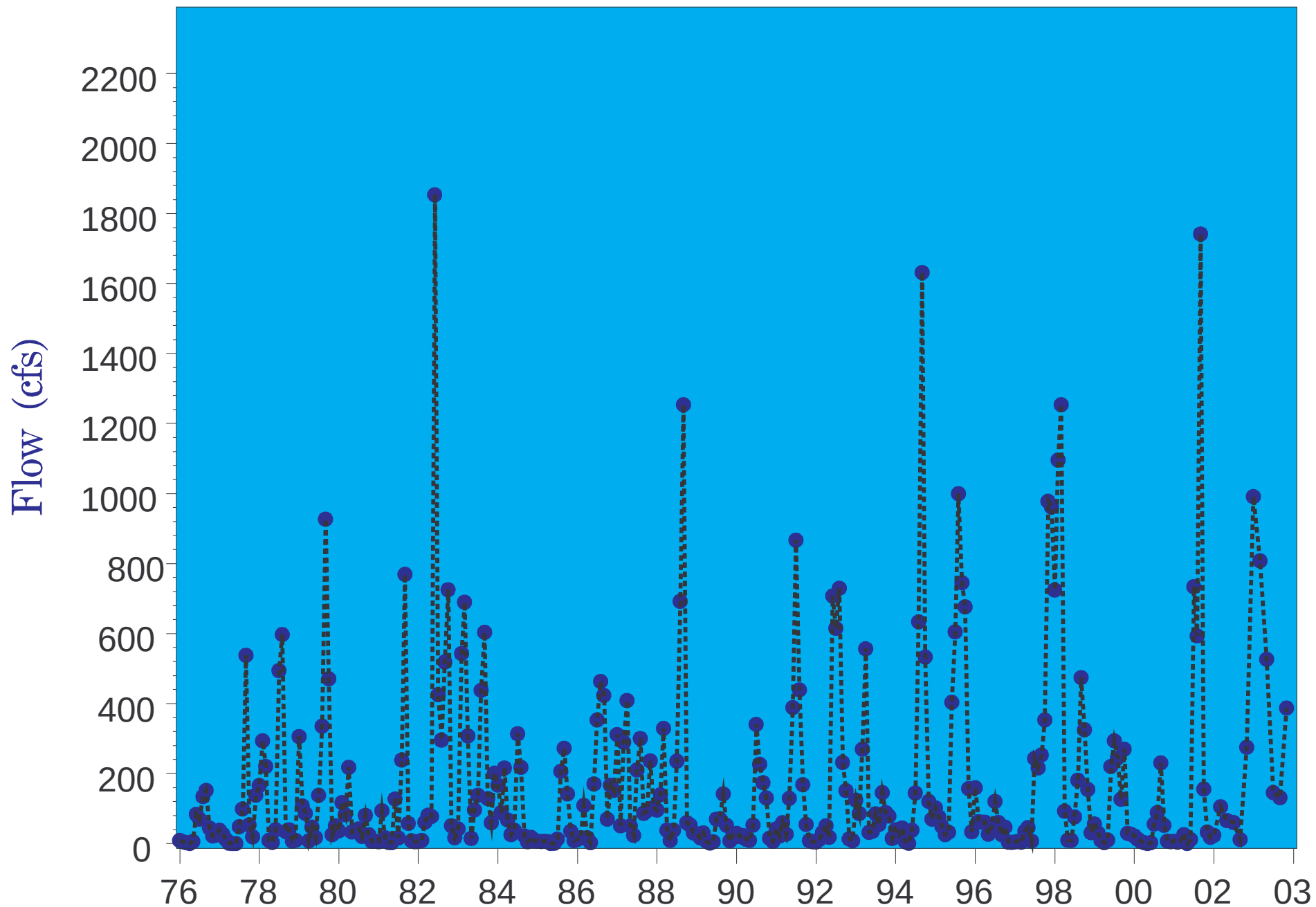


Figure 4.2.6 Monthly mean flow at long-term Horse Creek gage (1976-2002)

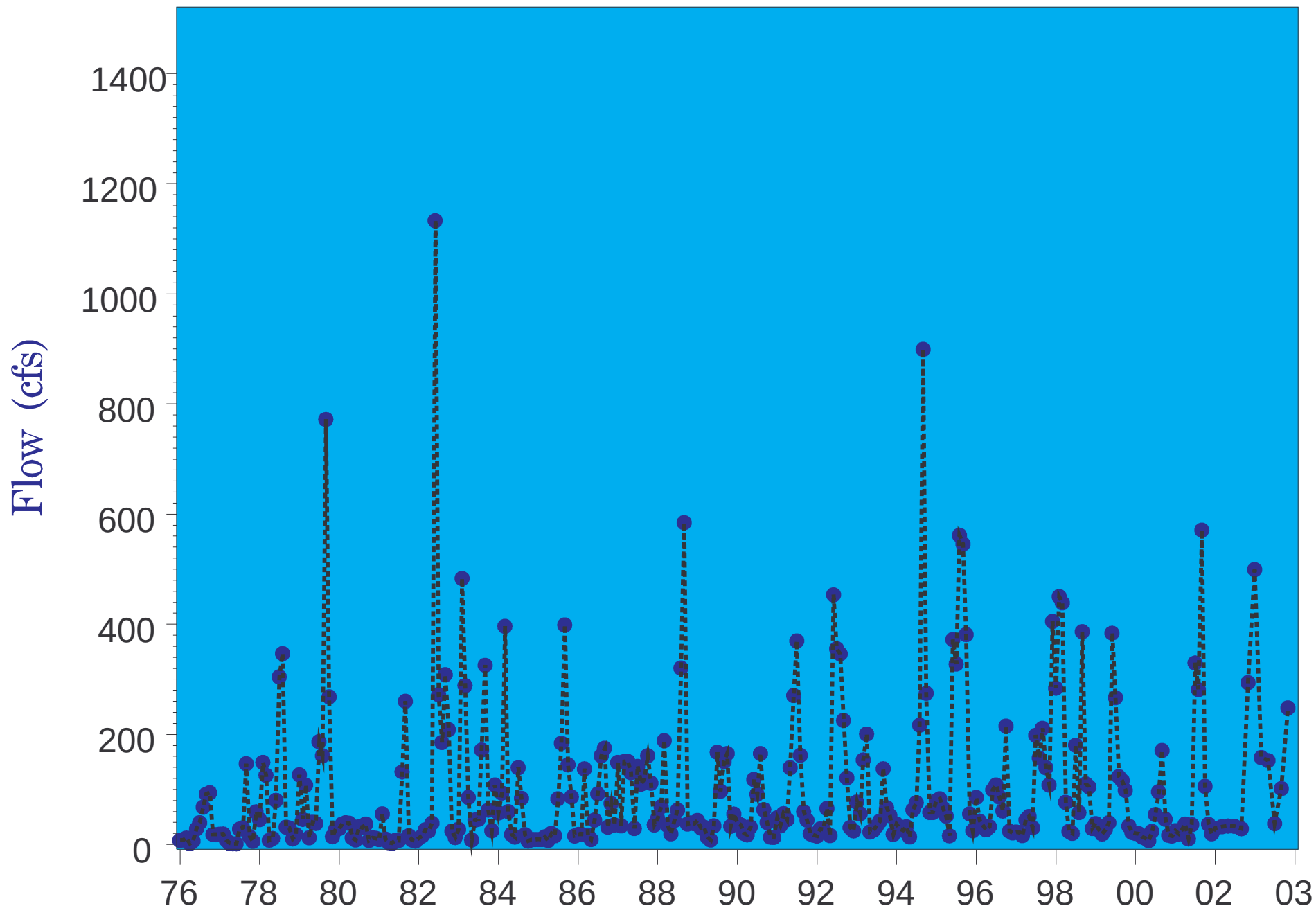


Figure 4.2.7 Monthly mean flow at long-term Joshua Creek gage (1976-2002)

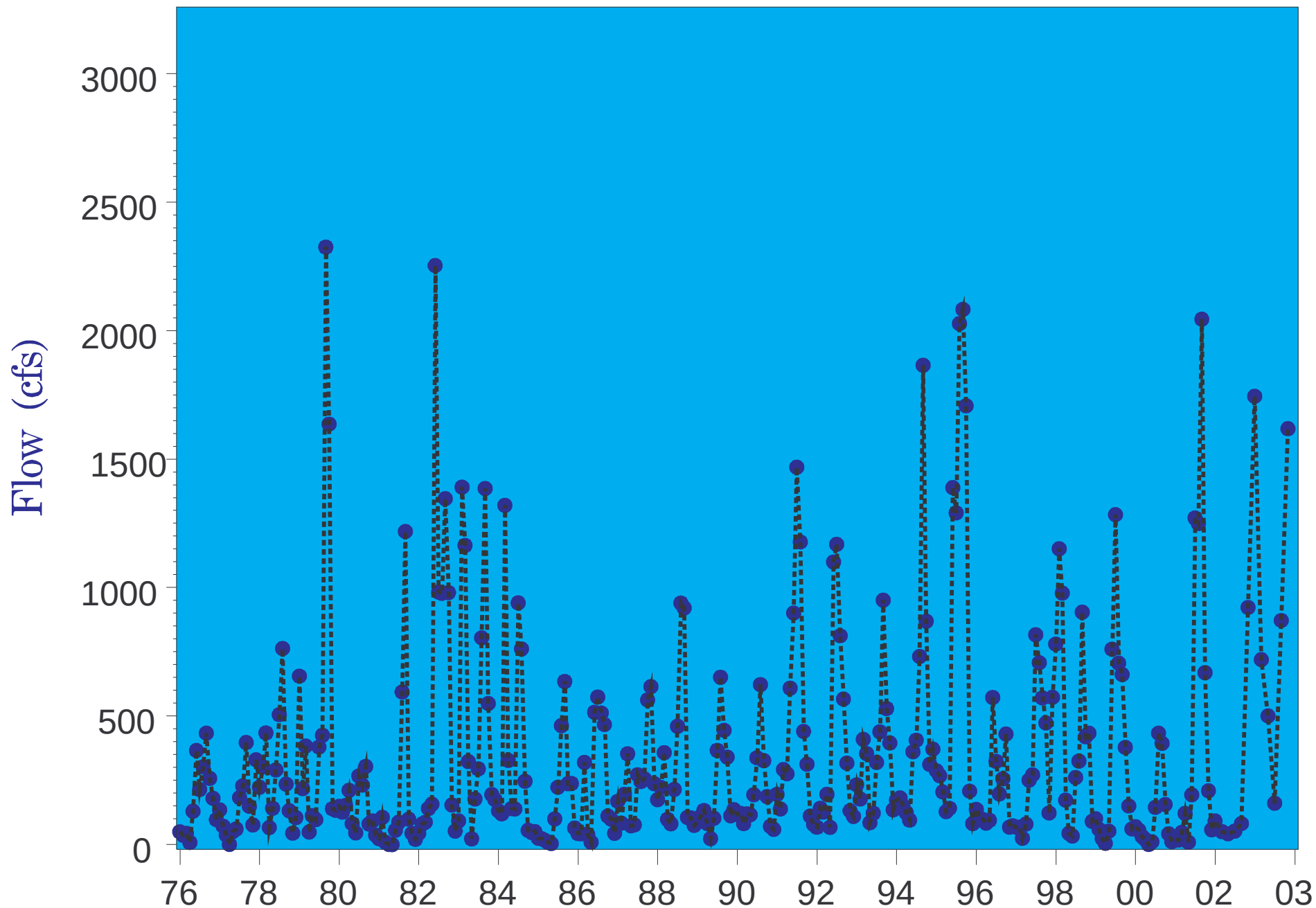


Figure 4.2.8 Monthly mean flow at long-term Shell Creek gage (1976-2002)

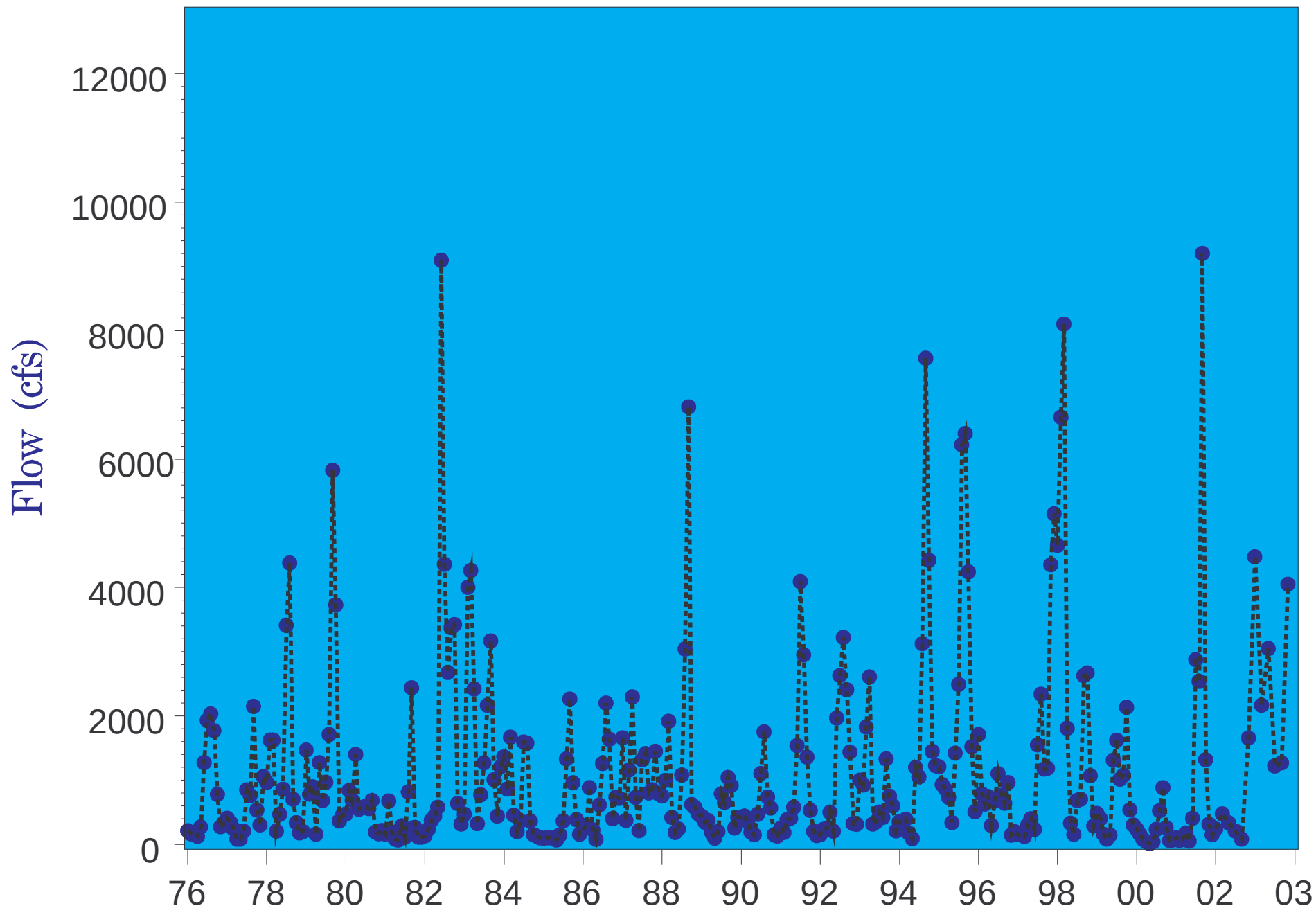


Figure 4.2.9 Total monthly gage flow upstream of the Water Treatment Facility (1976-2002)

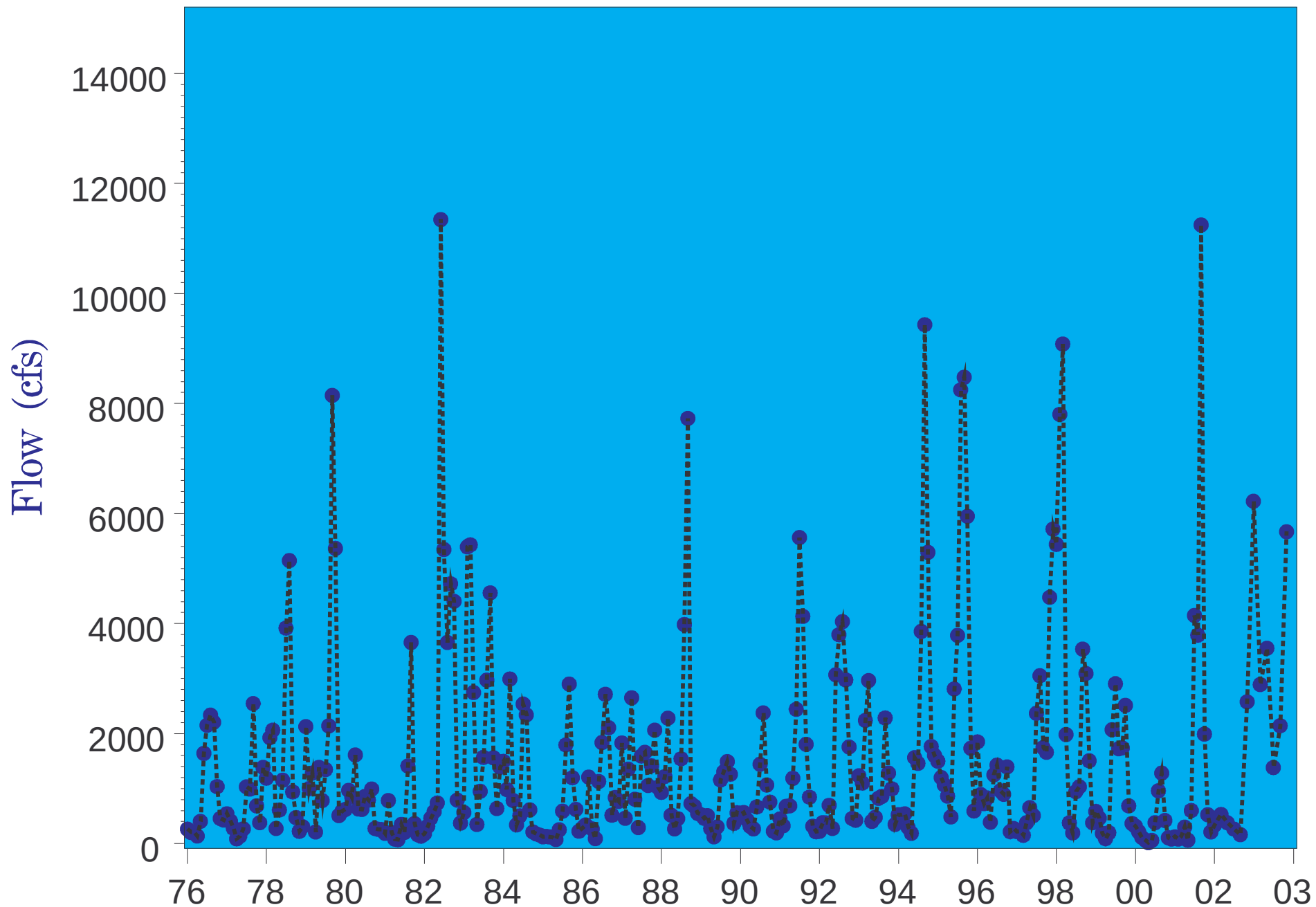


Figure 4.2.10 Total monthly gage flow upstream of the US41 Bridge (1976-2002)



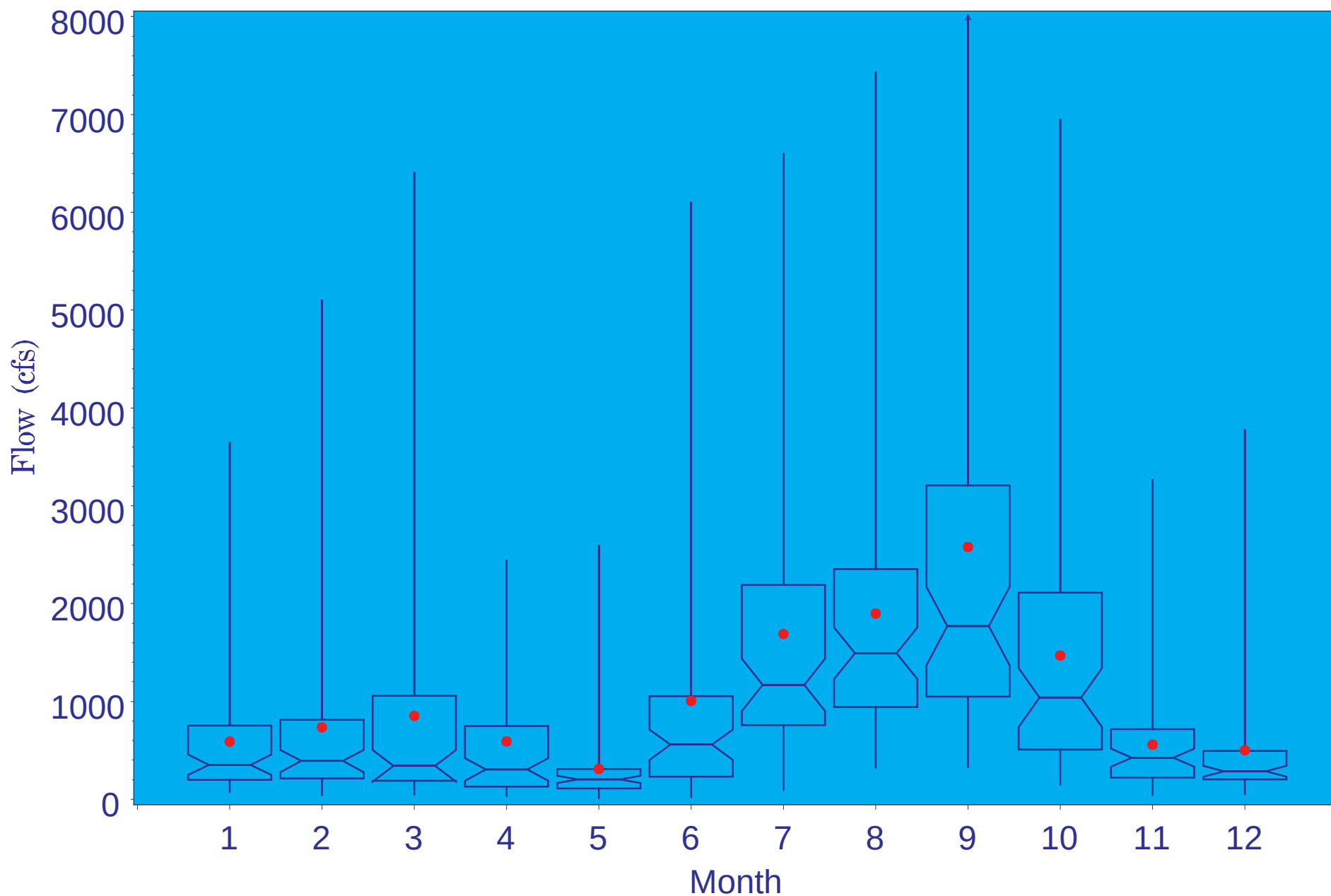


Figure 4.2.11 Monthly boxplots of mean Peace River Arcadia flow (1932-2002)

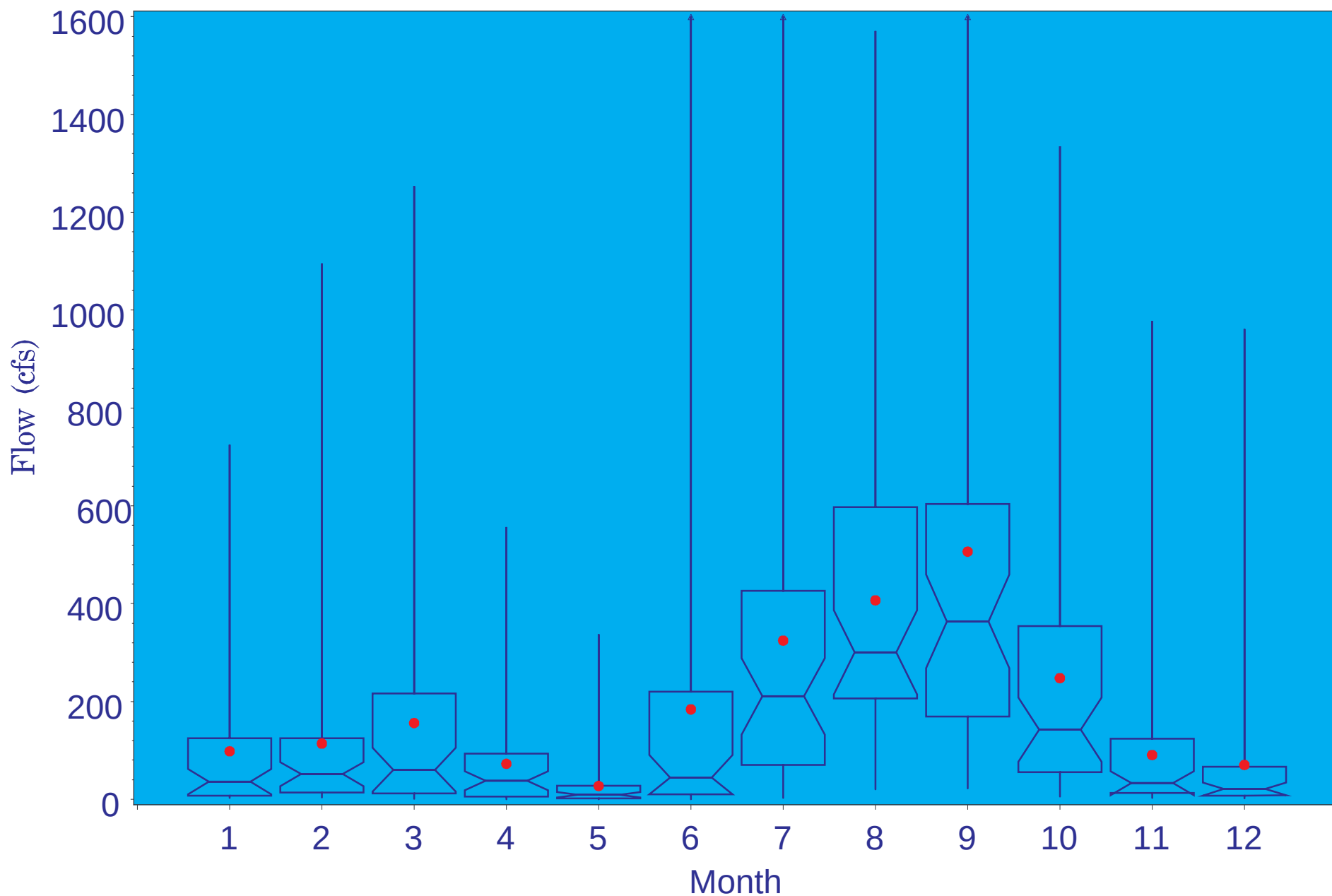


Figure 4.2.12 Monthly boxplots of mean Horse Creek flow (1951-2002)

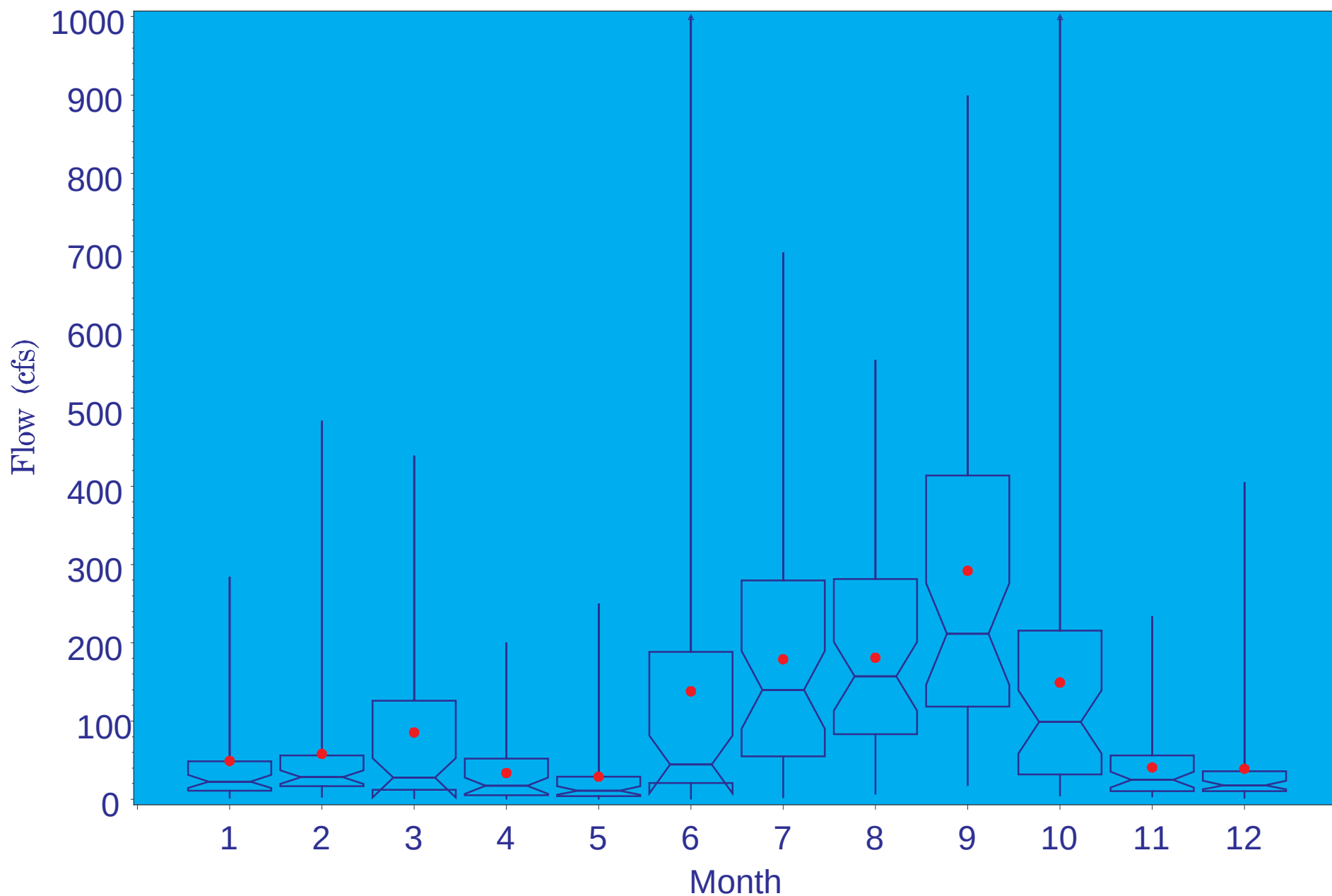


Figure 4.2.13 Monthly boxplots of mean Joshua Creek flow (1951-2002)

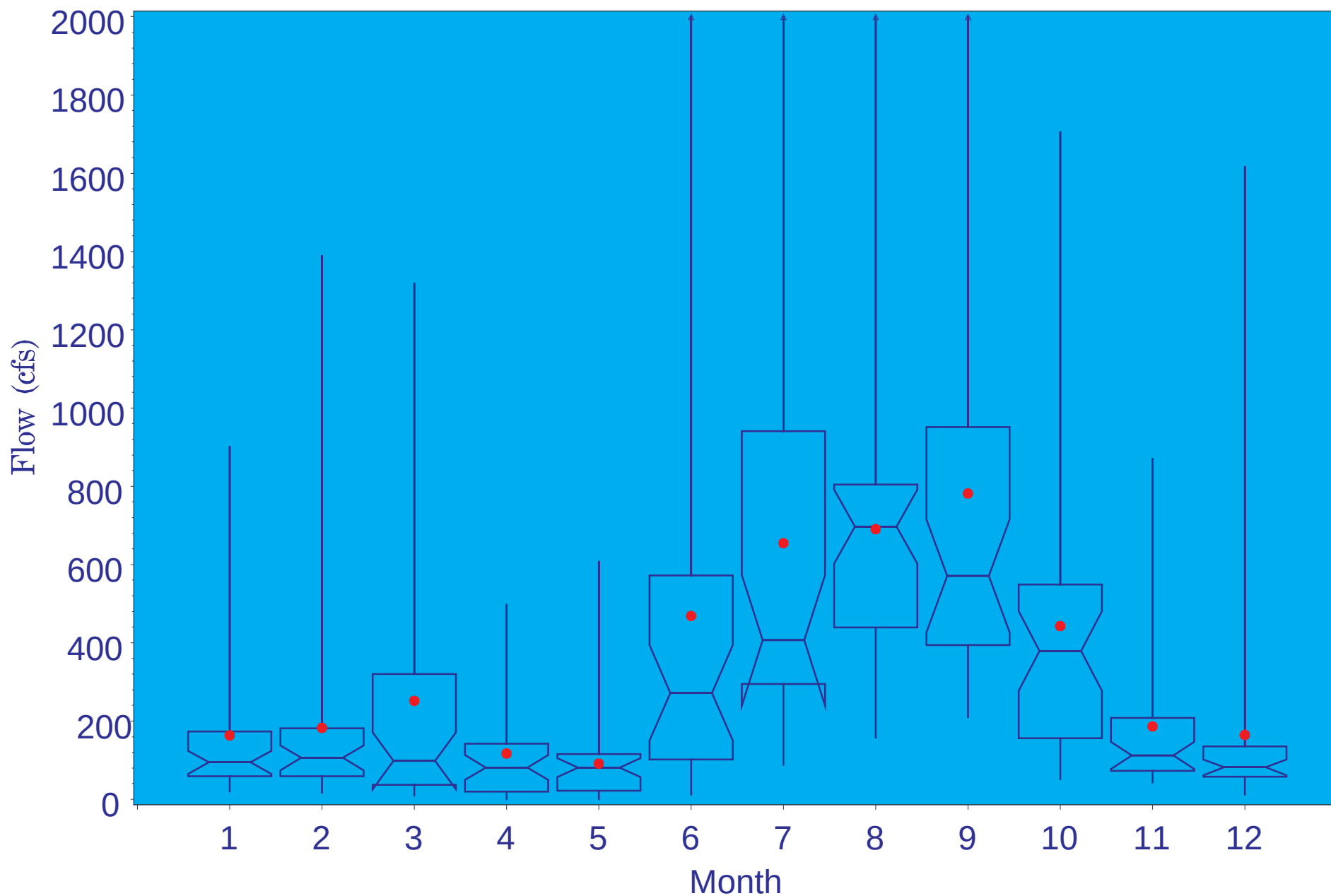


Figure 4.2.14 Monthly boxplots of mean Shell Creek flow (1966-2002)

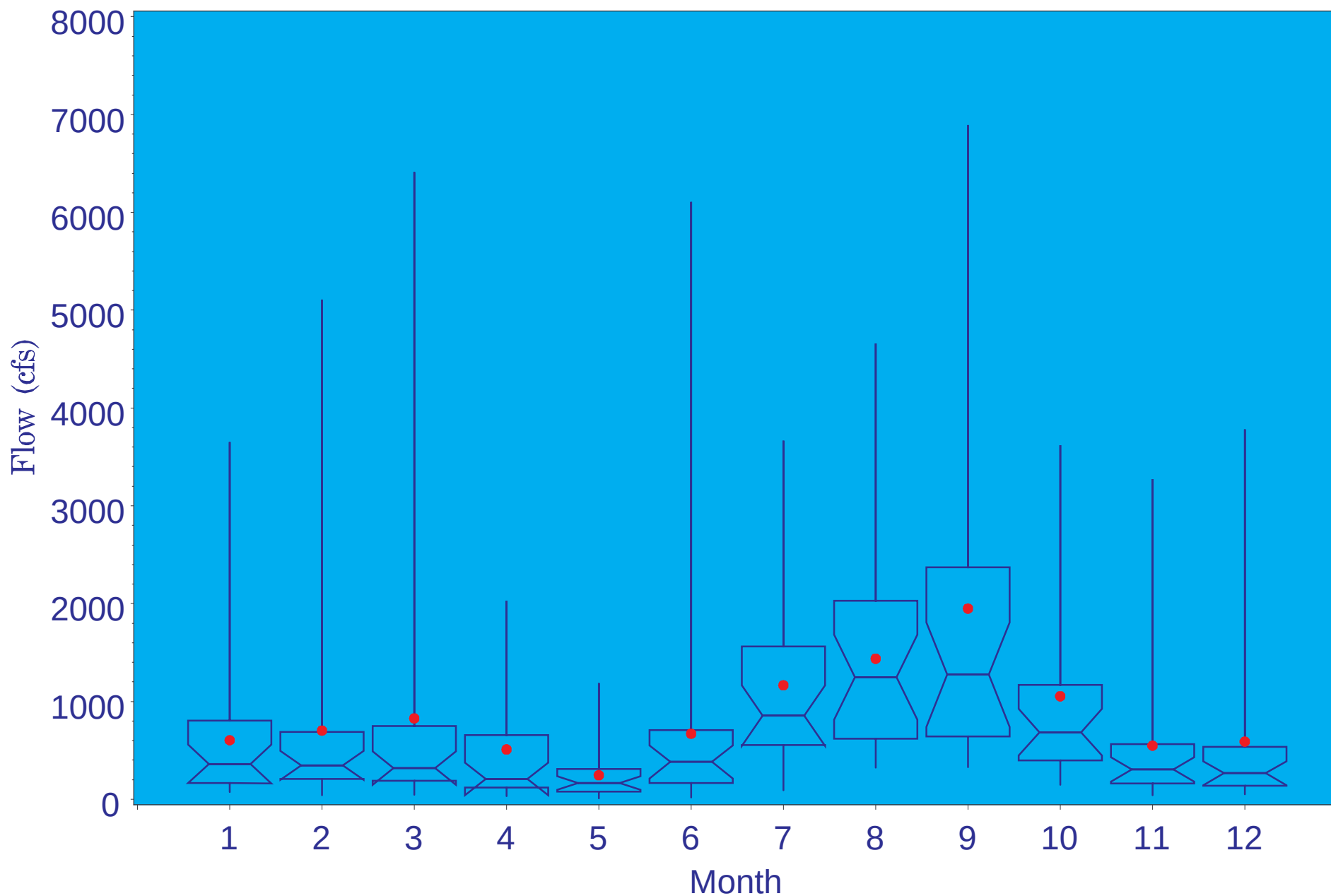


Figure 4.2.15 Monthly boxplots of mean Peace River Arcadia flow (1976-2002)

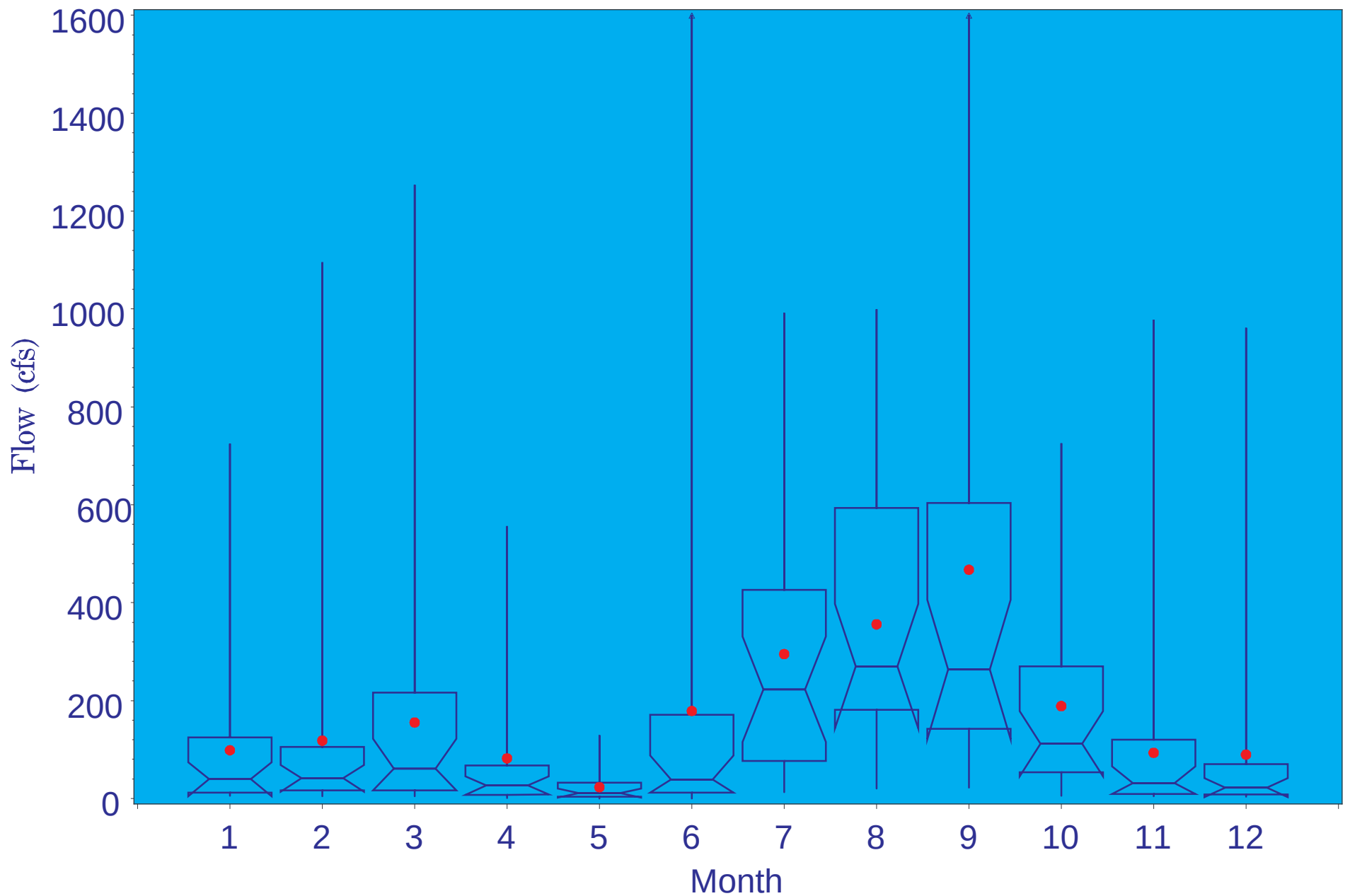


Figure 4.2.16 Monthly boxplots of mean Horse Creek flow (1976-2002)

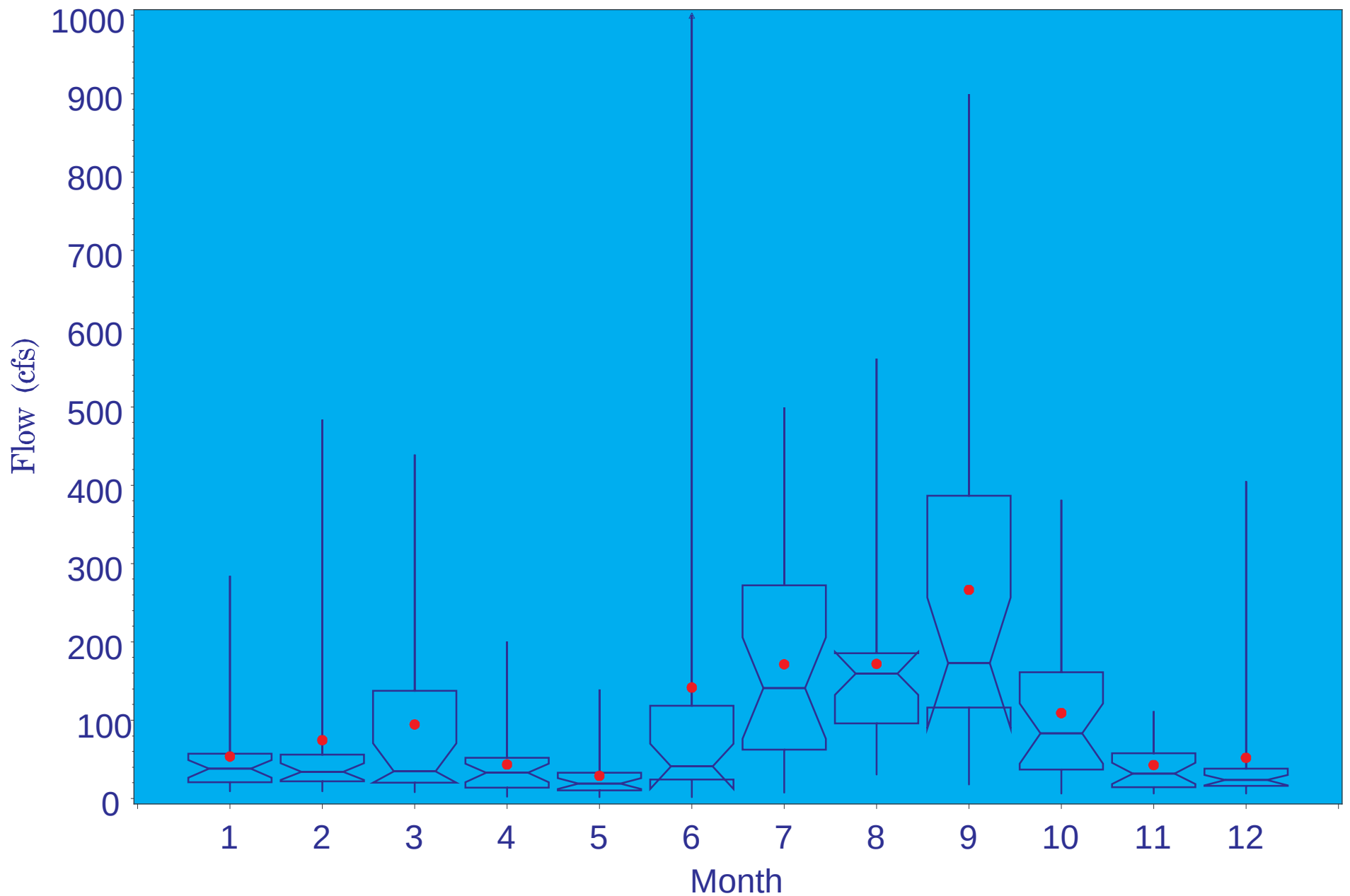


Figure 4.2.17 Monthly boxplots of mean Joshua Creek flow (1976-2002)

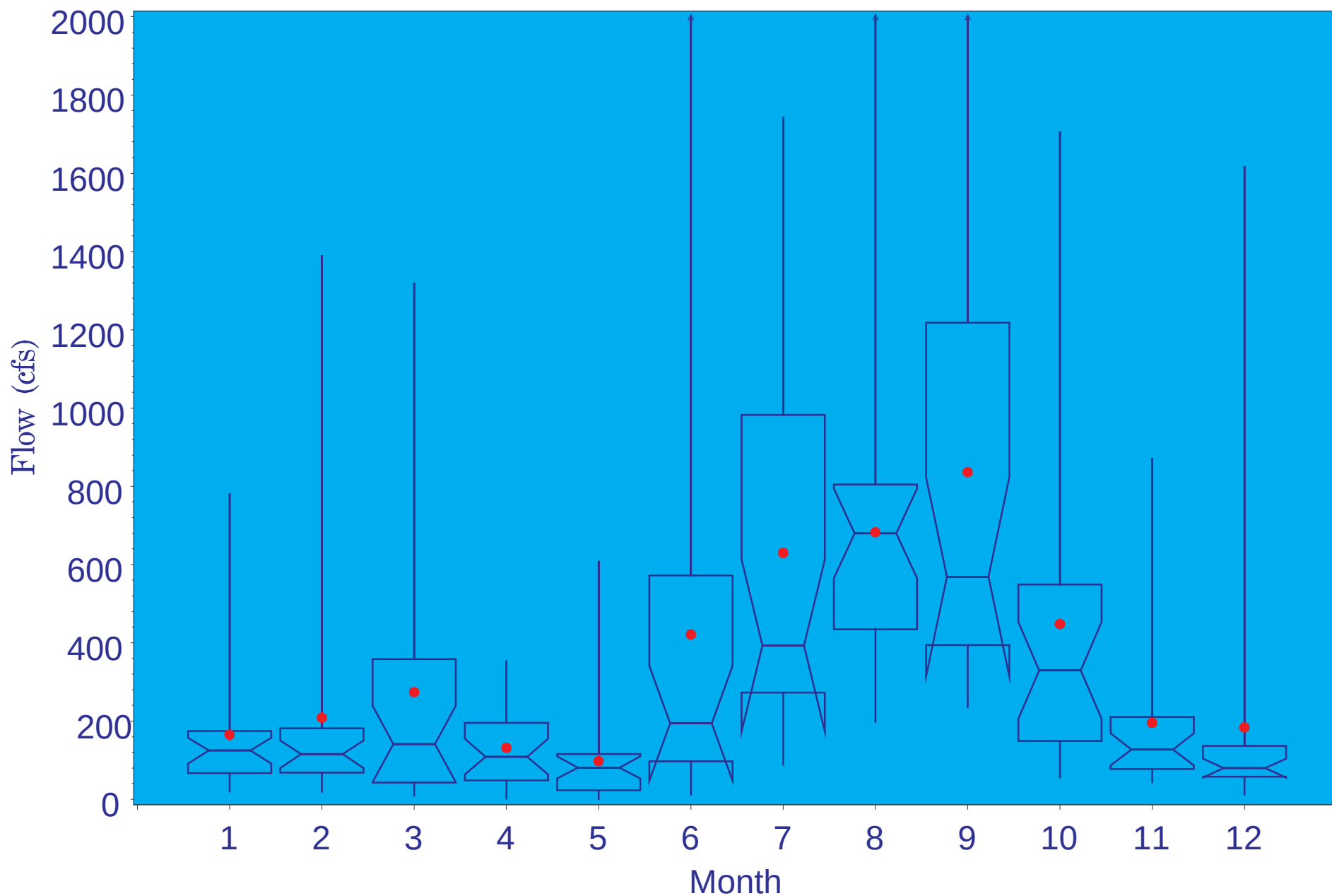


Figure 4.2.18 Monthly boxplots of mean Shell Creek flow (1976-2002)



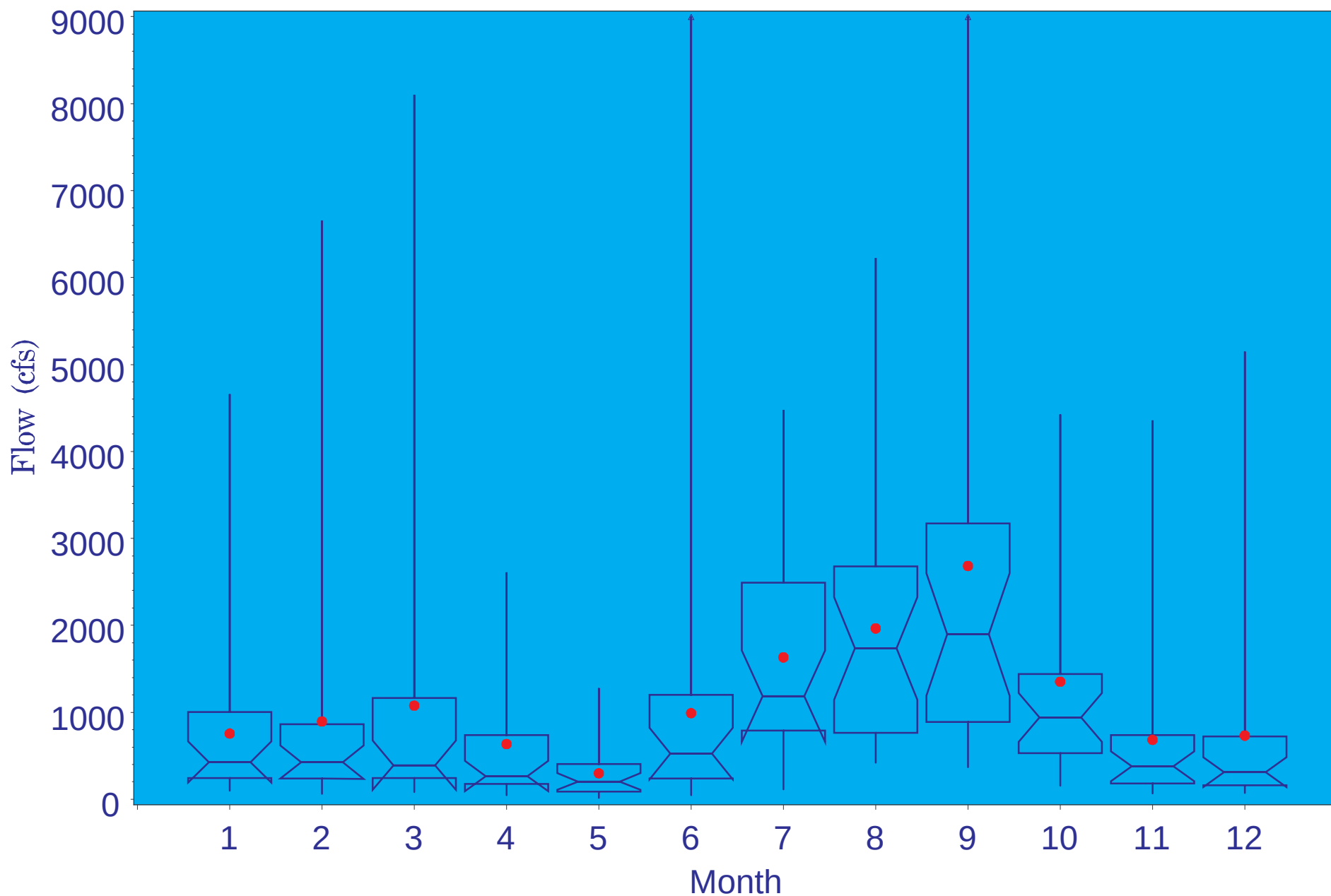


Figure 4.2.19 Monthly boxplots of mean flow upstream of the facility (1976-2002)

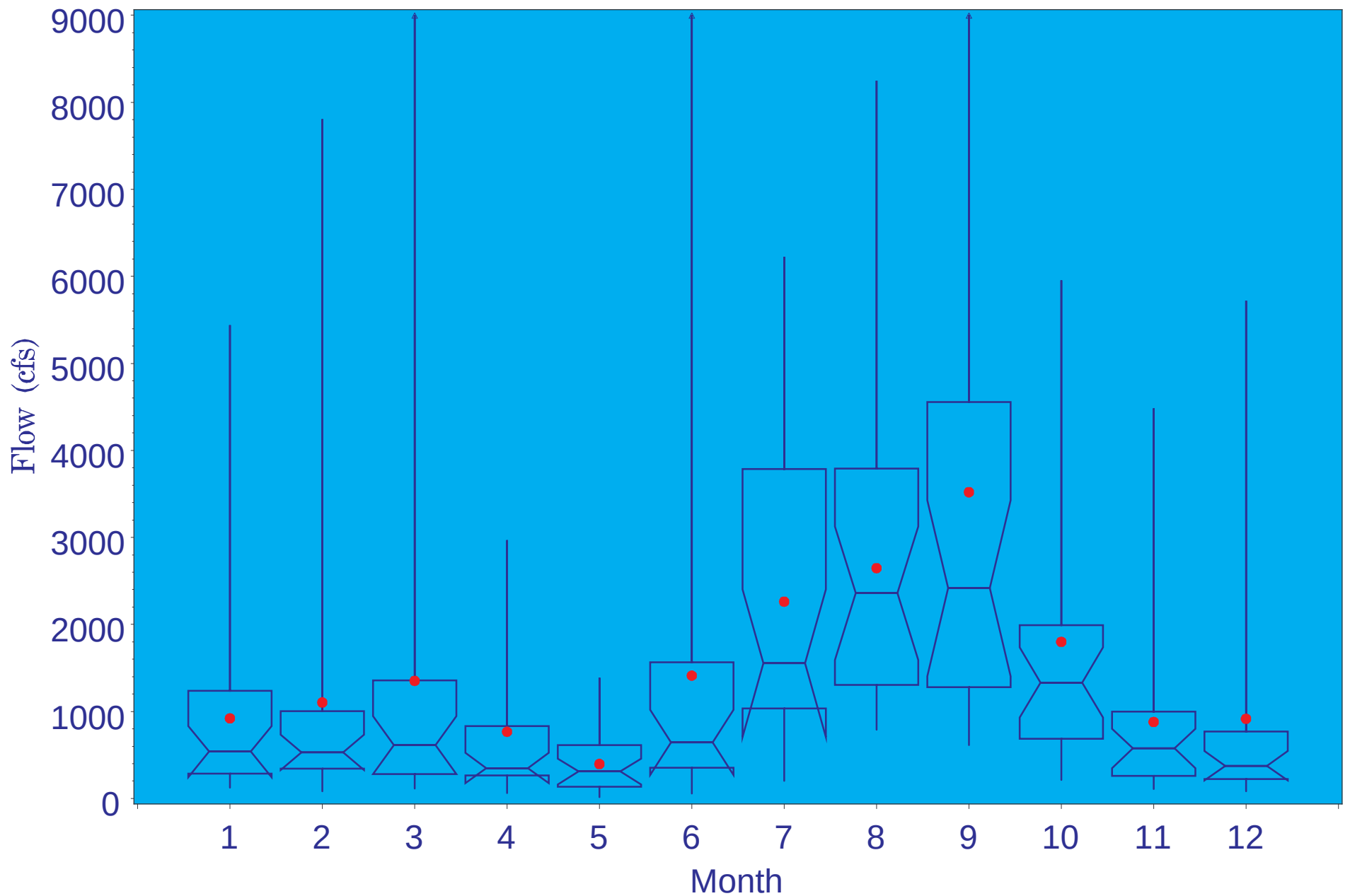


Figure 4.2.20 Monthly boxplots of mean flow upstream of the US41 Bridge (1976-2002)

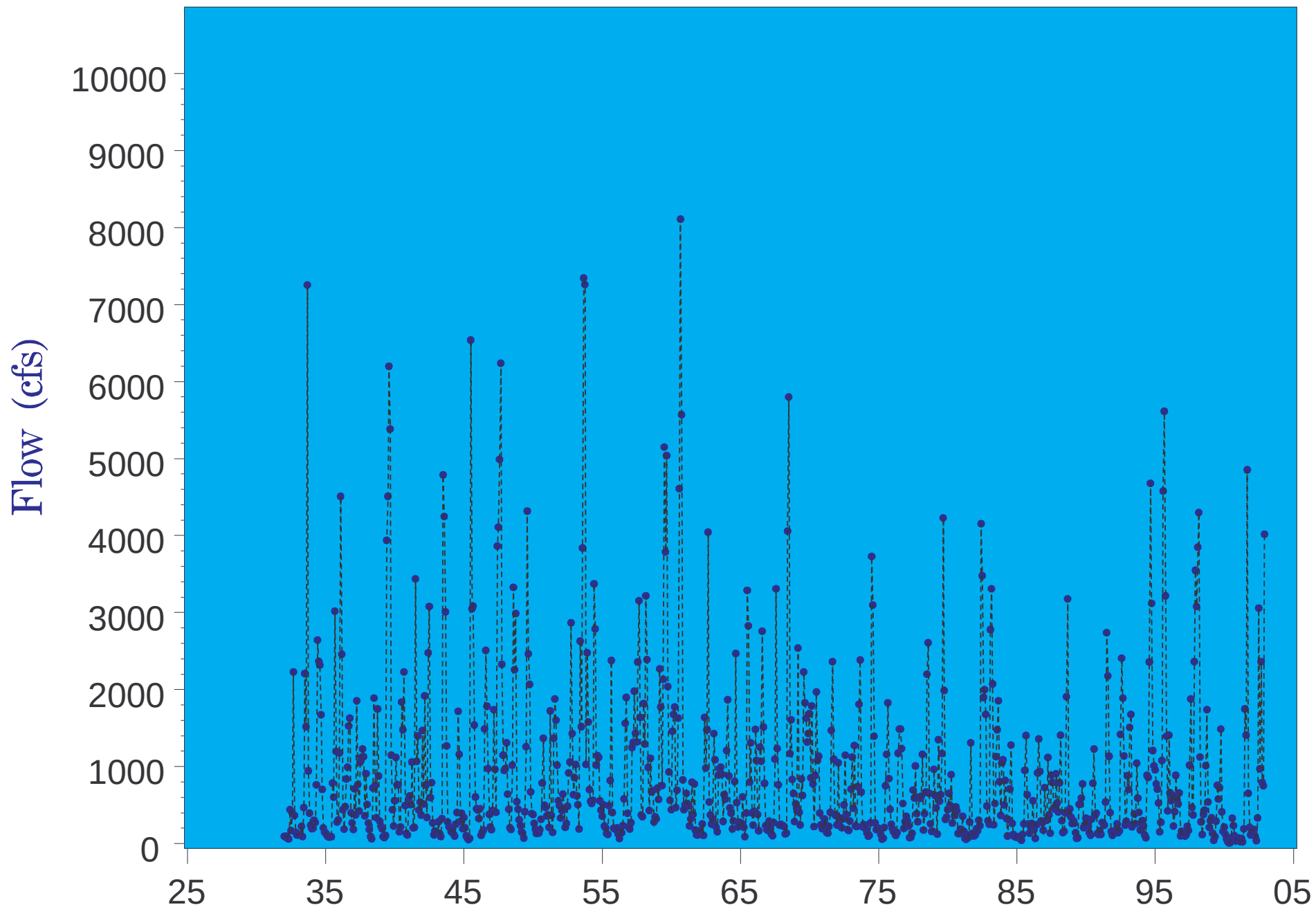


Figure 4.2.21 Monthly median flow at long-term Peace River Arcadia gage (1932-2002)

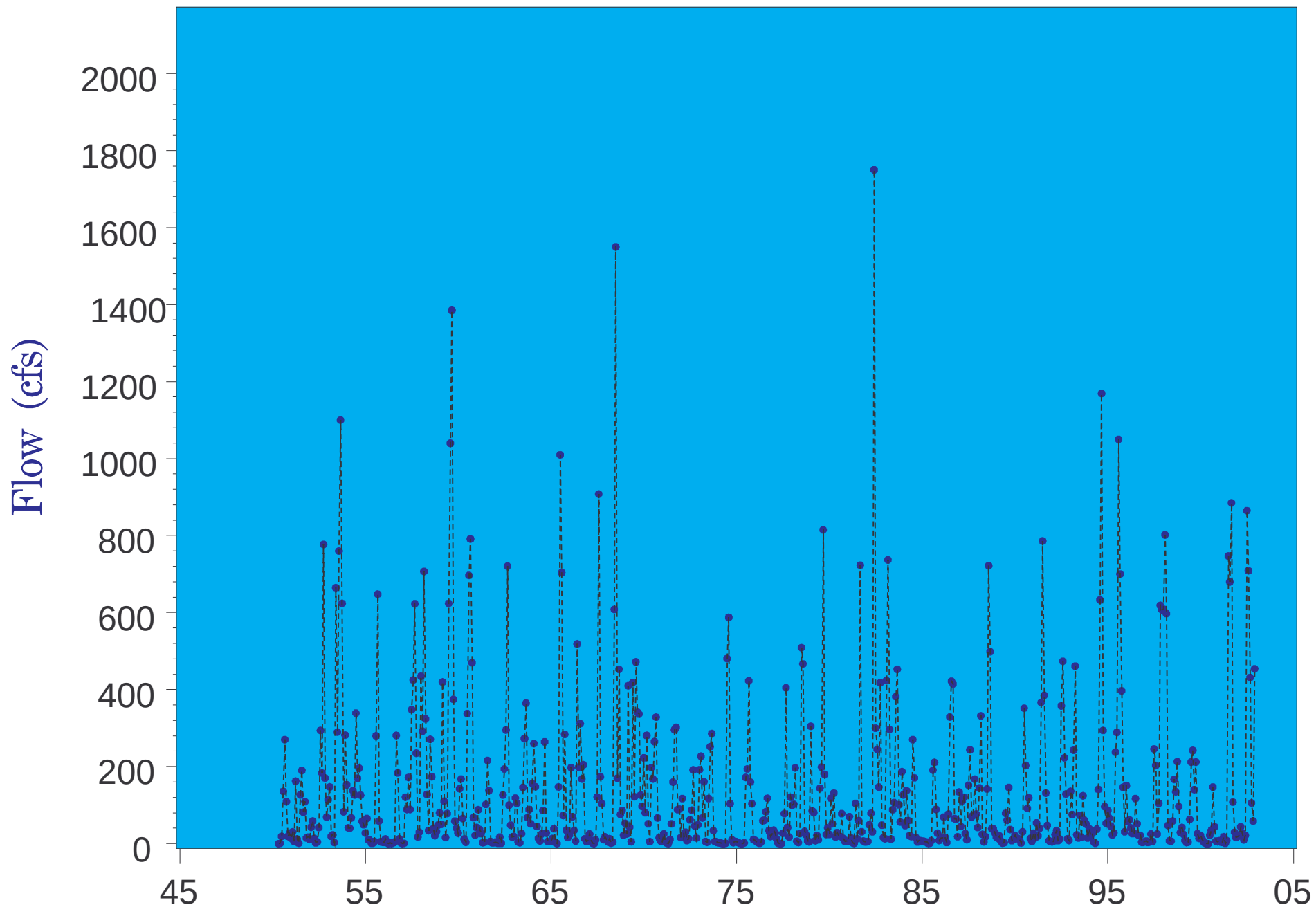


Figure 4.2.22 Monthly median flow at long-term Horse Creek gage (1951-2002)

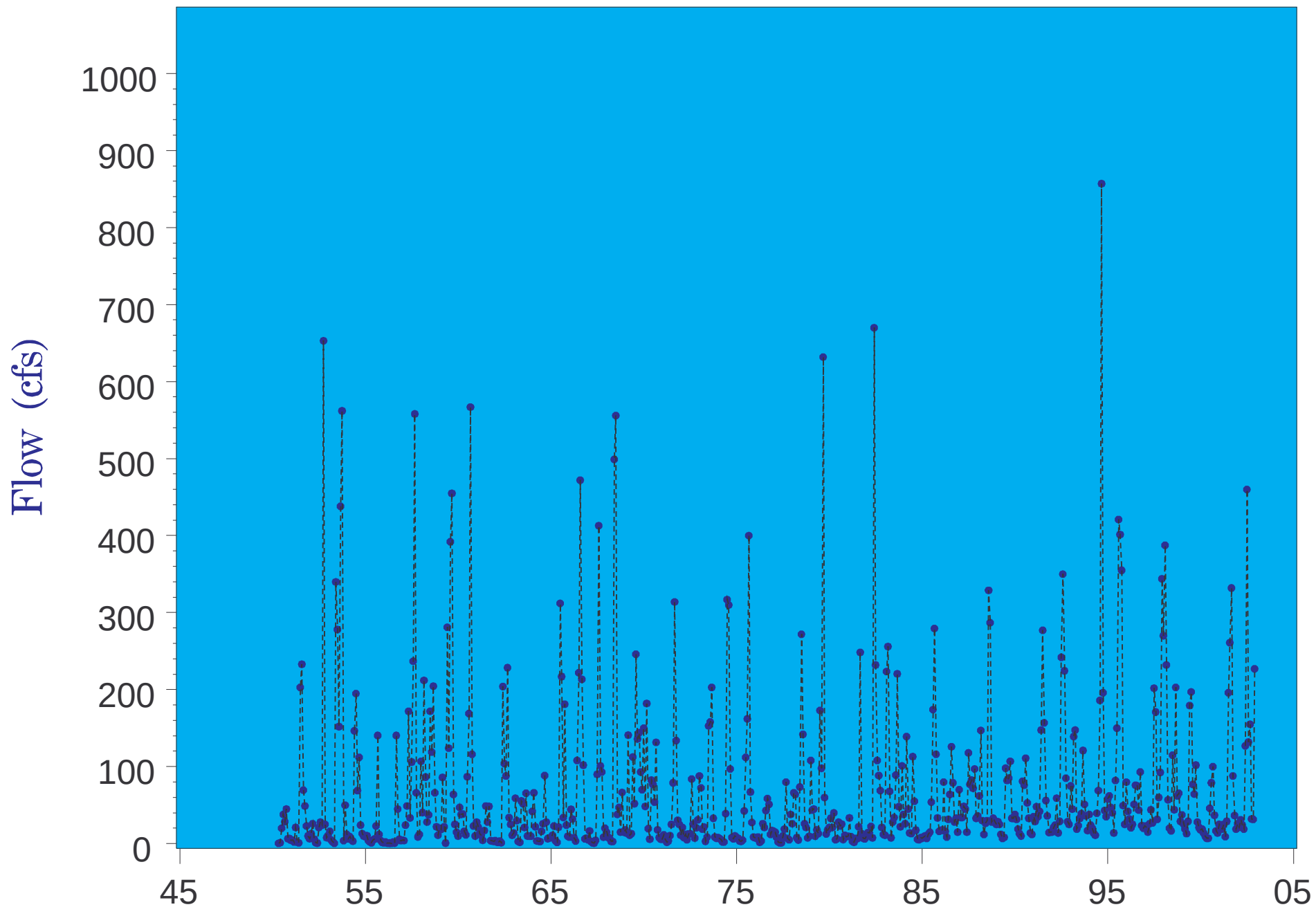


Figure 4.2.23 Monthly median flow at long-term Joshua Creek gage (1951-2002)

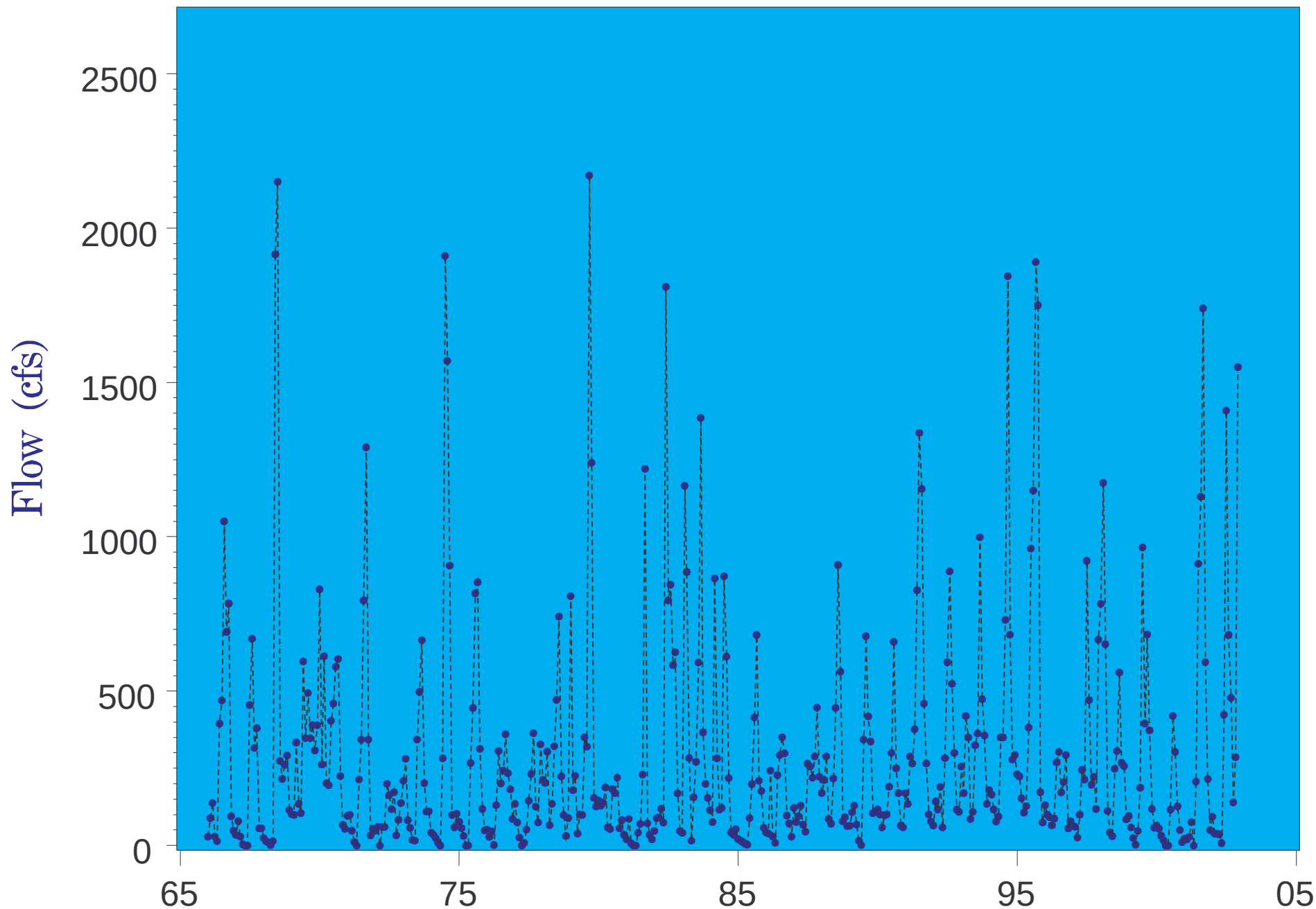


Figure 4.2.24 Monthly median flow at long-term Shell Creek gage (1966-2002)

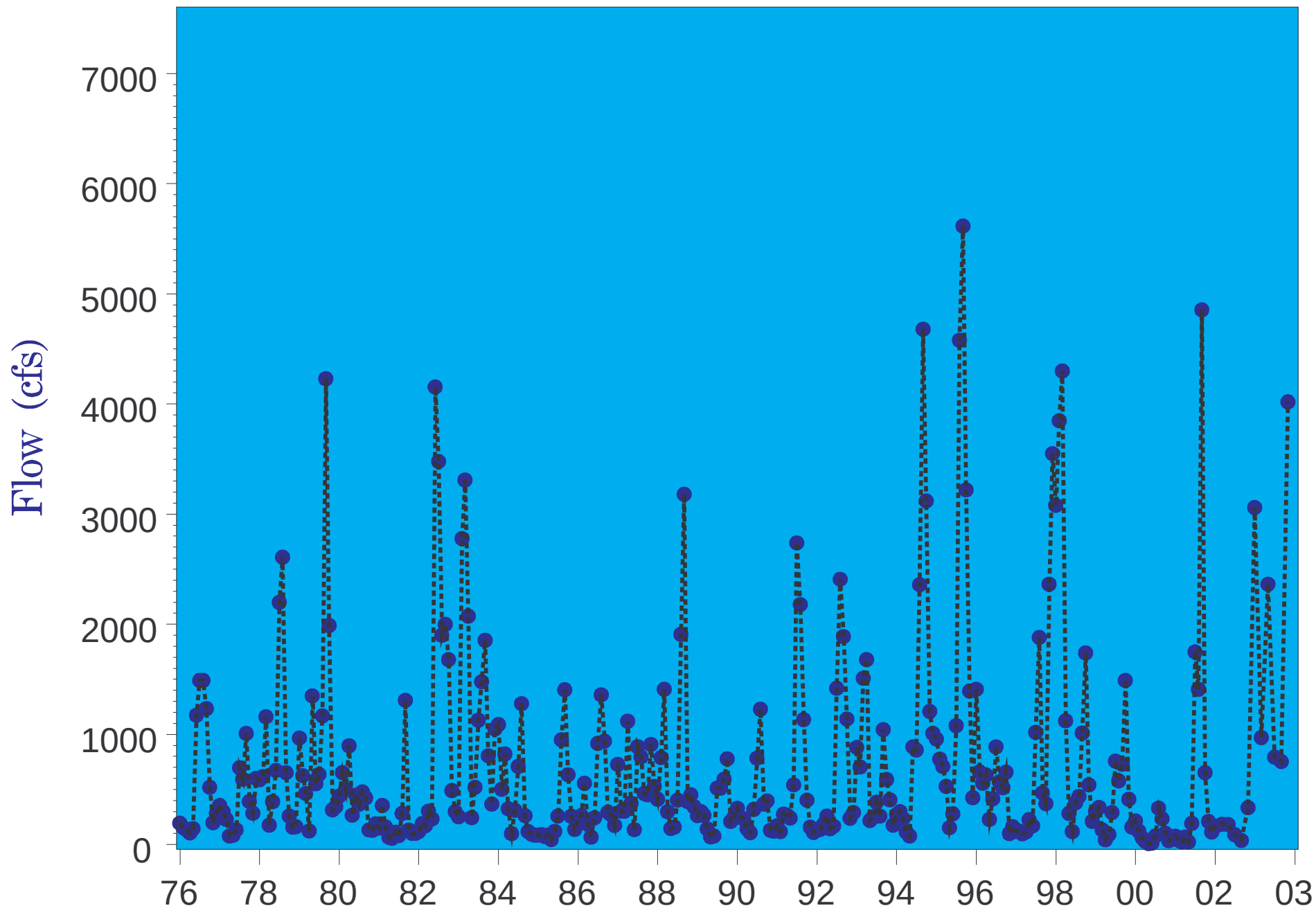


Figure 4.2.25 Monthly median flow at long-term Peace River Arcadia gage (1976-2002)

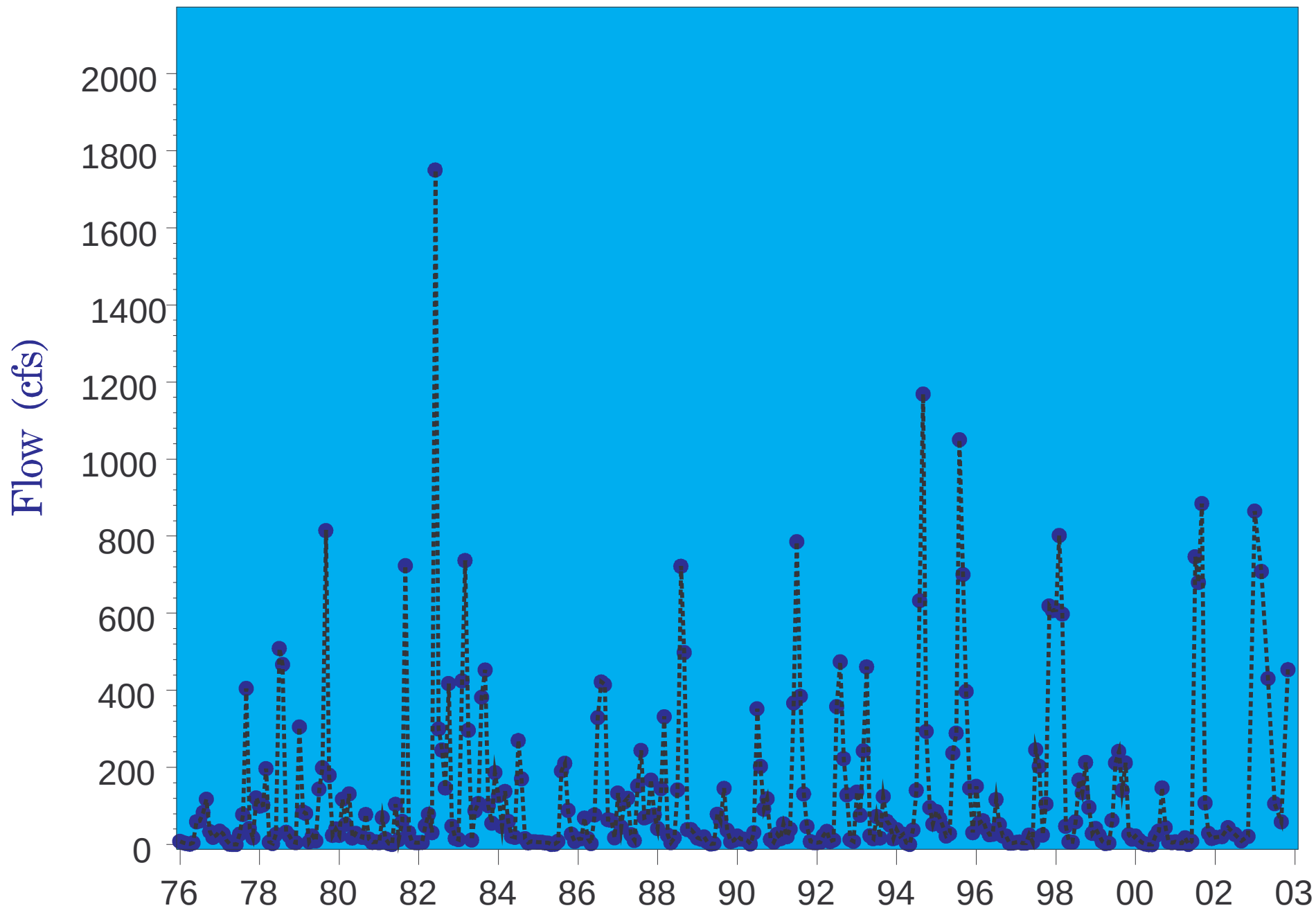


Figure 4.2.26 Monthly median flow at long-term Horse Creek gage (1976-2002)



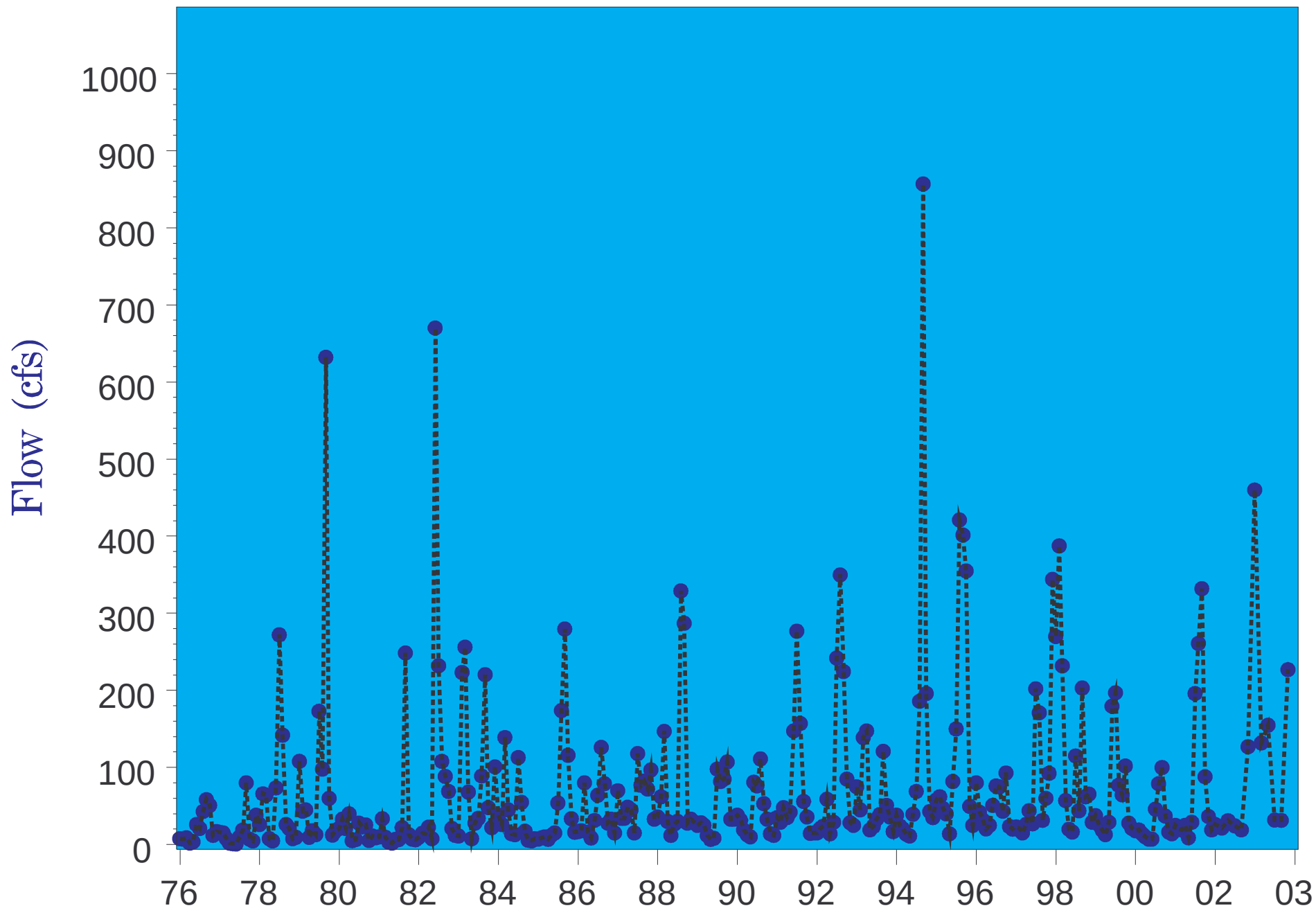


Figure 4.2.27 Monthly median flow at long-term Joshua Creek gage (1976-2002)

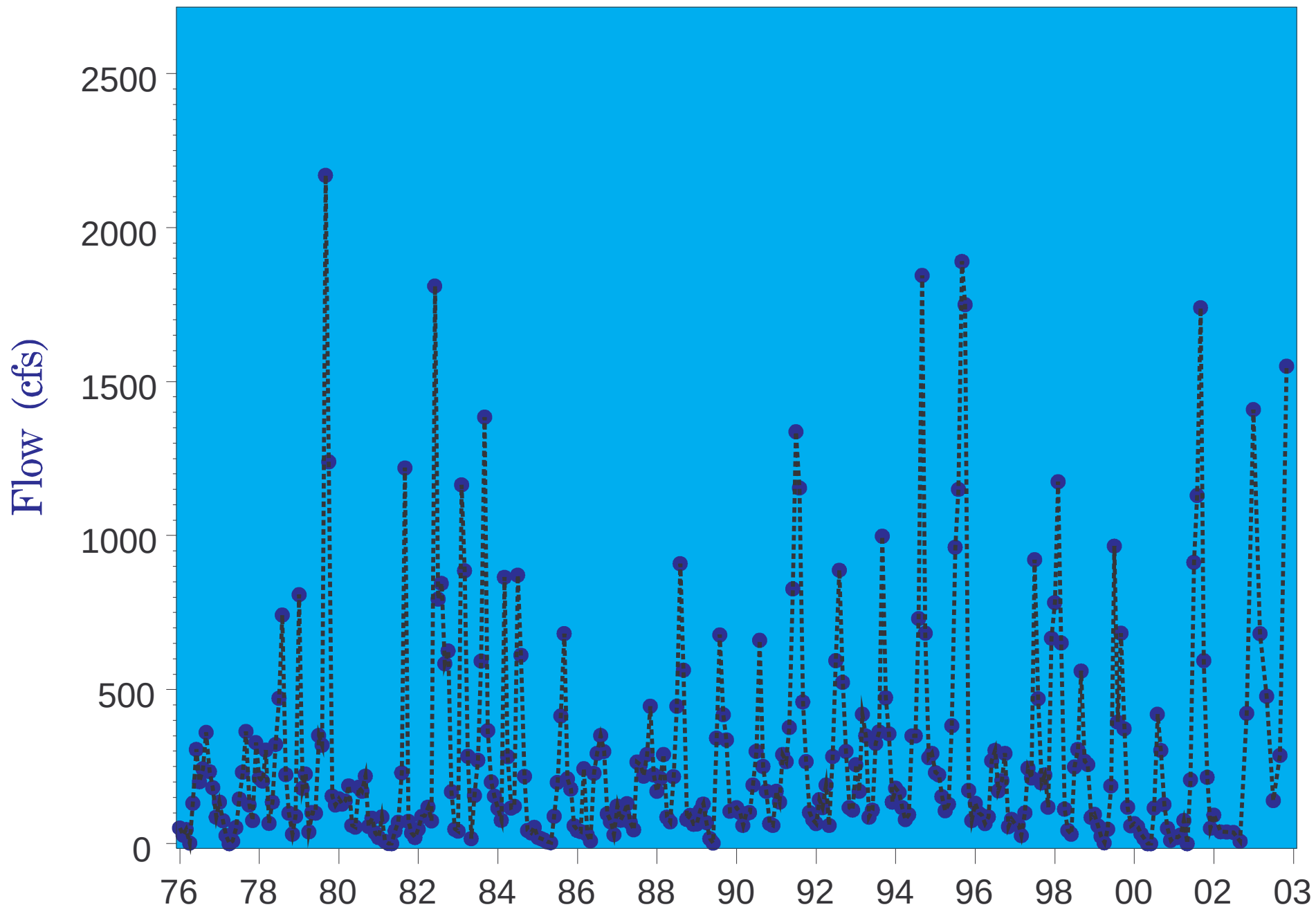


Figure 4.2.28 Monthly median flow at long-term Shell Creek gage (1976-2002)

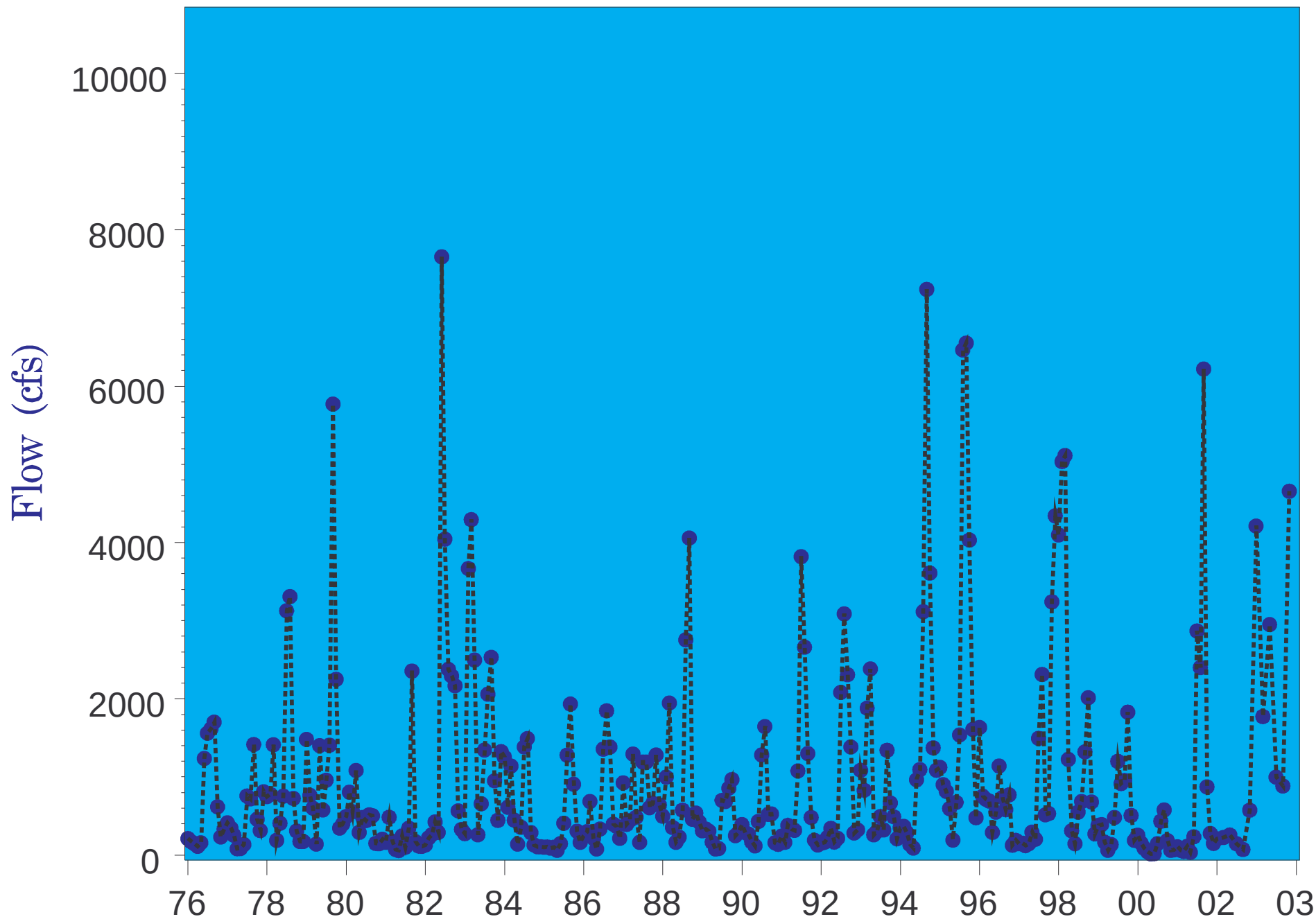


Figure 4.2.29 Median total monthly gage flow upstream of the Water Treatment Facility (1976-2002)

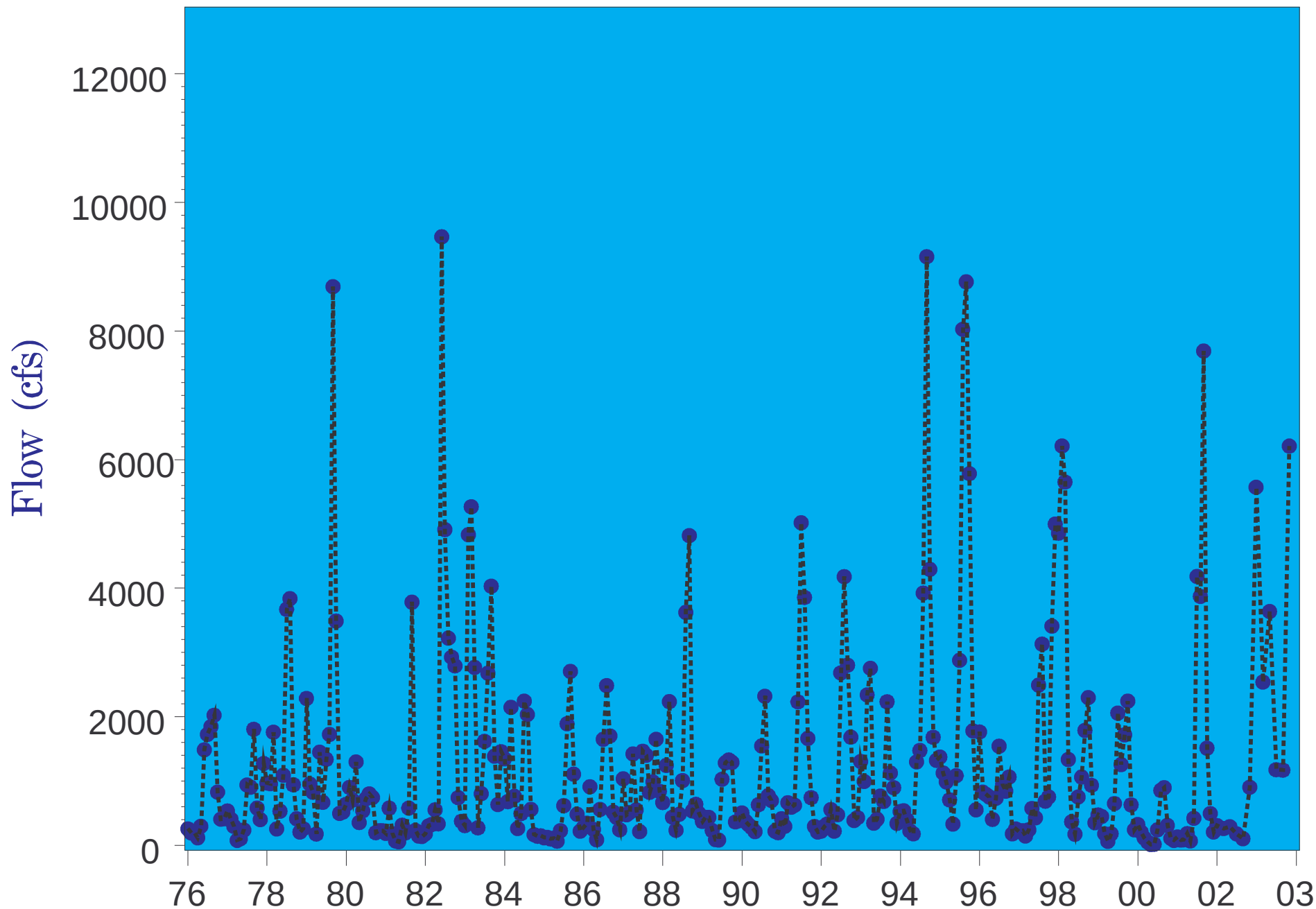


Figure 4.2.30 Median total monthly gage flow upstream of the US41 Bridge (1976-2002)

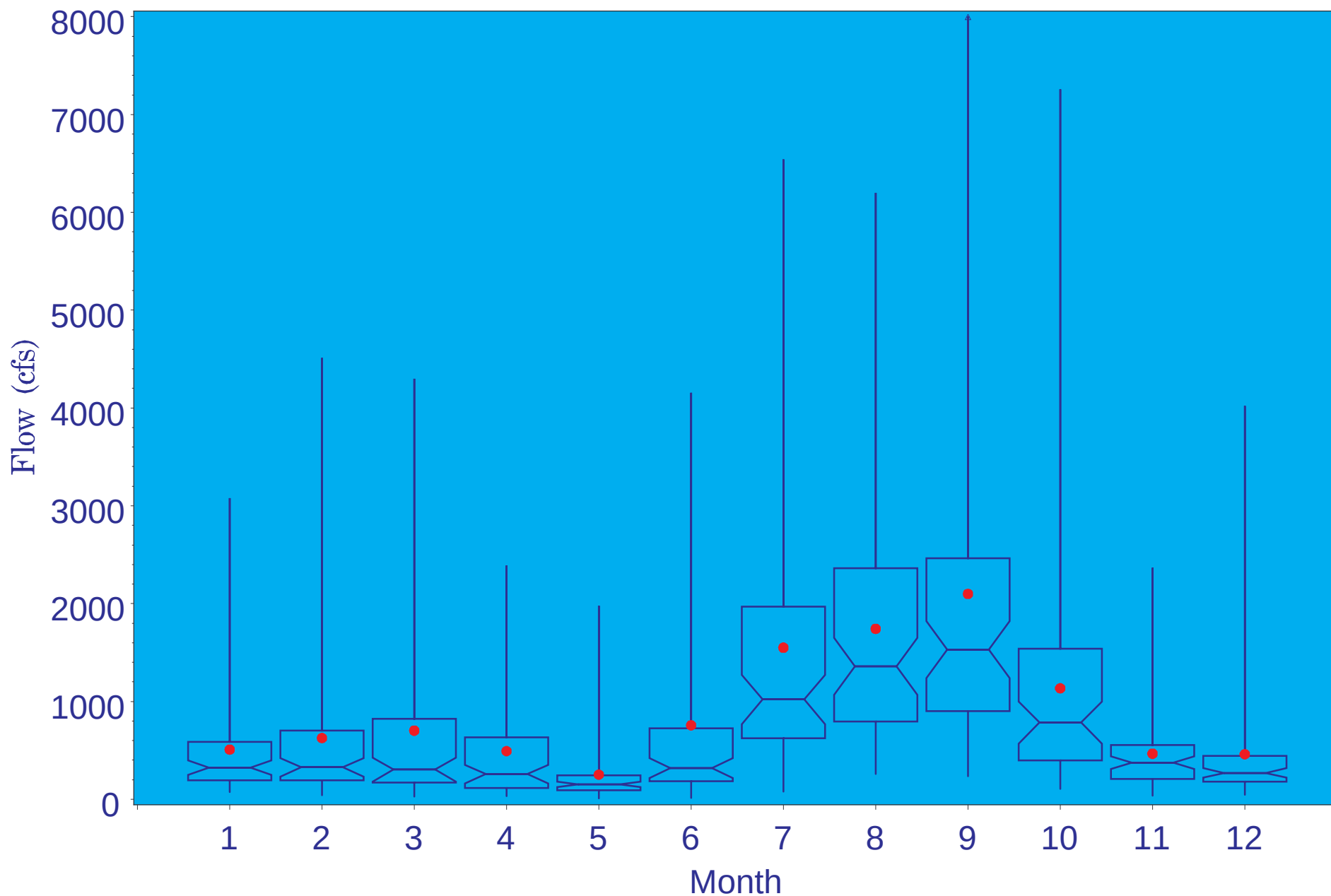


Figure 4.2.31 Monthly boxplots of median Peace River Arcadia flow (1932-2002)

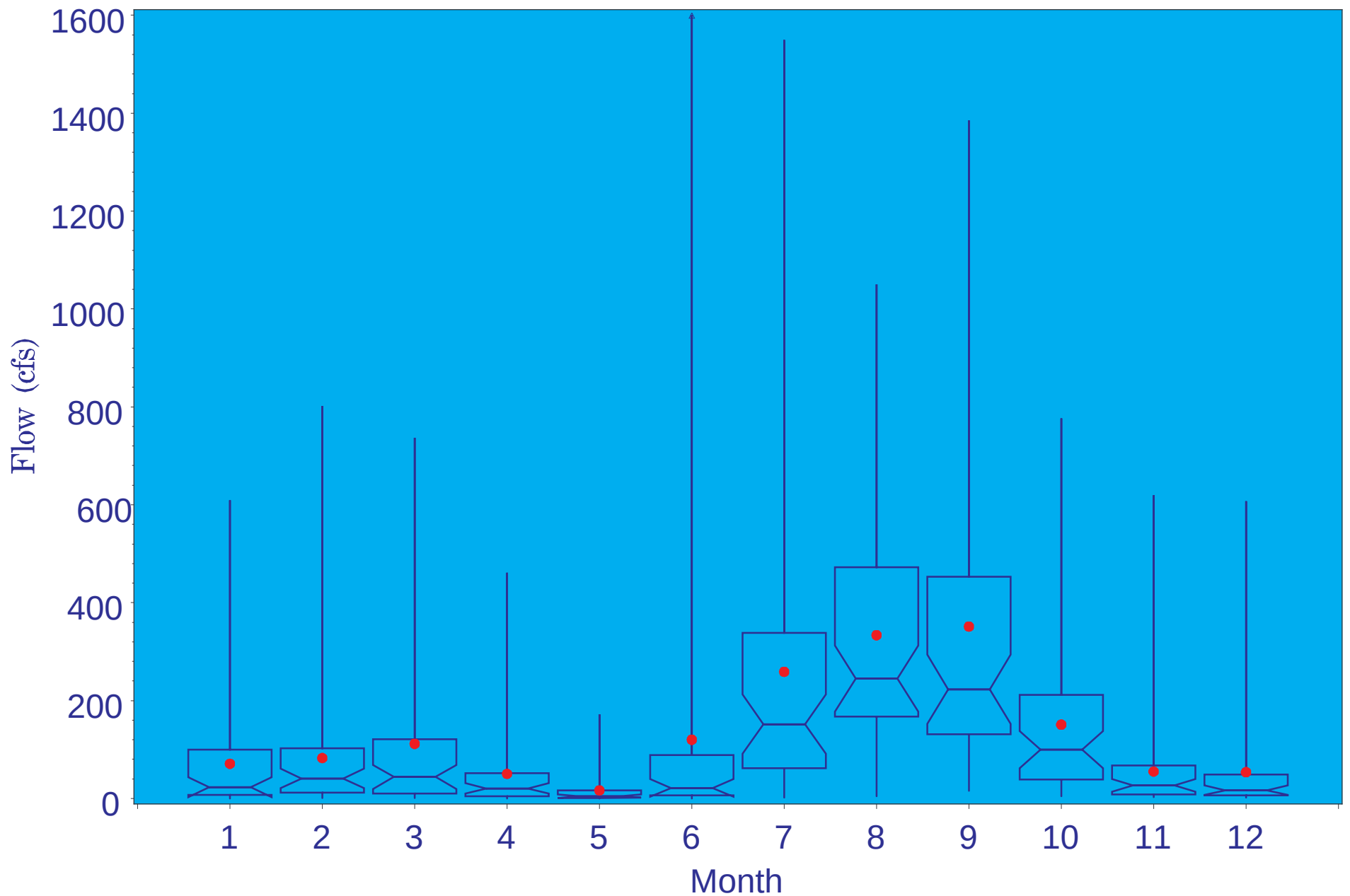


Figure 4.2.32 Monthly boxplots of median Horse Creek flow (1951-2002)

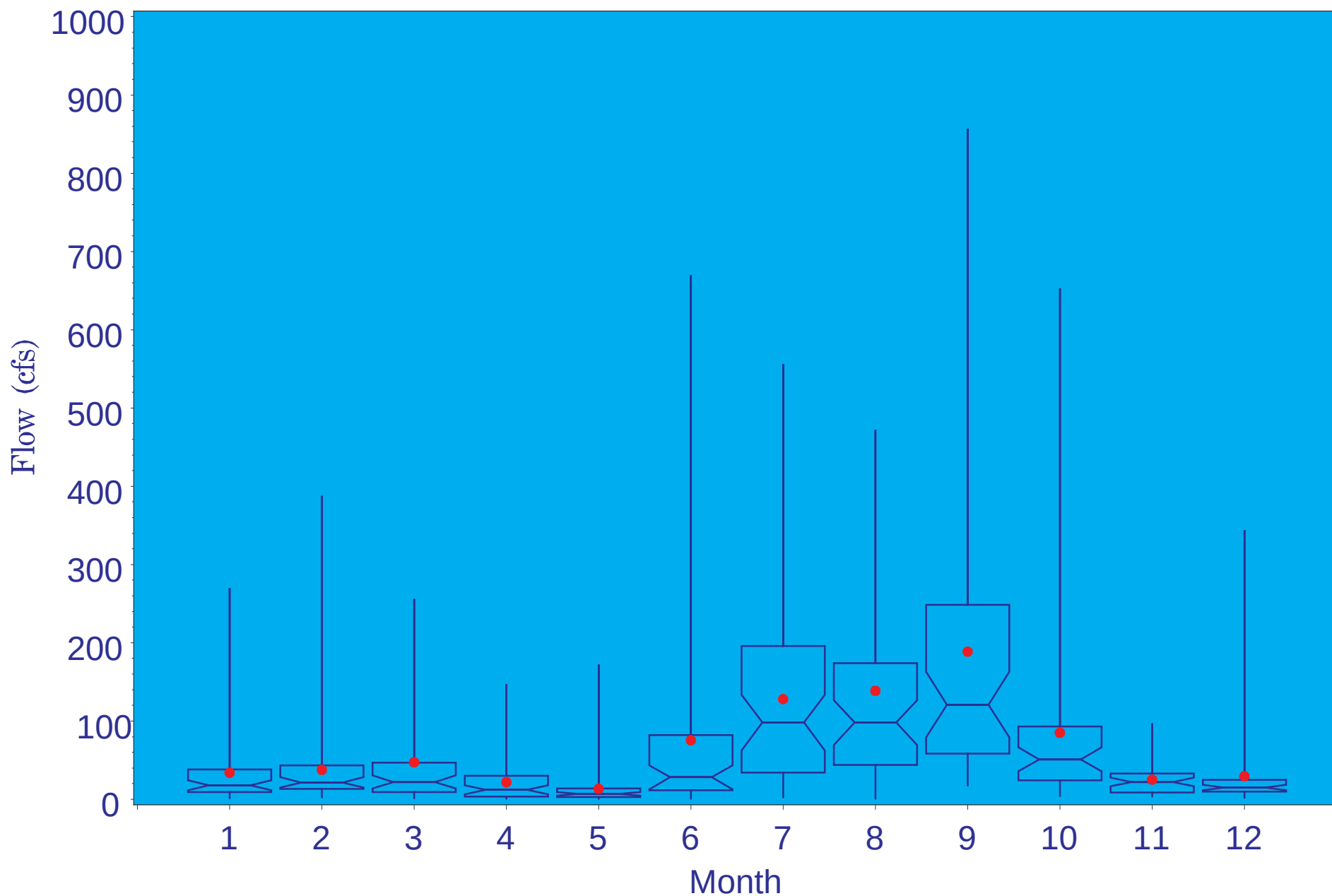


Figure 4.2.33 Monthly boxplots of median Joshua Creek flow (1951-2002)

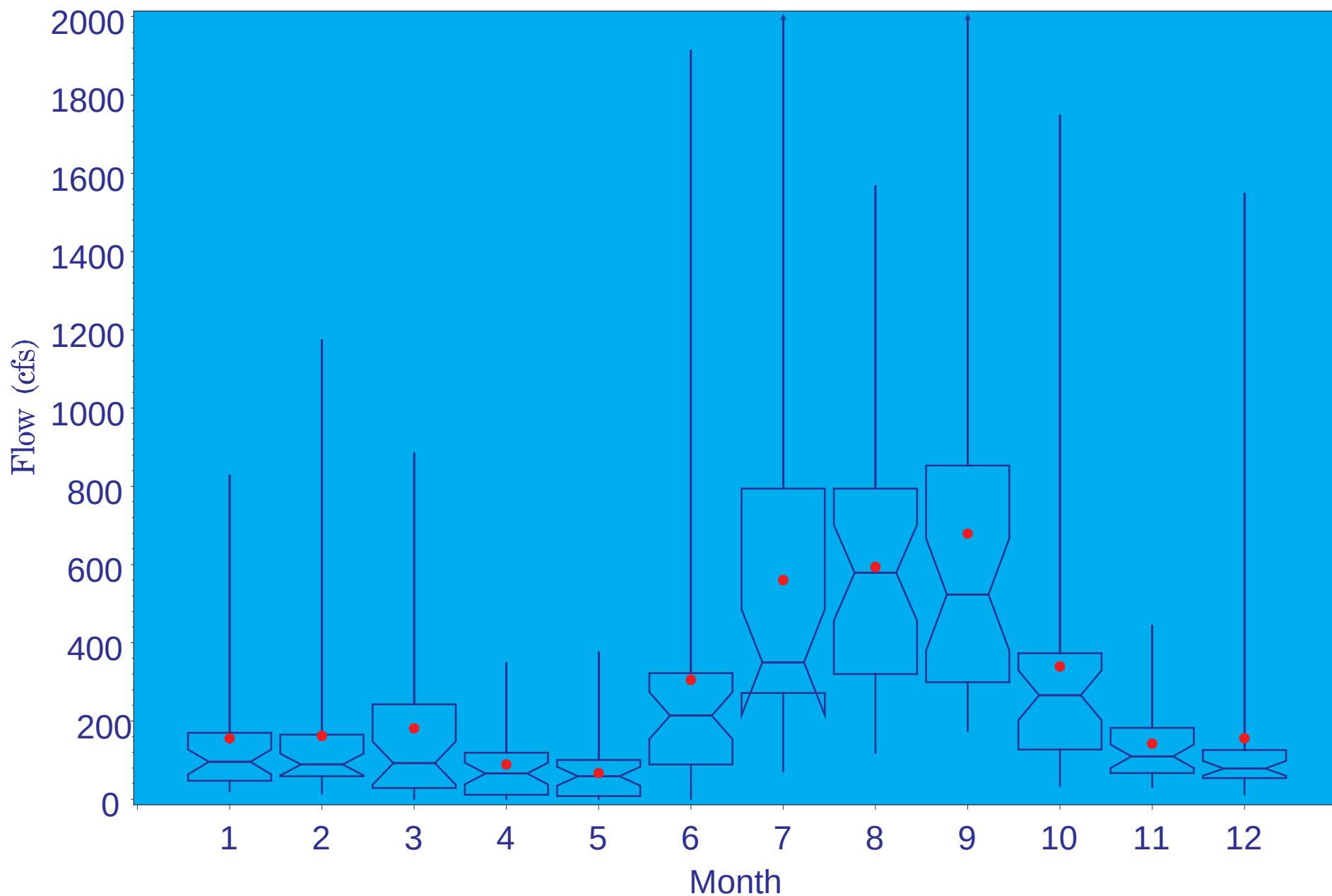


Figure 4.2.34 Monthly boxplots of median Shell Creek flow (1966-2002)



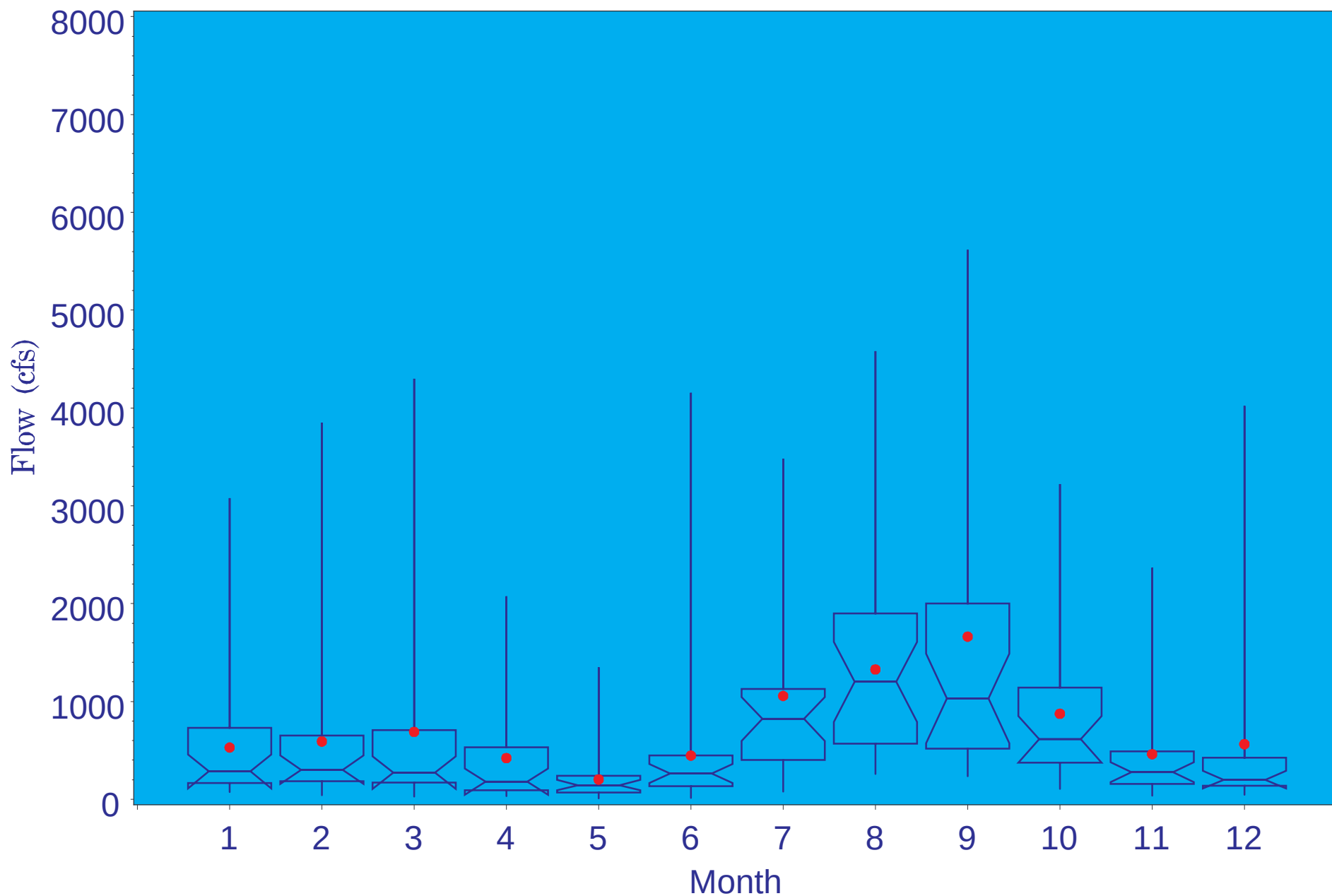


Figure 4.2.35 Monthly boxplots of median Peace River Arcadia flow (1976-2002)

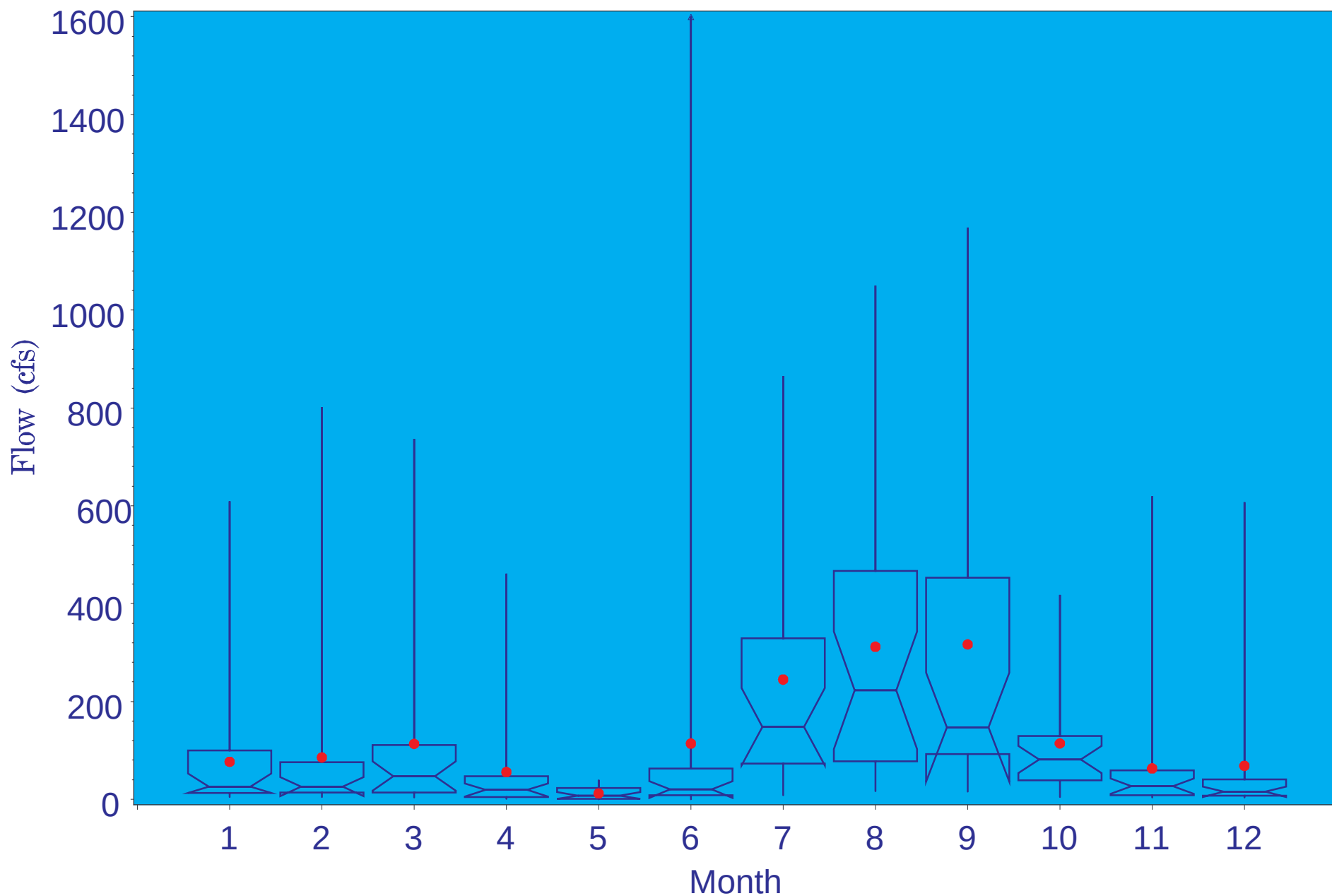


Figure 4.2.36 Monthly boxplots of median Horse Creek flow (1976-2002)

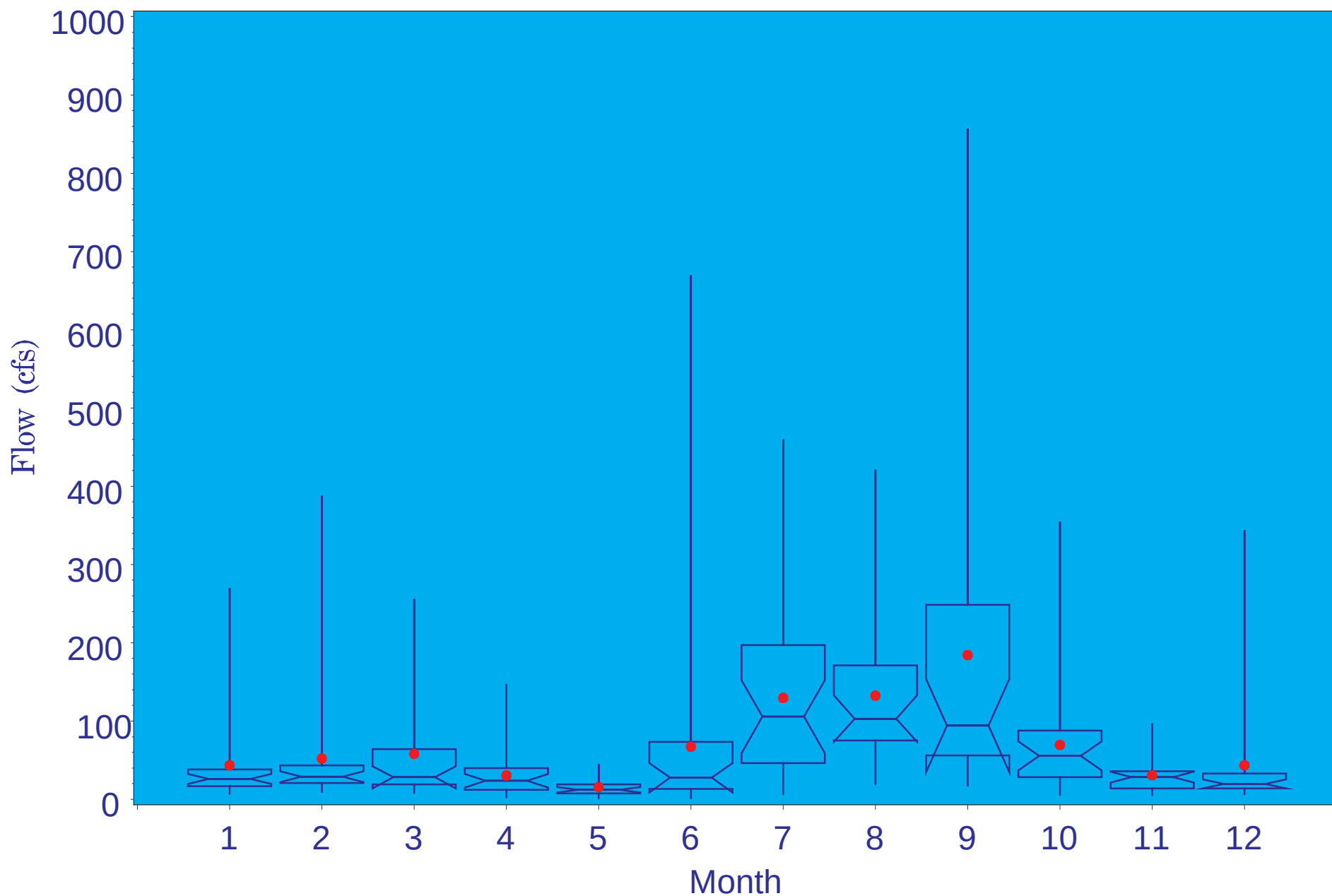


Figure 4.2.37 Monthly boxplots of median Joshua Creek flow (1976-2002)

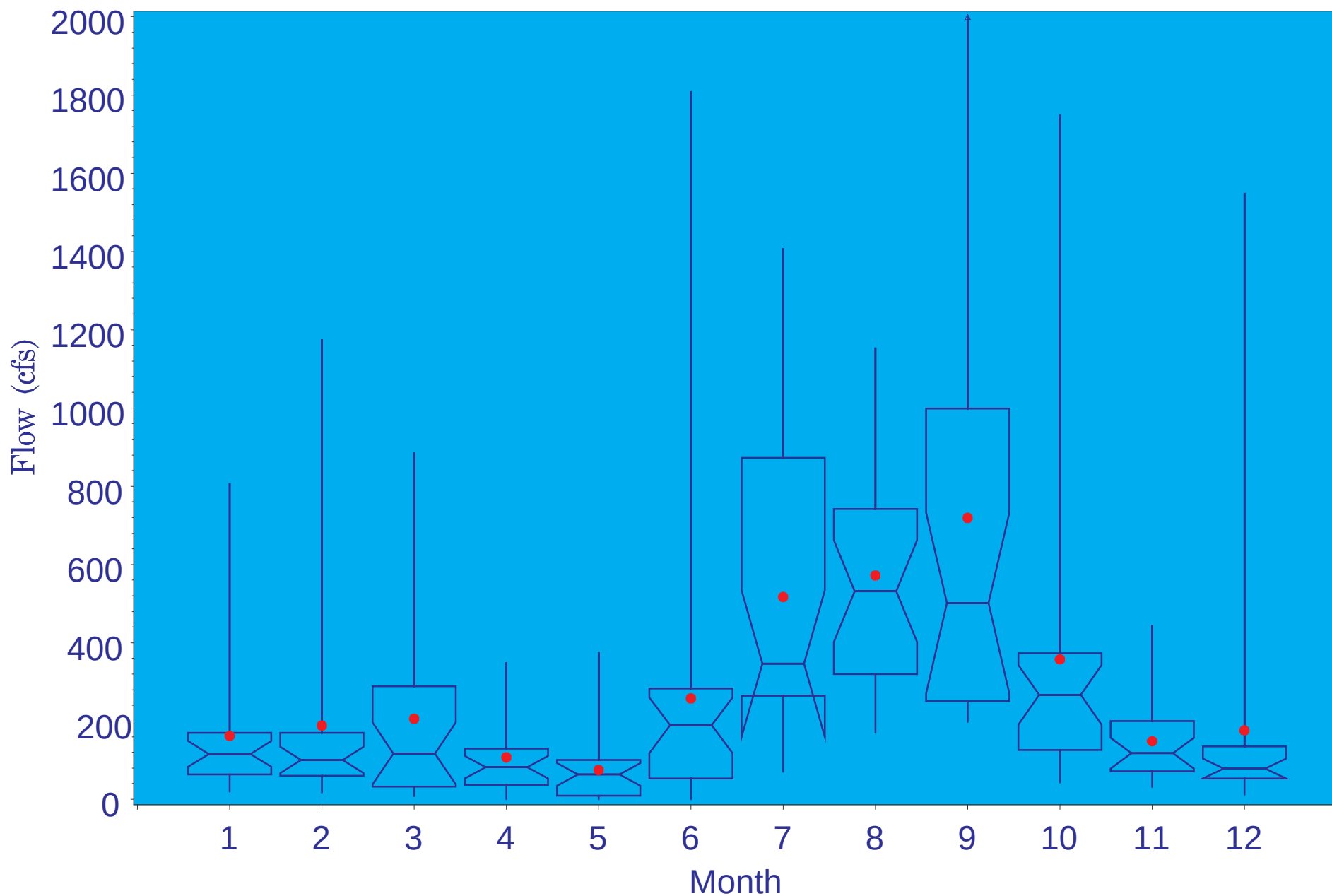


Figure 4.2.38 Monthly boxplots of median Shell Creek flow (1976-2002)

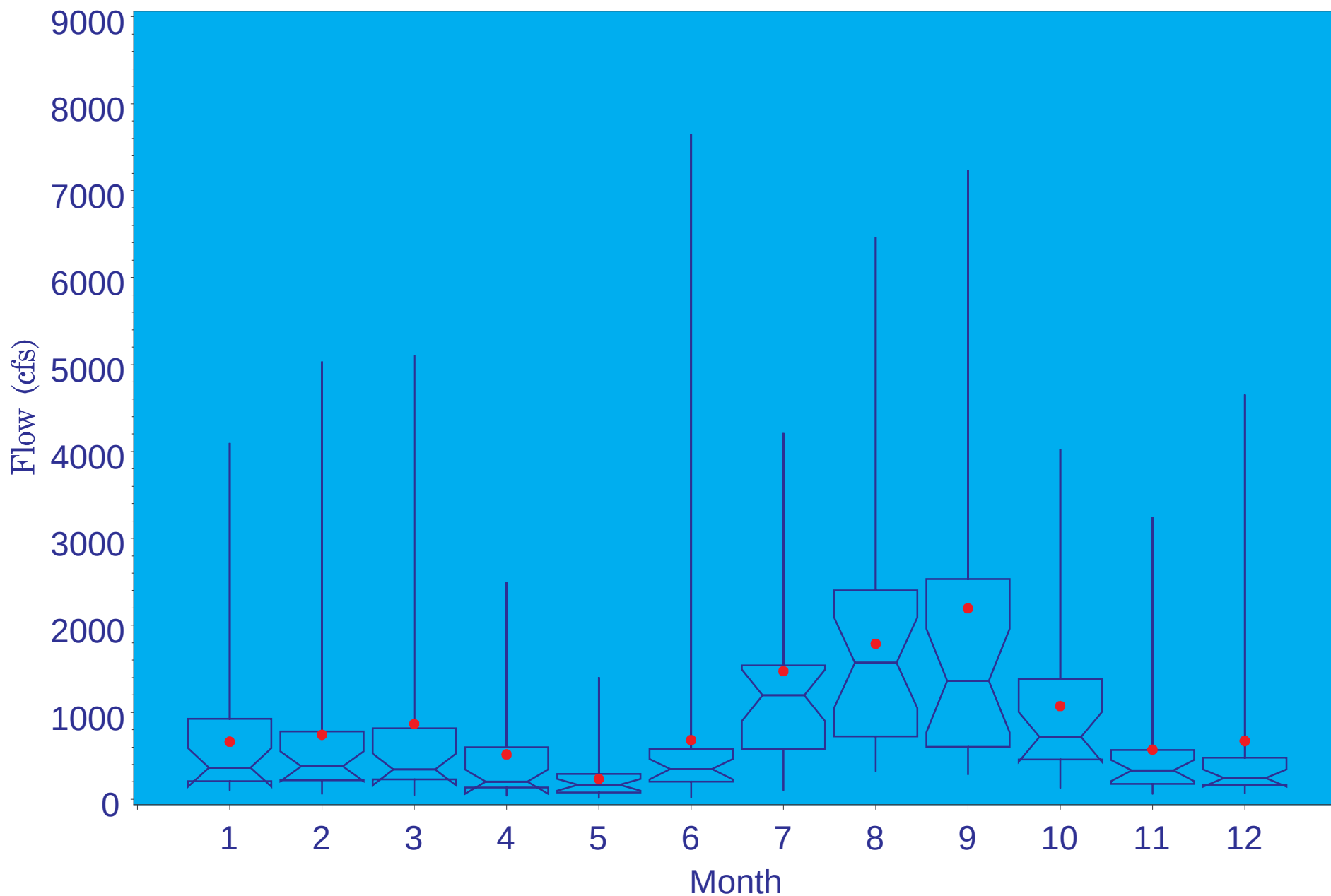


Figure 4.2.39 Monthly boxplots of median flow upstream of the facility (1976-2002)

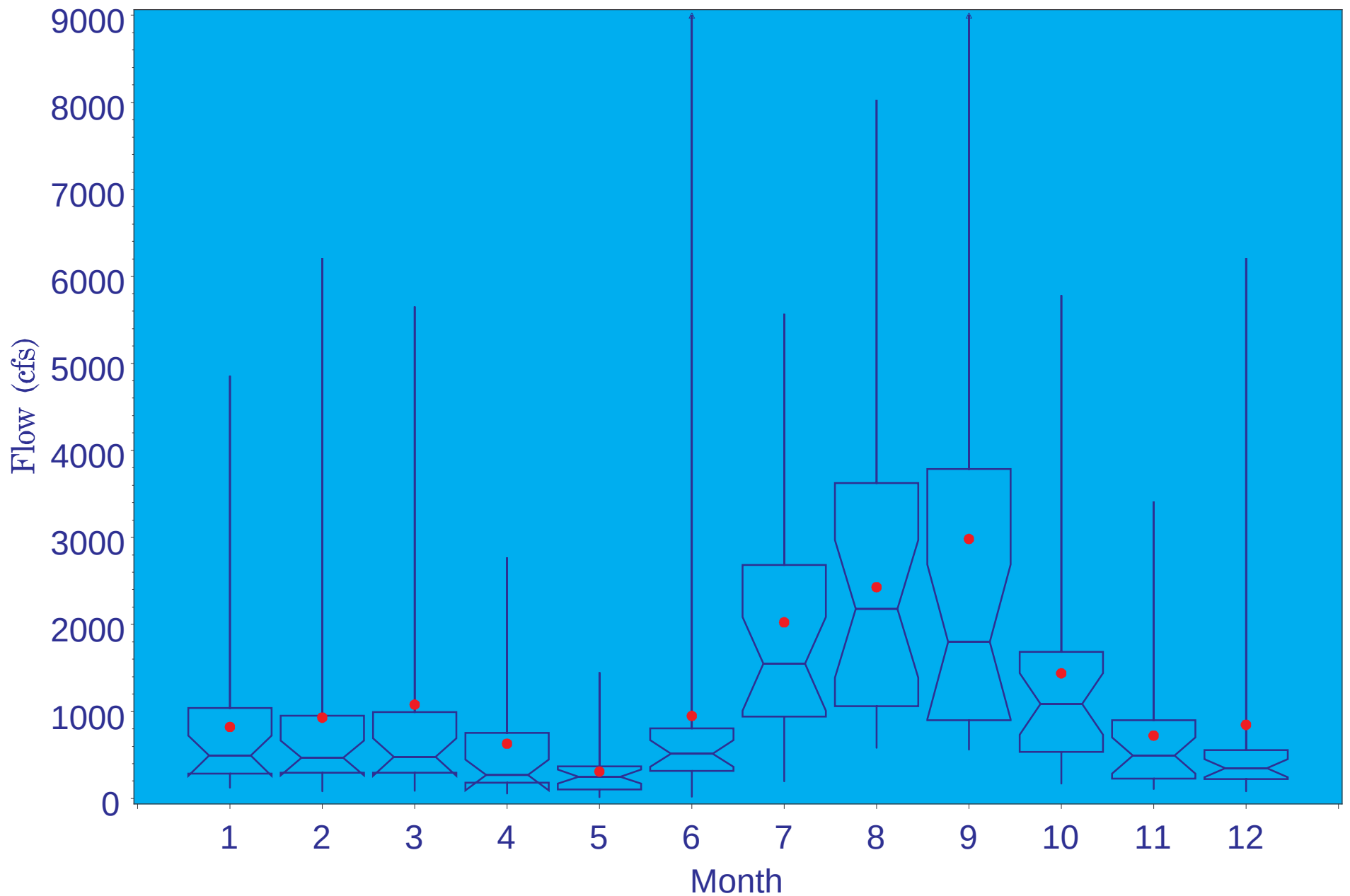


Figure 4.2.40 Monthly boxplots of median flow upstream of the US41 Bridge (1976-2002)

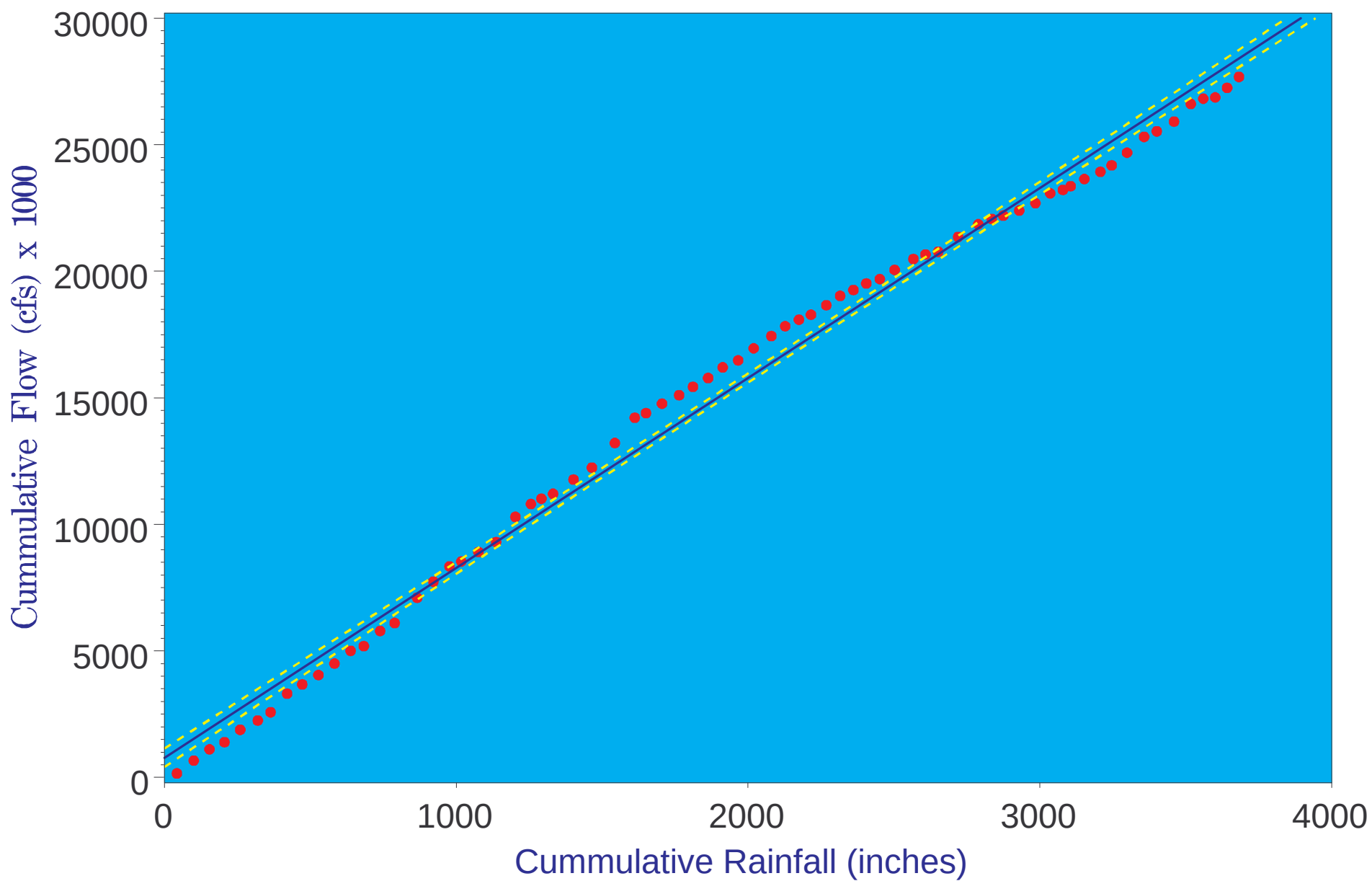


Figure 4.3.1 Average upper watershed rainfall vs. Peace River at Arcadia Flow

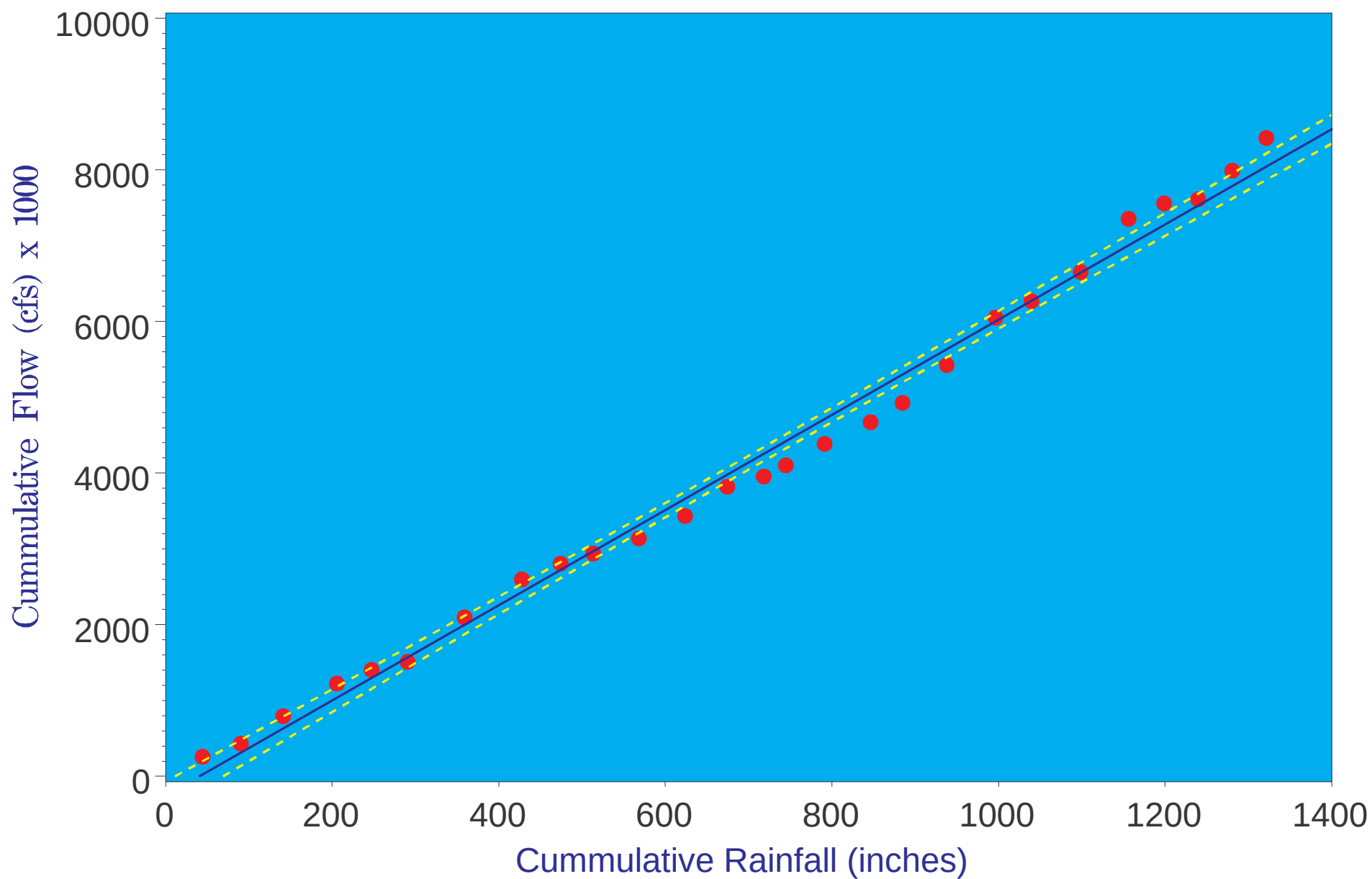


Figure 4.3.2 Average upper watershed rainfall vs. Peace River at Arcadia Flow (1976-2002)



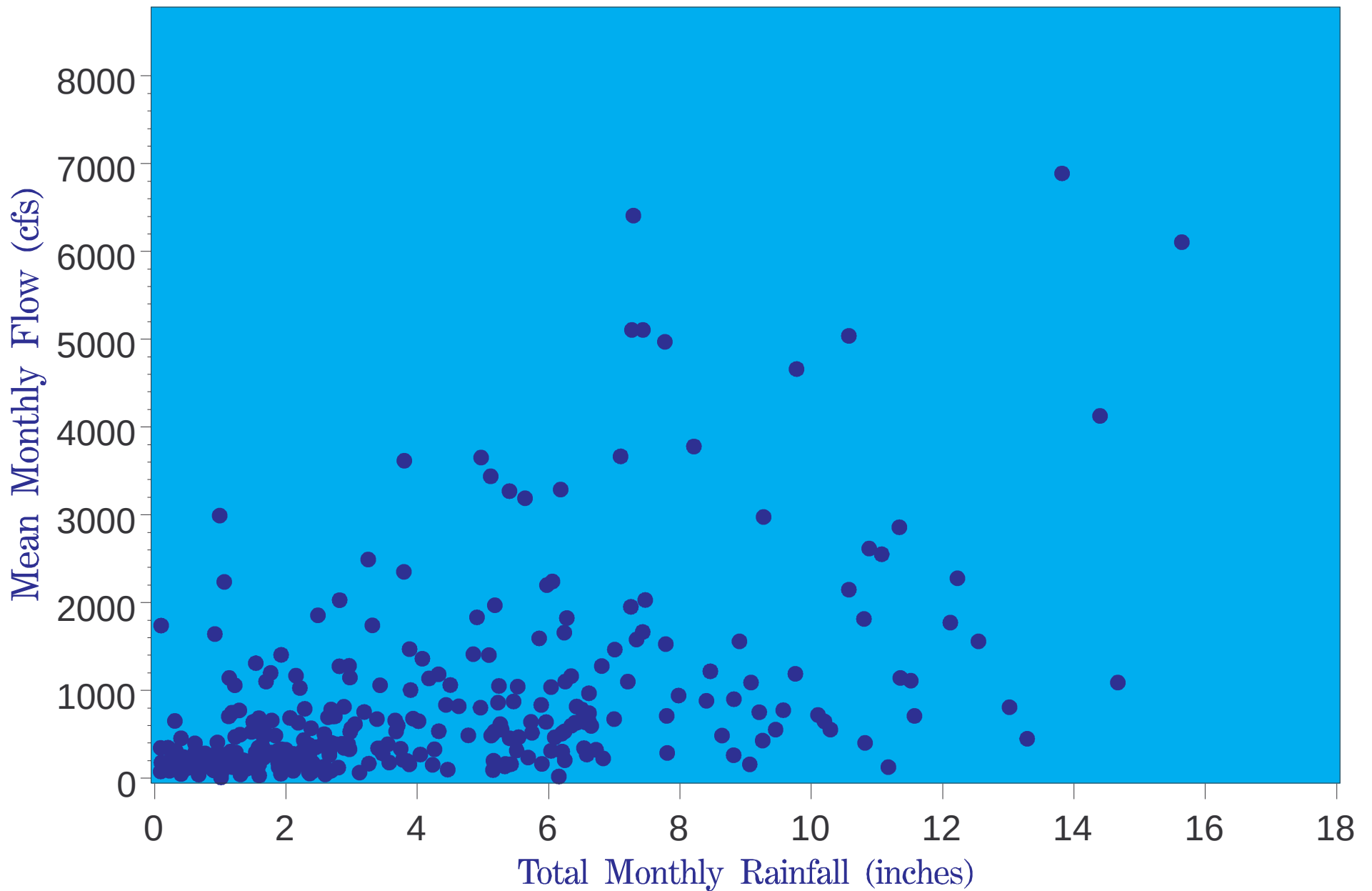


Figure 4.3.3 Peace River flow at Arcadia versus rainfall - overall

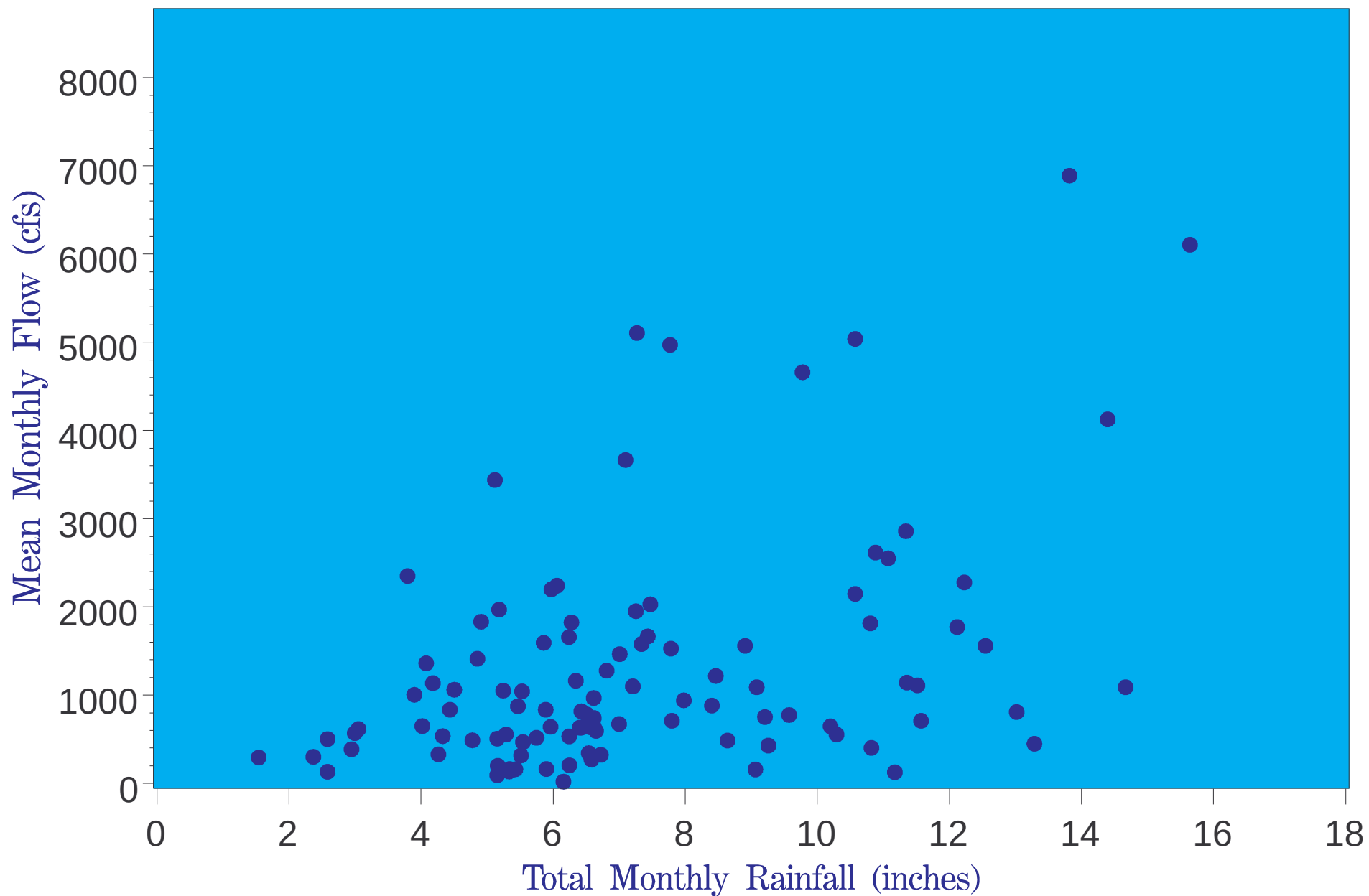


Figure 4.3.4 Peace River flow at Arcadia versus rainfall - wet season

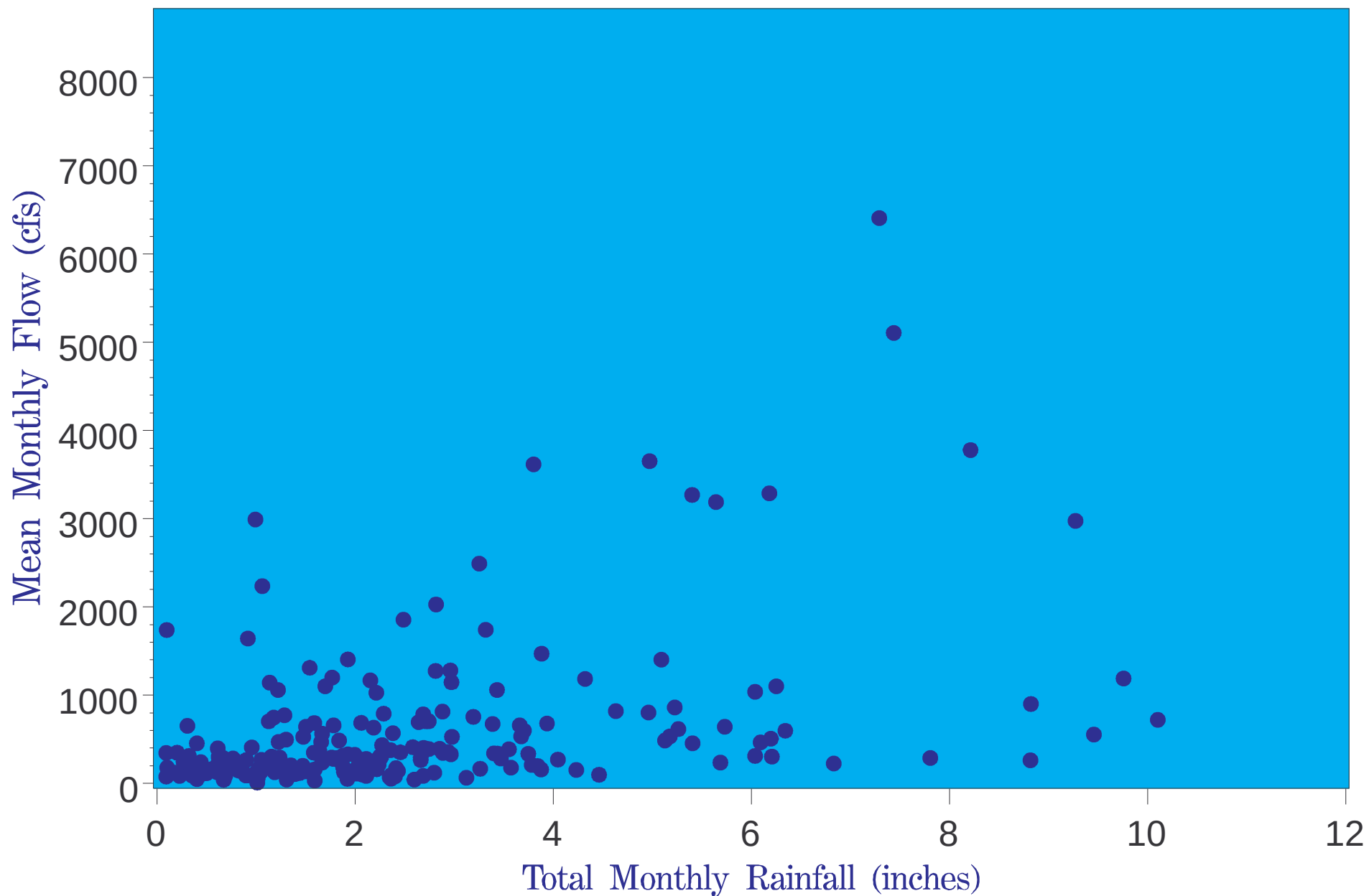


Figure 4.3.5 Peace River flow at Arcadia versus rainfall - dry season

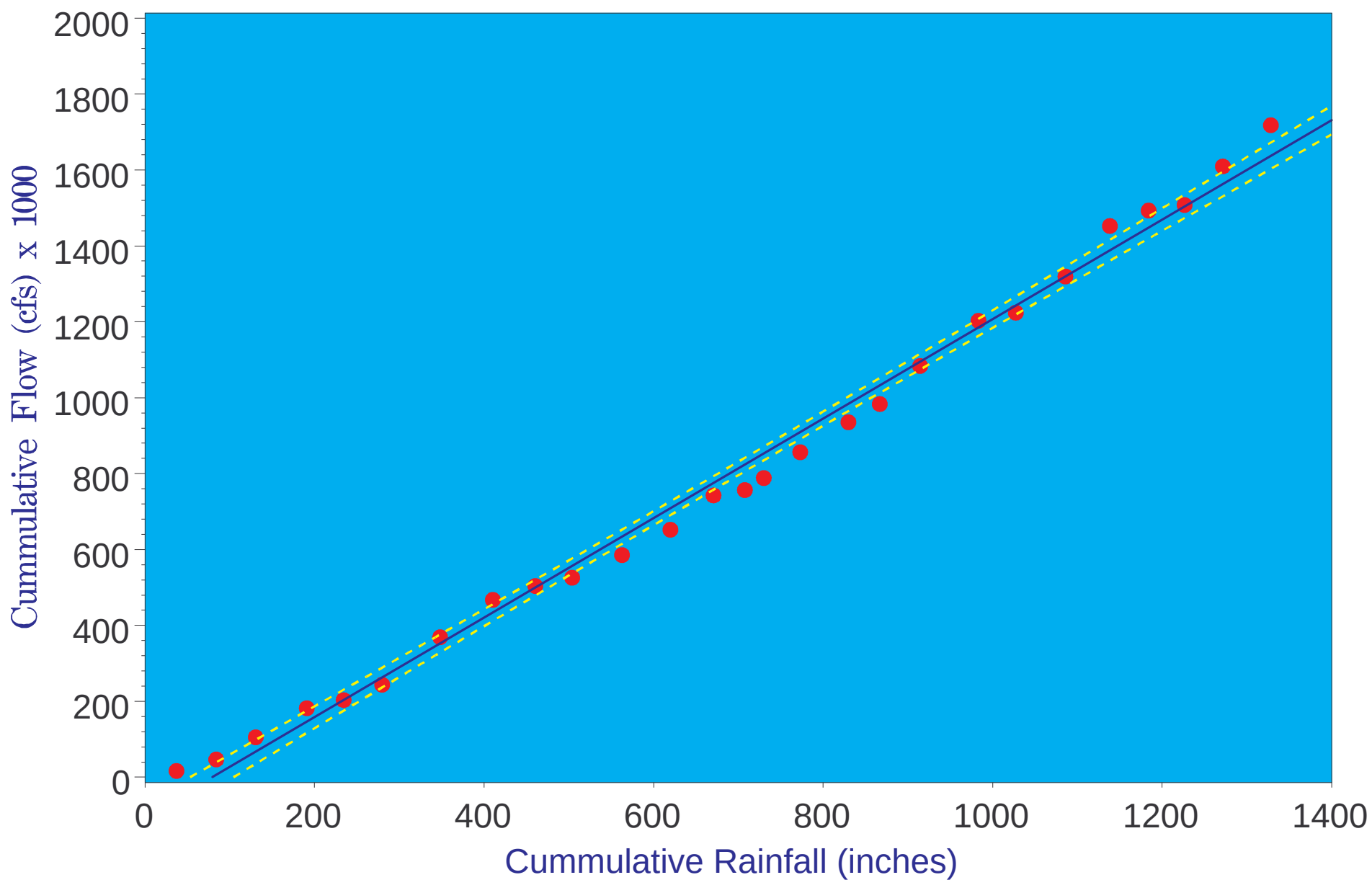


Figure 4.3.6 Average upper watershed rainfall vs. Horse Creek flow (1976-2002)

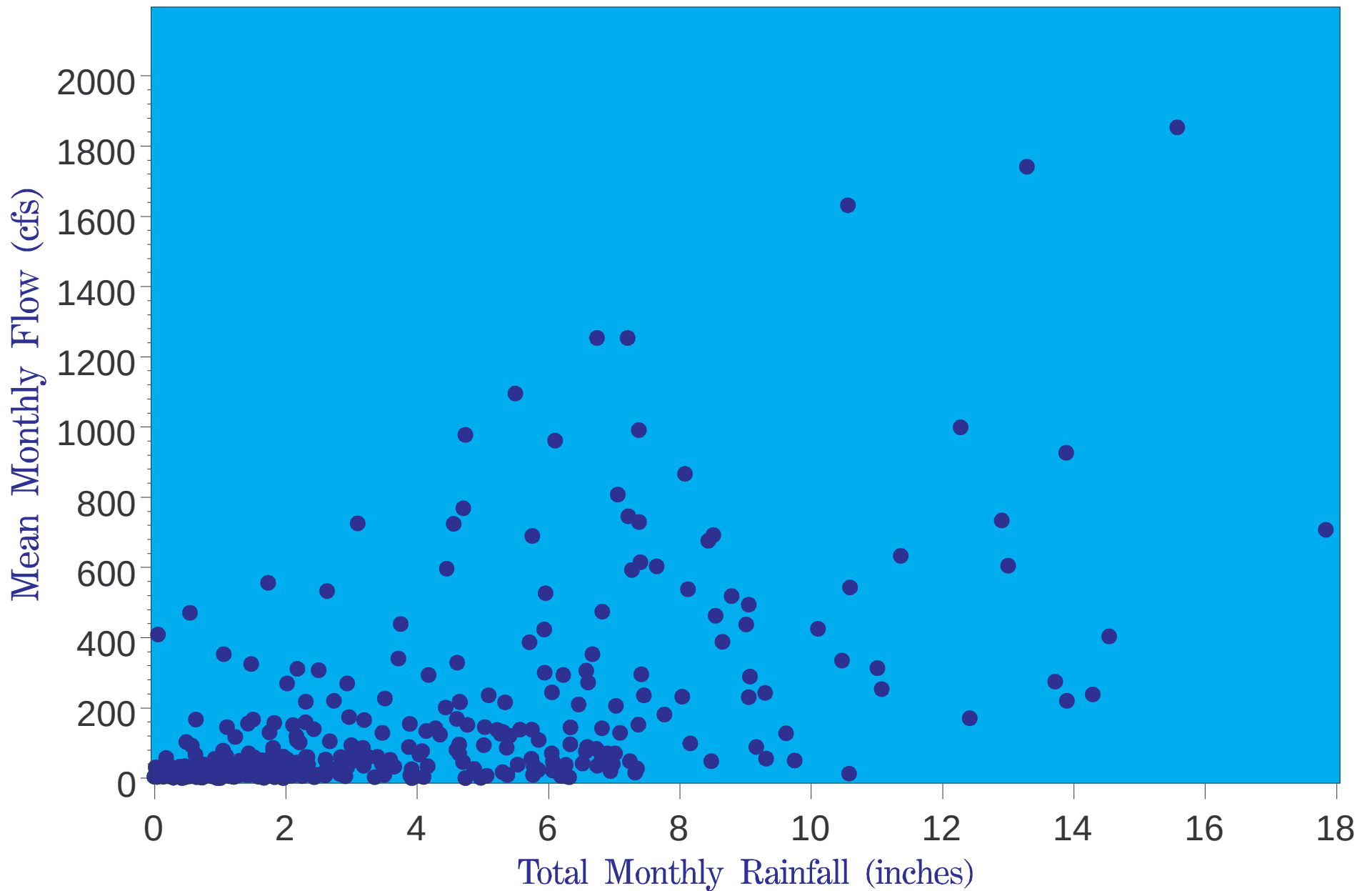


Figure 4.3.7 Horse Creek flow versus rainfall - overall

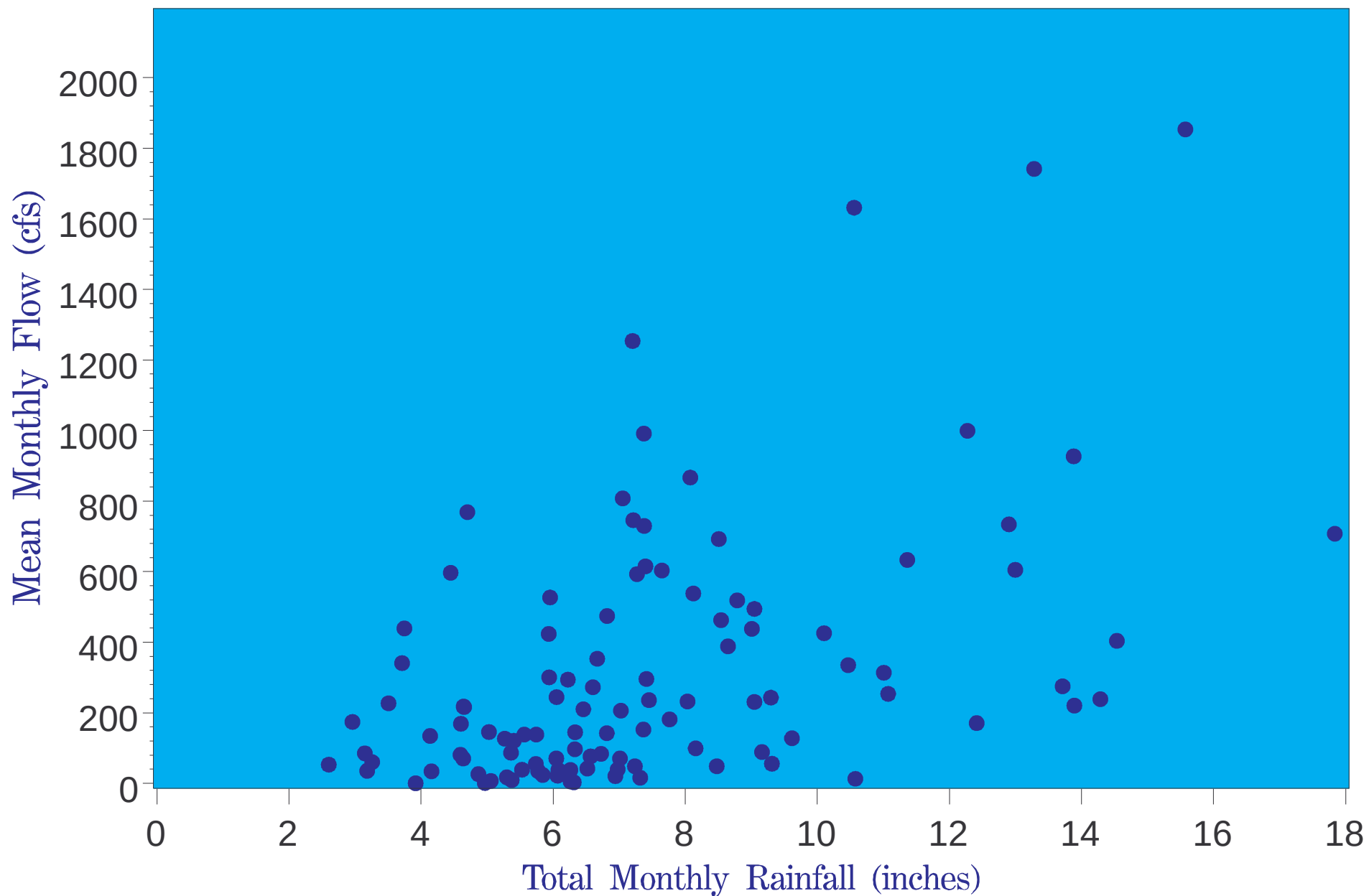


Figure 4.3.8 Horse Creek flow versus rainfall - wet season

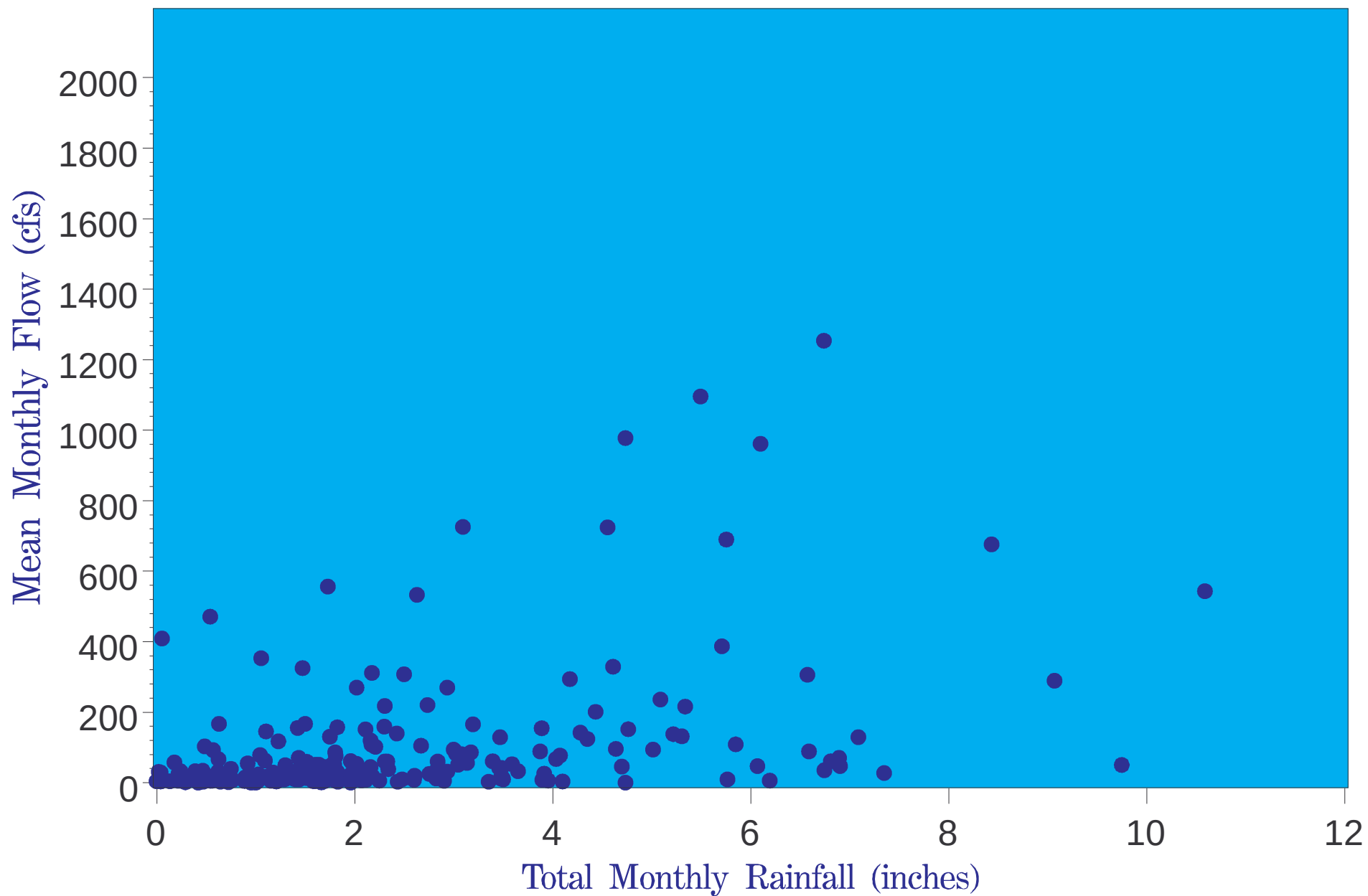


Figure 4.3.9 Horse Creek flow versus rainfall - dry season

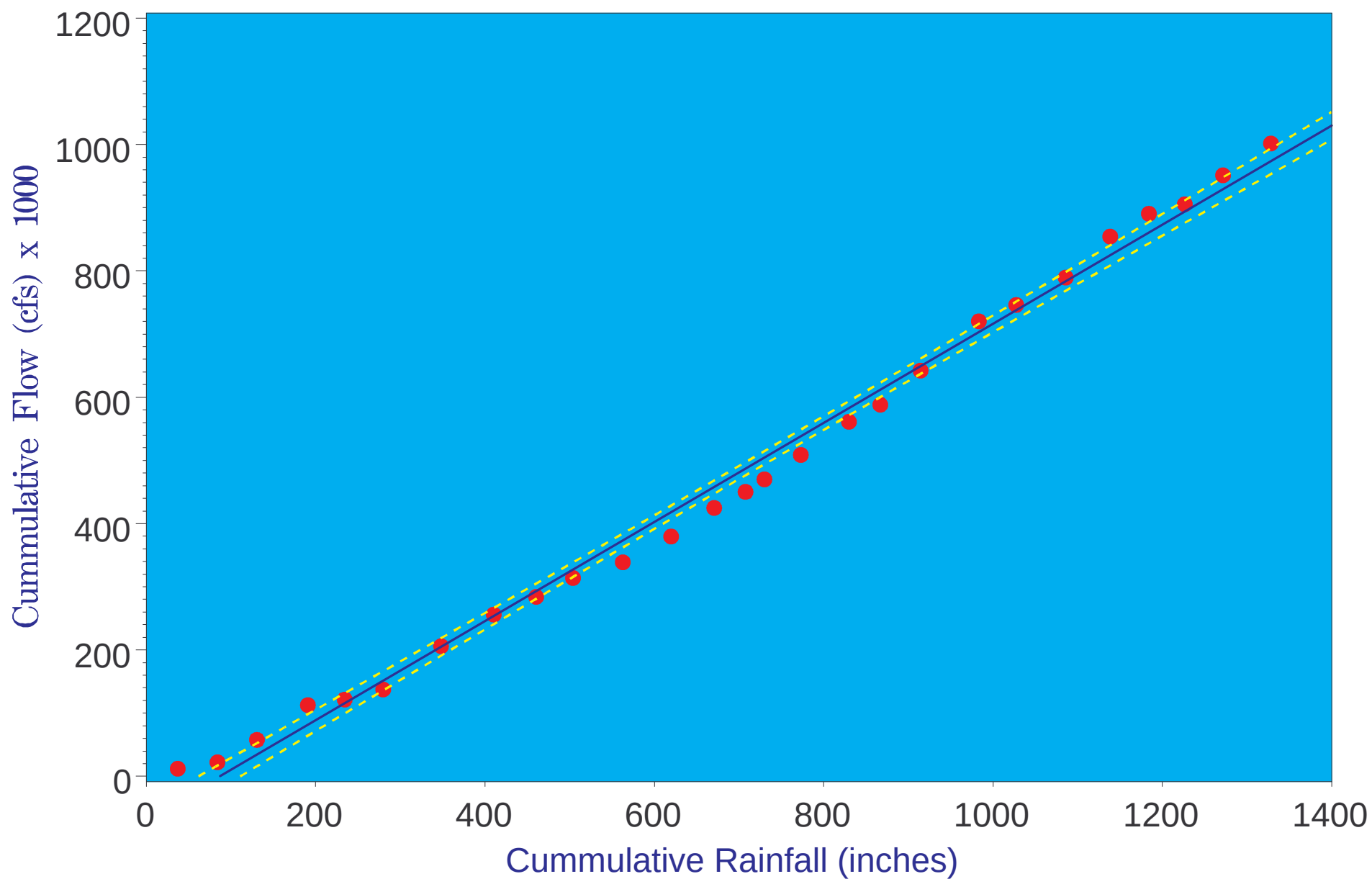


Figure 4.3.10 Average upper watershed rainfall vs. Joshua Creek flow (1976-2002)



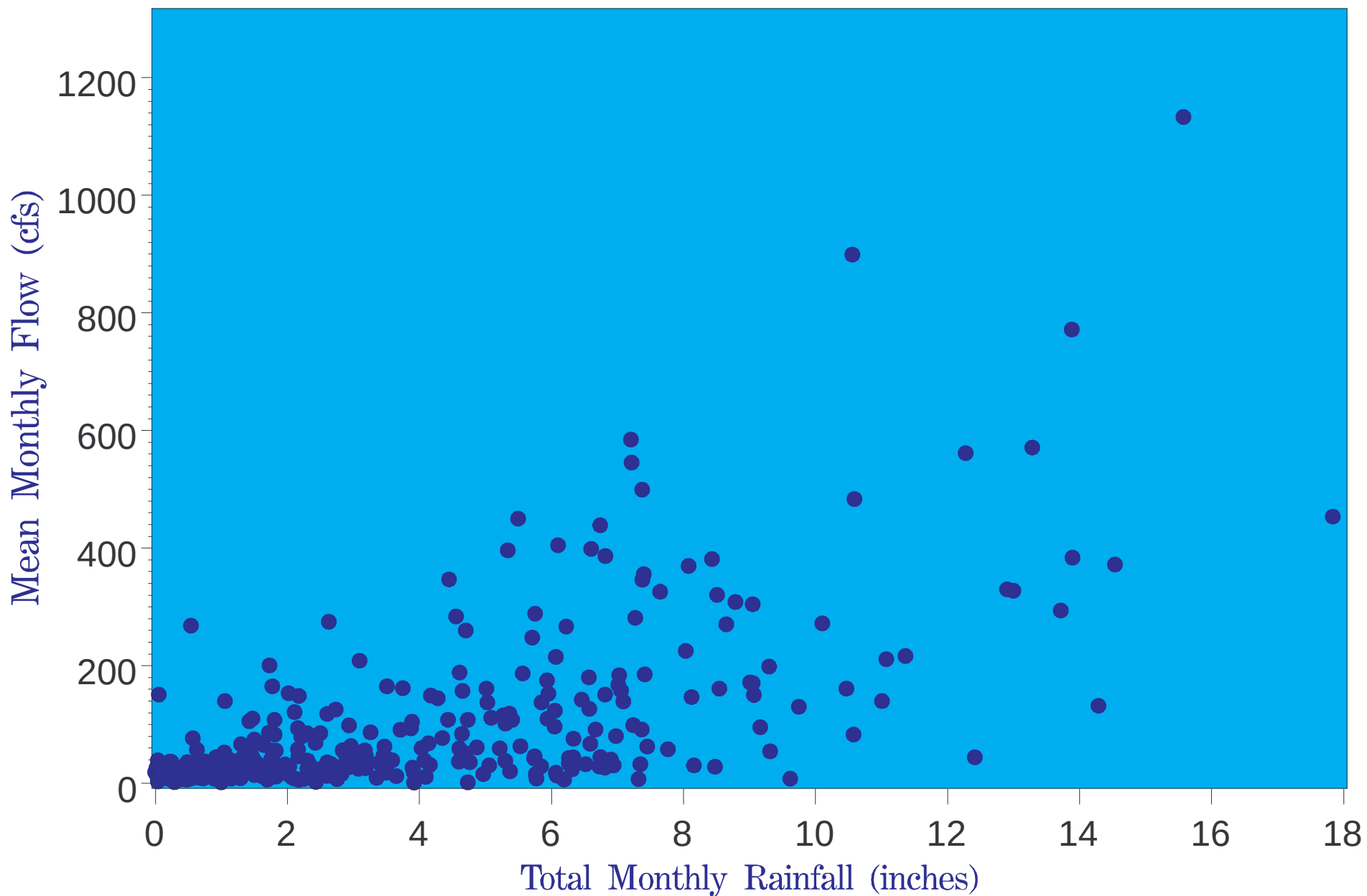


Figure 4.3.11 Joshua Creek flow versus rainfall - overall

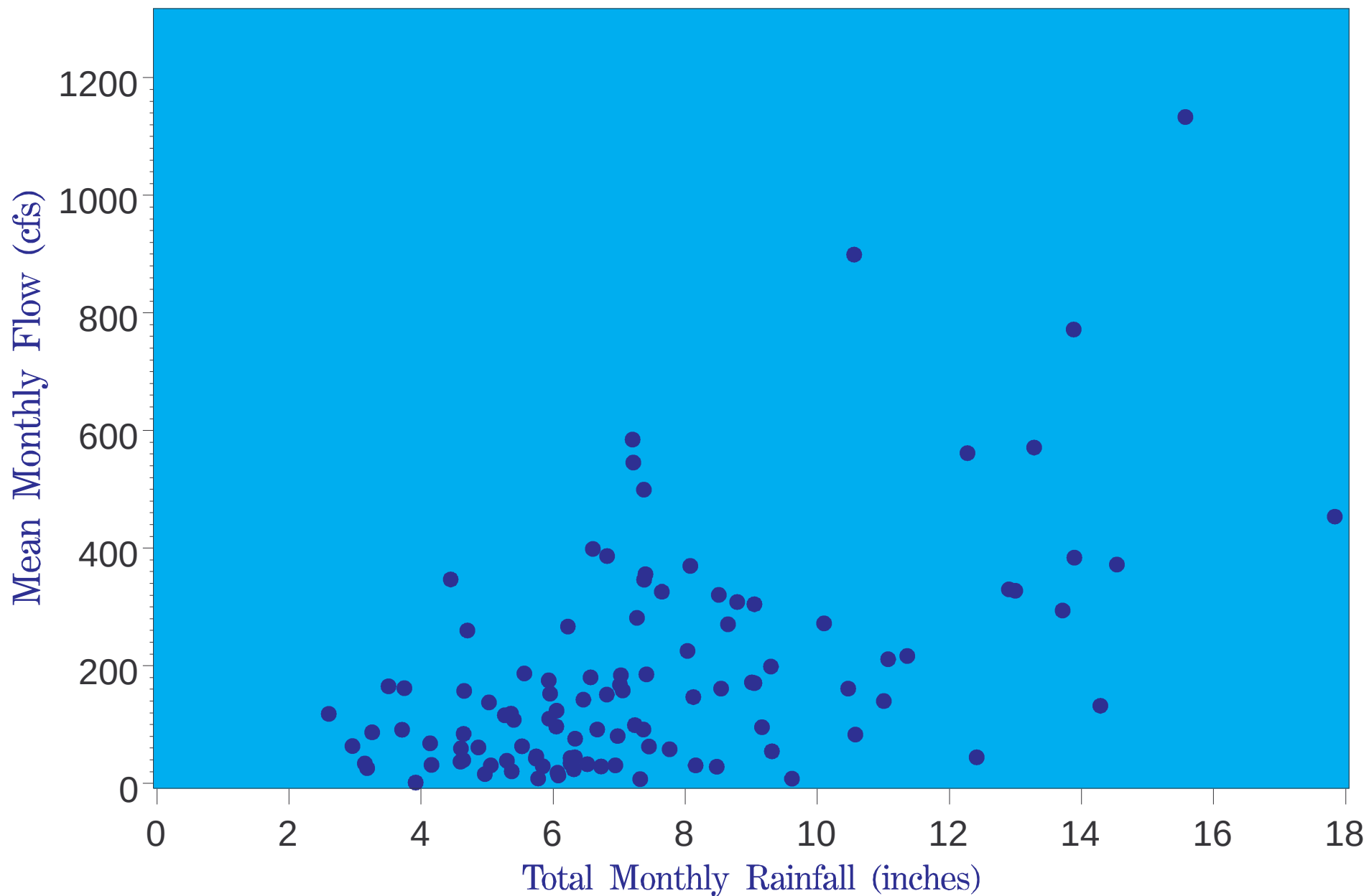


Figure 4.3.12 Joshua Creek flow versus rainfall - wet season

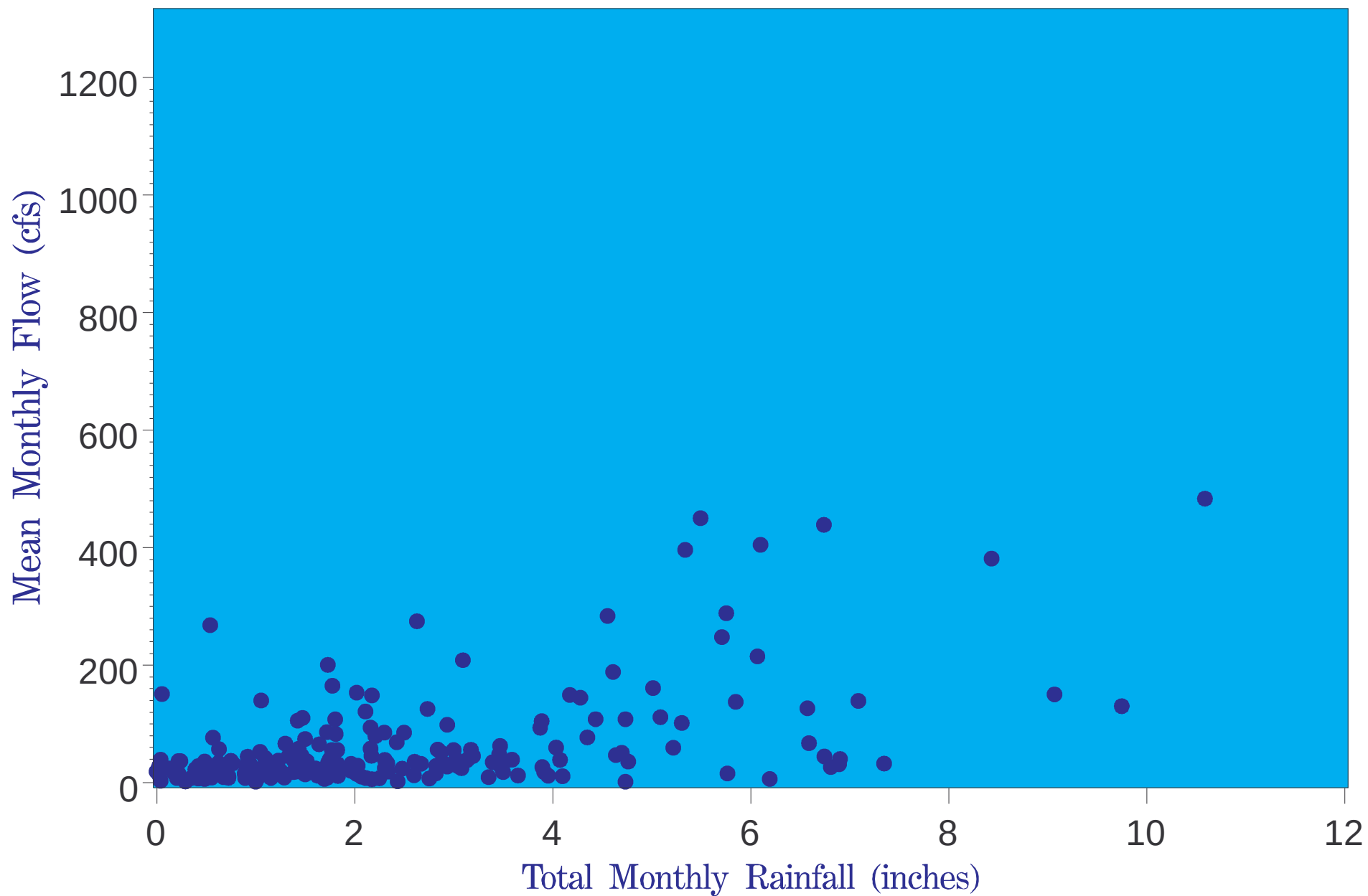


Figure 4.3.13 Joshua Creek flow versus rainfall - dry season

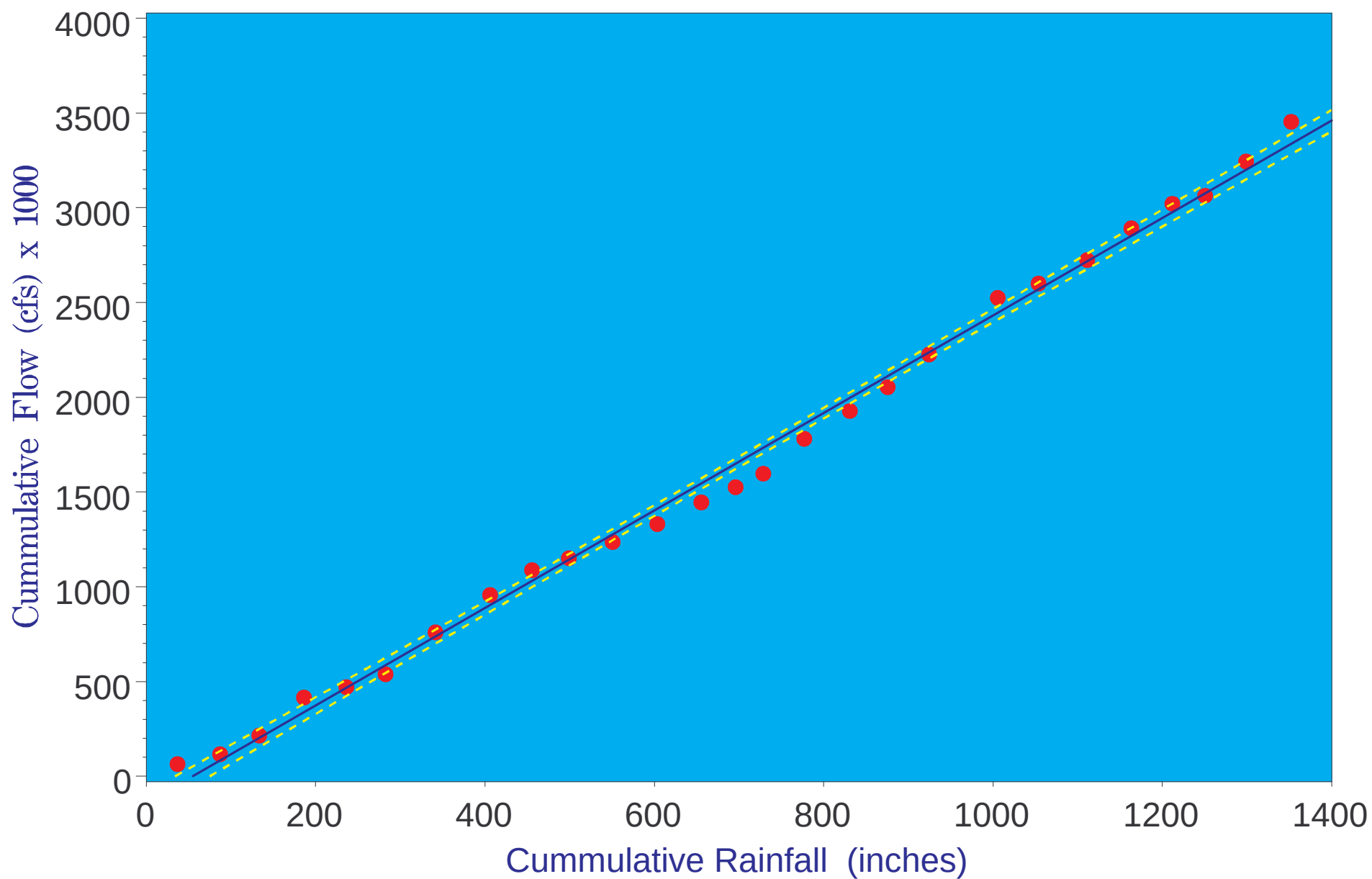


Figure 4.3.14 Average upper watershed rainfall vs. Shell Creek flow (1976-2002)

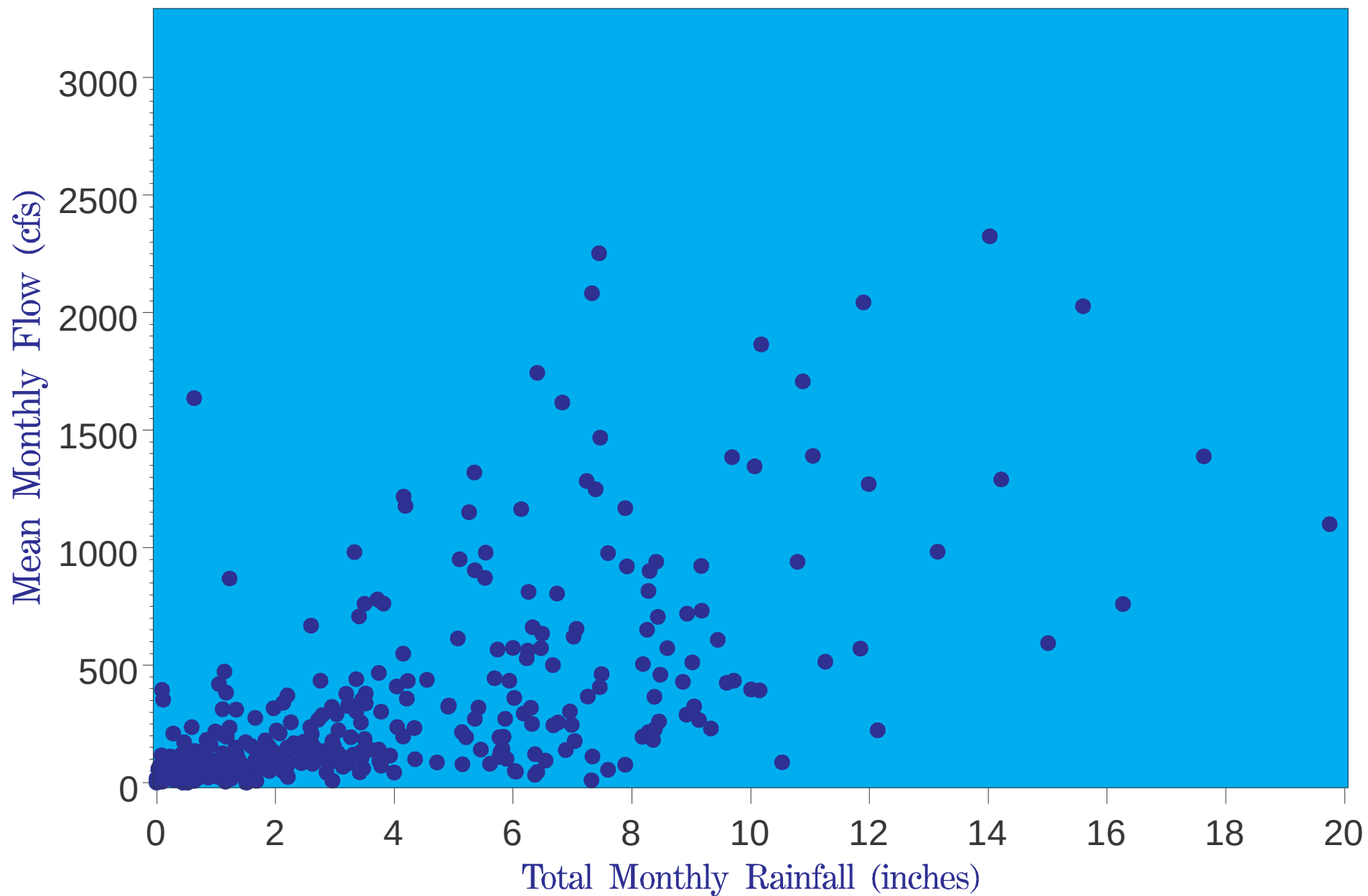


Figure 4.3.15 Shell Creek flow versus rainfall - overall

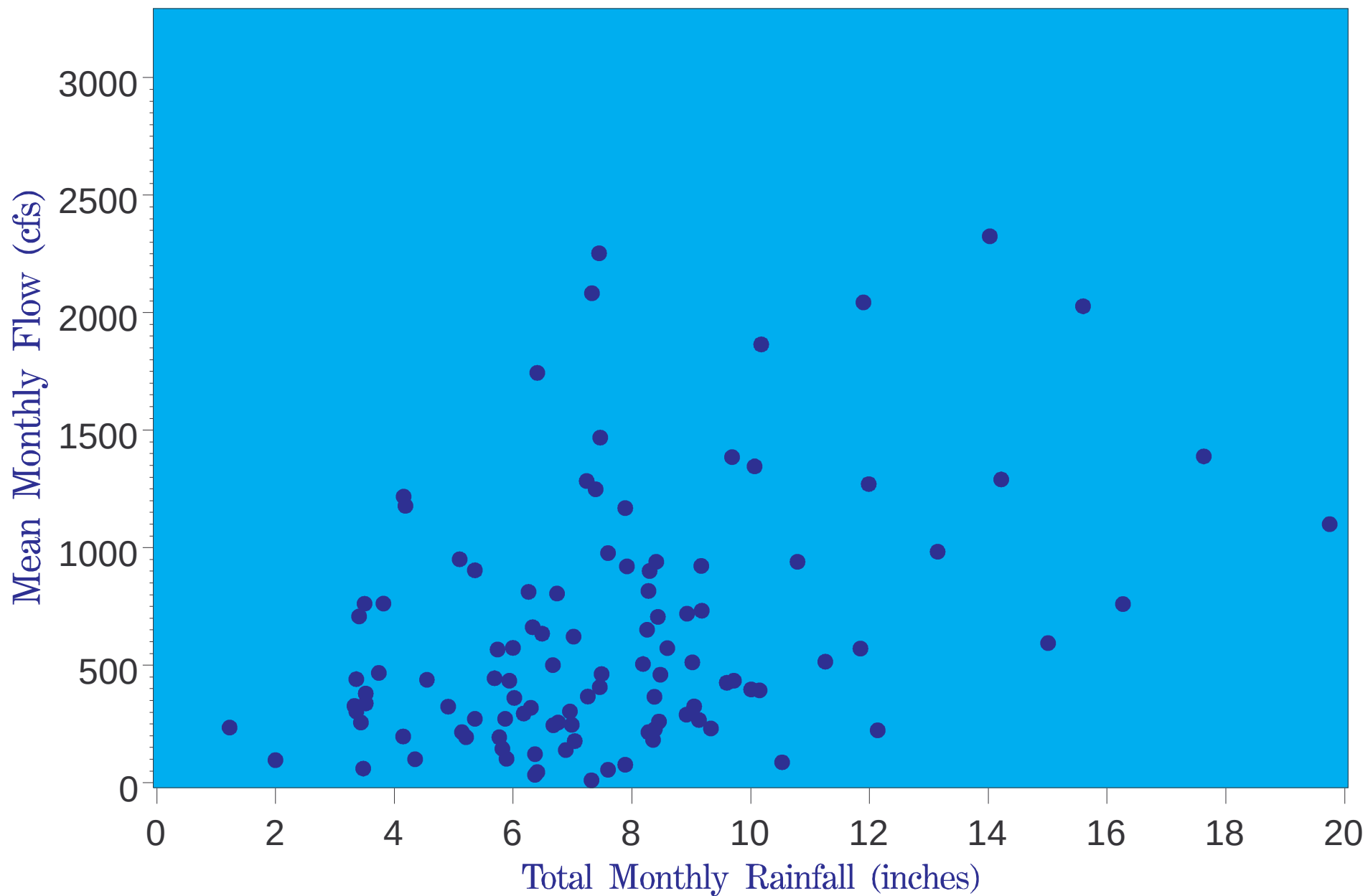


Figure 4.3.16 Shell Creek flow versus rainfall - wet season

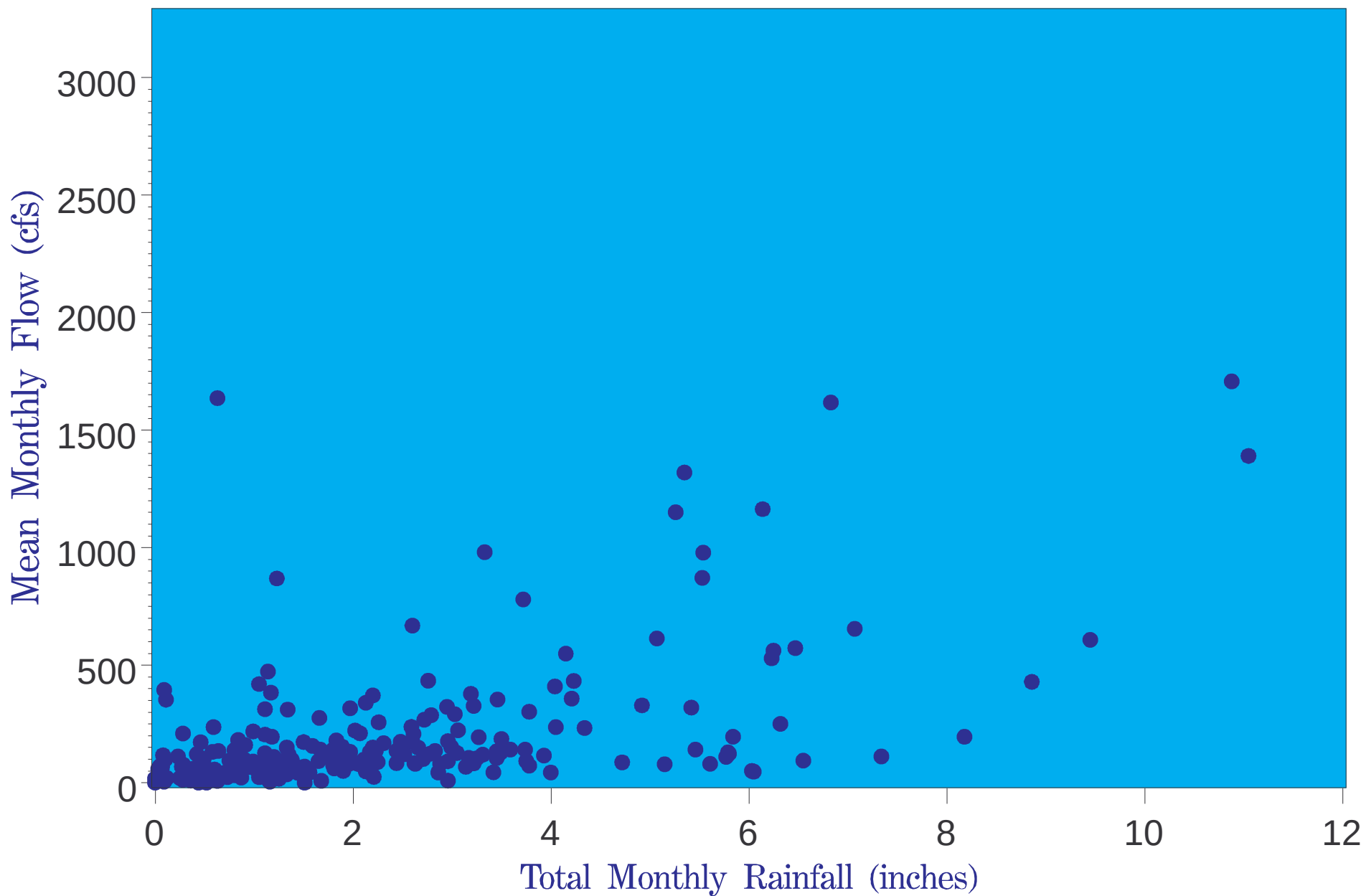


Figure 4.3.17 Shell Creek flow versus rainfall - dry season

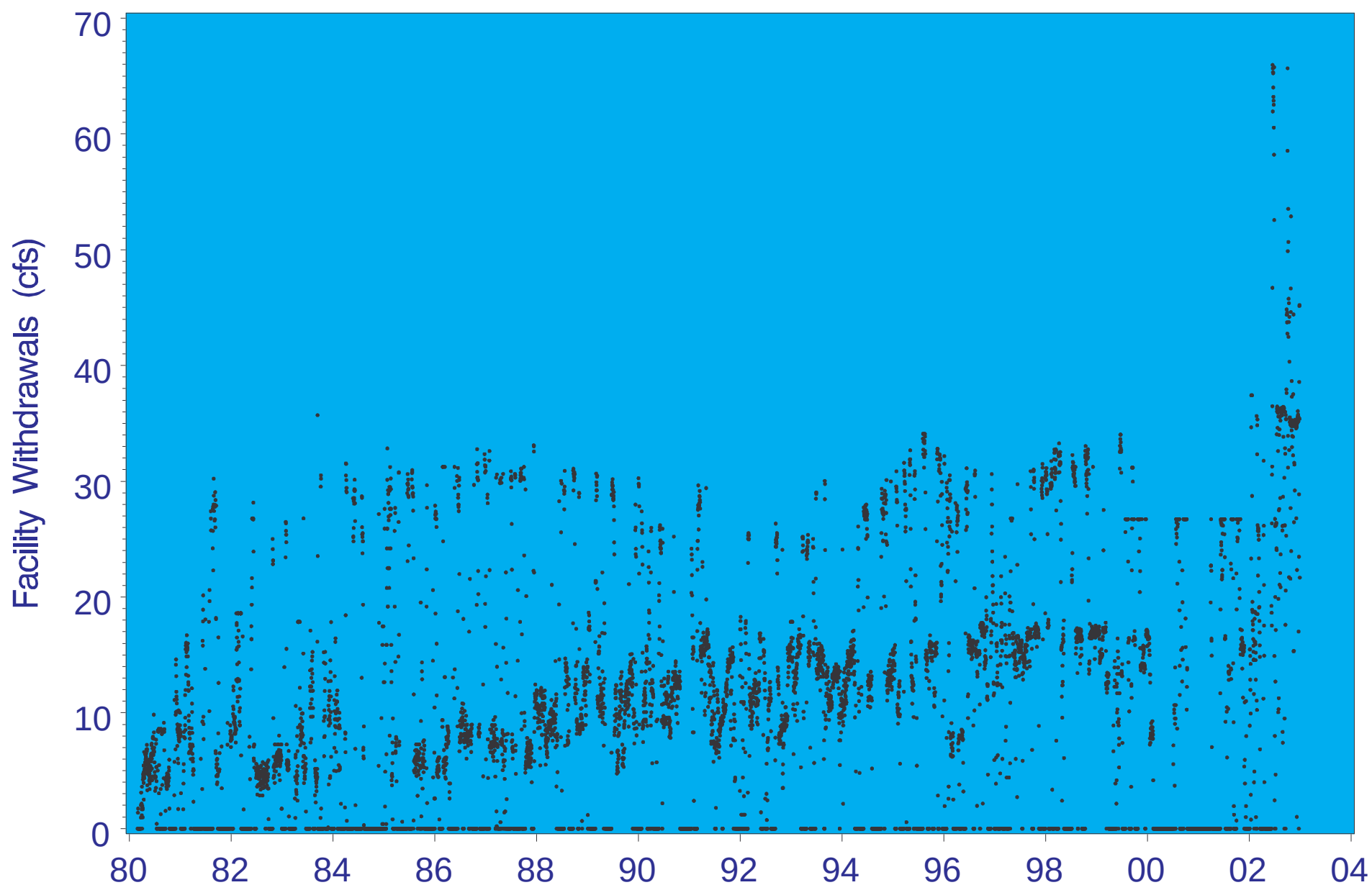


Figure 4.4.1 Daily water treatment facility withdrawals (1980-2002)



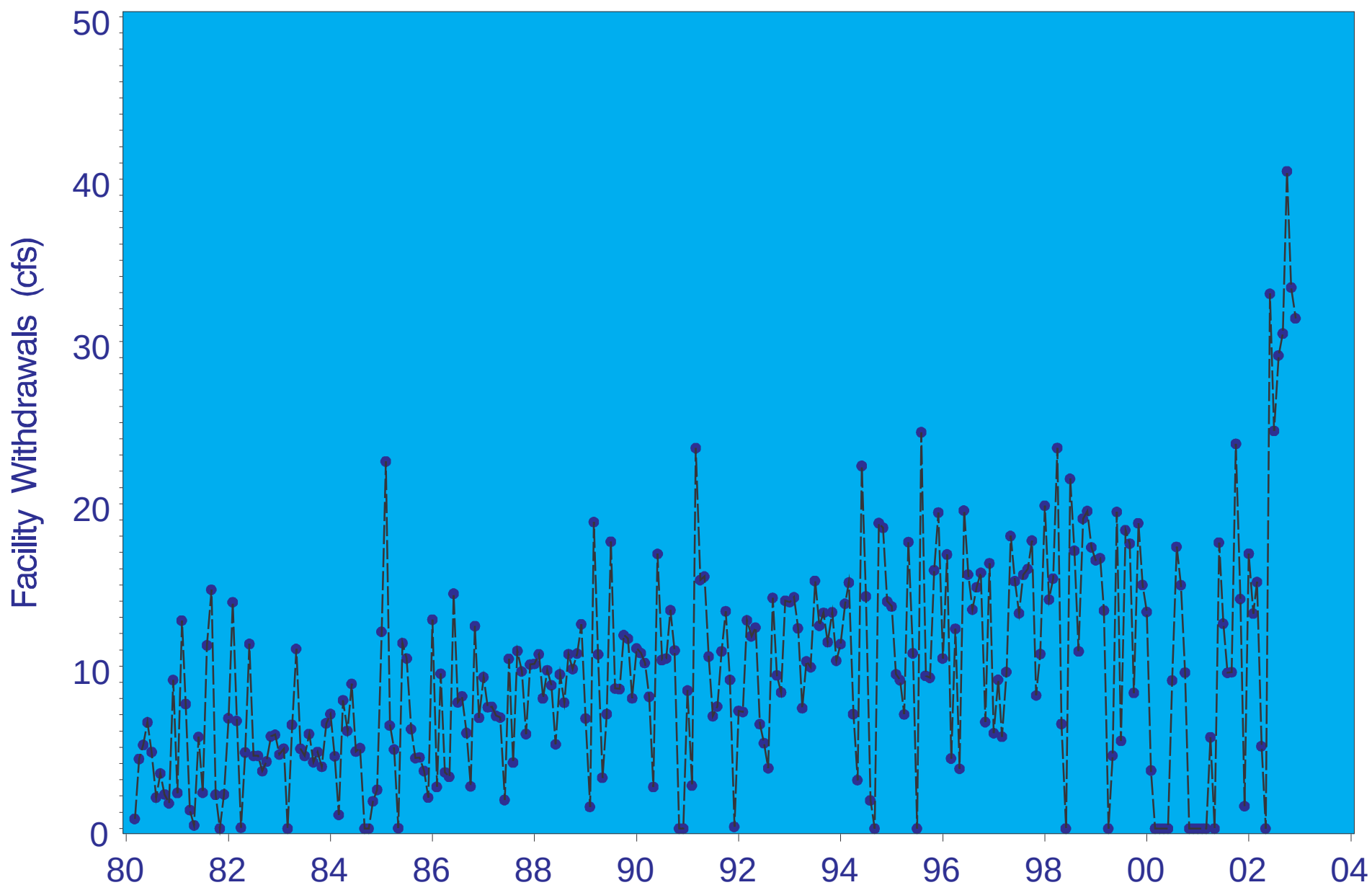


Figure 4.4.2 Monthly mean water treatment facility withdrawals (1980-2002)

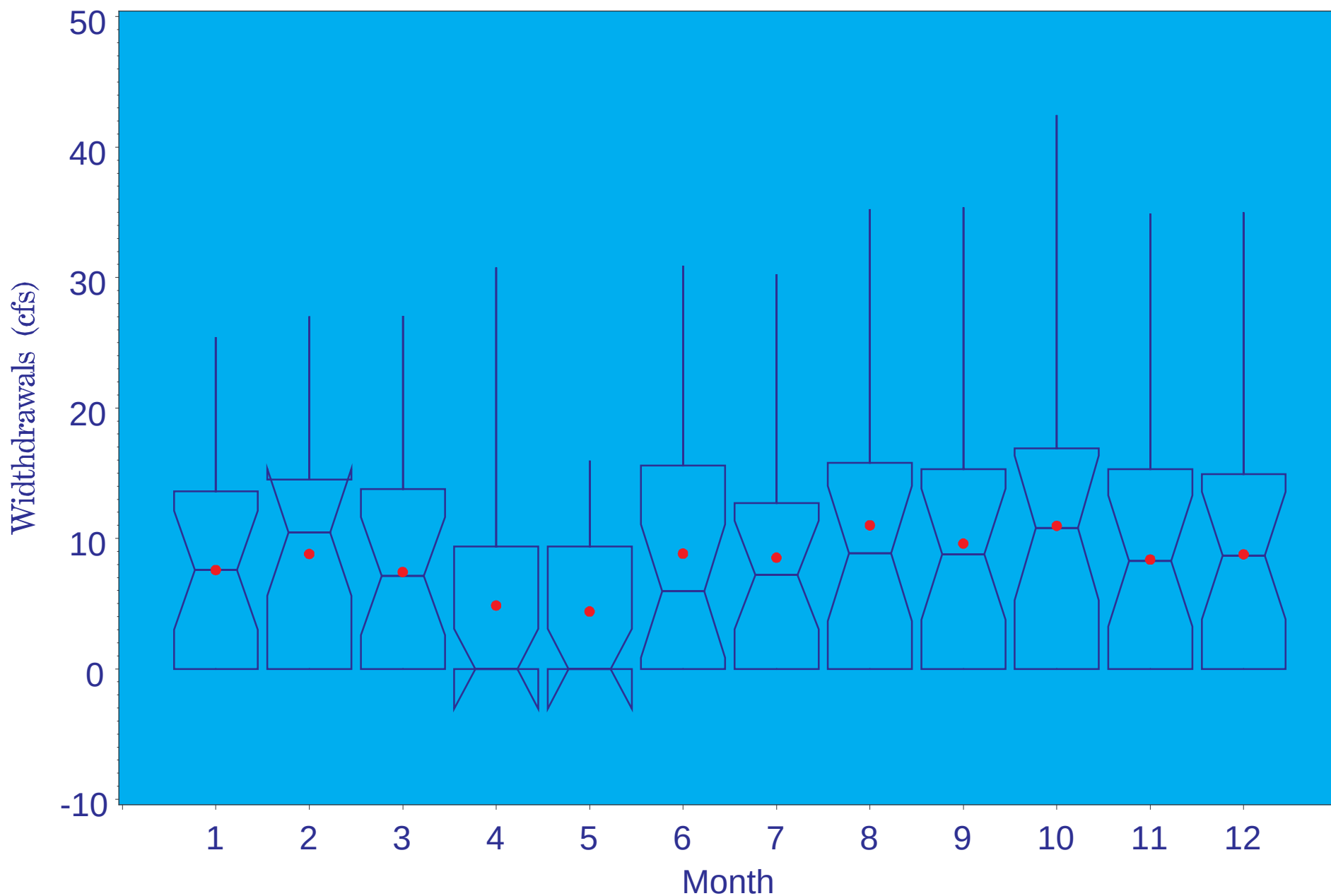


Figure 4.4.3 Monthly boxplots of facility withdrawals (1980-2002)

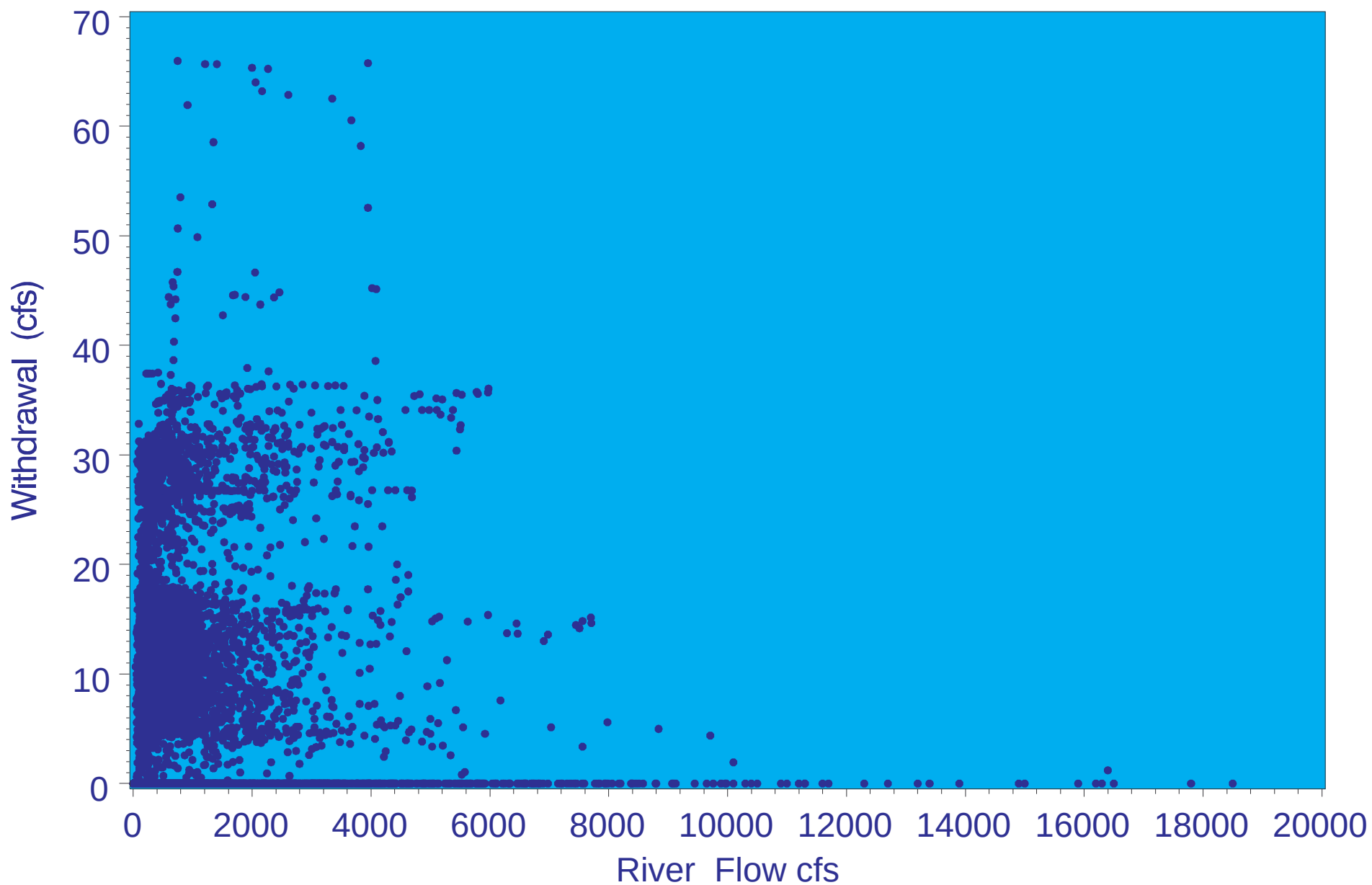


Figure 4.4.4a Water treatment facility withdrawals versus Arcadia flow

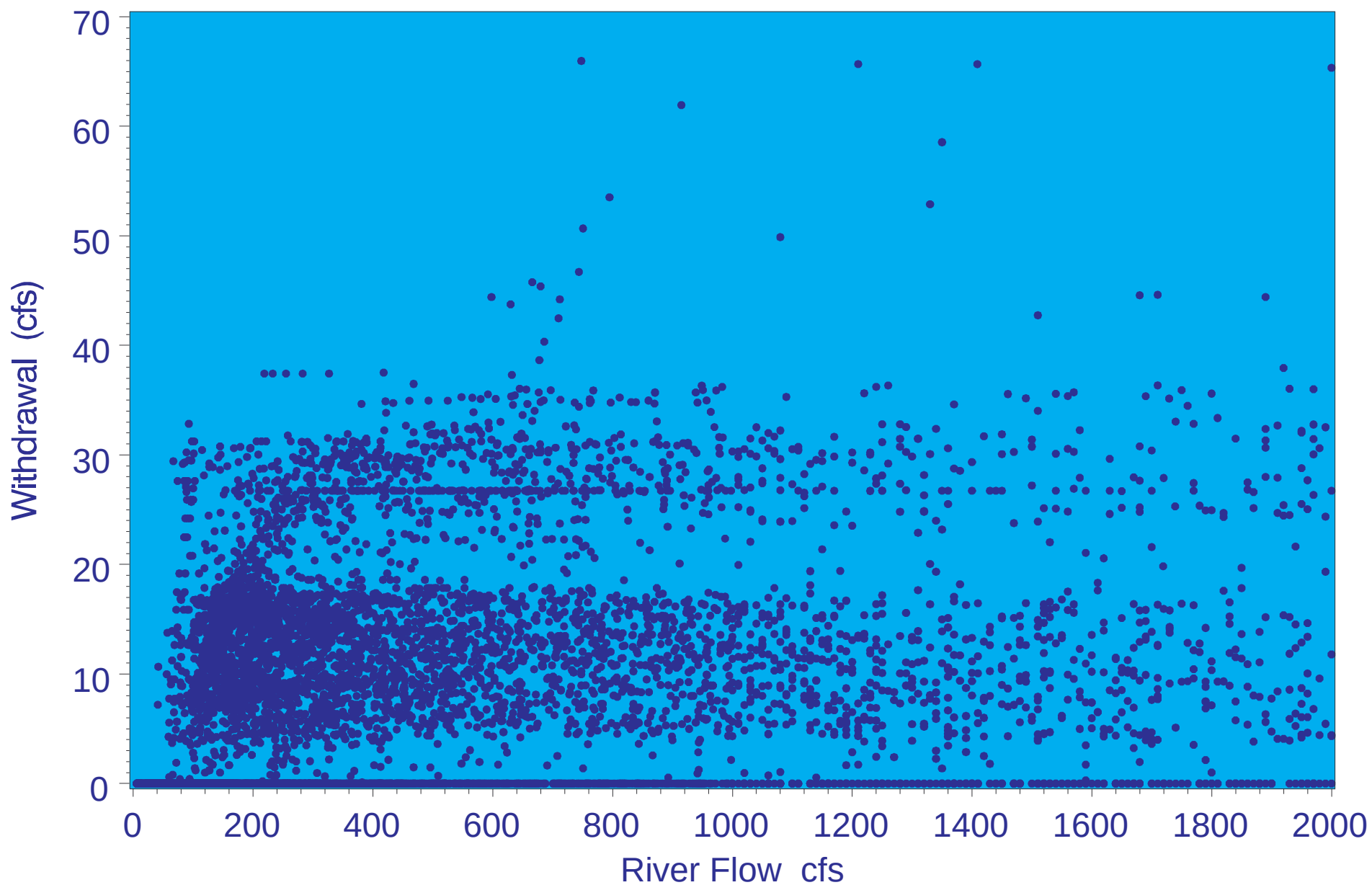


Figure 4.4.4b Water treatment facility withdrawals versus Arcadia flow

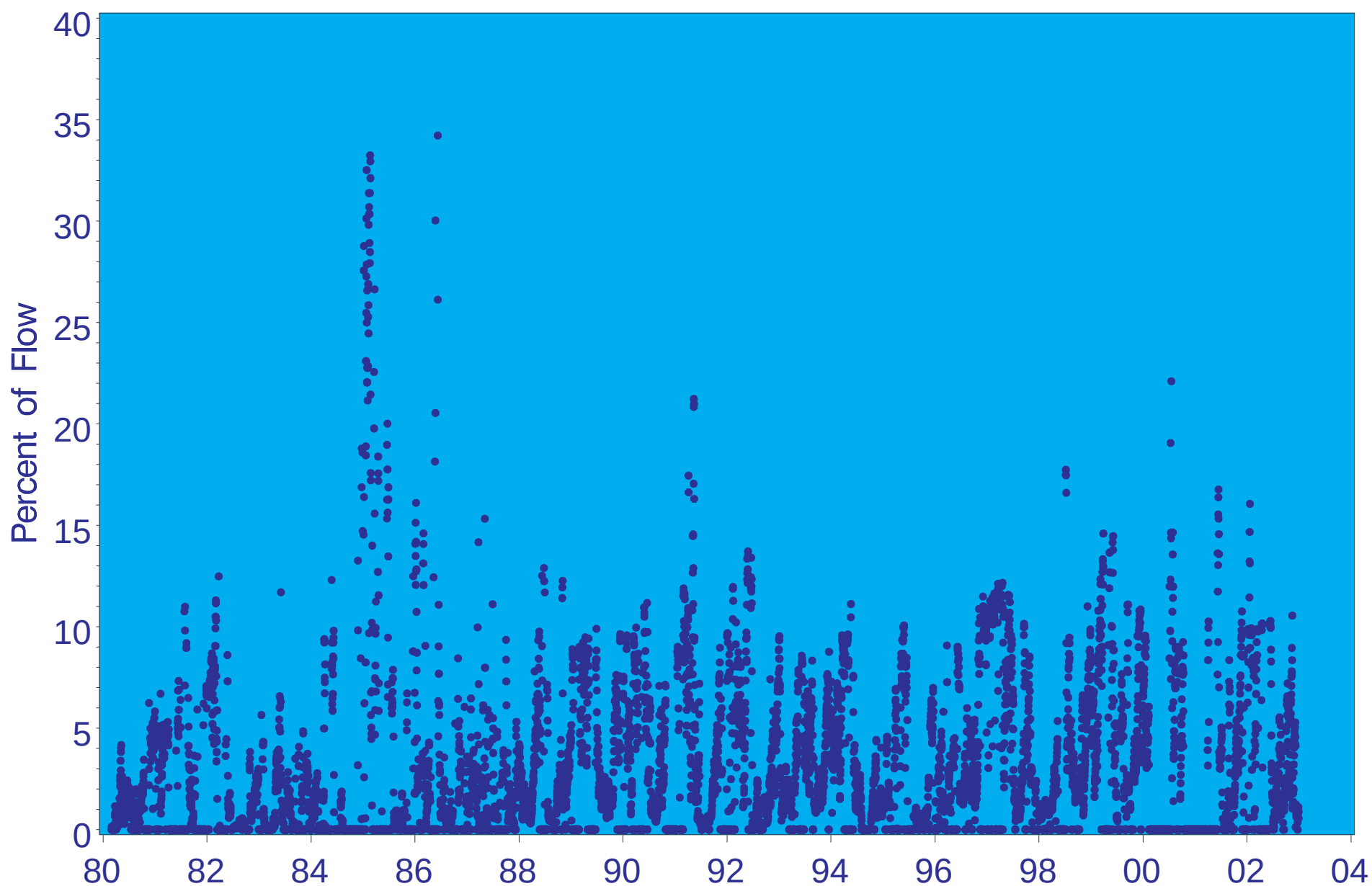


Figure 4.4.5 Facility withdrawals as a percent of Peace River Arcadia flow (1980-2002)

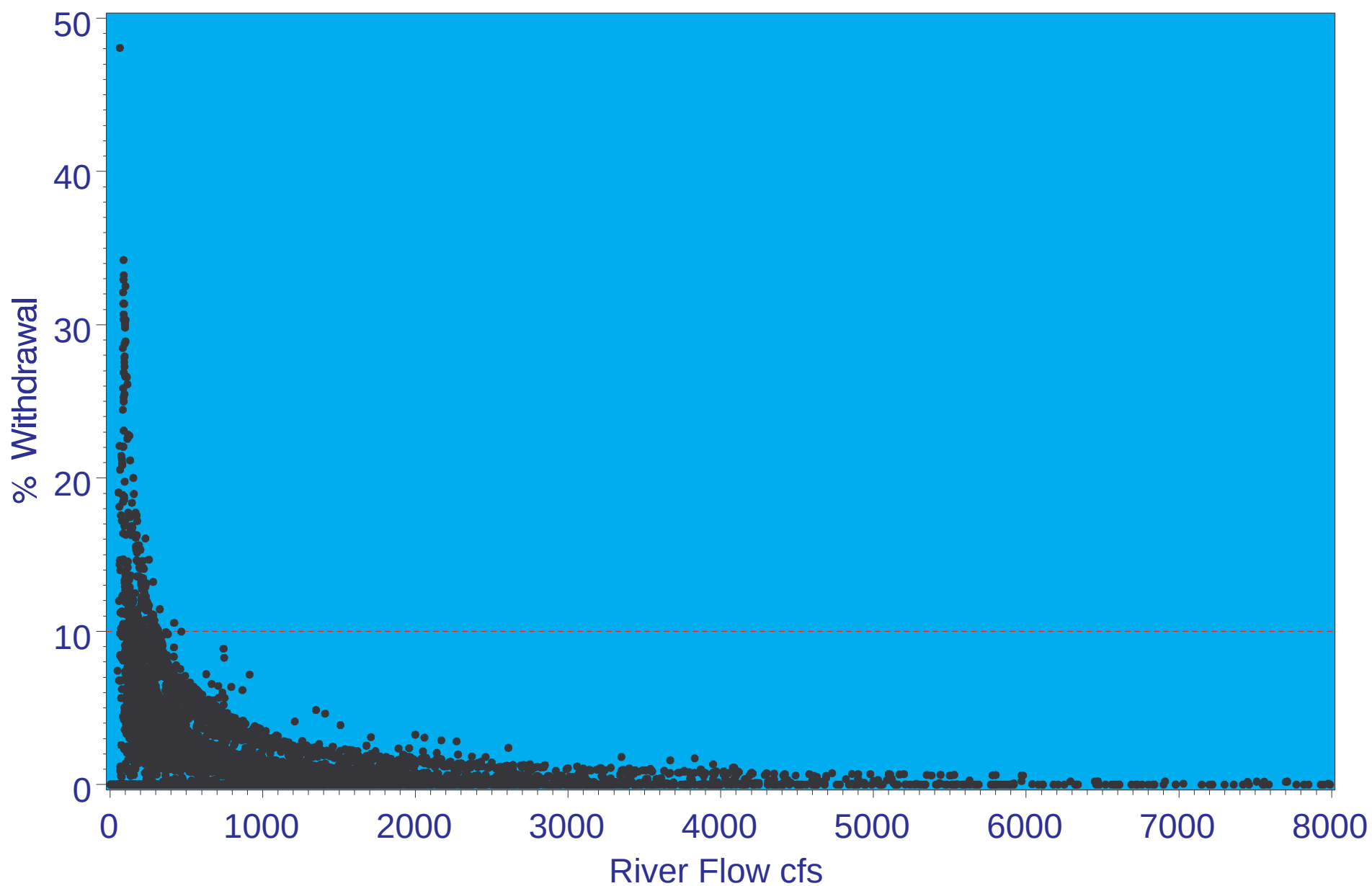


Figure 4.4.6a Peace River flows at Arcadia vs. % water treatment facility withdrawals

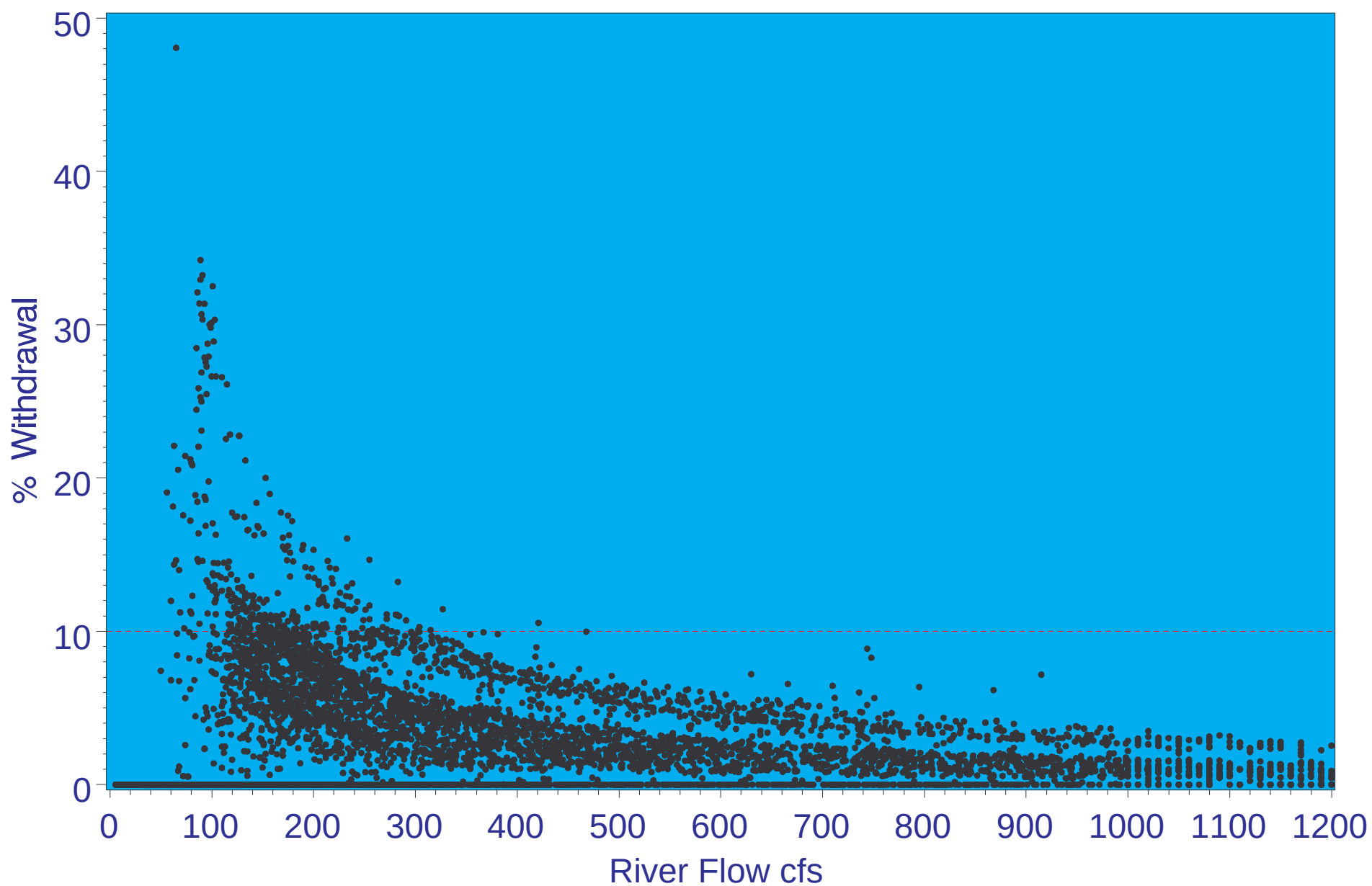


Figure 4.4.6b Peace River flows at Arcadia vs. % water treatment facility withdrawals

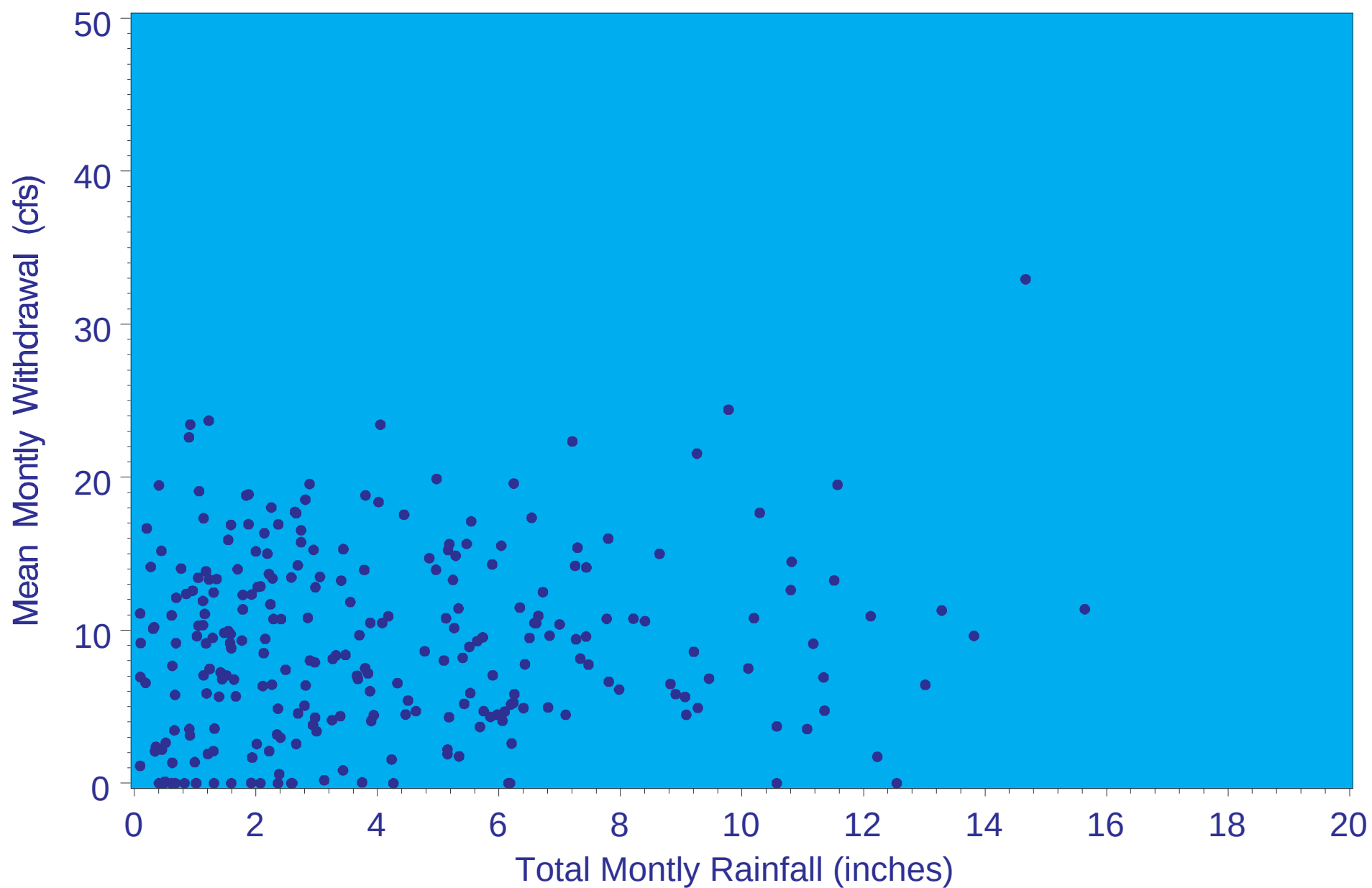


Figure 4.4.7 Facility withdrawals versus monthly rainfall



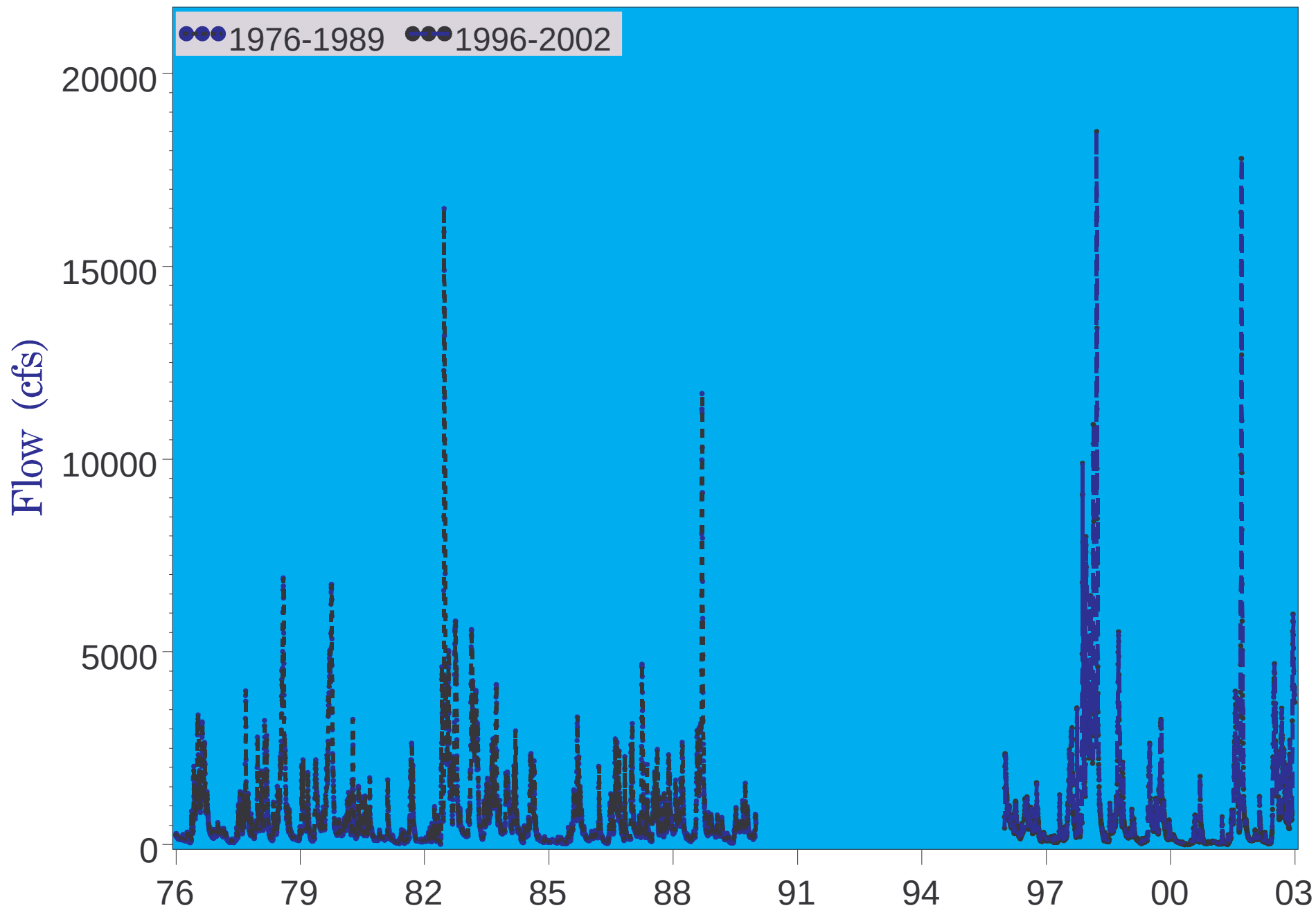


Figure 4.5.1 Peace River at Arcadia Gaged Flow

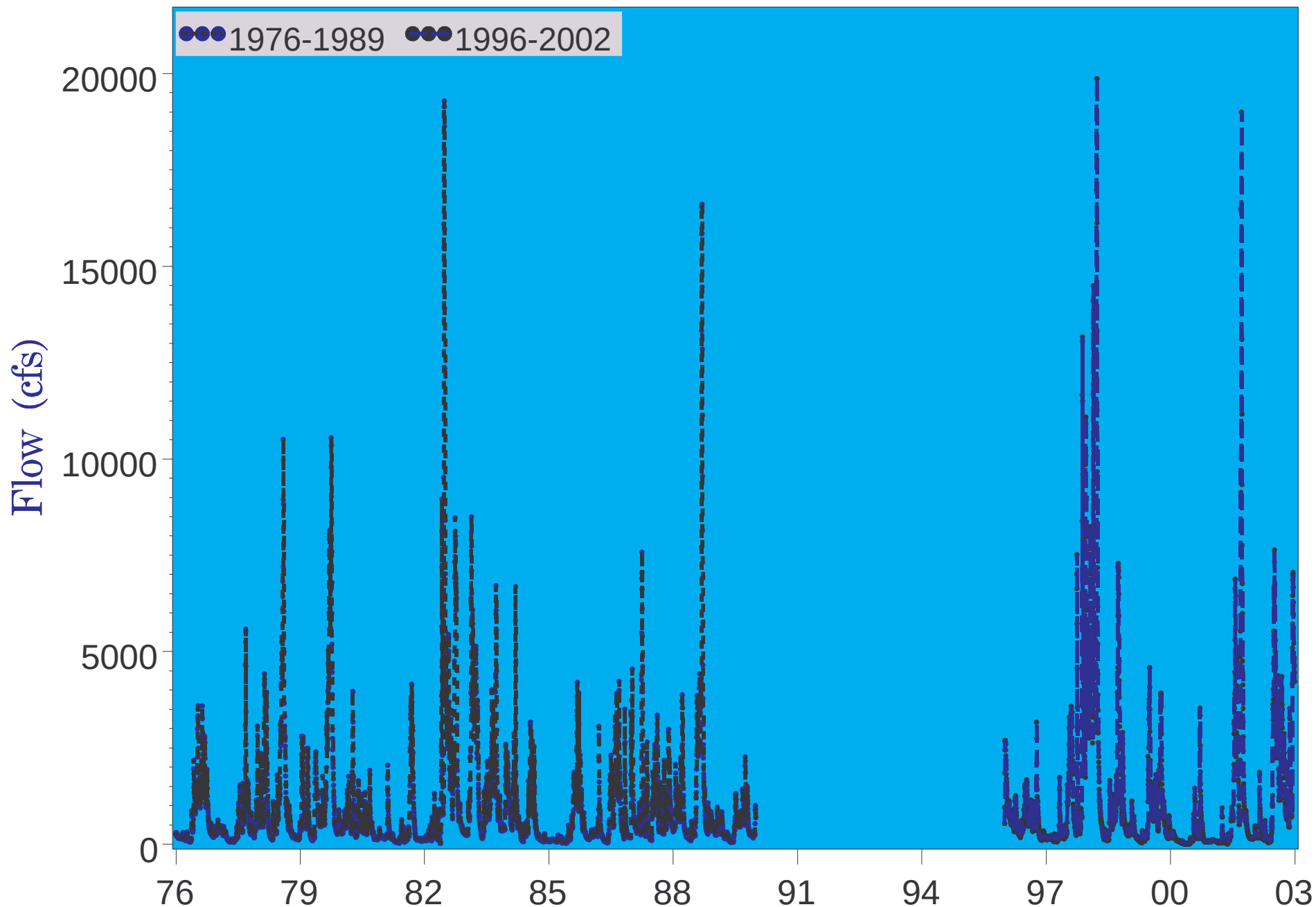


Figure 4.5.2 Peace River at Arcadia + Horse & Joshua Creeks Gaged Flows

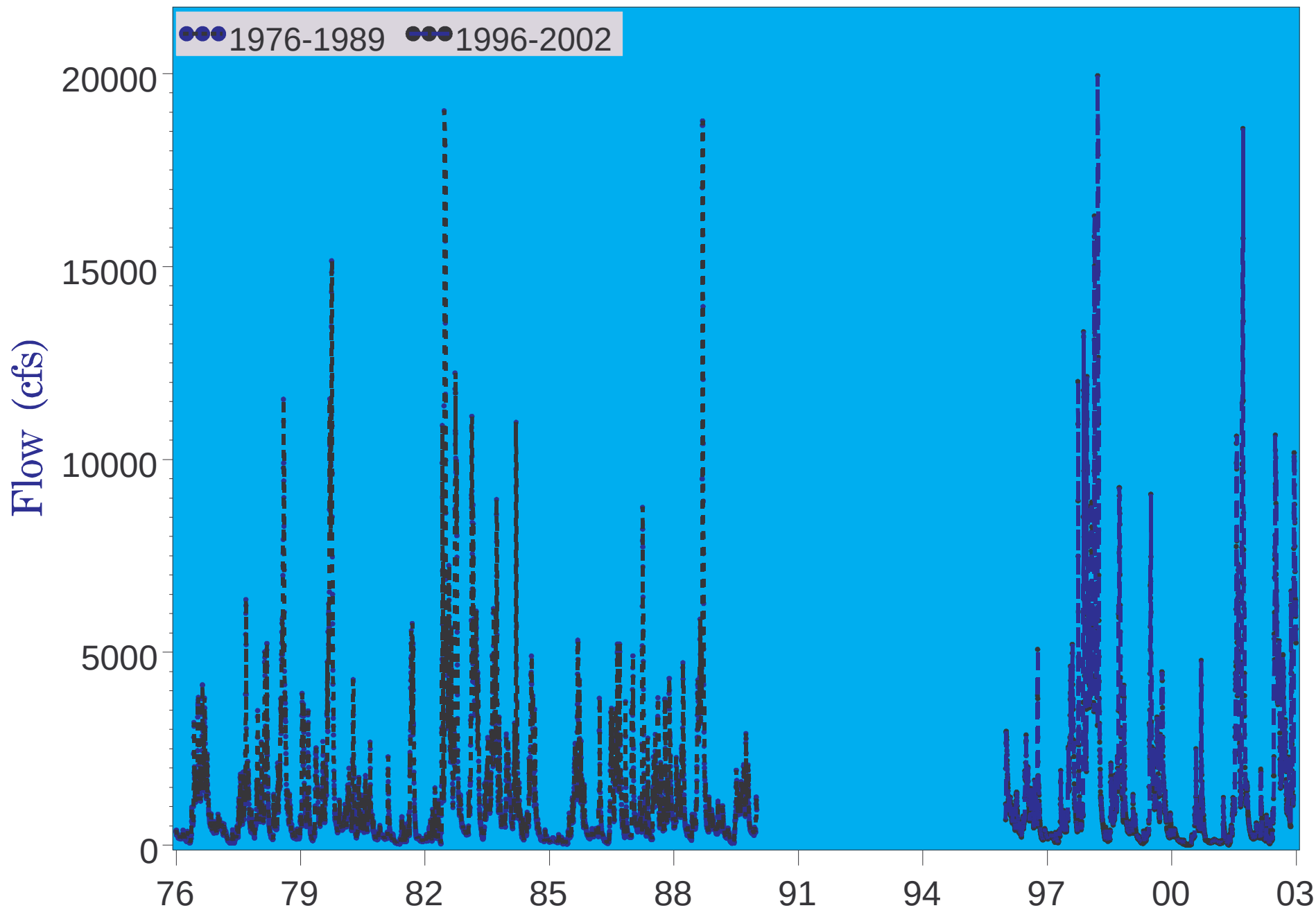


Figure 4.5.3 Peace River at Arcadia + Horse + Joshua & Shell Creeks Gaged Flows

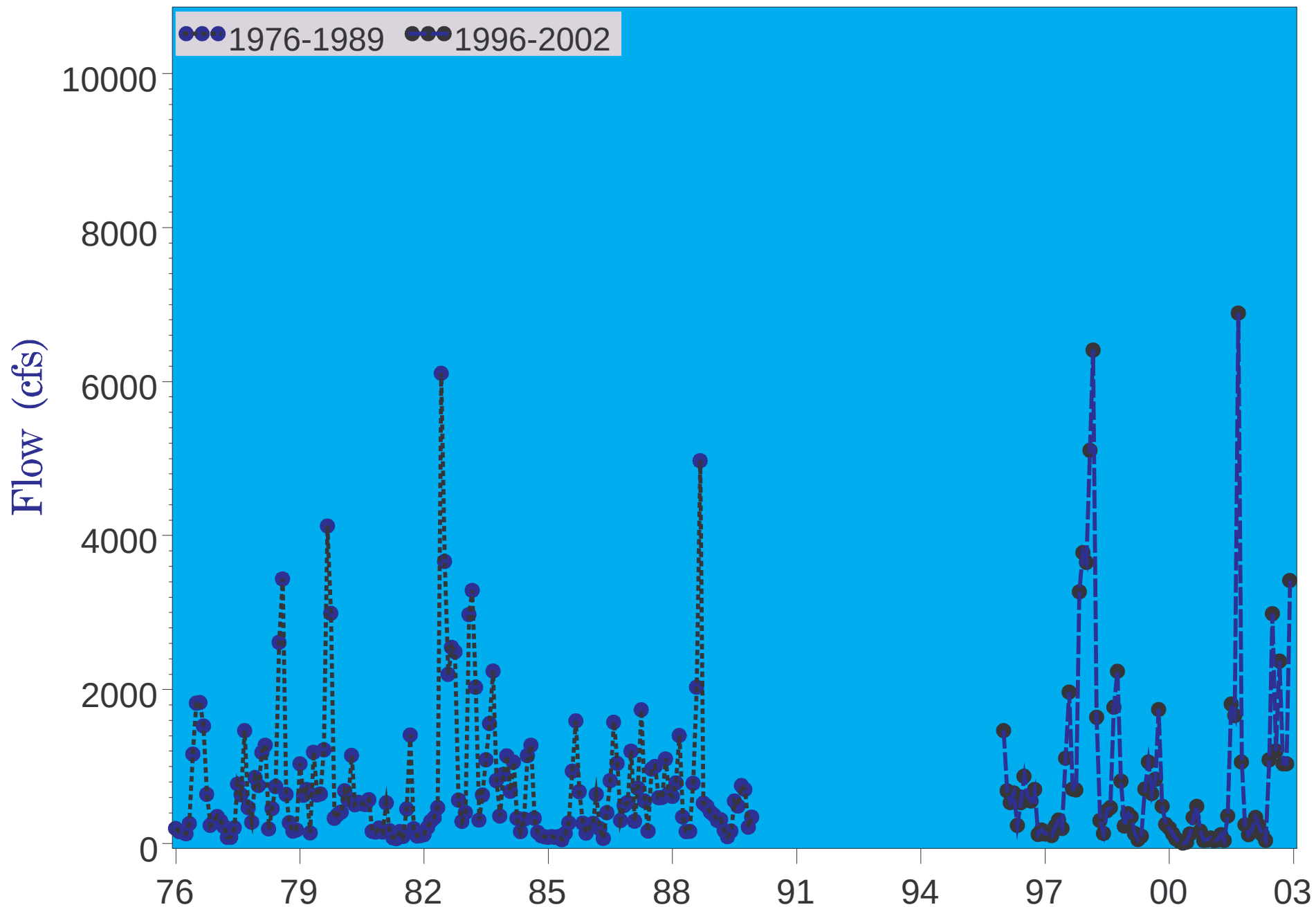


Figure 4.5.4 Mean Monthly Peace River at Arcadia Gaged Flow

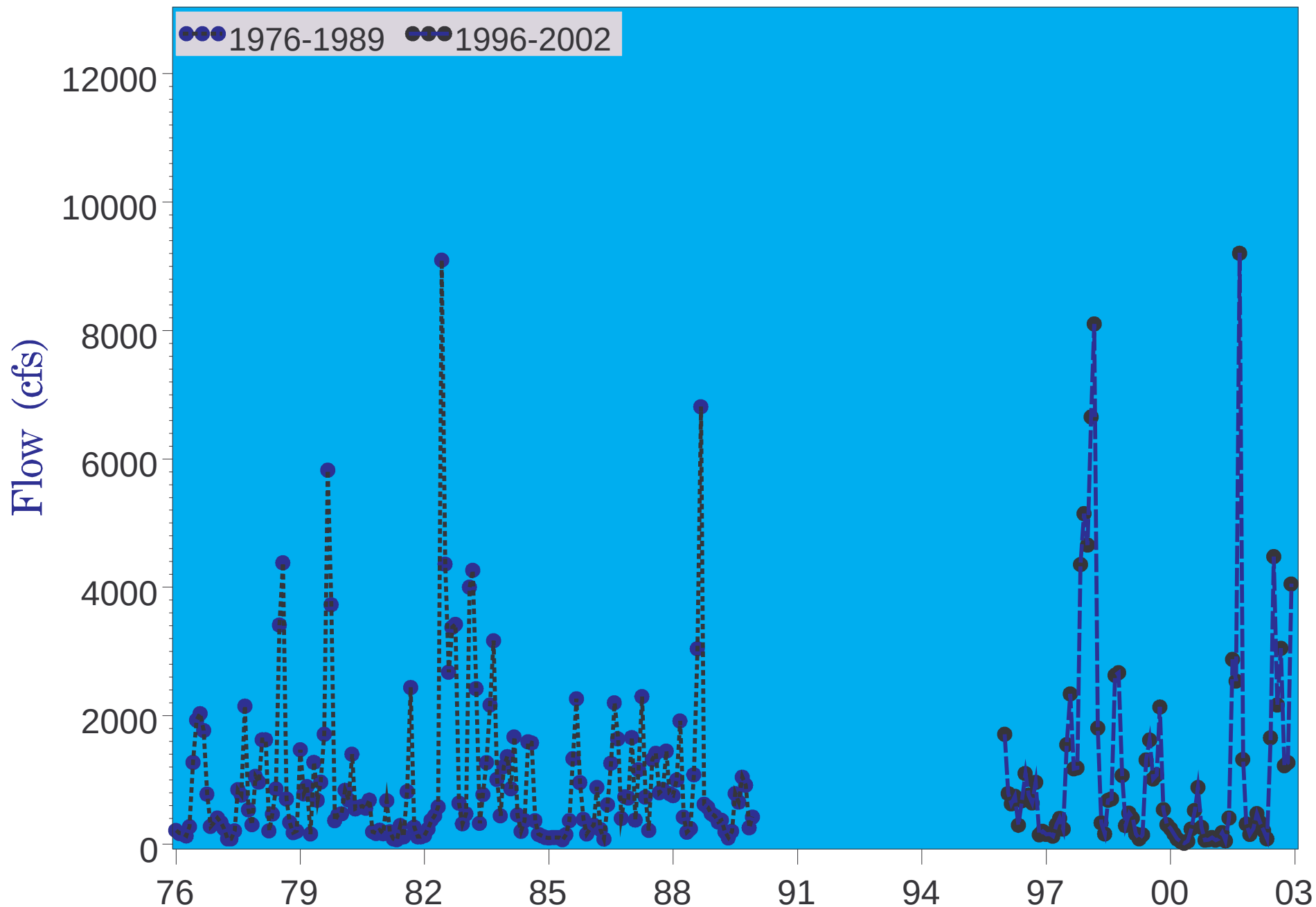


Figure 4.5.5 Mean Monthly Peace River at Arcadia + Horse & Joshua Creeks Gaged Flows

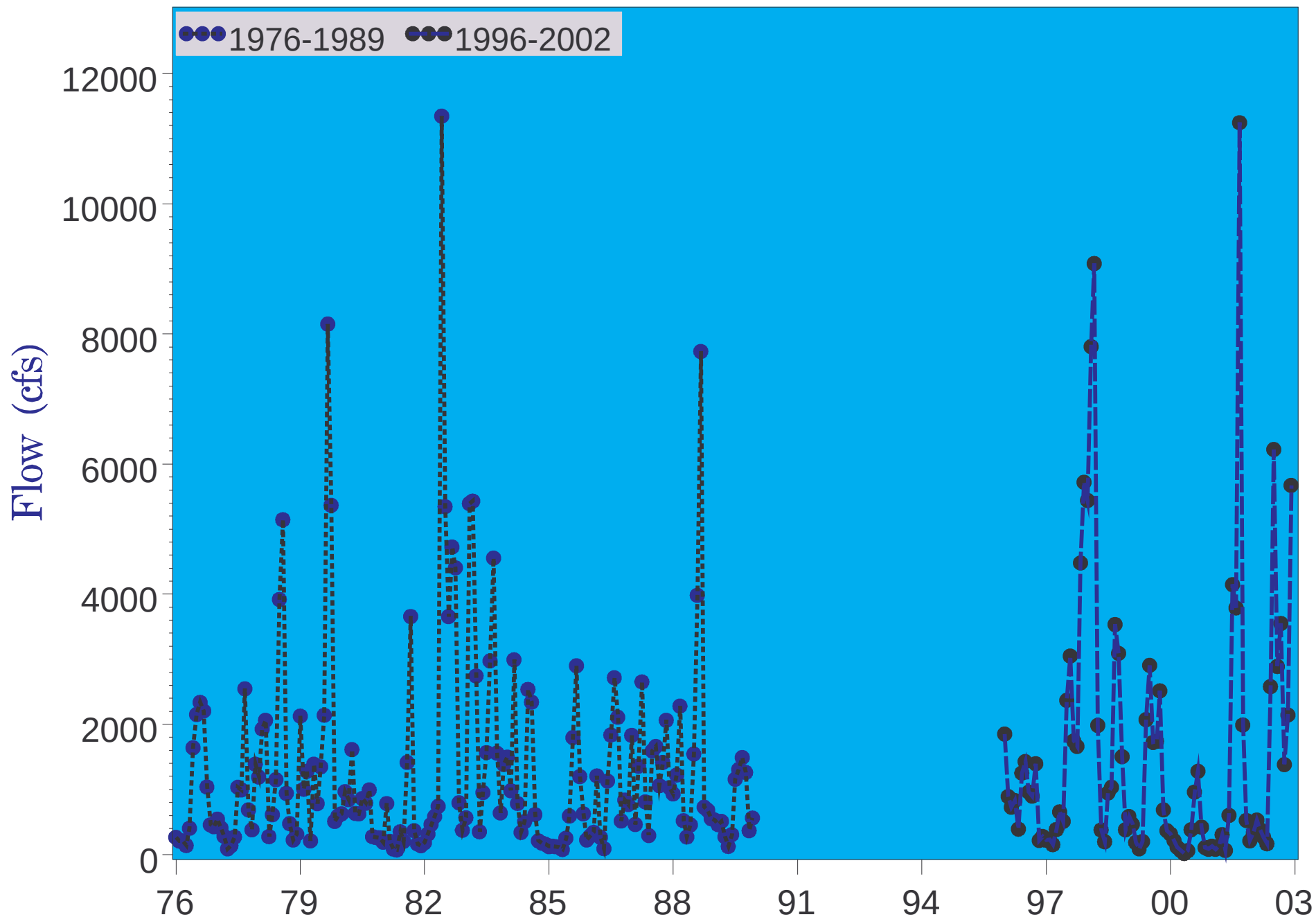


Figure 4.5.6 Mean Monthly Peace River at Arcadia + Horse + Joshua & Shell Creeks Gaged Flows

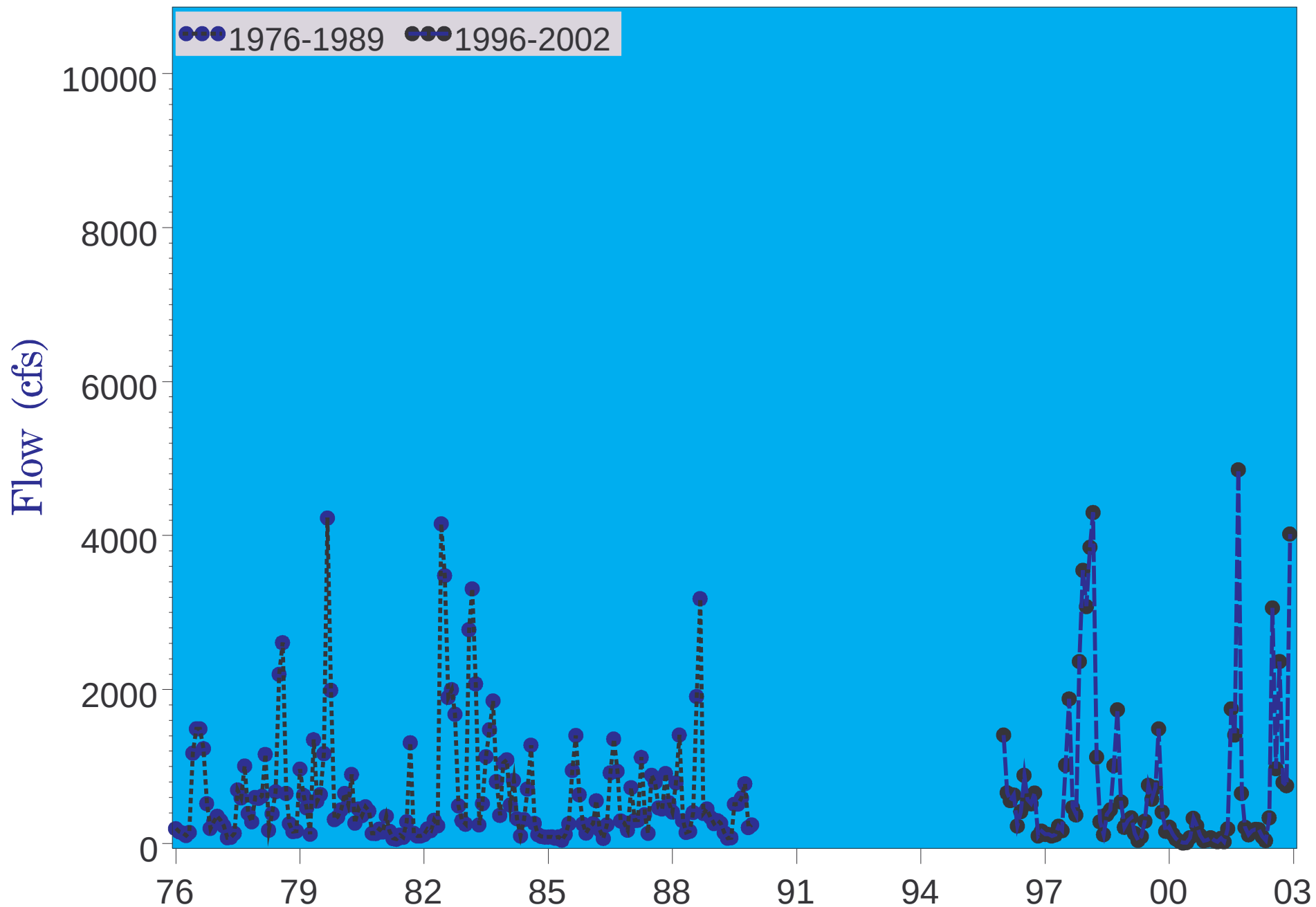


Figure 4.5.7 Median Monthly Peace River at Arcadia Gaged Flow

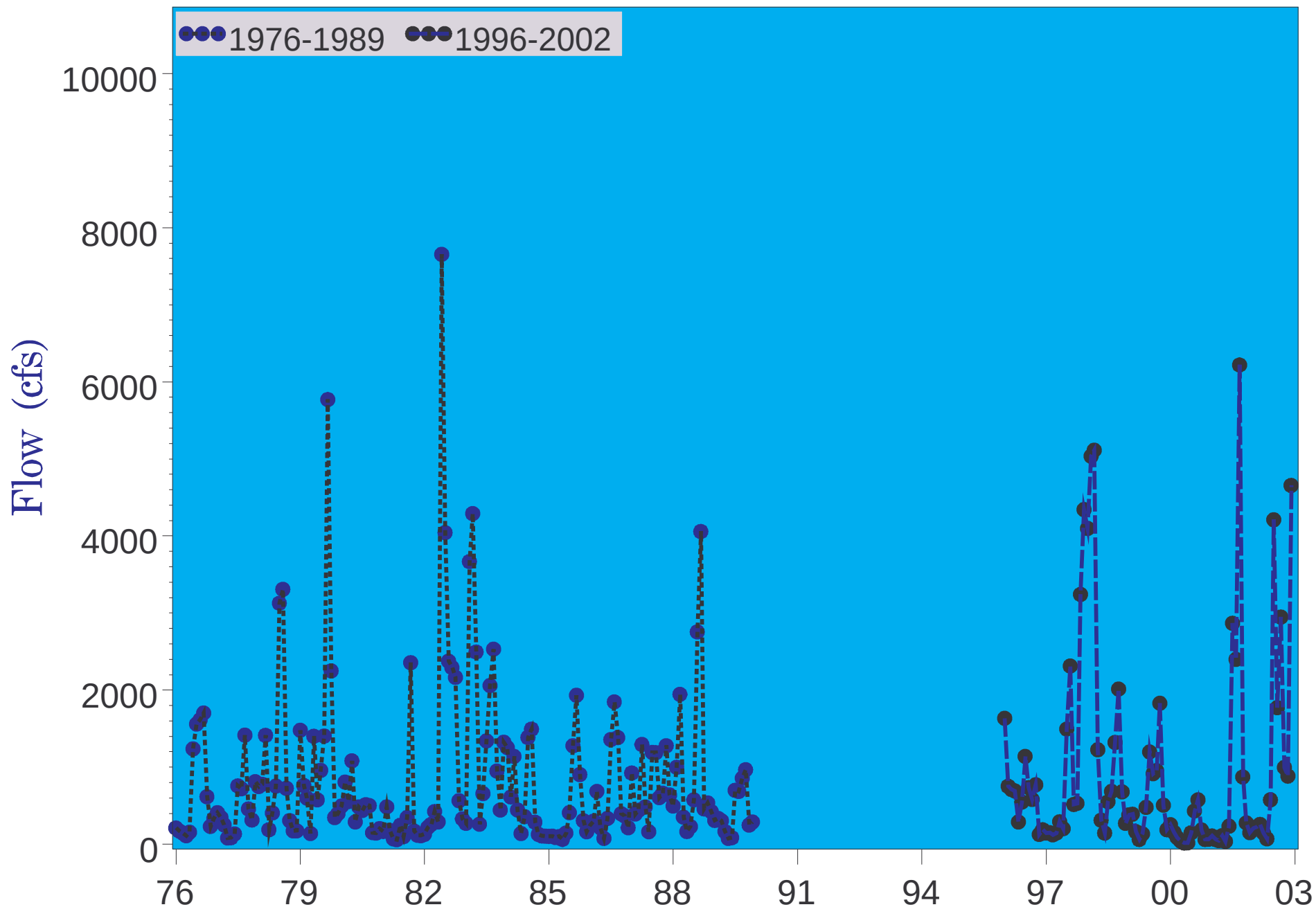


Figure 4.5.8 Median Monthly Peace River at Arcadia + Horse & Joshua Creeks Gaged Flows



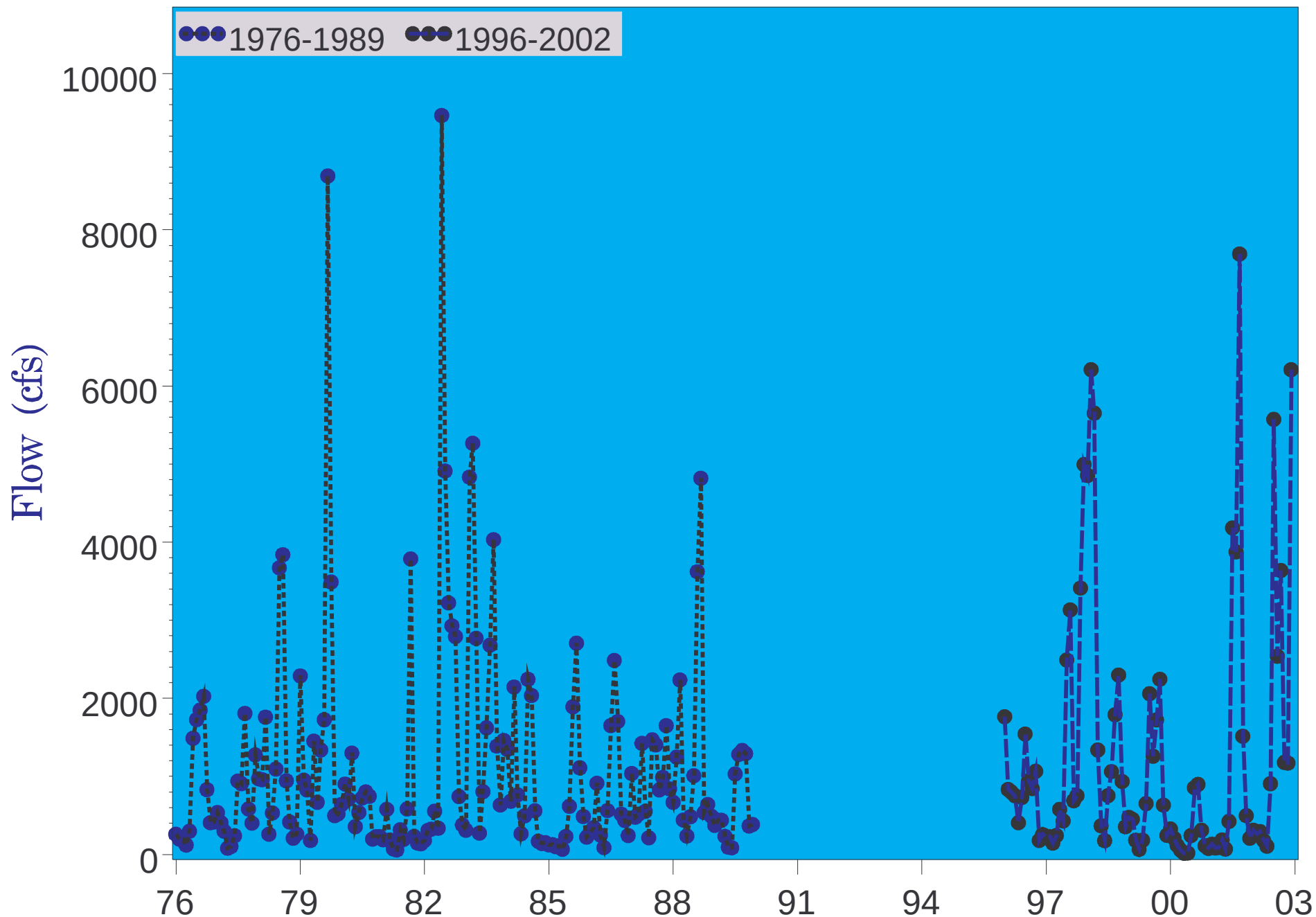


Figure 4.5.9 Median Monthly Peace River at Arcadia + Horse + Joshua & Shell Creeks Gaged Flows

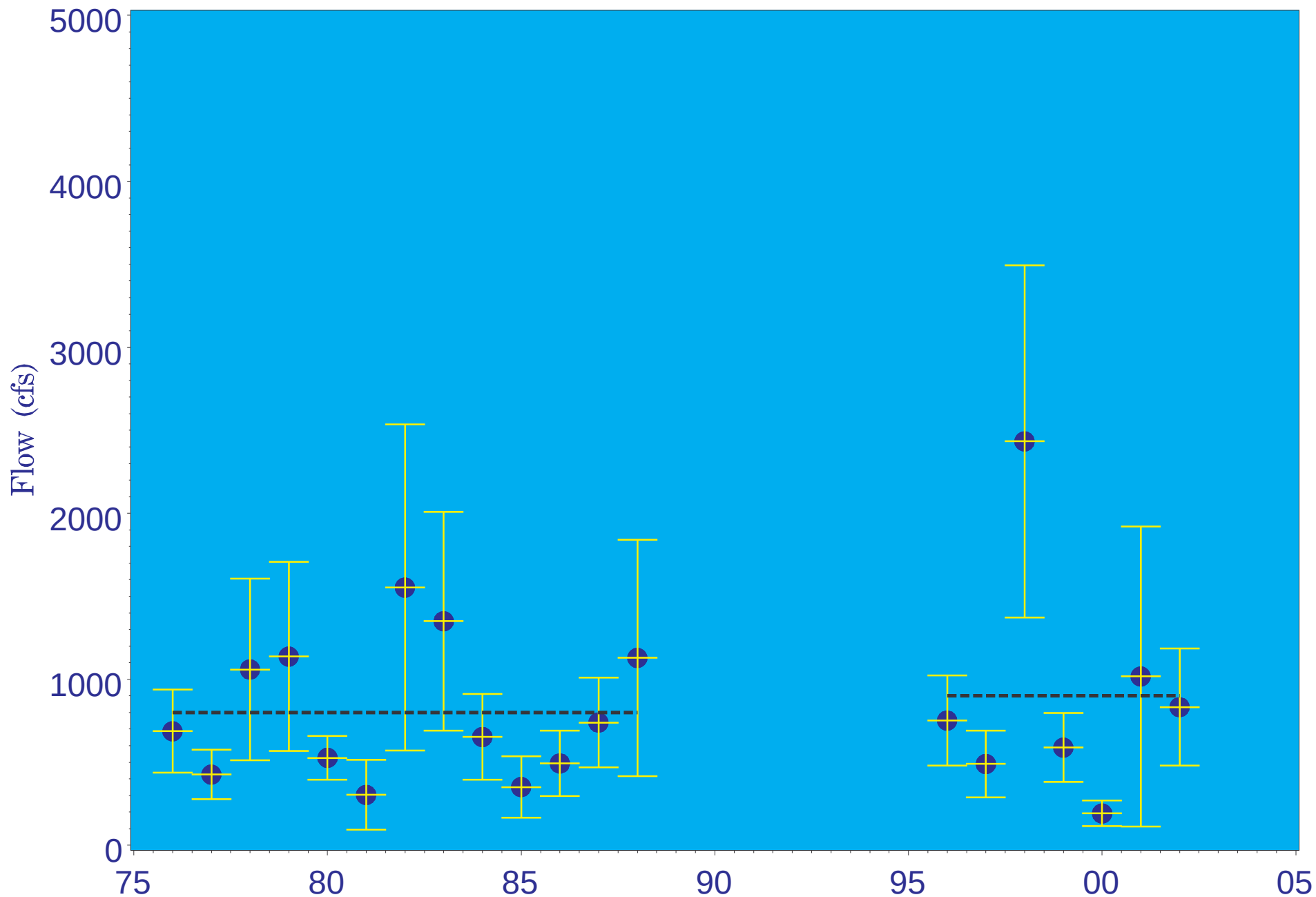


Figure 4.5.10 Annual monthly mean Peace River at Arcadia gaged flow

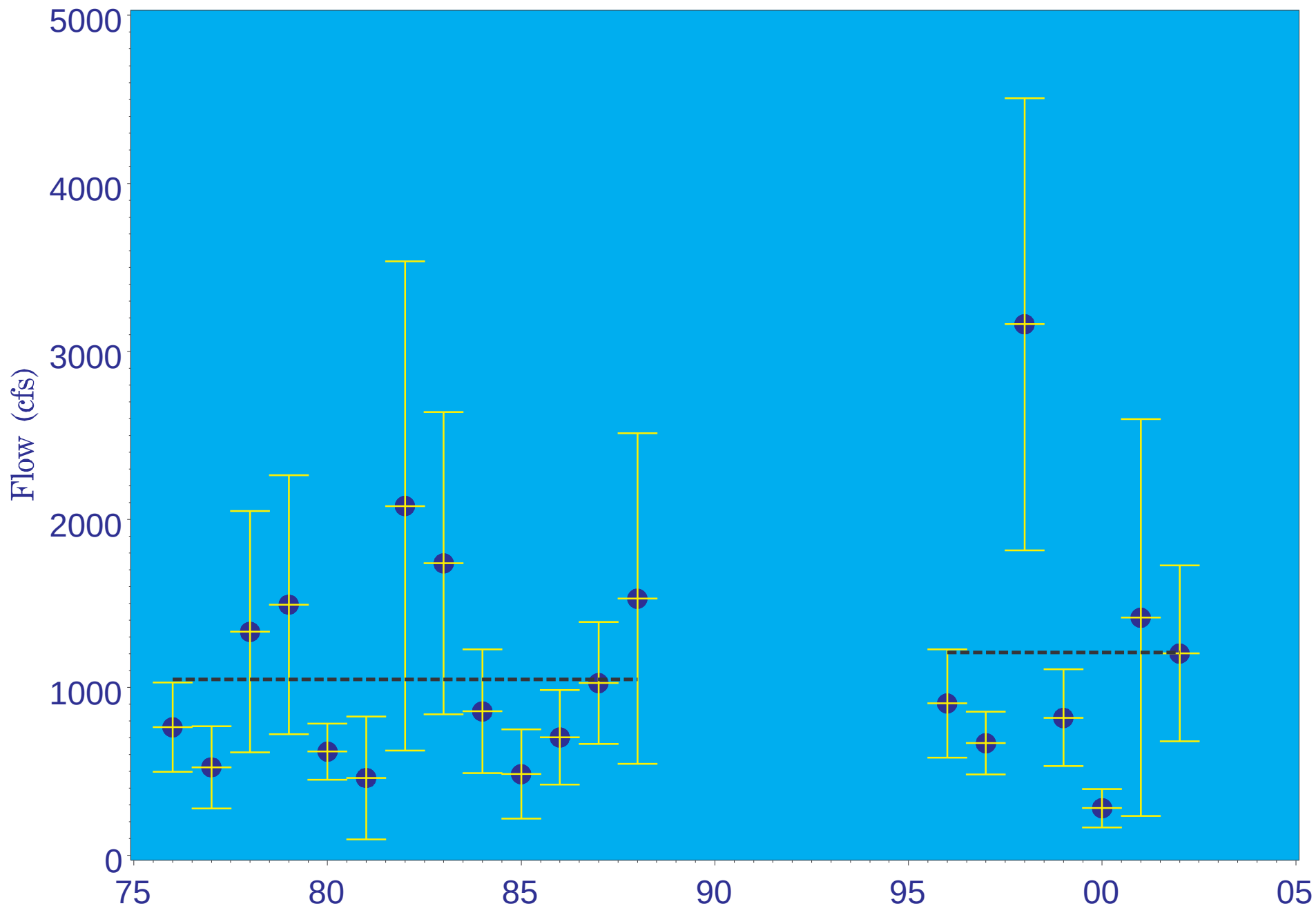


Figure 4.5.11 Annual monthly mean Peace River at Arcadia + Horse & Joshua Creeks gaged flows

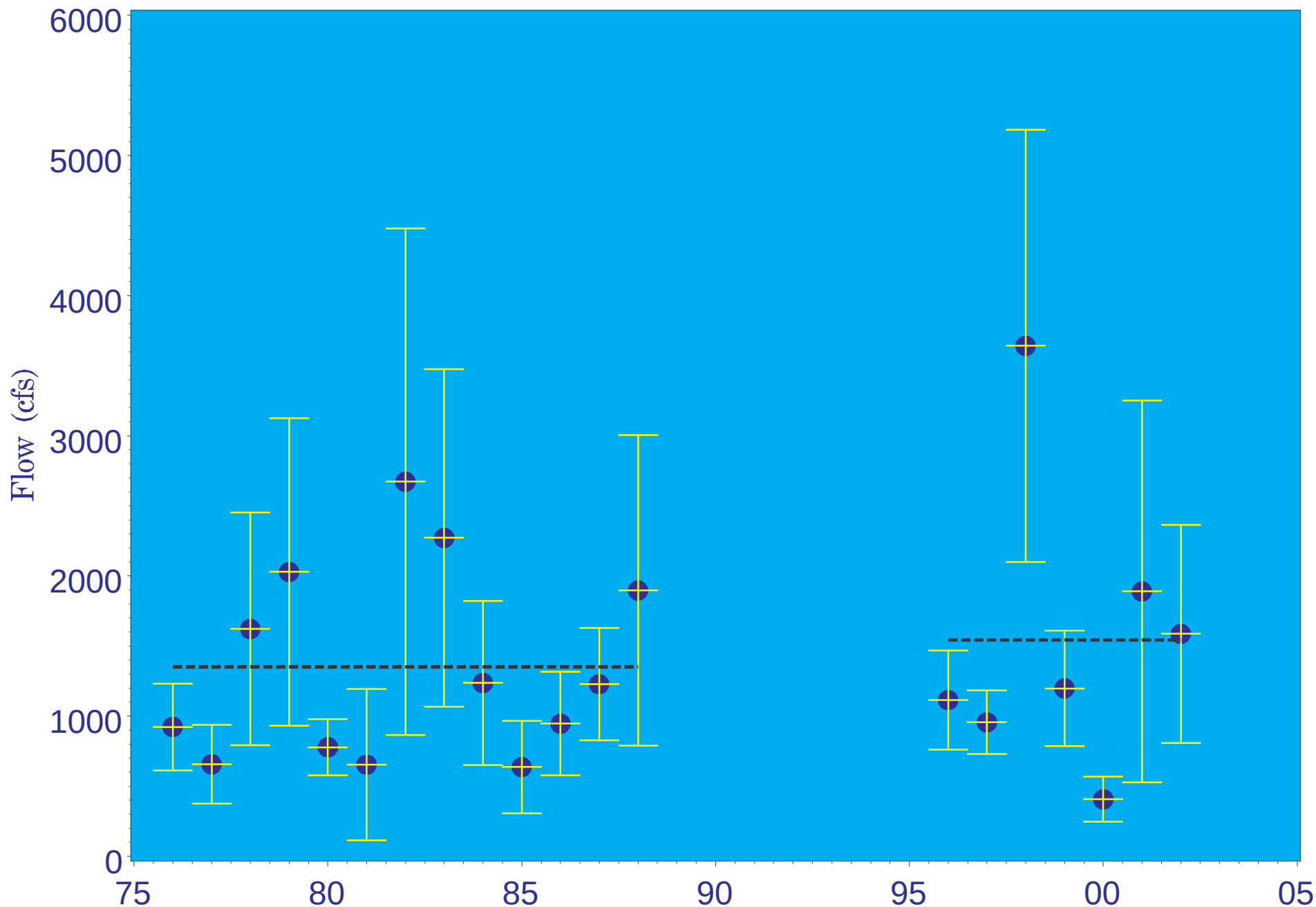


Figure 4.5.12 Annual monthly mean Peace River at Arcadia + Horse + Joshua & Shell Creeks gaged flows

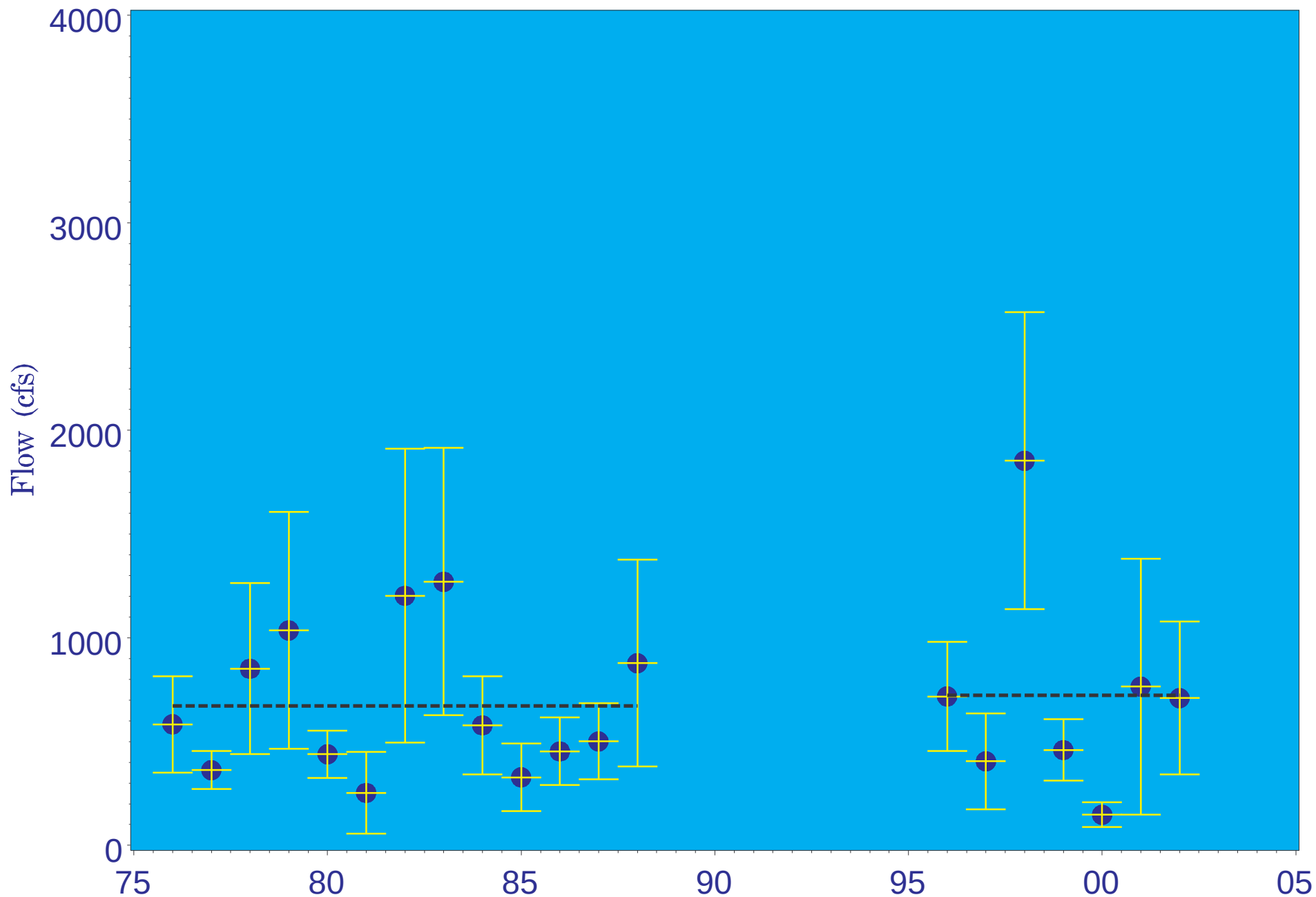


Figure 4.5.13. Annual monthly median Peace River at Arcadia gaged flow

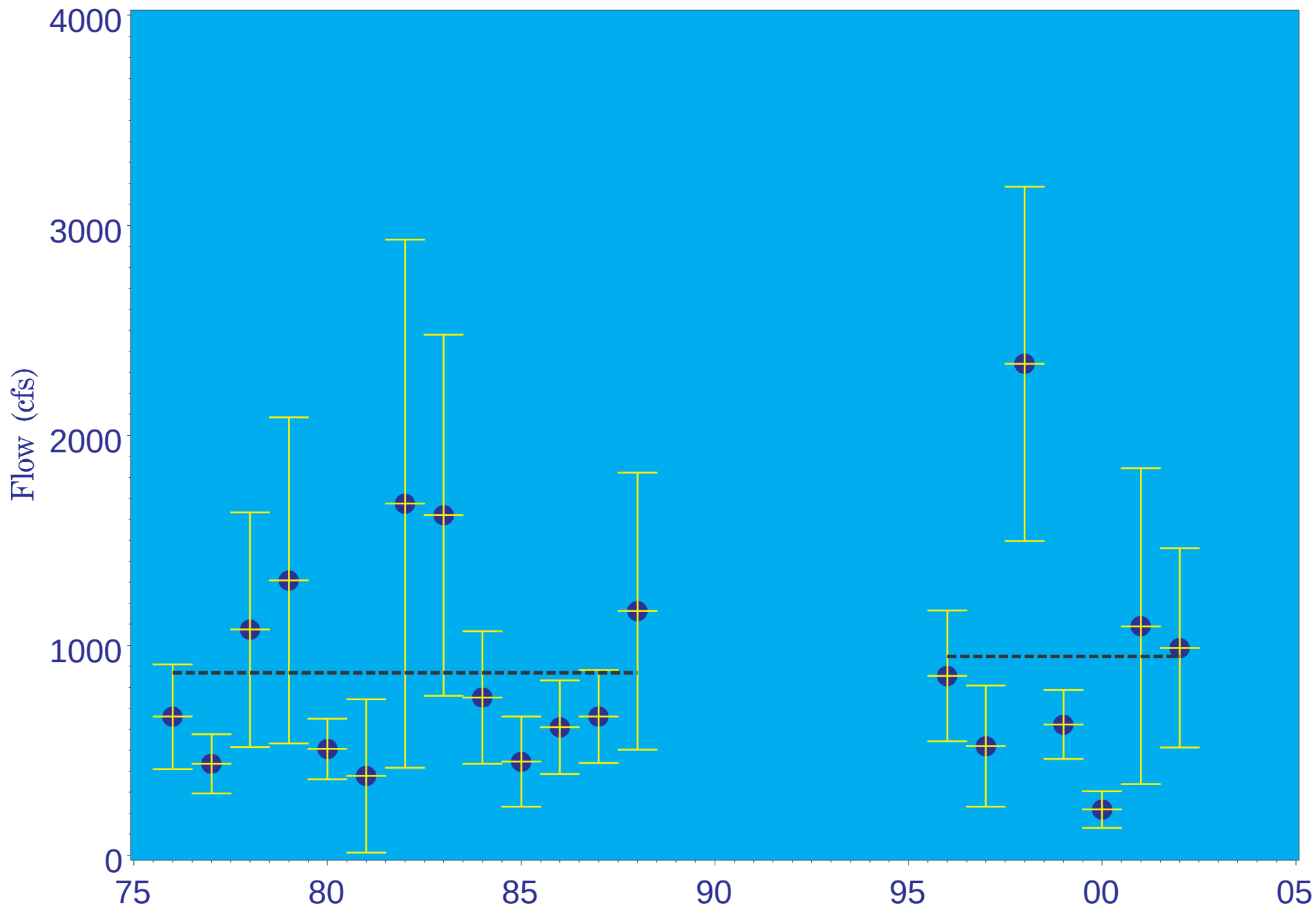


Figure 4.5.14 Annual monthly median Peace River at Arcadia + Horse & Joshua Creeks gaged flows

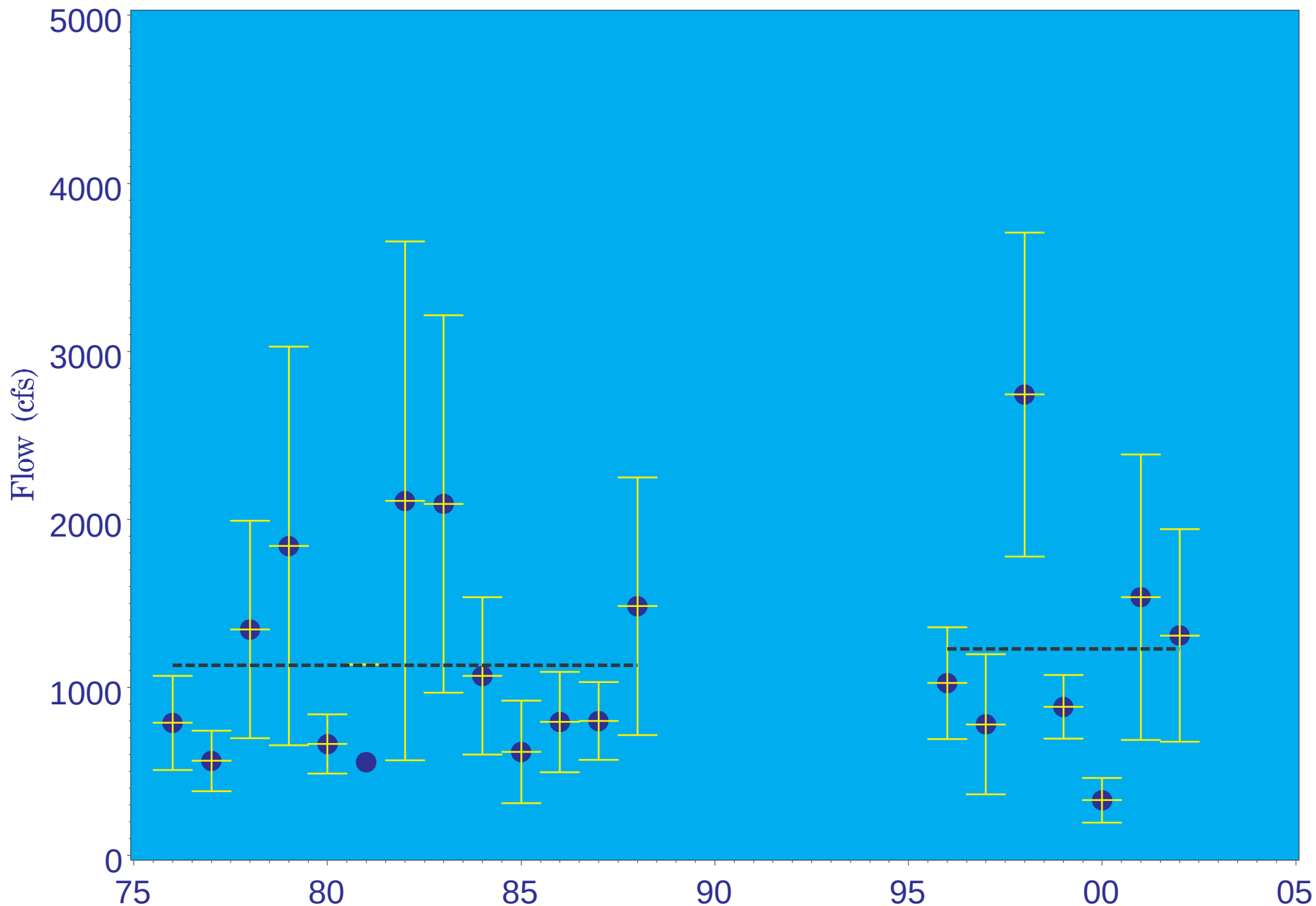


Figure 4.5.15 Annual monthly median Peace River at Arcadia + Horse + Joshua & Shell Creeks gaged flows

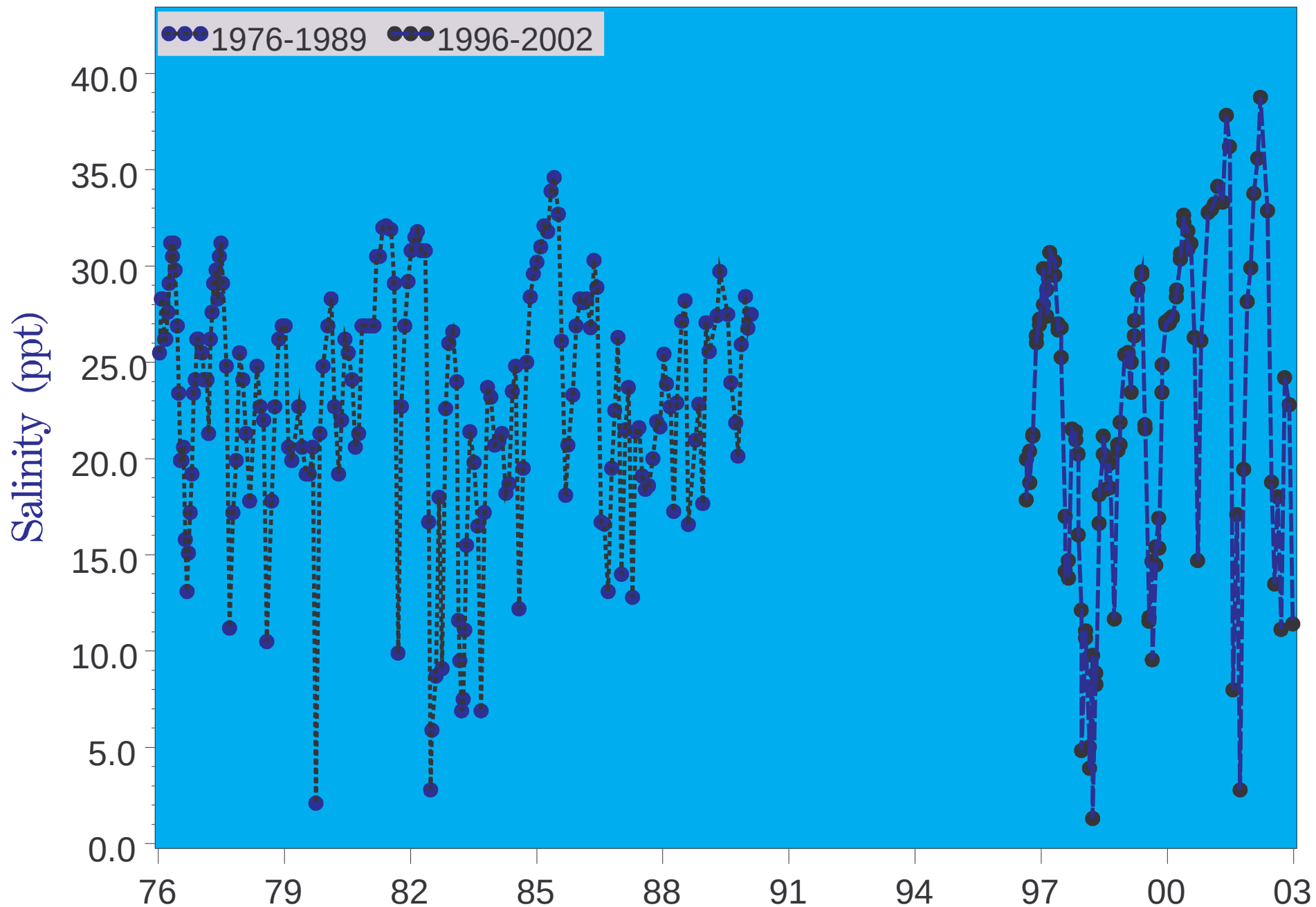


Figure 4.5.16 Long-term surface salinity at river kilometer -2.4



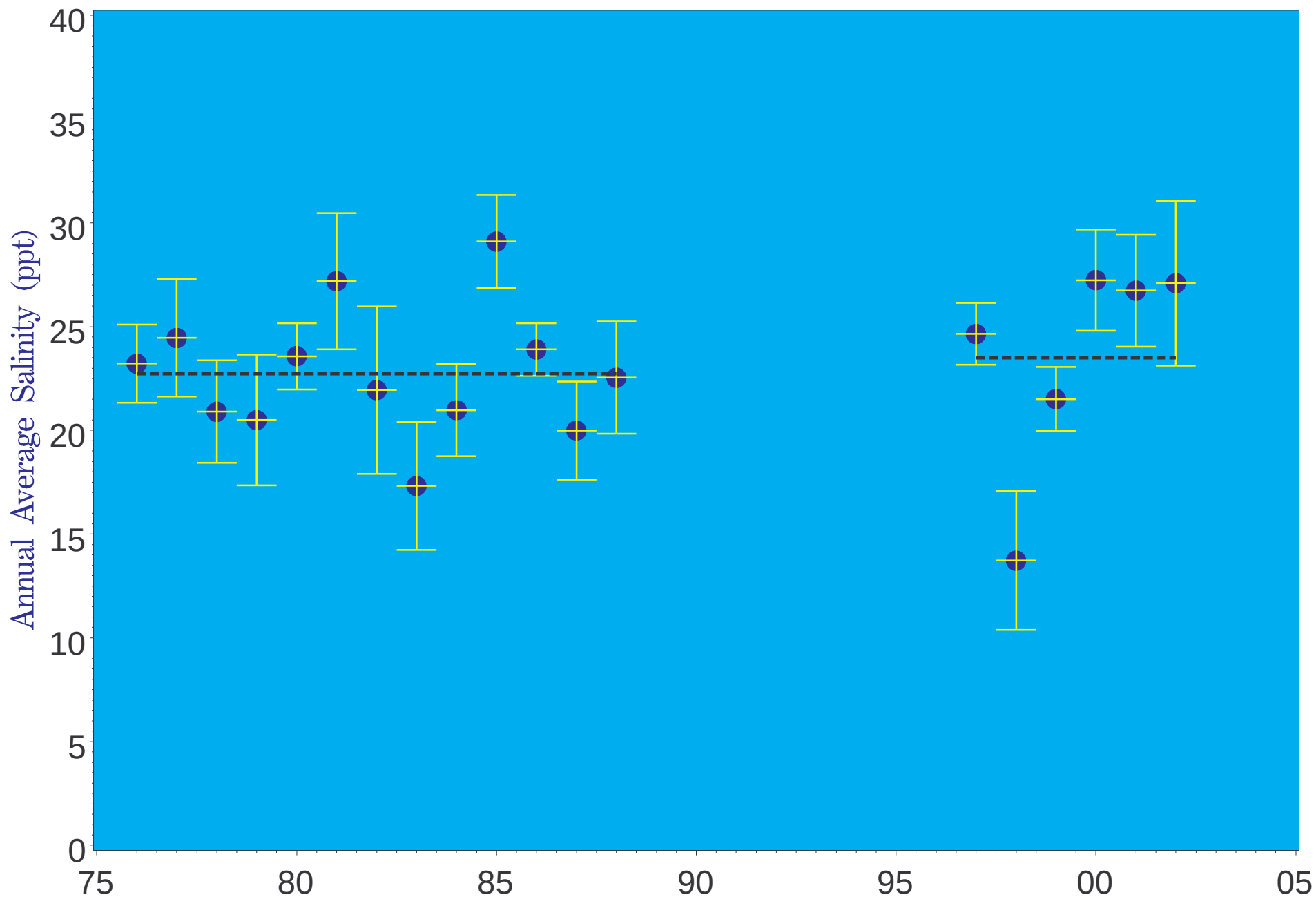


Figure 4.5.17 Long-term surface salinity at river kilometer -2.4

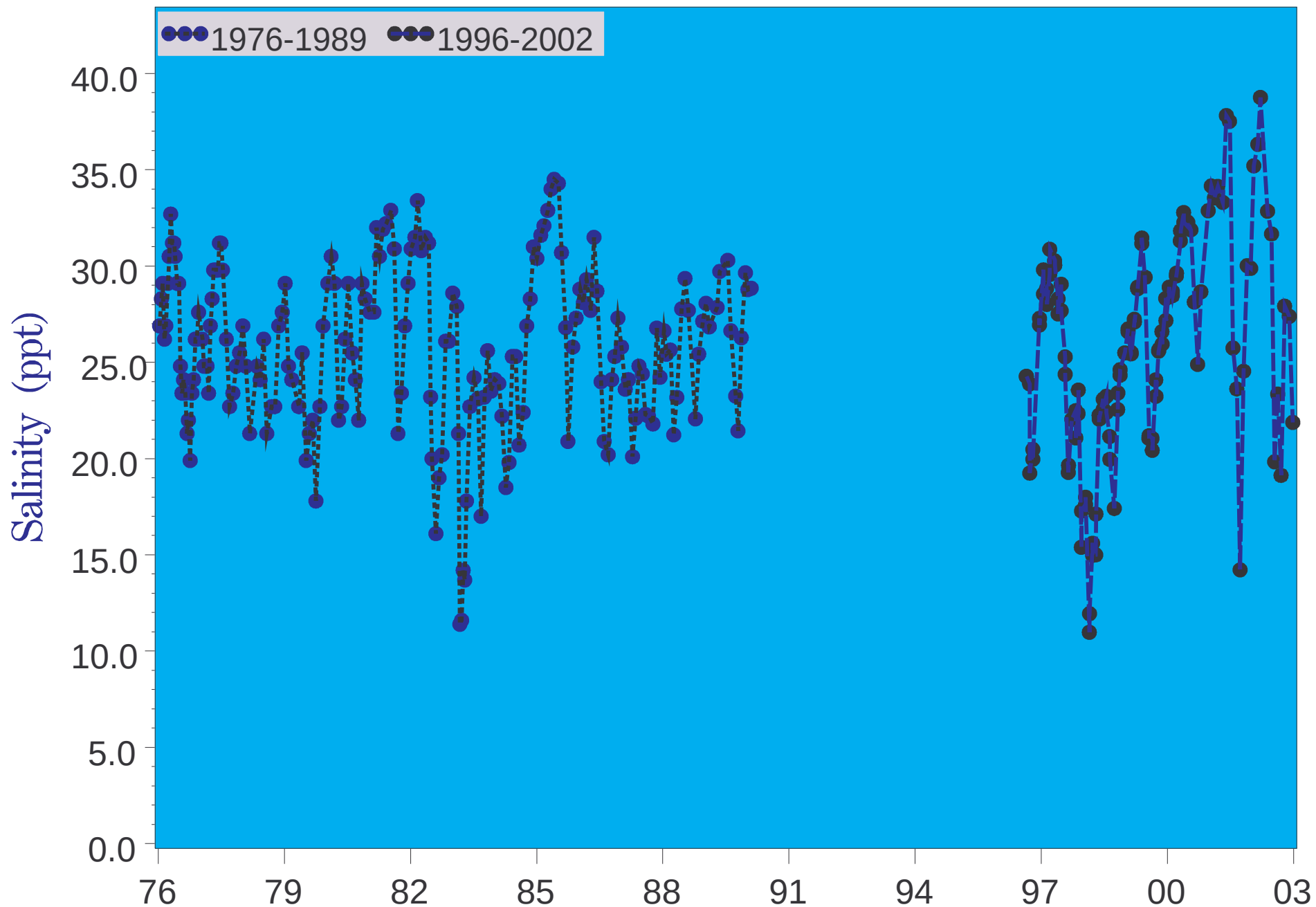


Figure 4.5.18 Long-term bottom salinity at river kilometer -2.4

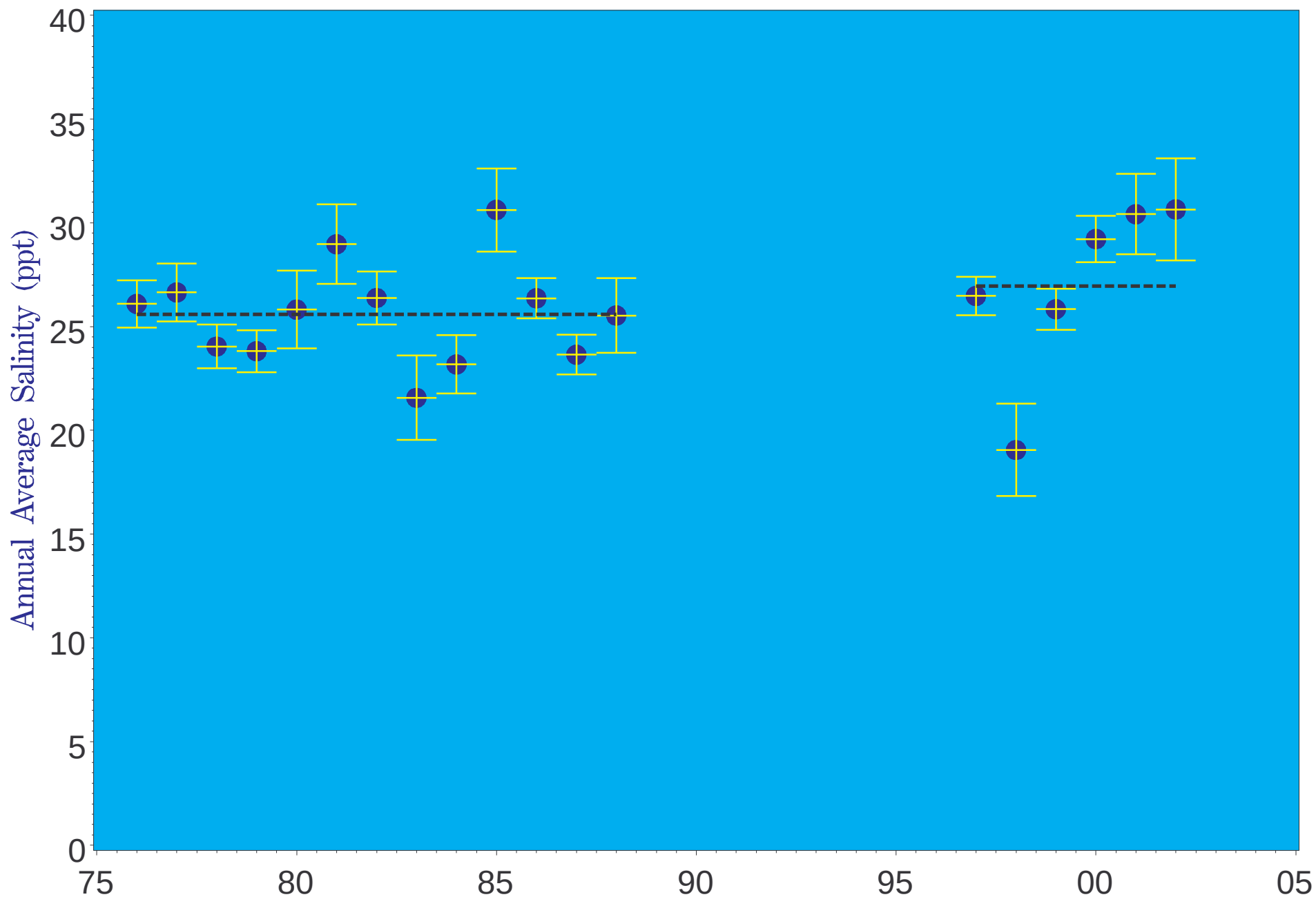


Figure 4.5.19 Long-term bottom salinity at river kilometer -2.4

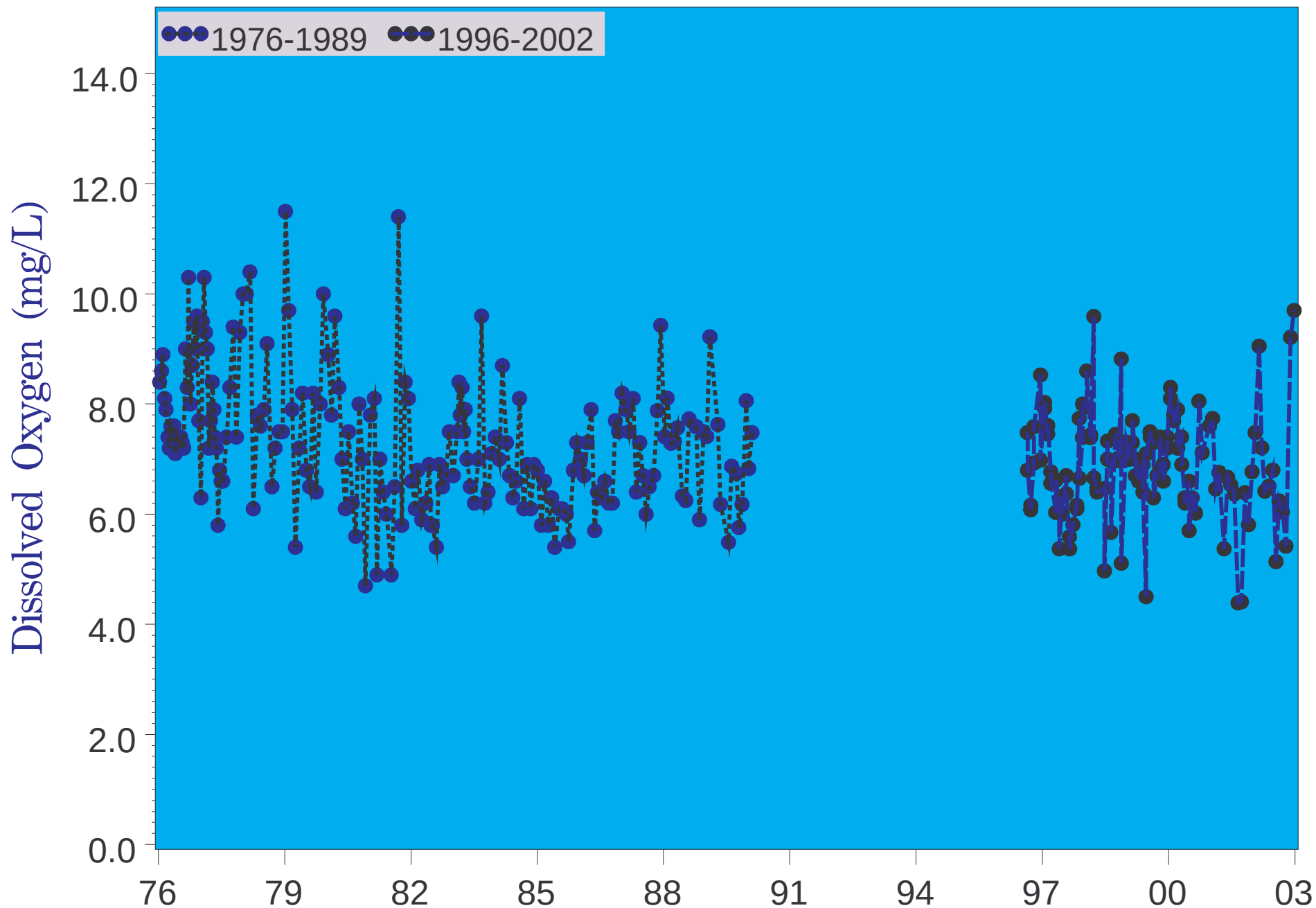


Figure 4.5.20 Long-term surface dissolved oxygen at river kilometer -2.4

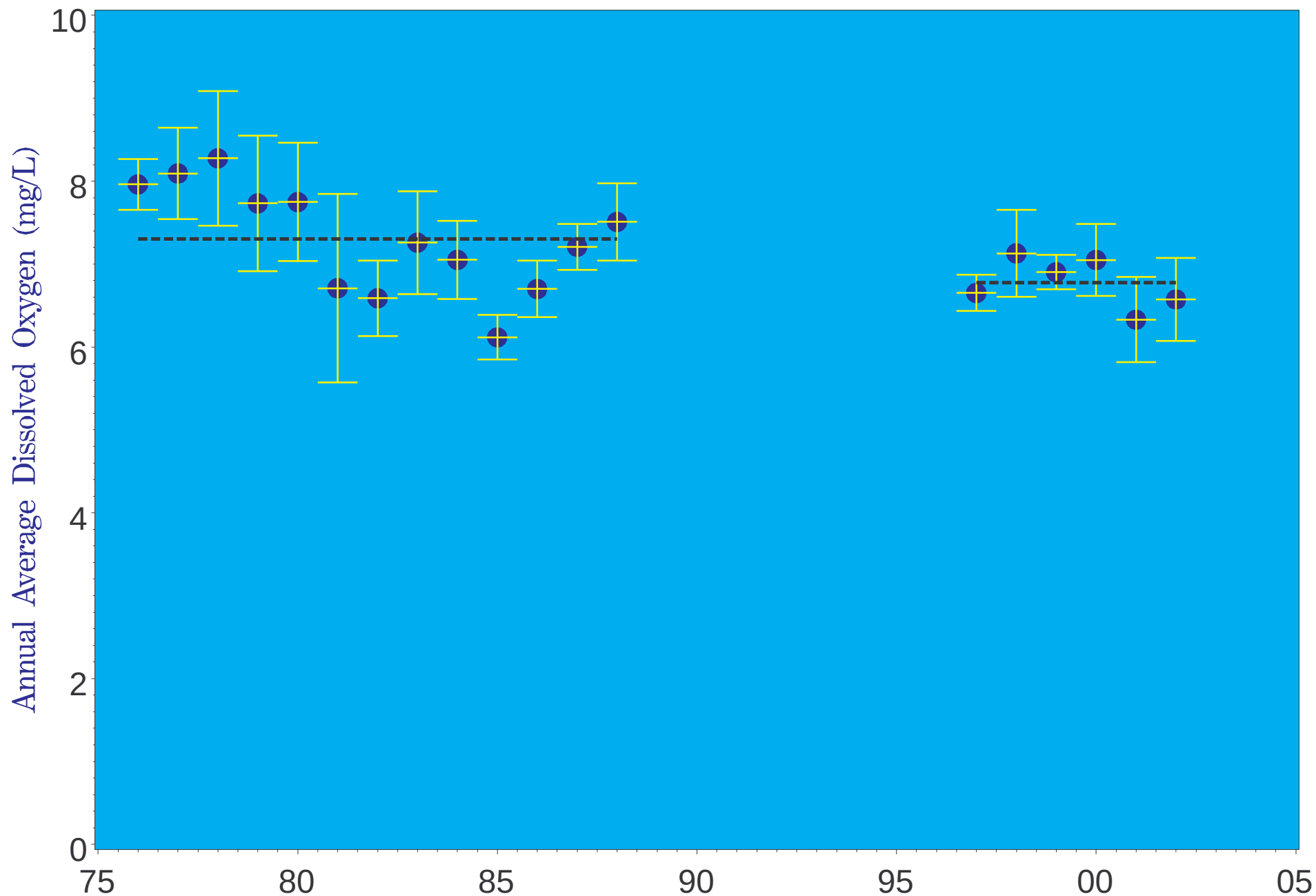


Figure 4.5.21 Long-term surface dissolved oxygen at river kilometer -2.4

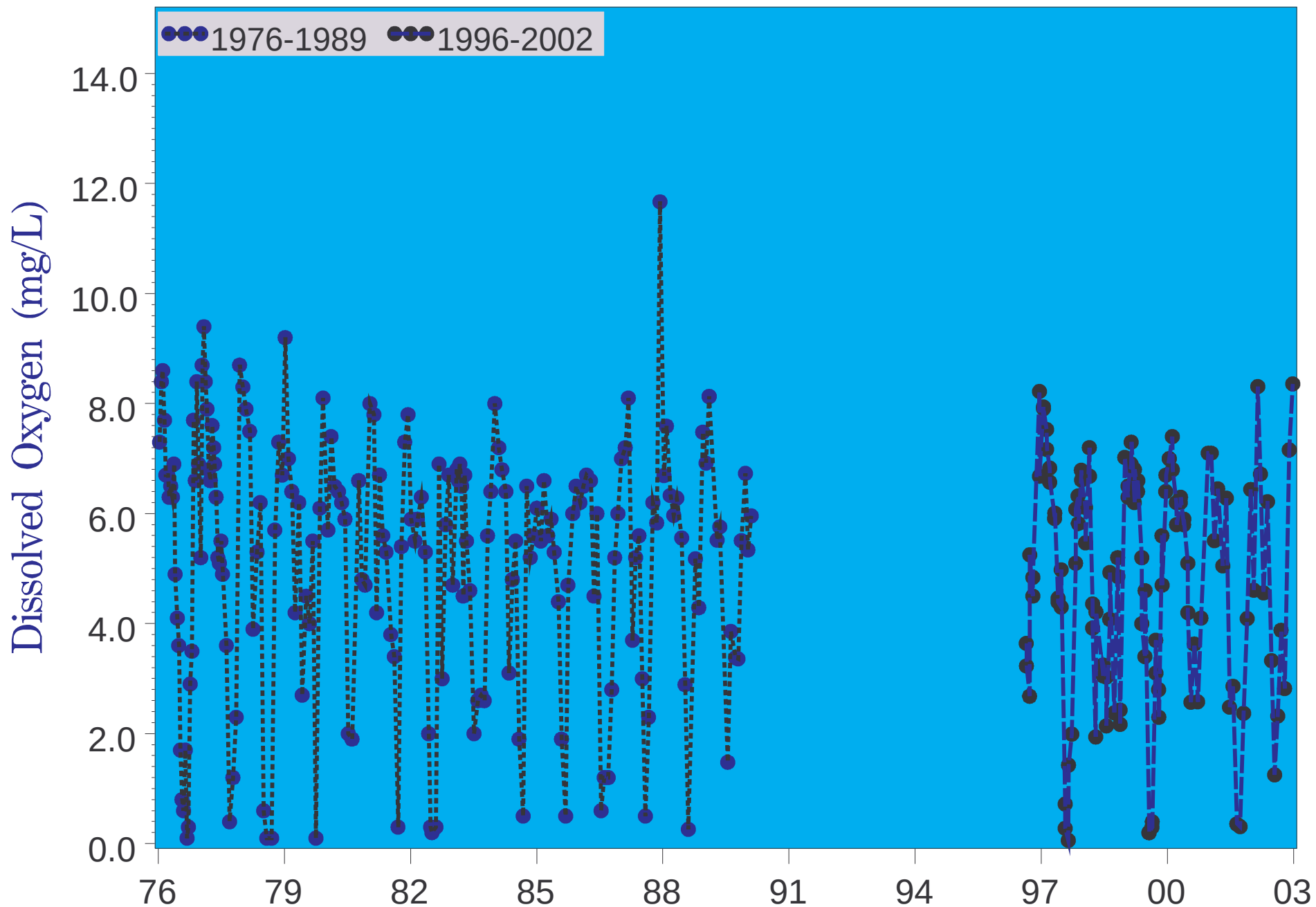


Figure 4.5.22 Long-term bottom dissolved oxygen at river kilometer -2.4

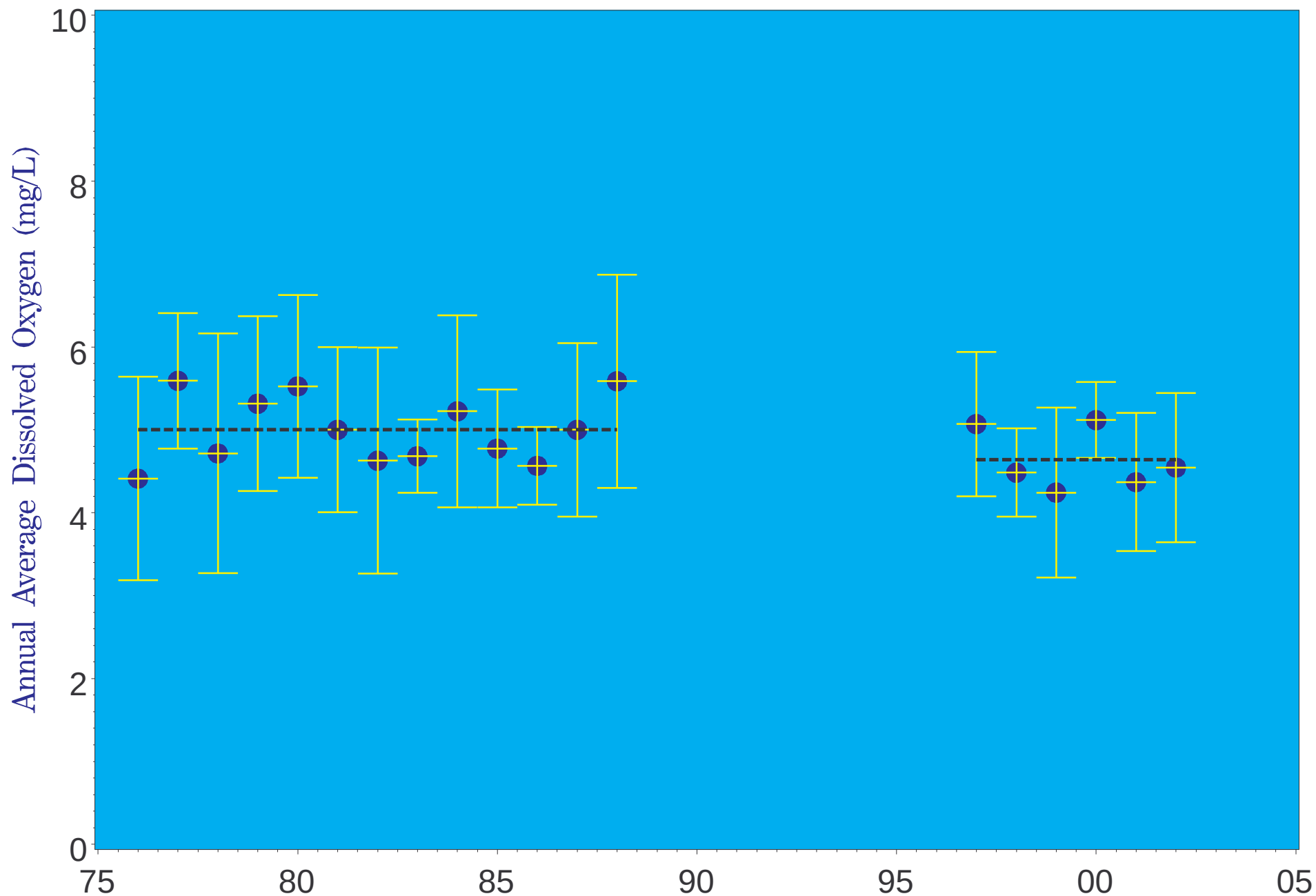


Figure 4.5.23 Long-term bottom dissolved oxygen at river kilometer -2.4

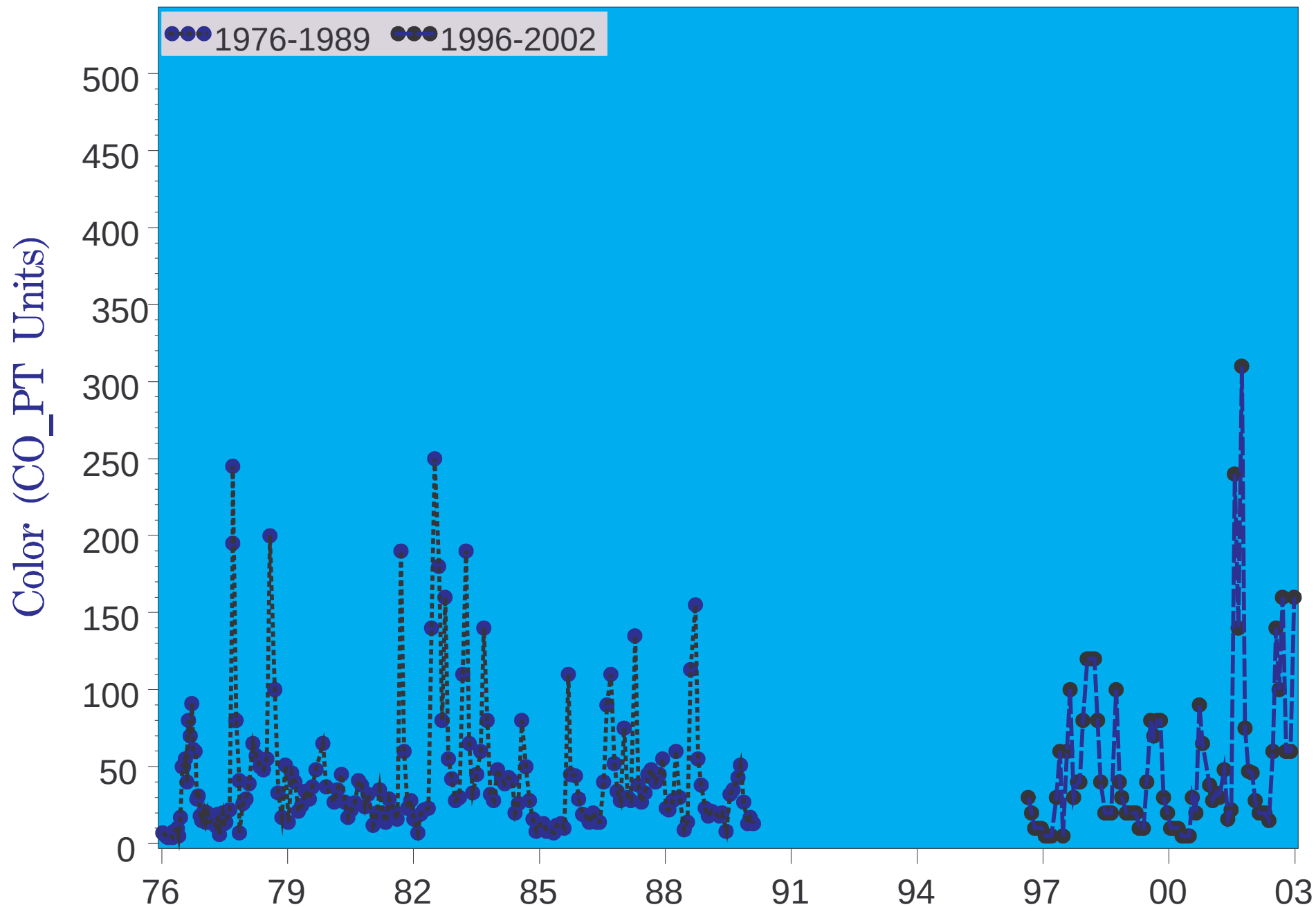


Figure 4.5.24 Long-term surface color at river kilometer -2.4



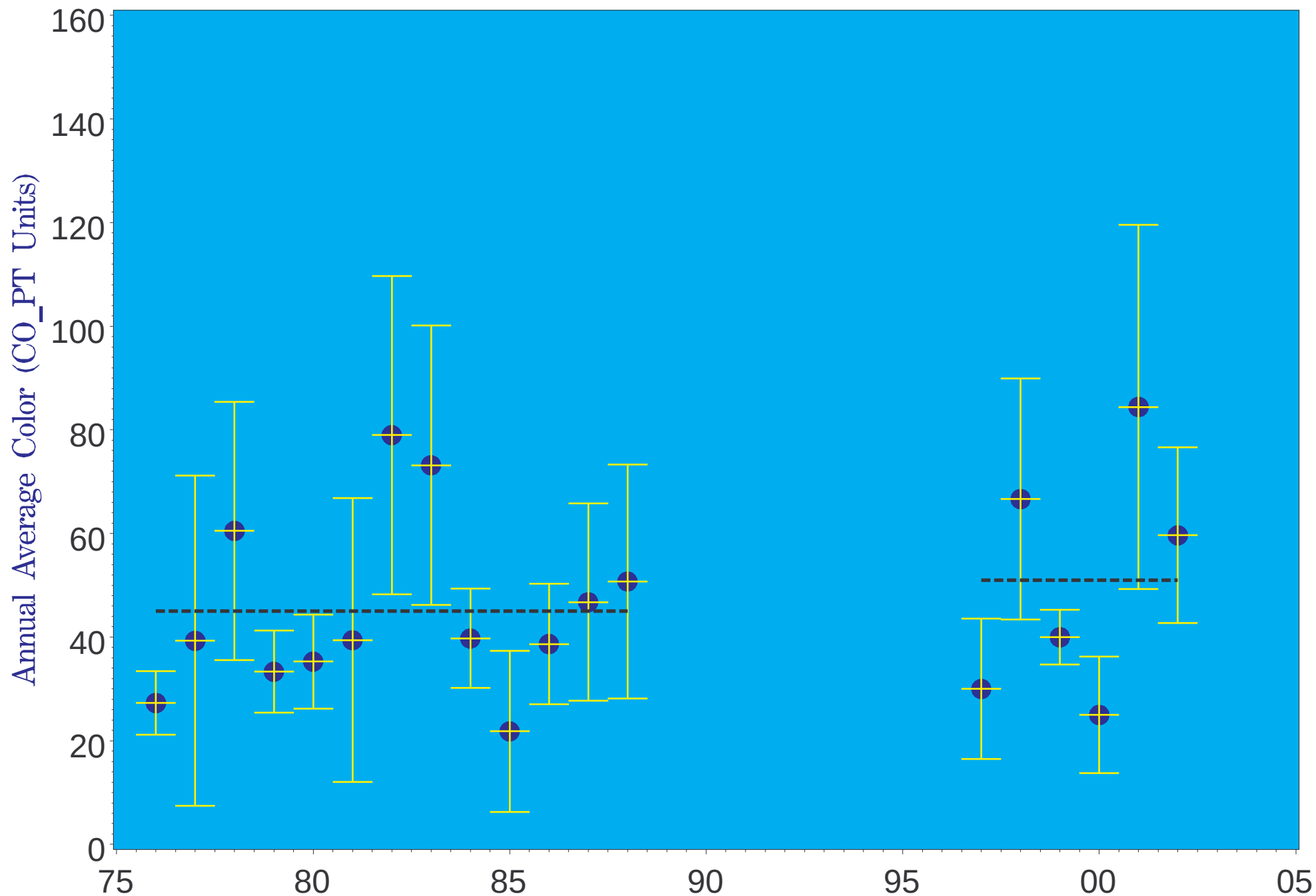


Figure 4.5.25 Long-term surface color at river kilometer -2.4

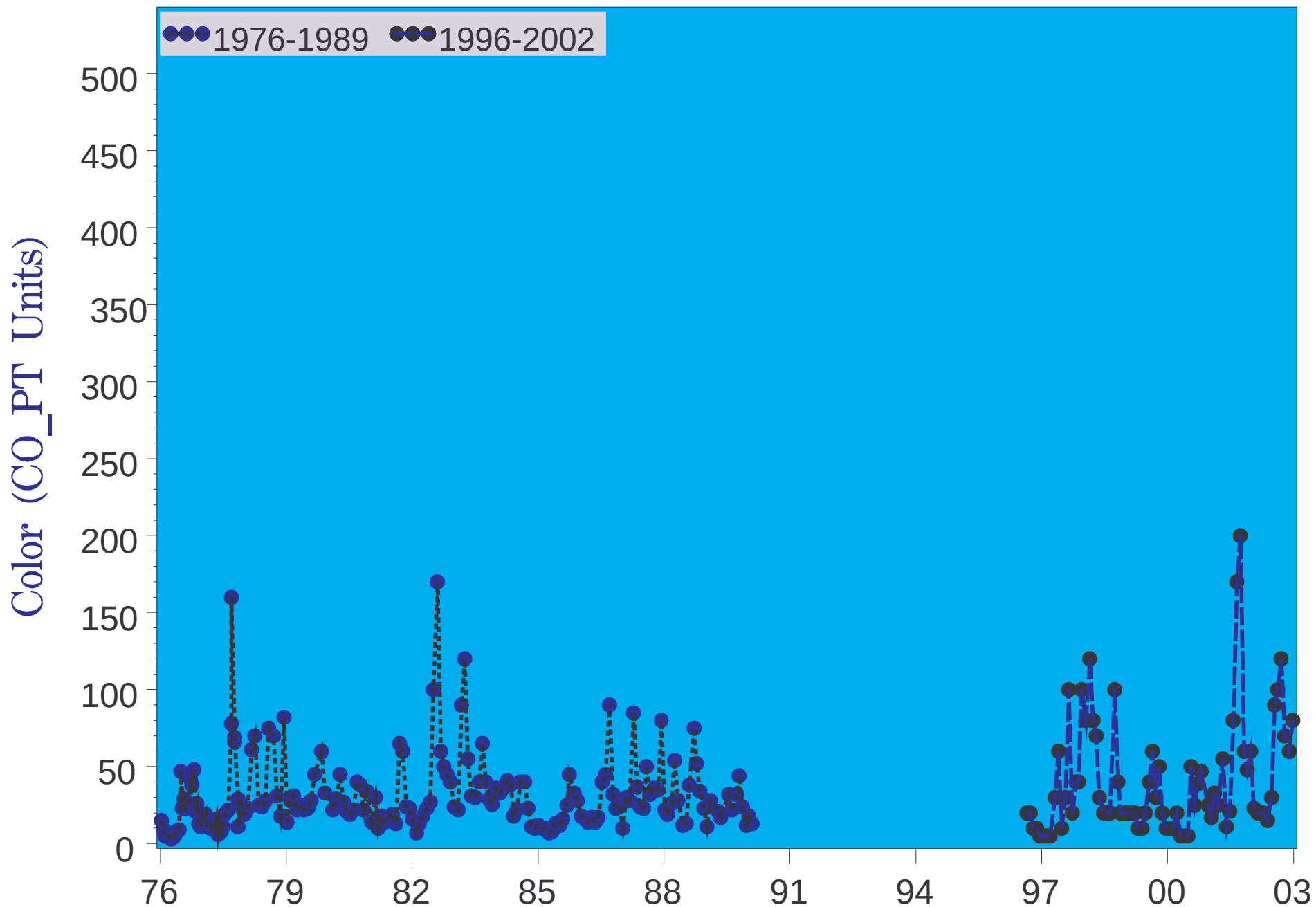


Figure 4.5.26 Long-term bottom color at river kilometer -2.4

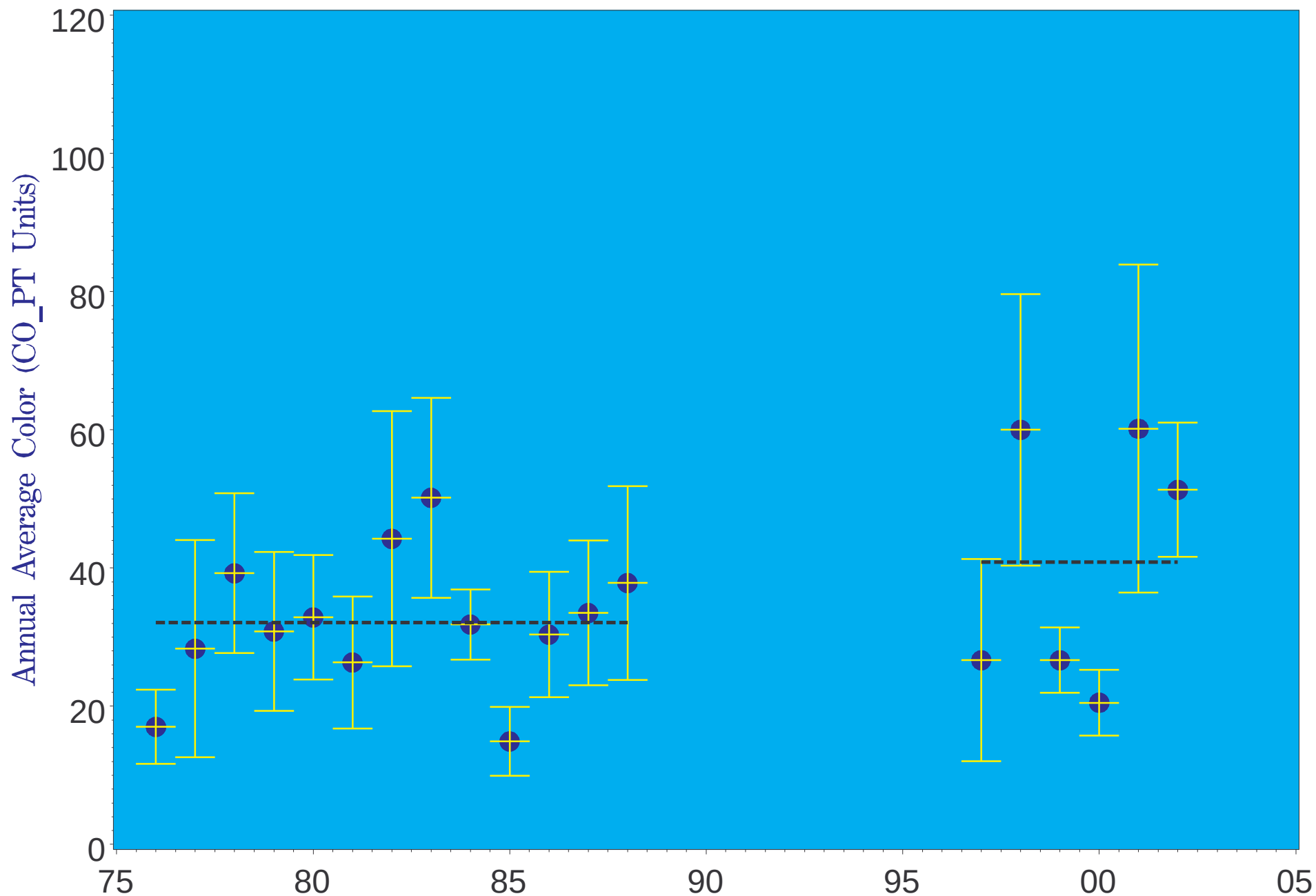


Figure 4.5.27 Long-term bottom color at river kilometer -2.4

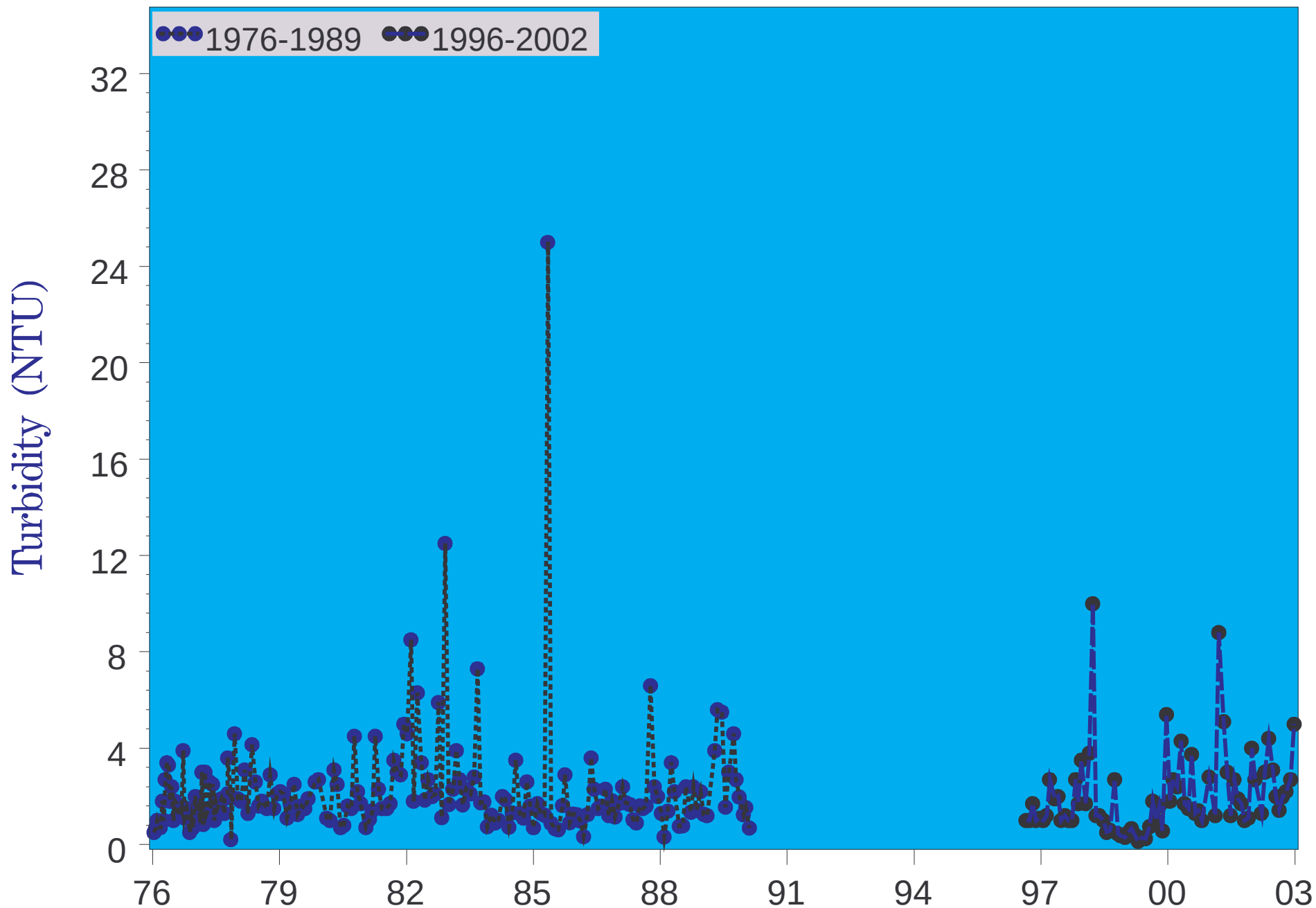


Figure 4.5.28 Long-term surface turbidity at river kilometer -2.4

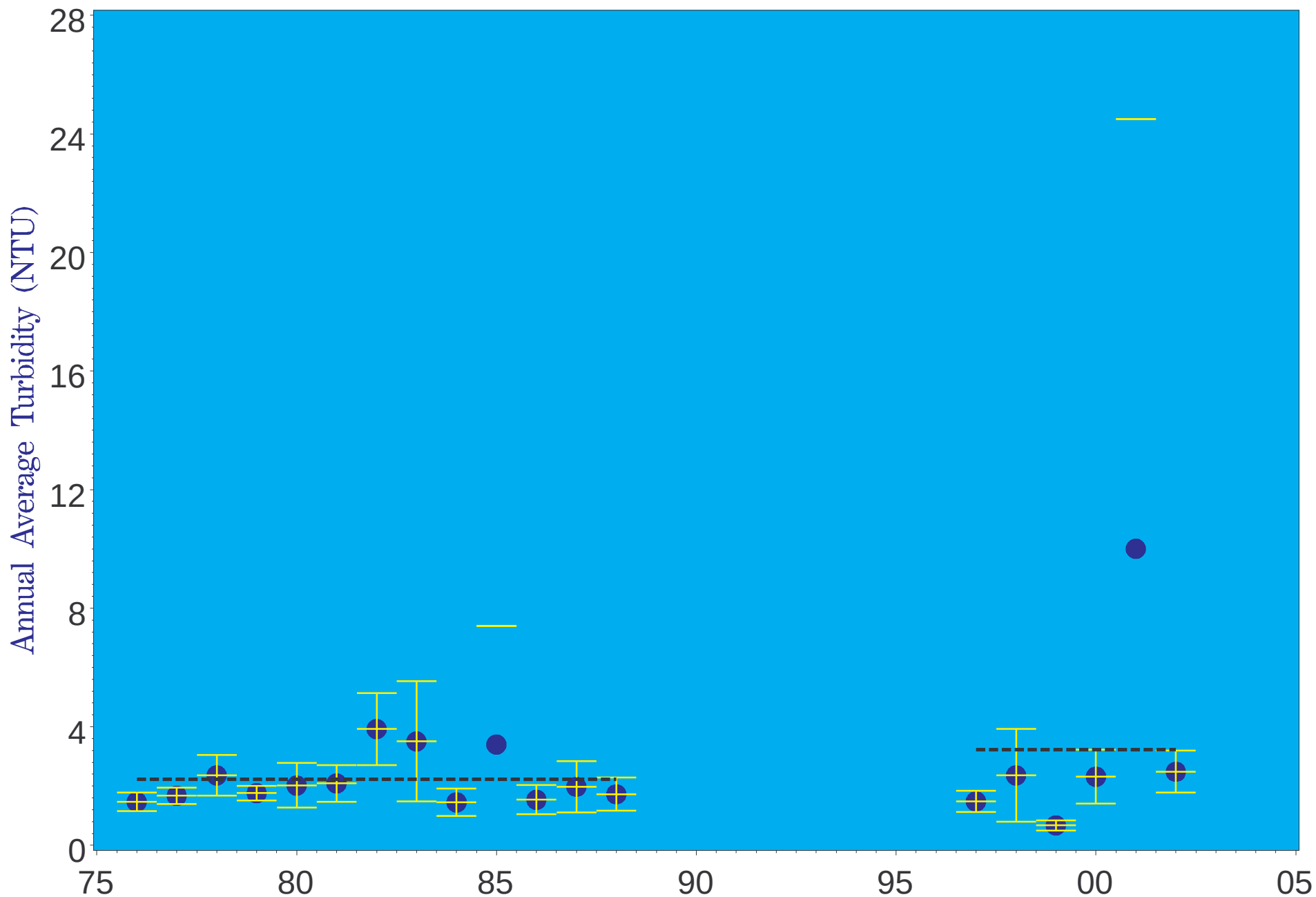


Figure 4.5.29 Long-term surface turbidity at river kilometer -2.4

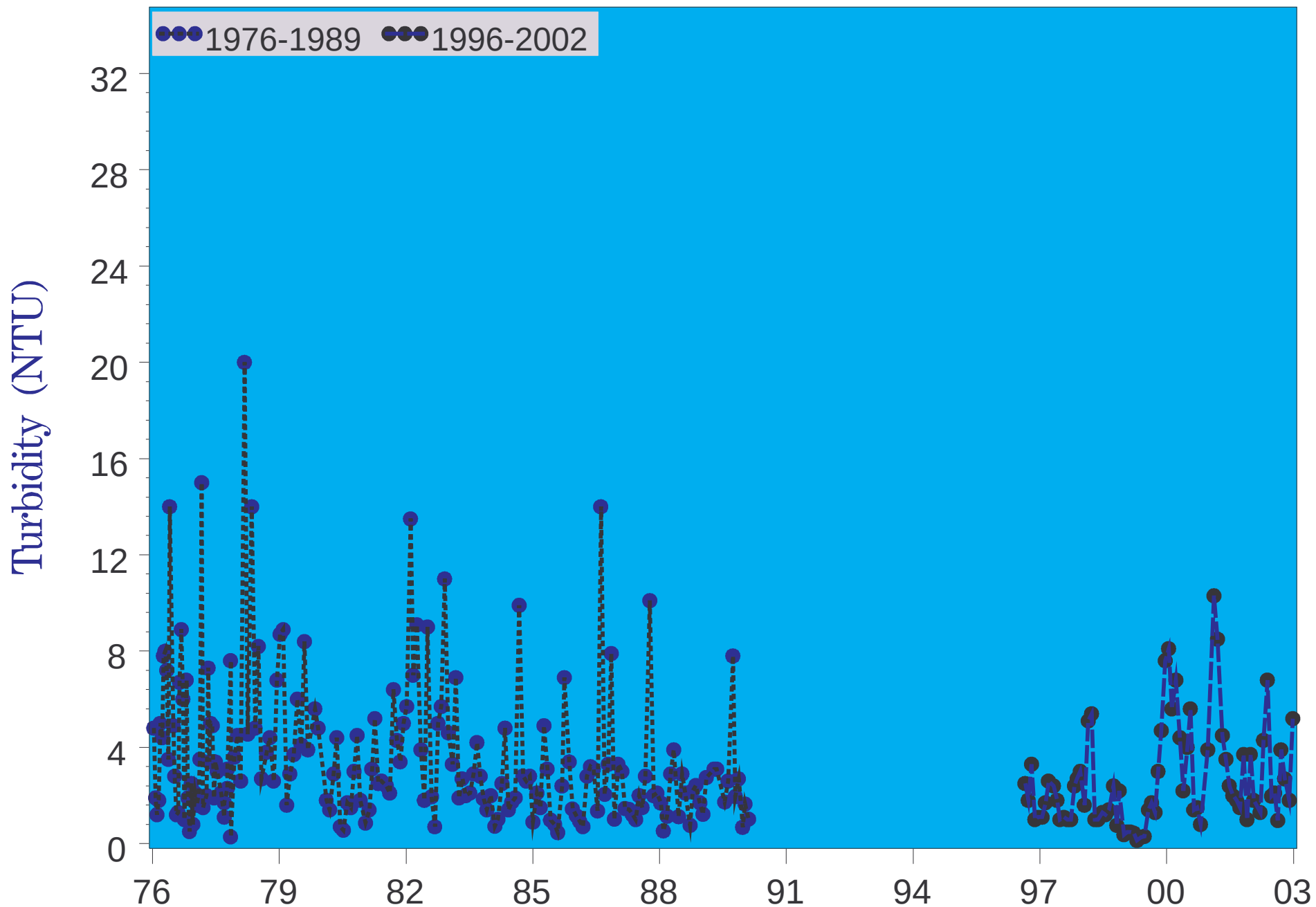


Figure 4.5.30 Long-term bottom turbidity at river kilometer -2.4

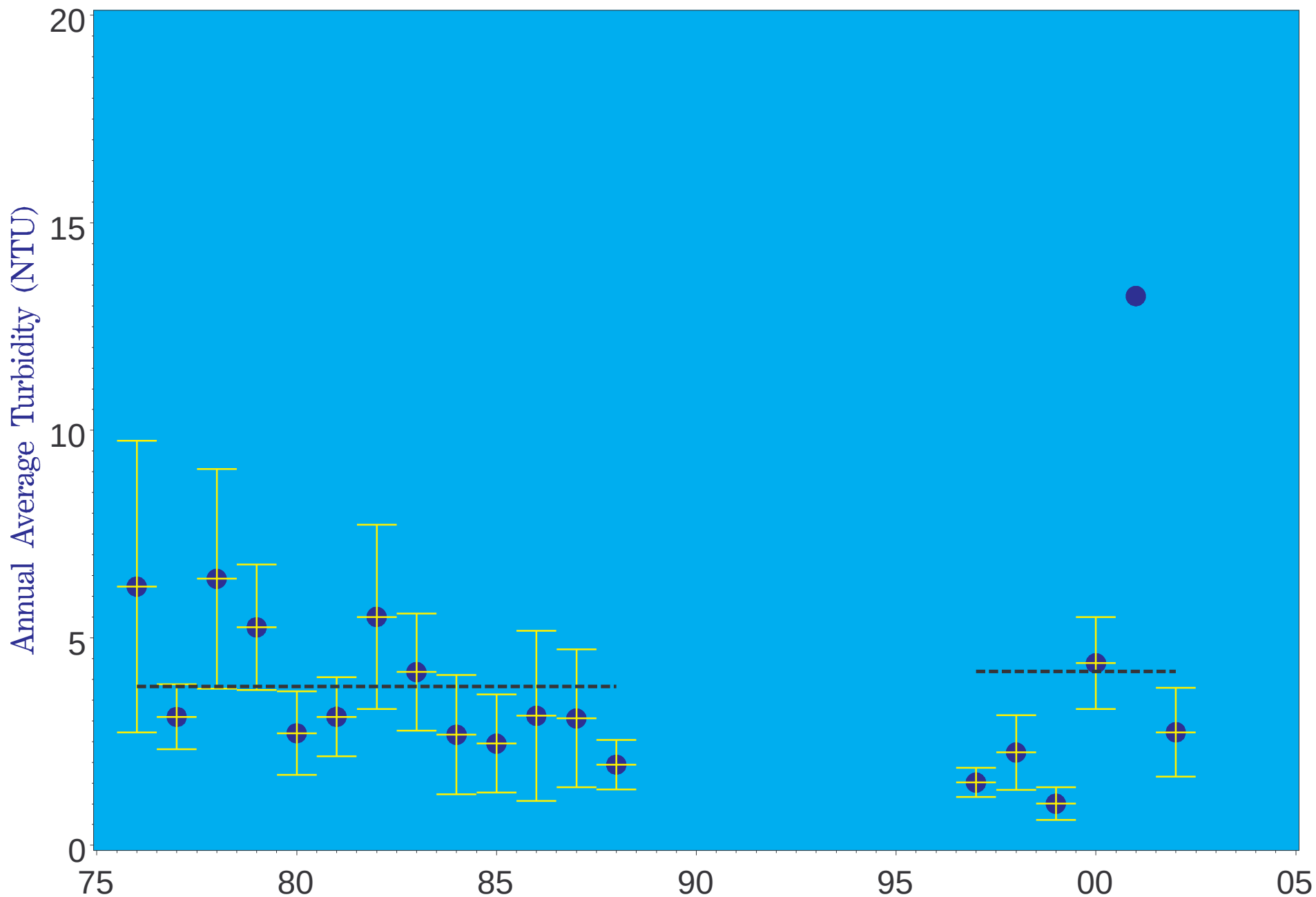


Figure 4.5.31 Long-term bottom turbidity at river kilometer -2.4

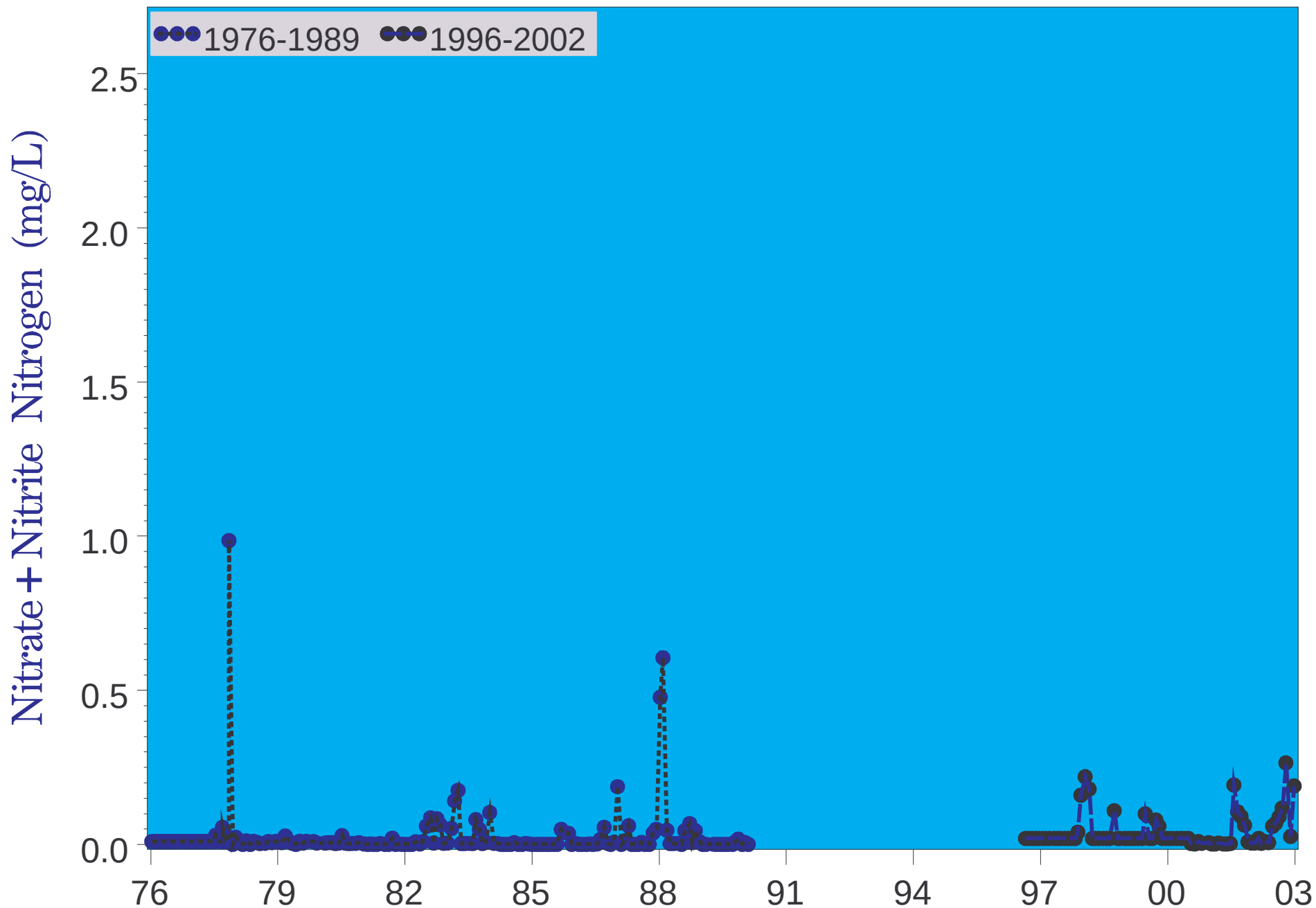


Figure 4.5.32 Long-term surface nitrate/nitrite nitrogen at river kilometer -2.4



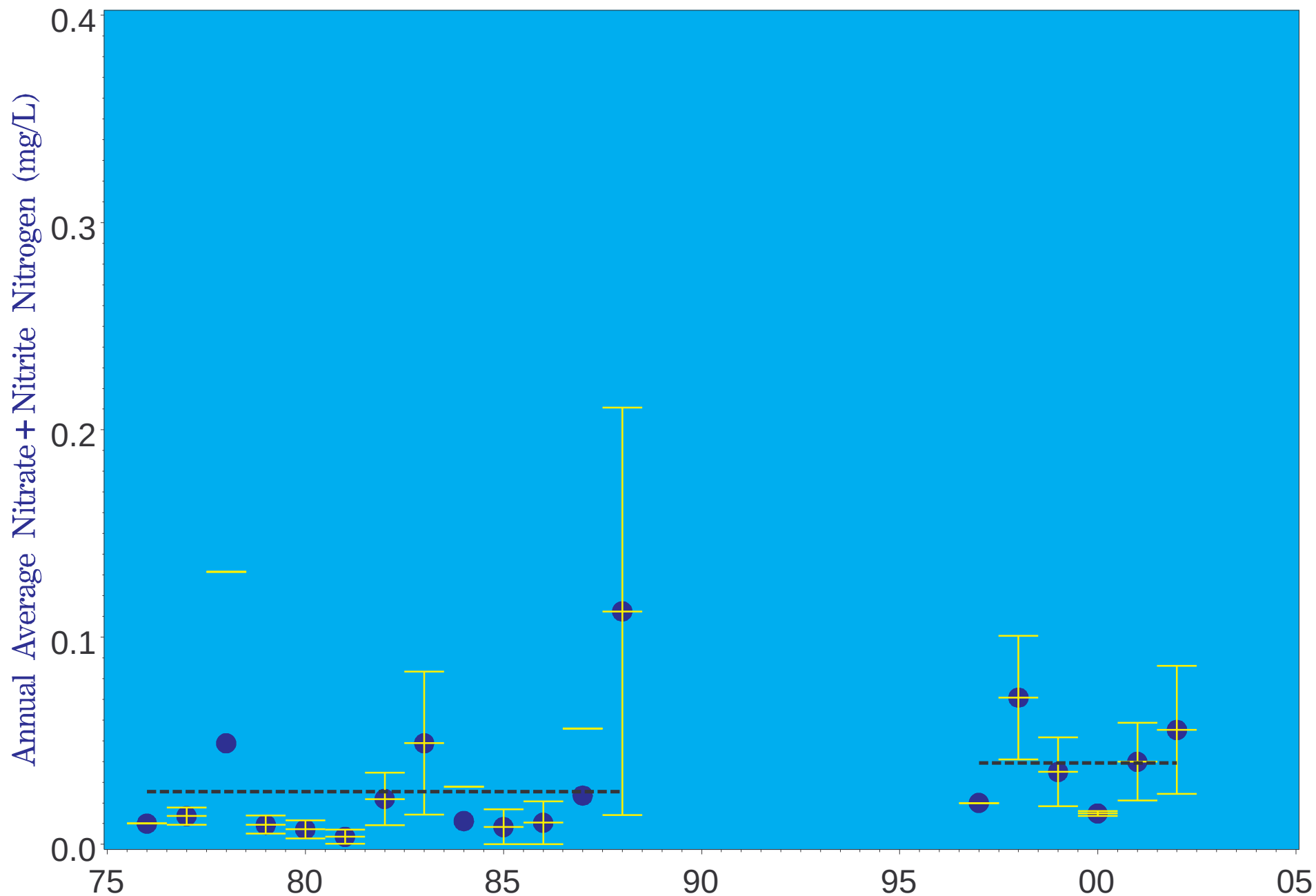


Figure 4.5.33 Long-term surface nitrate/nitrite nitrogen at river kilometer -2.4

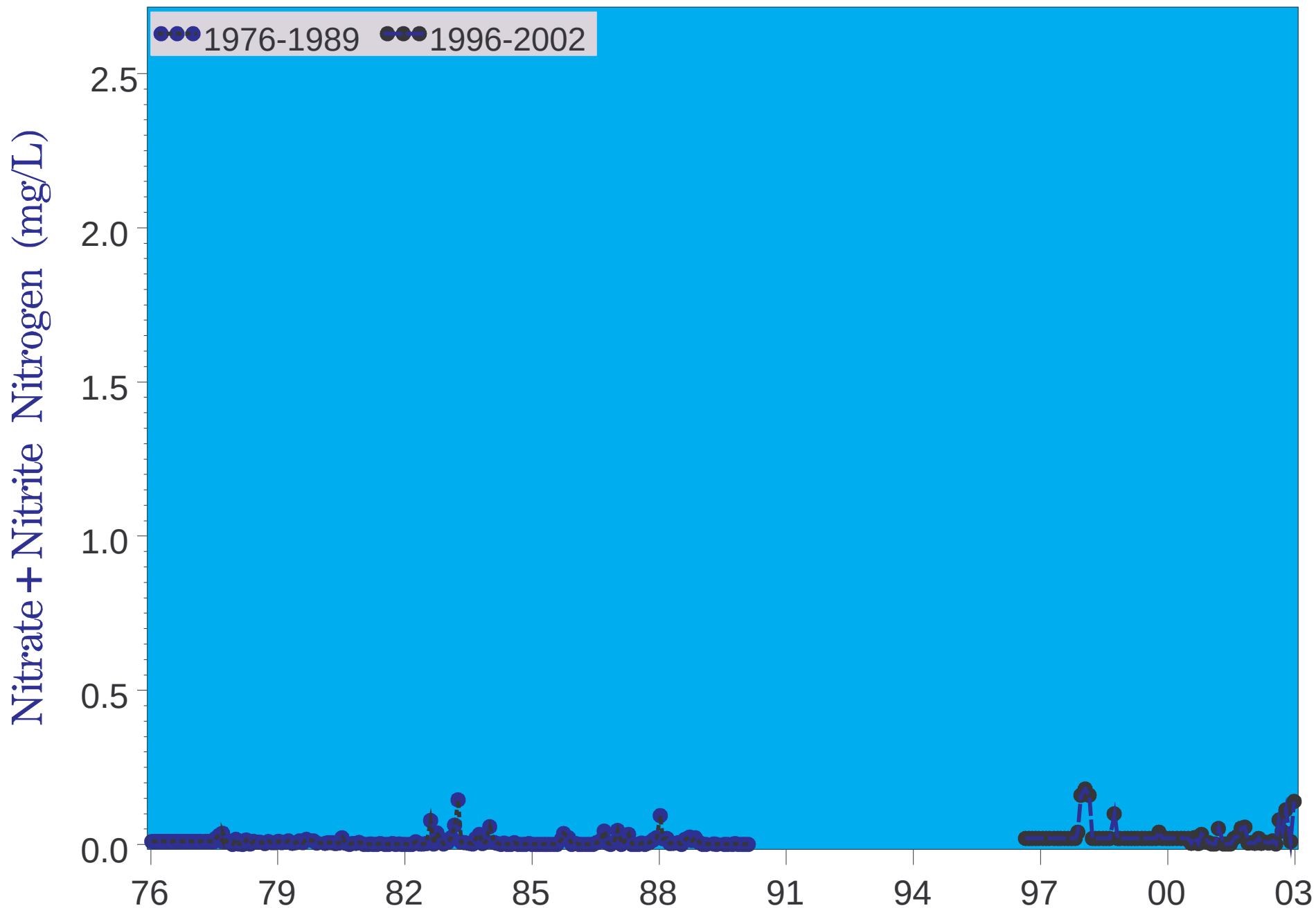


Figure 4.5.34 Long-term bottom nitrate/nitrite nitrogen at river kilometer -2.4

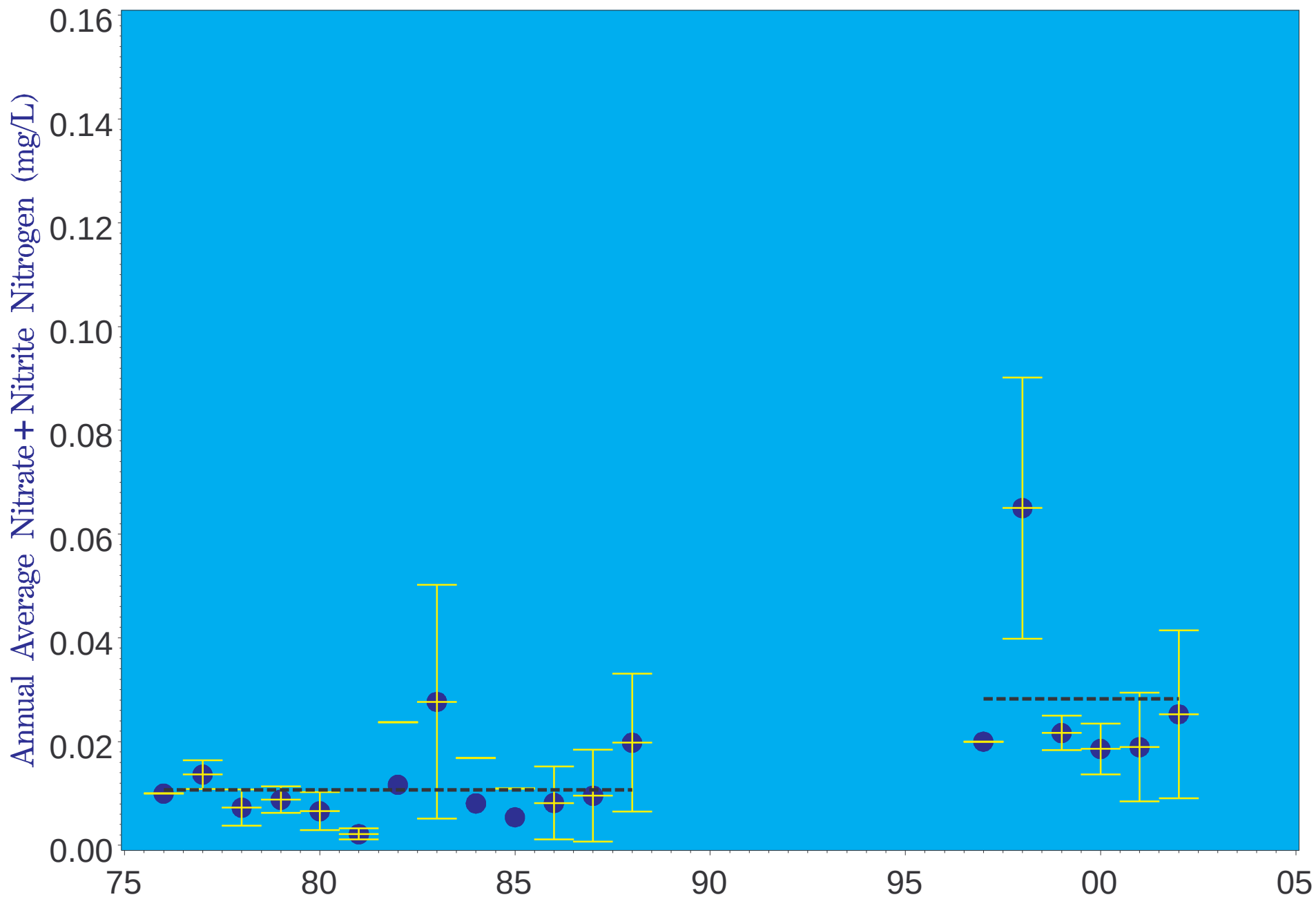


Figure 4.5.35 Long-term bottom nitrate/nitrite nitrogen at river kilometer -2.4

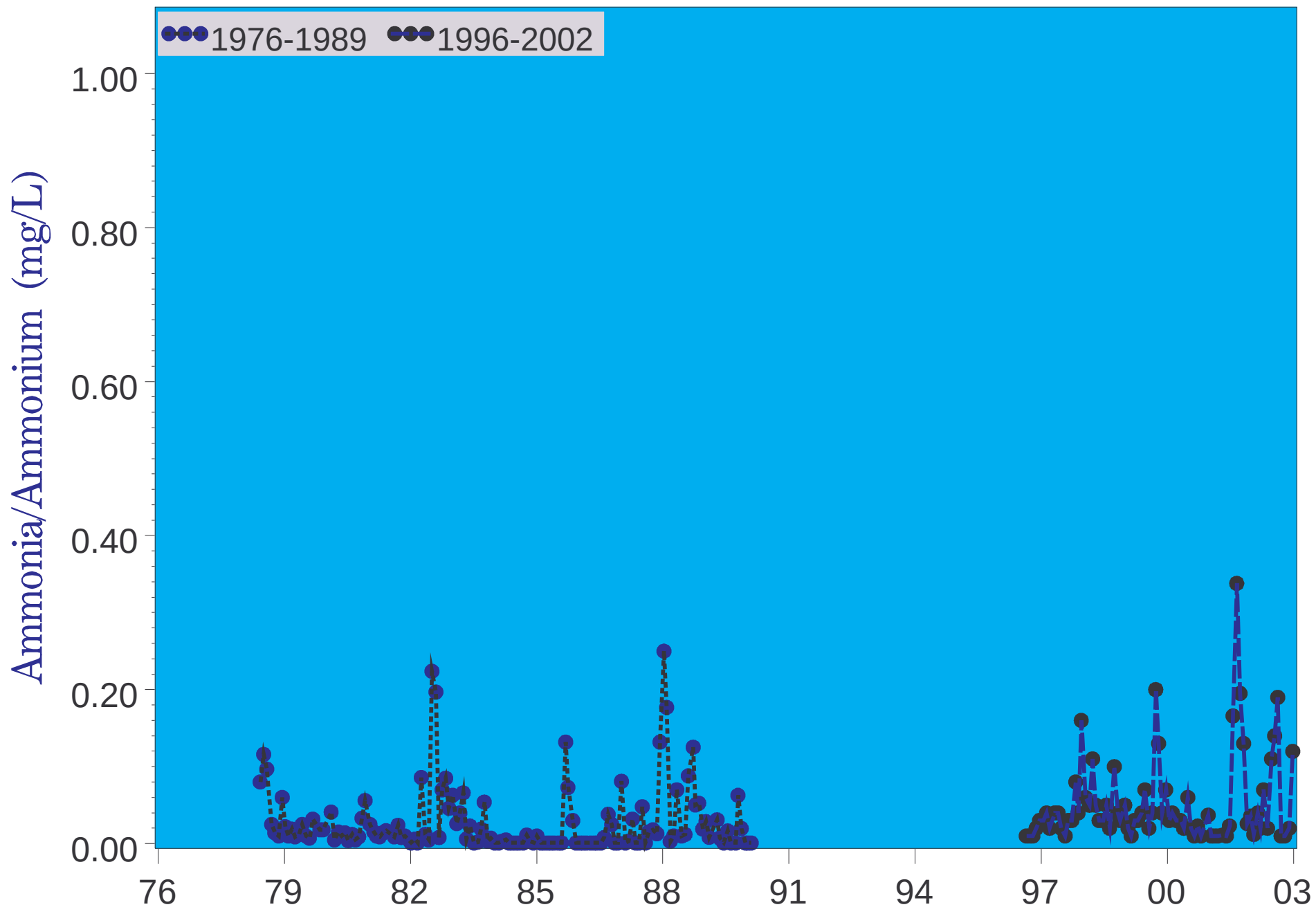


Figure 4.5.36 Long-term surface ammonia/ammonium at river kilometer -2.4

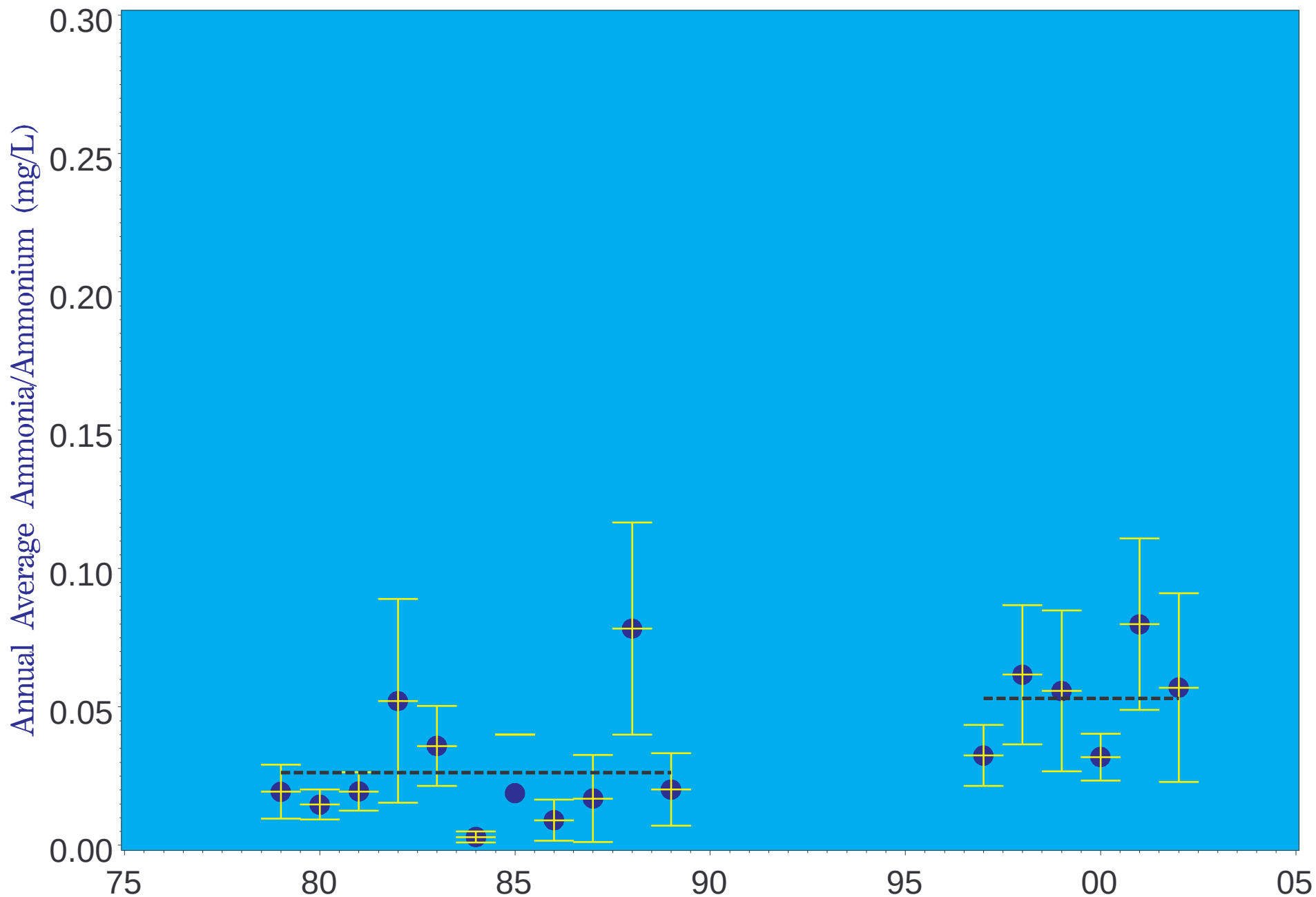


Figure 4.5.37 Long-term surface ammonia/ammonium at river kilometer -2.4

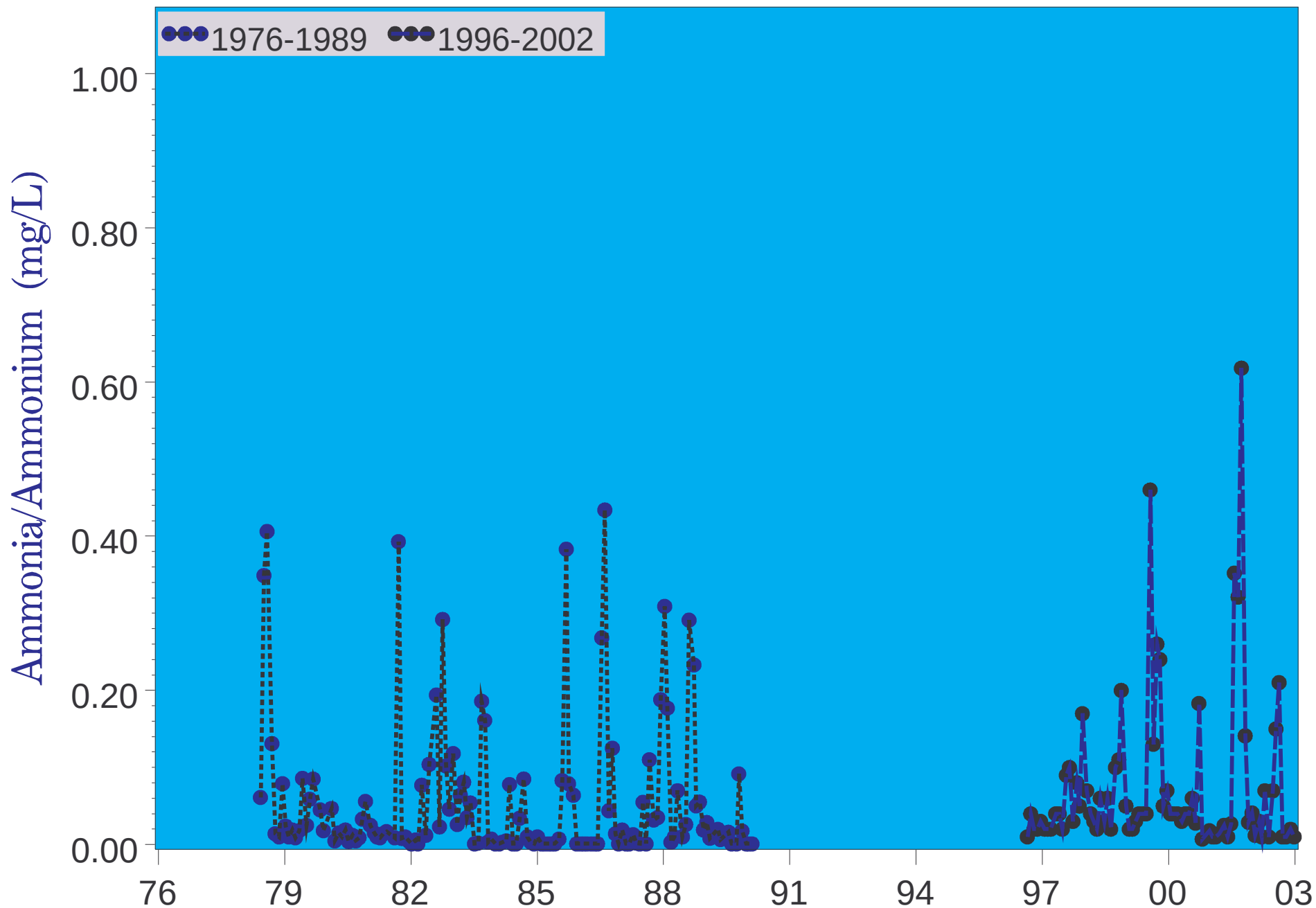


Figure 4.5.38 Long-term bottom ammonia/ammonium at river kilometer -2.4

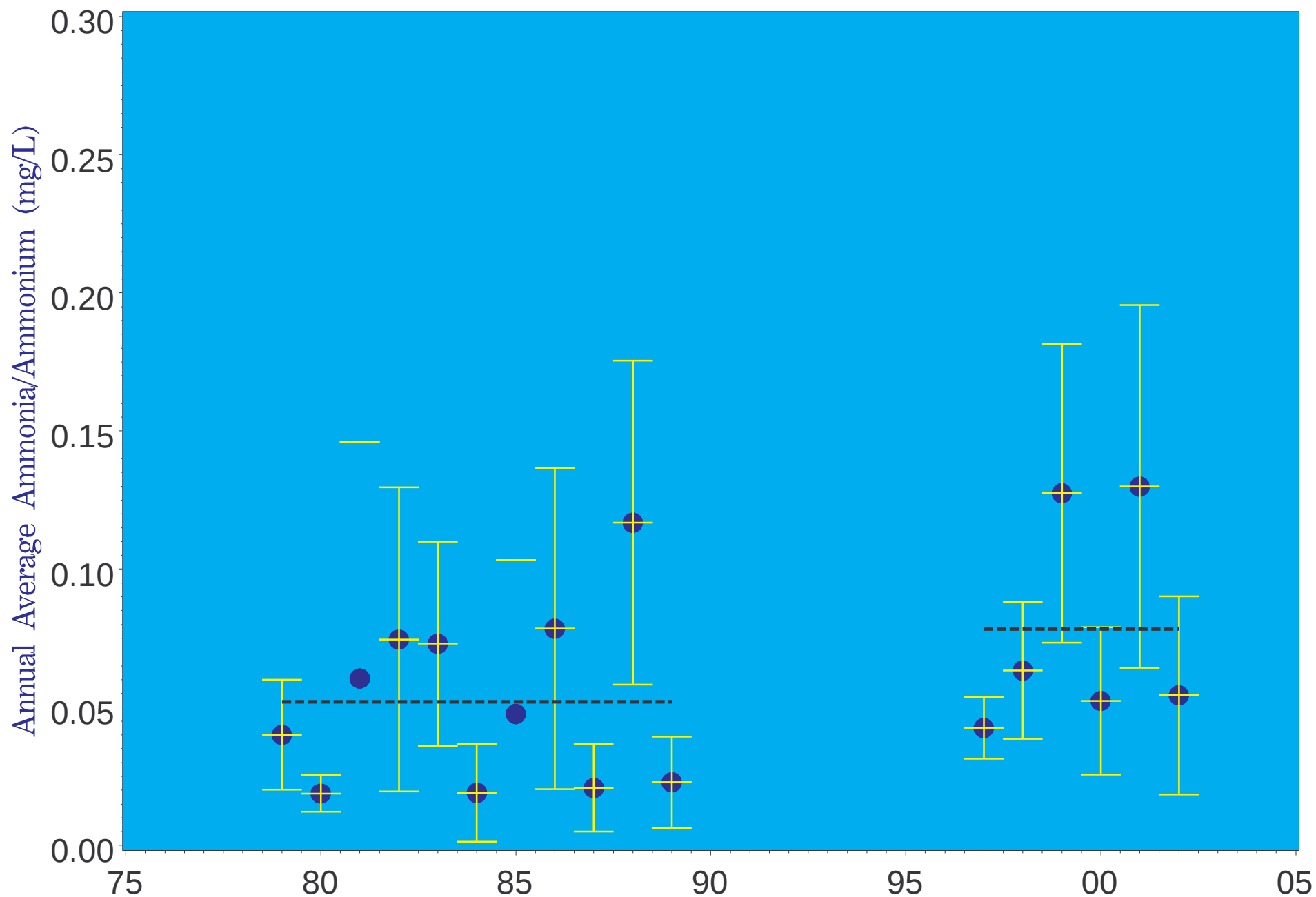


Figure 4.5.39 Long-term bottom ammonia/ammonium at river kilometer -2.4

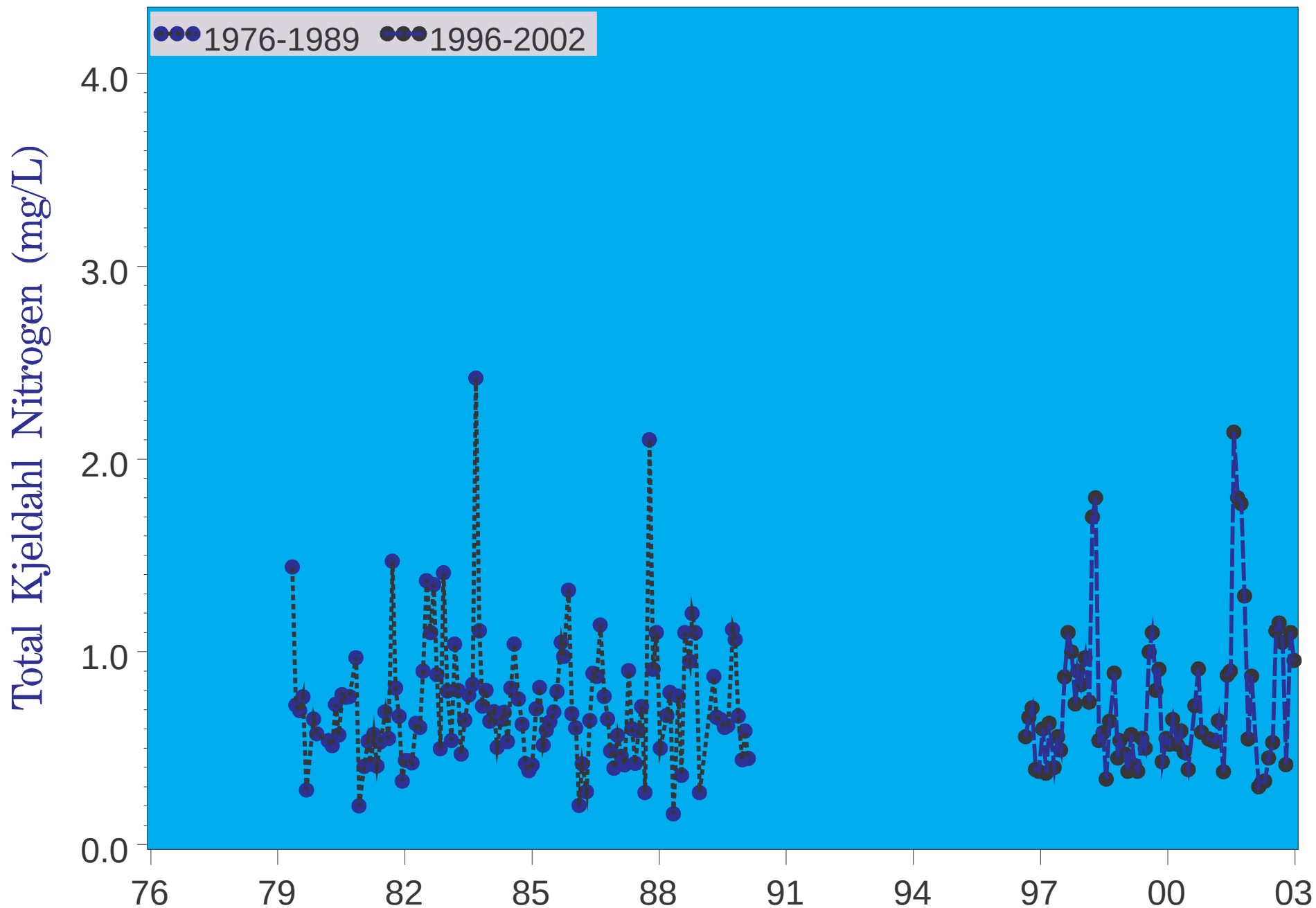


Figure 4.5.40 Long-term surface total Kjeldahl nitrogen at river kilometer -2.4



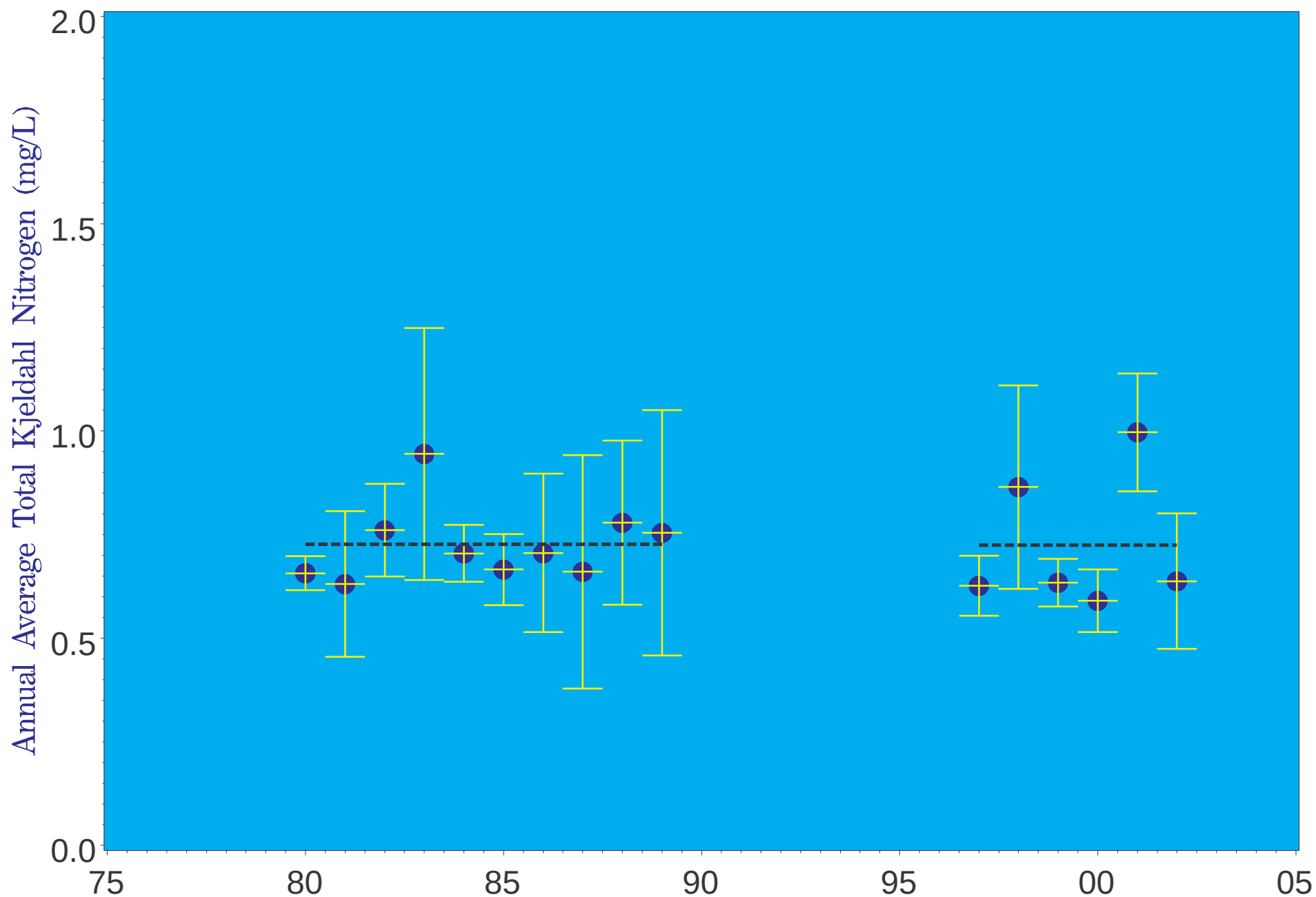


Figure 4.5.41 Long-term surface total Kjeldahl nitrogen at river kilometer -2.4

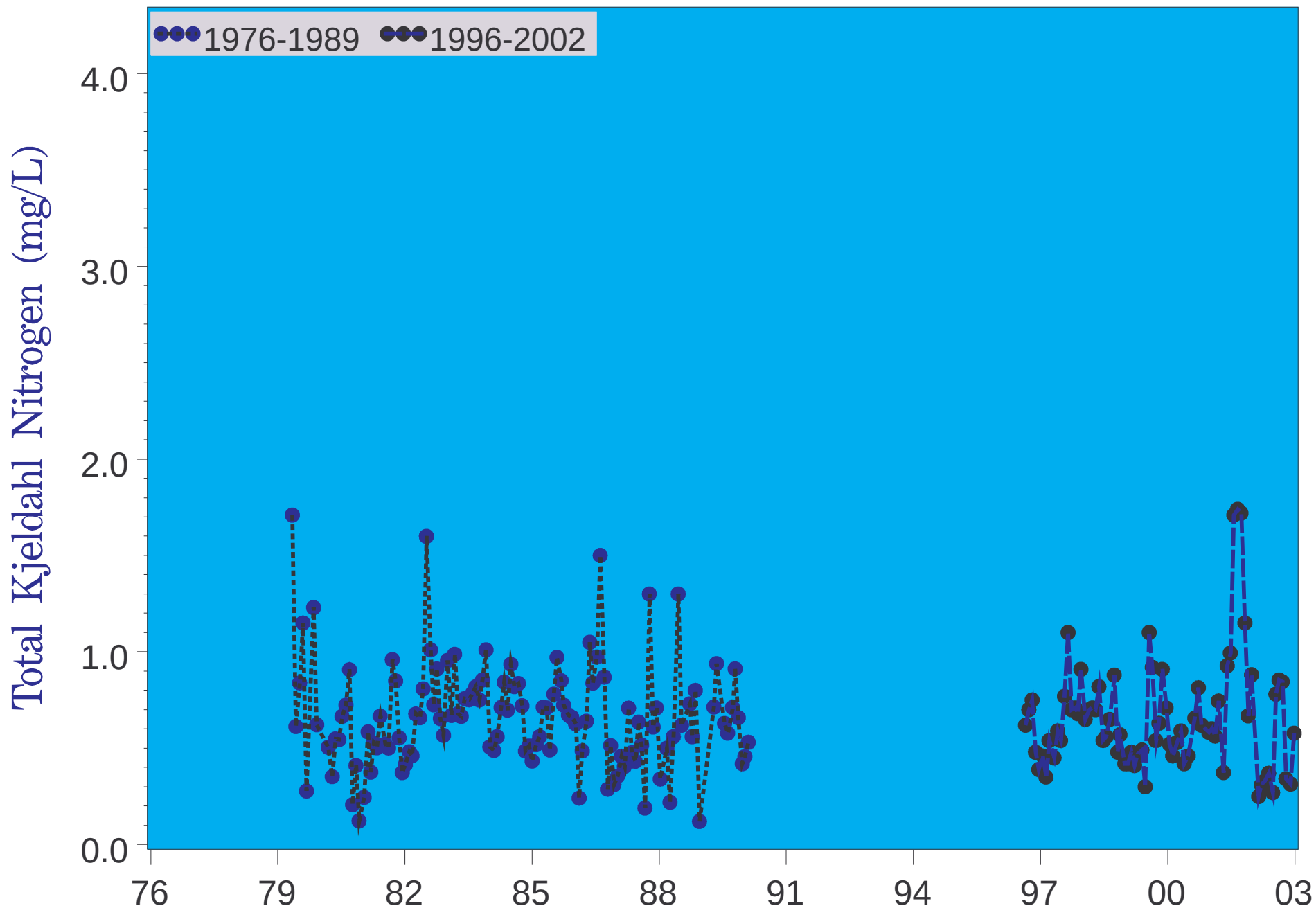


Figure 4.5.42 Long-term bottom total Kjeldhal nitrogen at river kilometer -2.4

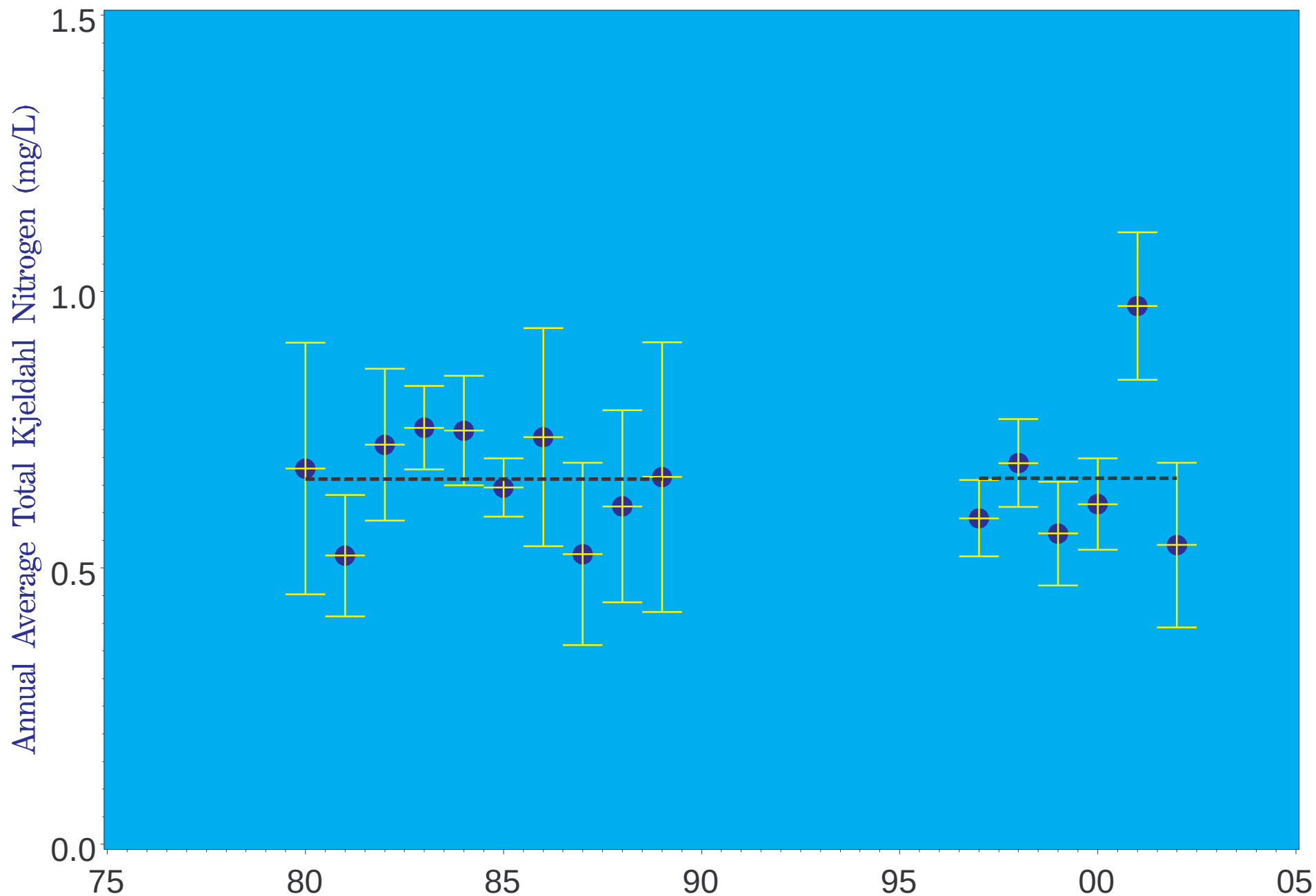


Figure 4.5.43 Long-term bottom total Kjeldhal nitrogen at river kilometer -2.4

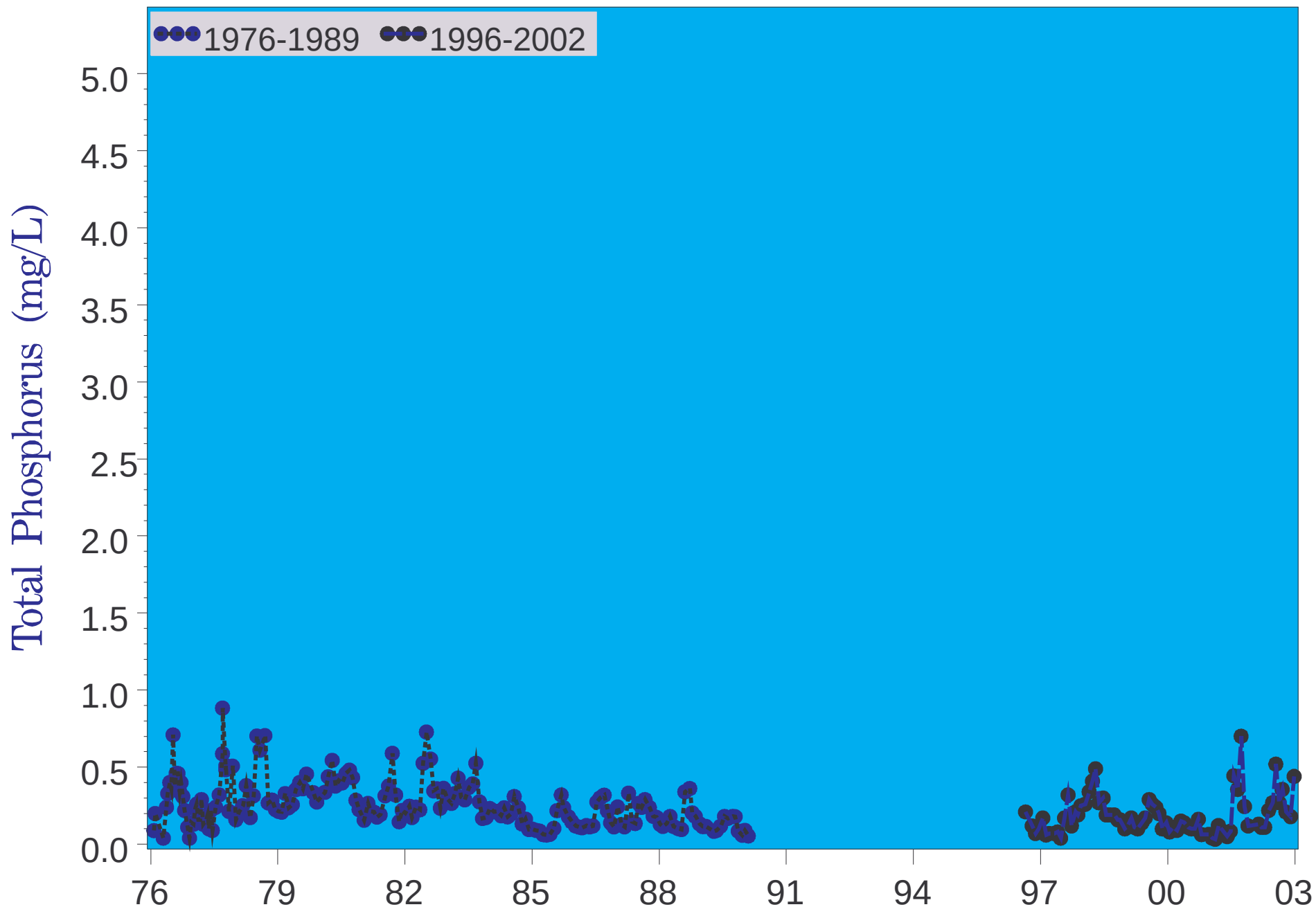


Figure 4.5.44 Long-term surface total phosphorus at river kilometer -2.4

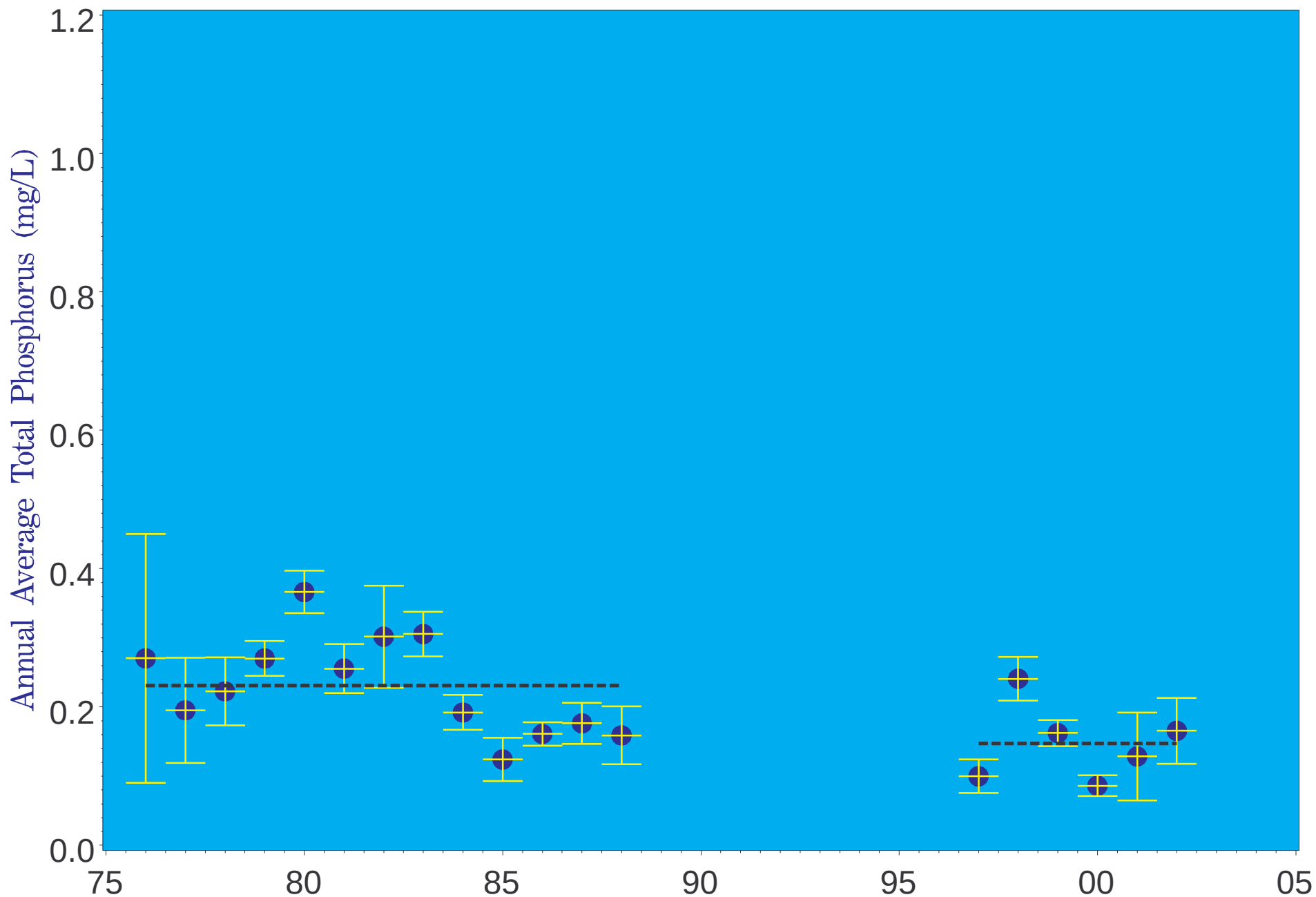


Figure 4.5.45 Long-term surface total phosphorus at river kilometer -2.4

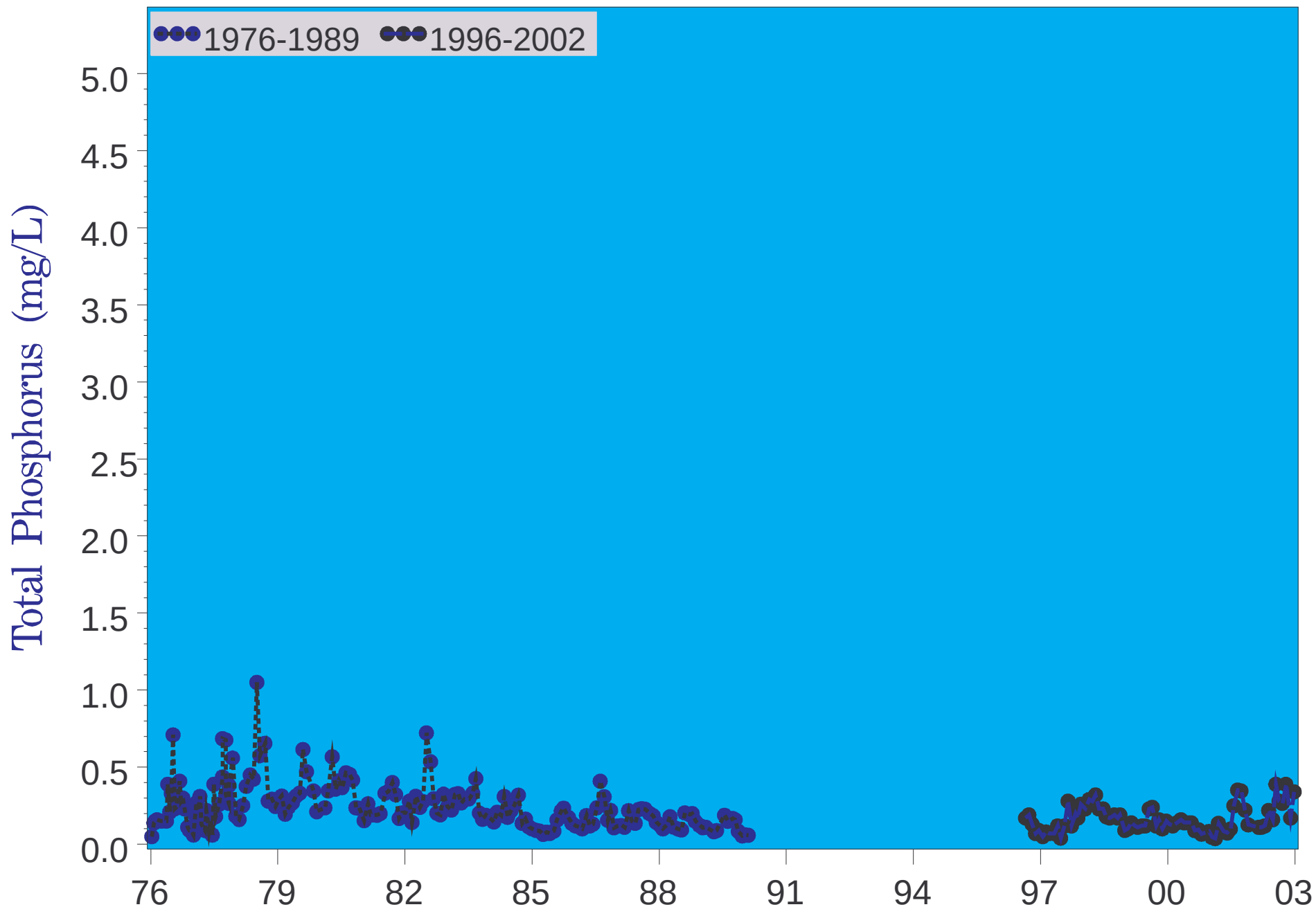


Figure 4.5.46 Long-term bottom total phosphorus at river kilometer -2.4

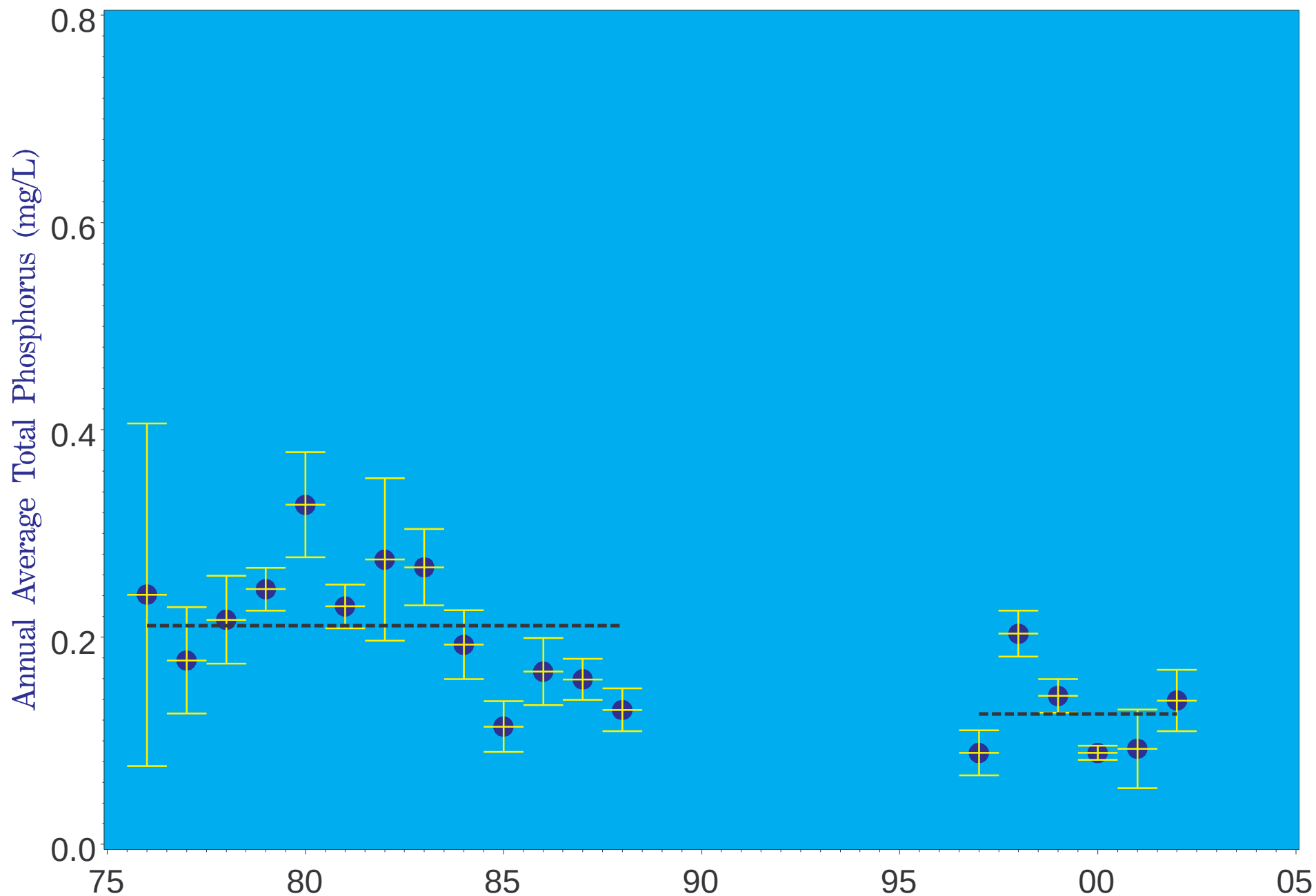


Figure 4.5.47 Long-term bottom total phosphorus at river kilometer -2.4

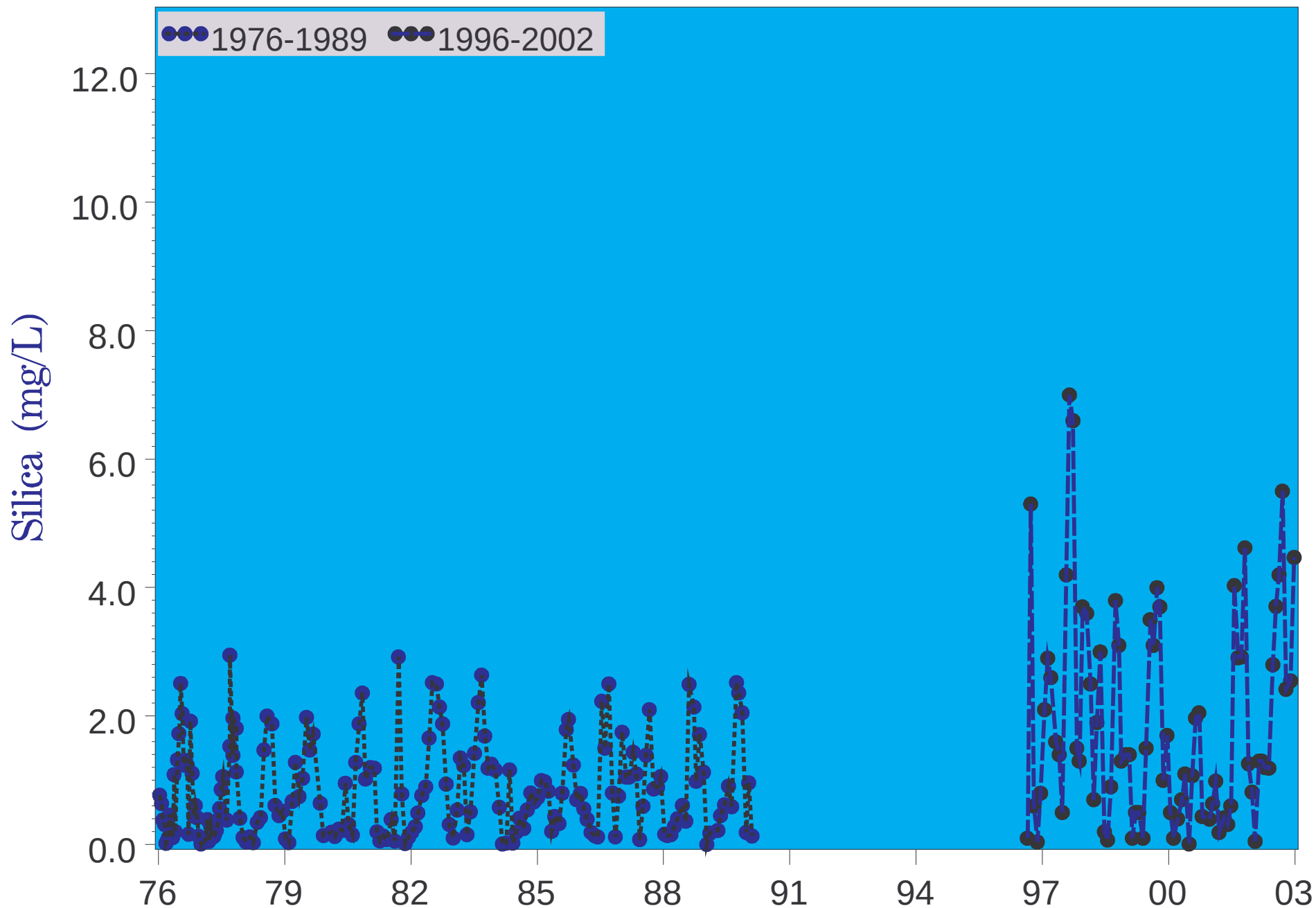


Figure 4.5.48 Long-term surface silica at river kilometer -2.4



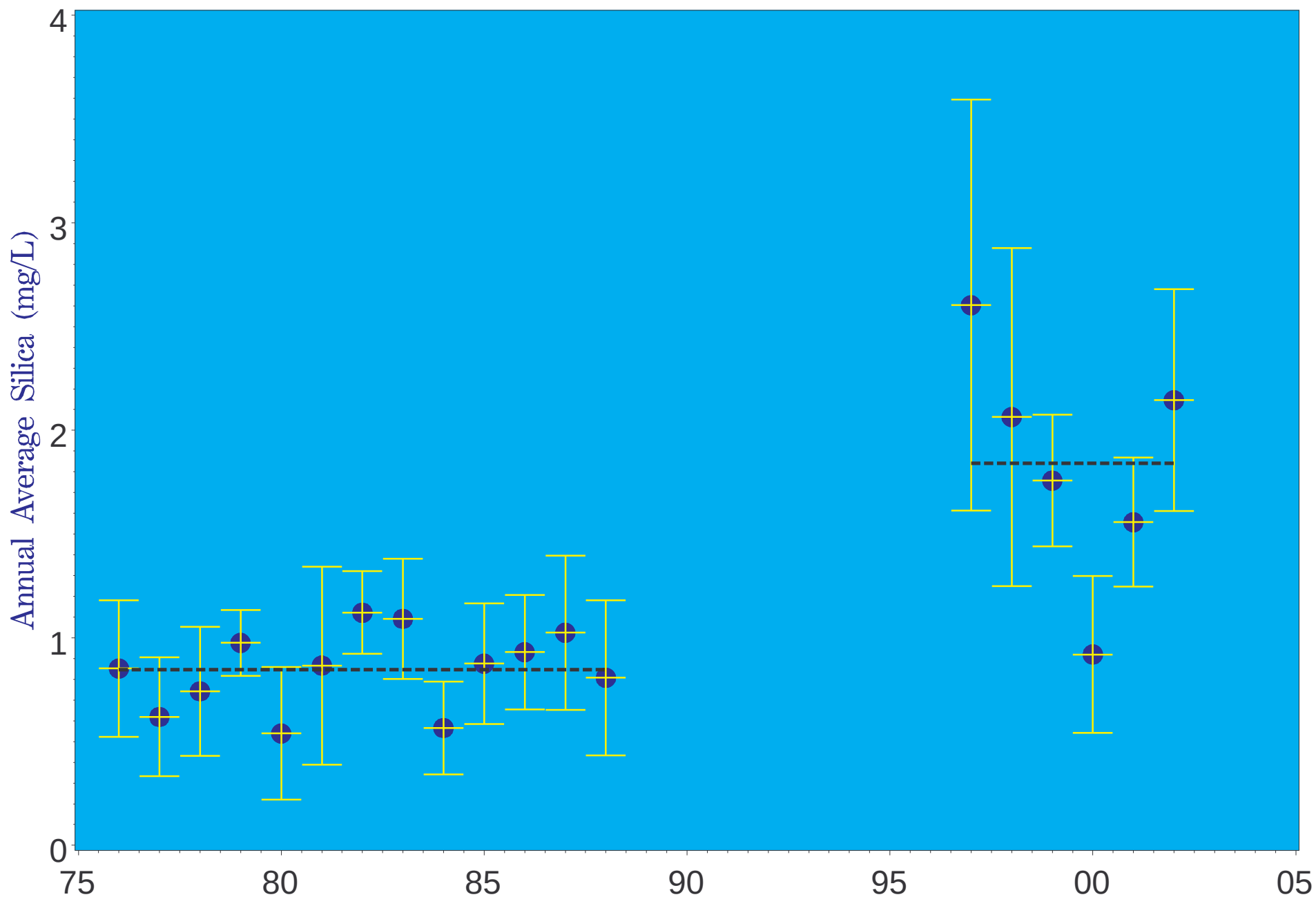


Figure 4.5.49 Long-term surface silica at river kilometer -2.4

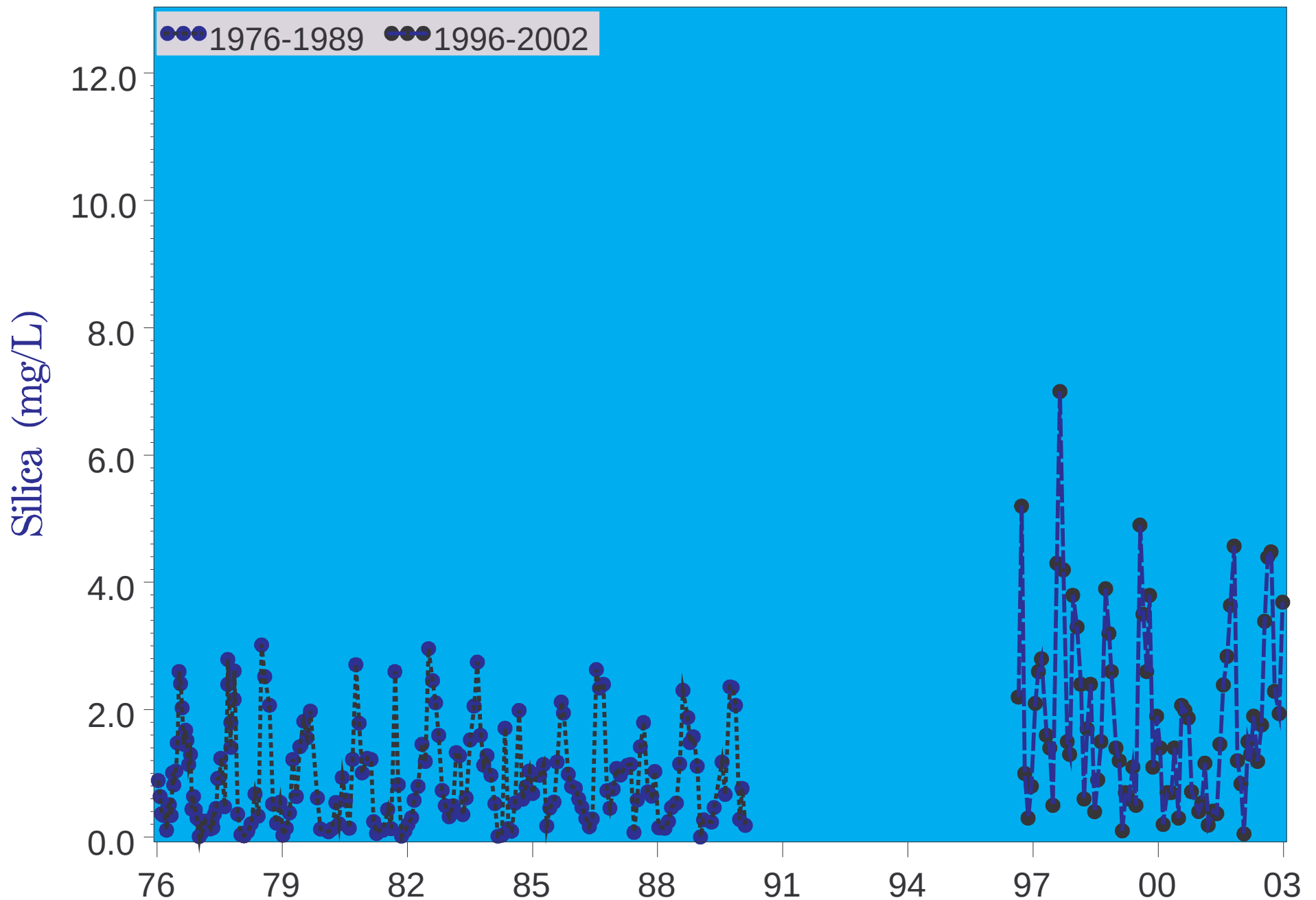


Figure 4.5.50 Long-term bottom silica at river kilometer -2.4

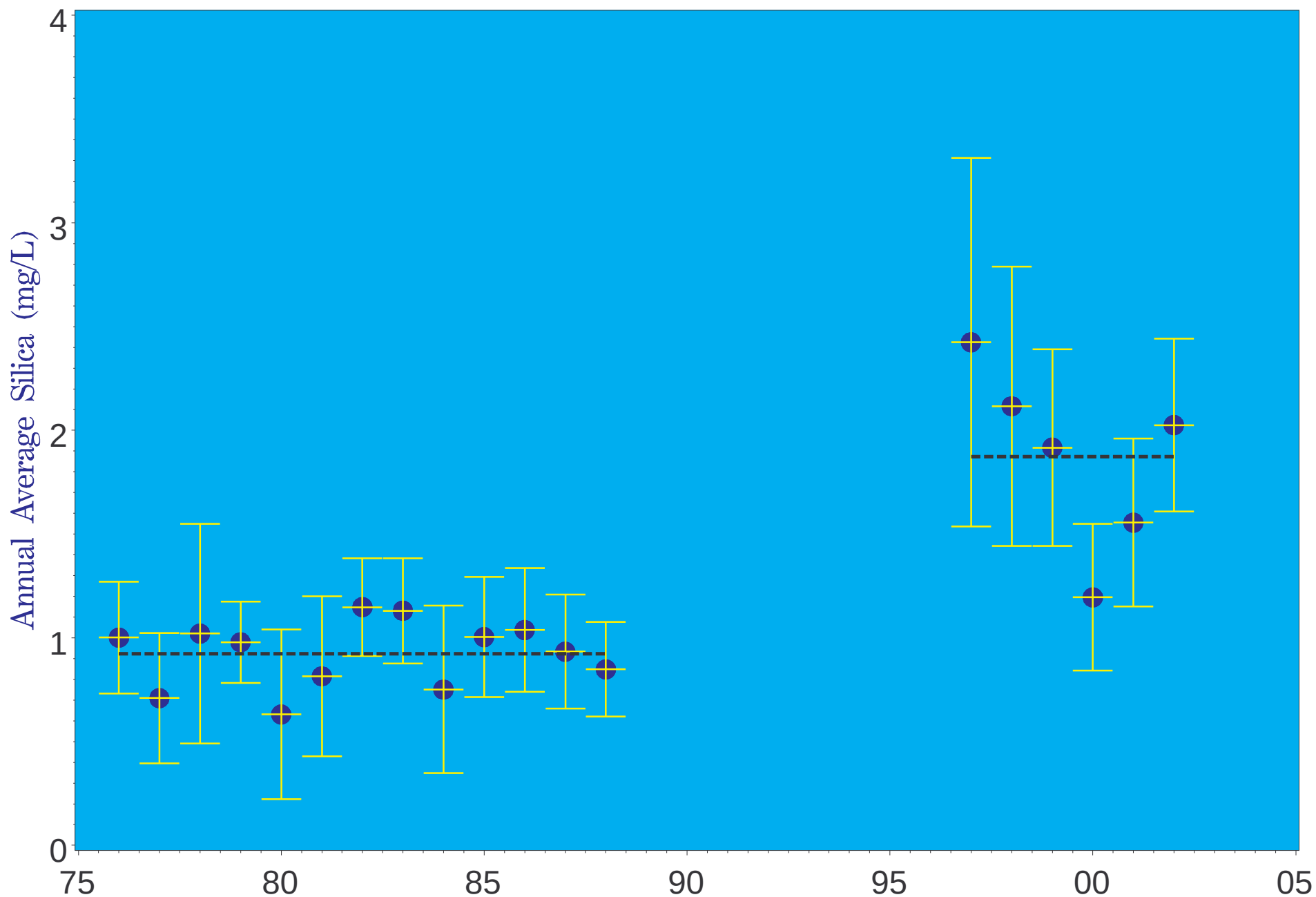


Figure 4.5.51 Long-term bottom silica at river kilometer -2.4

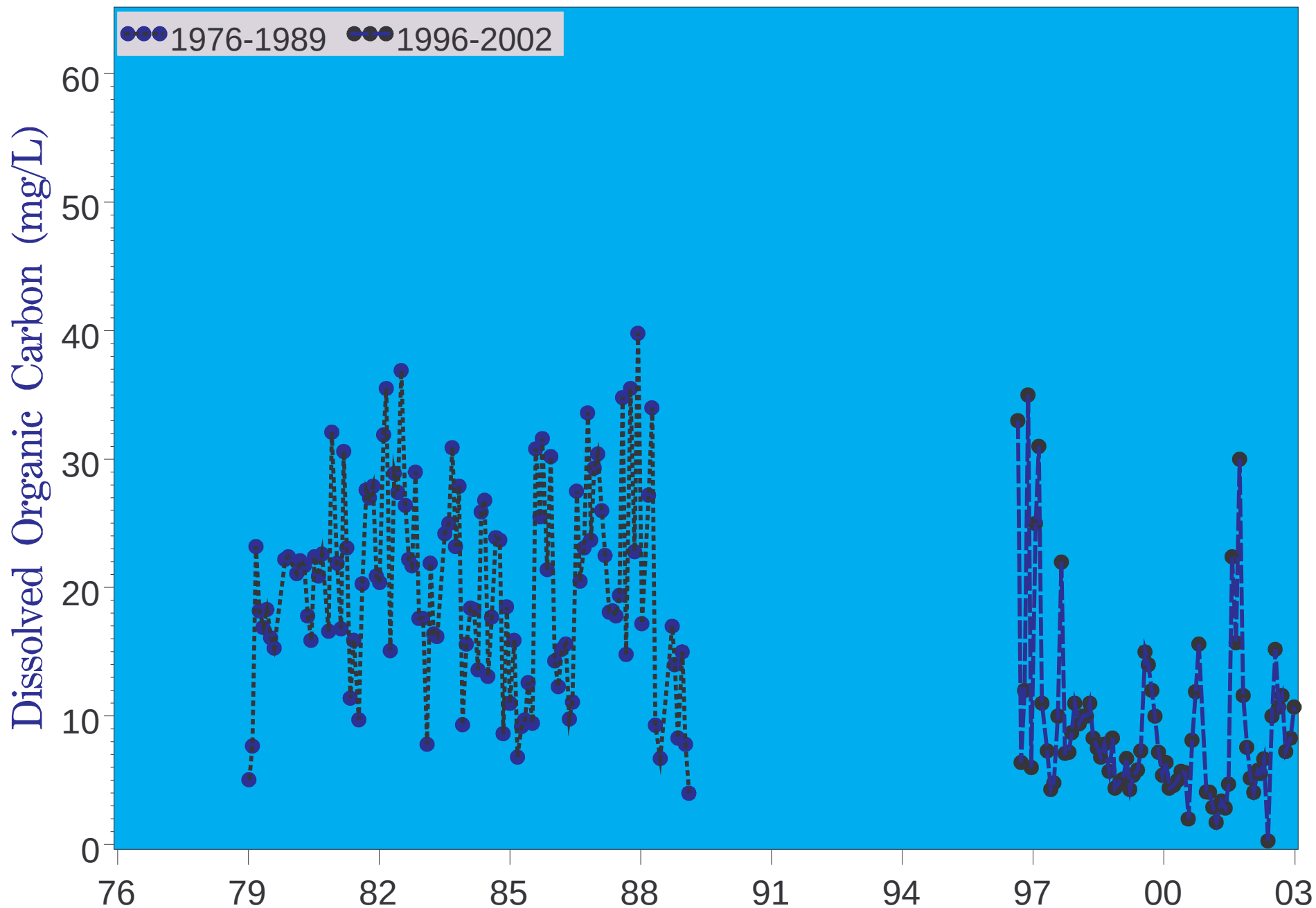


Figure 4.5.52 Long-term surface dissolved organic carbon at river kilometer -2.4

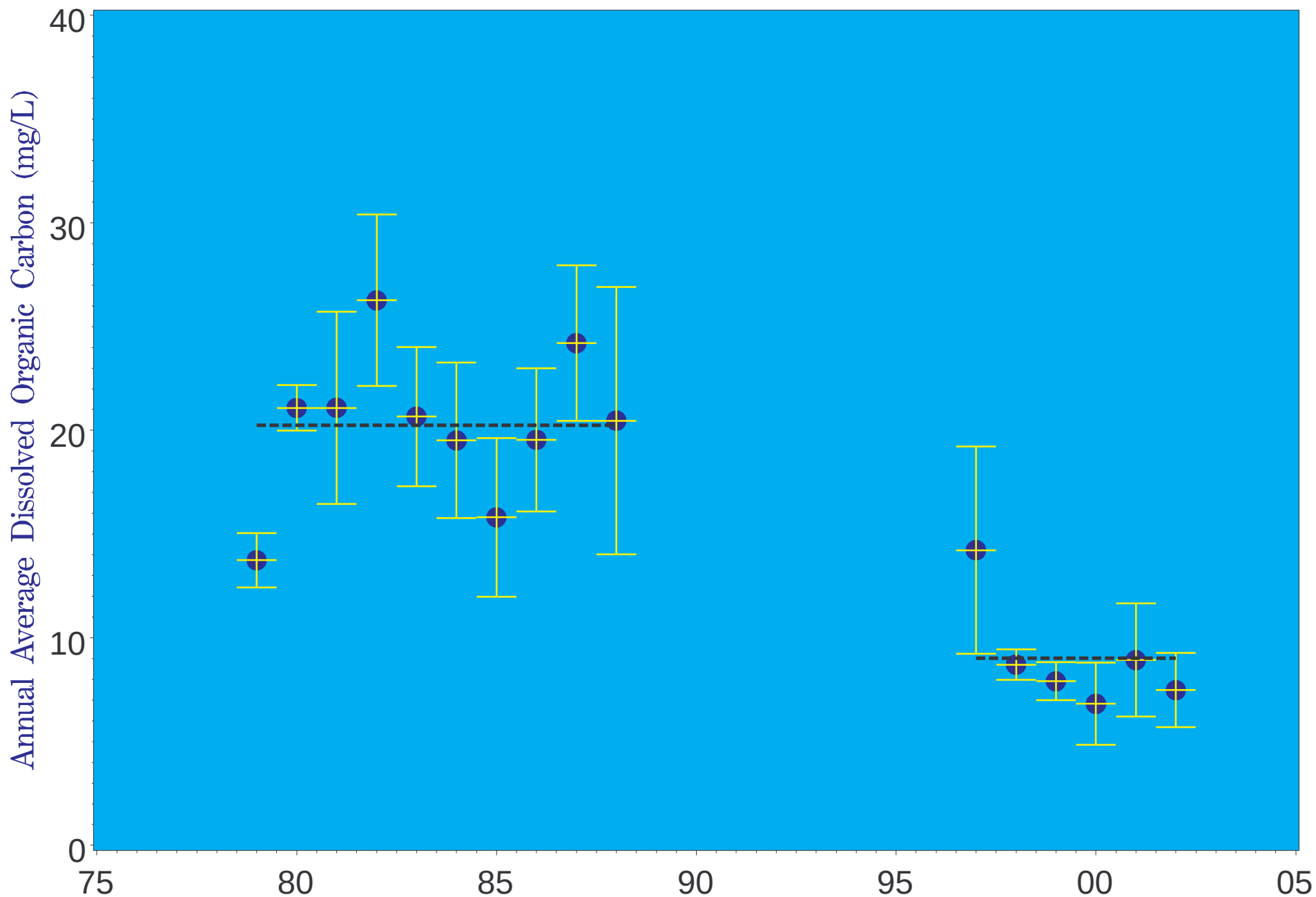


Figure 4.5.53 Long-term surface dissolved organic carbon at river kilometer -2.4

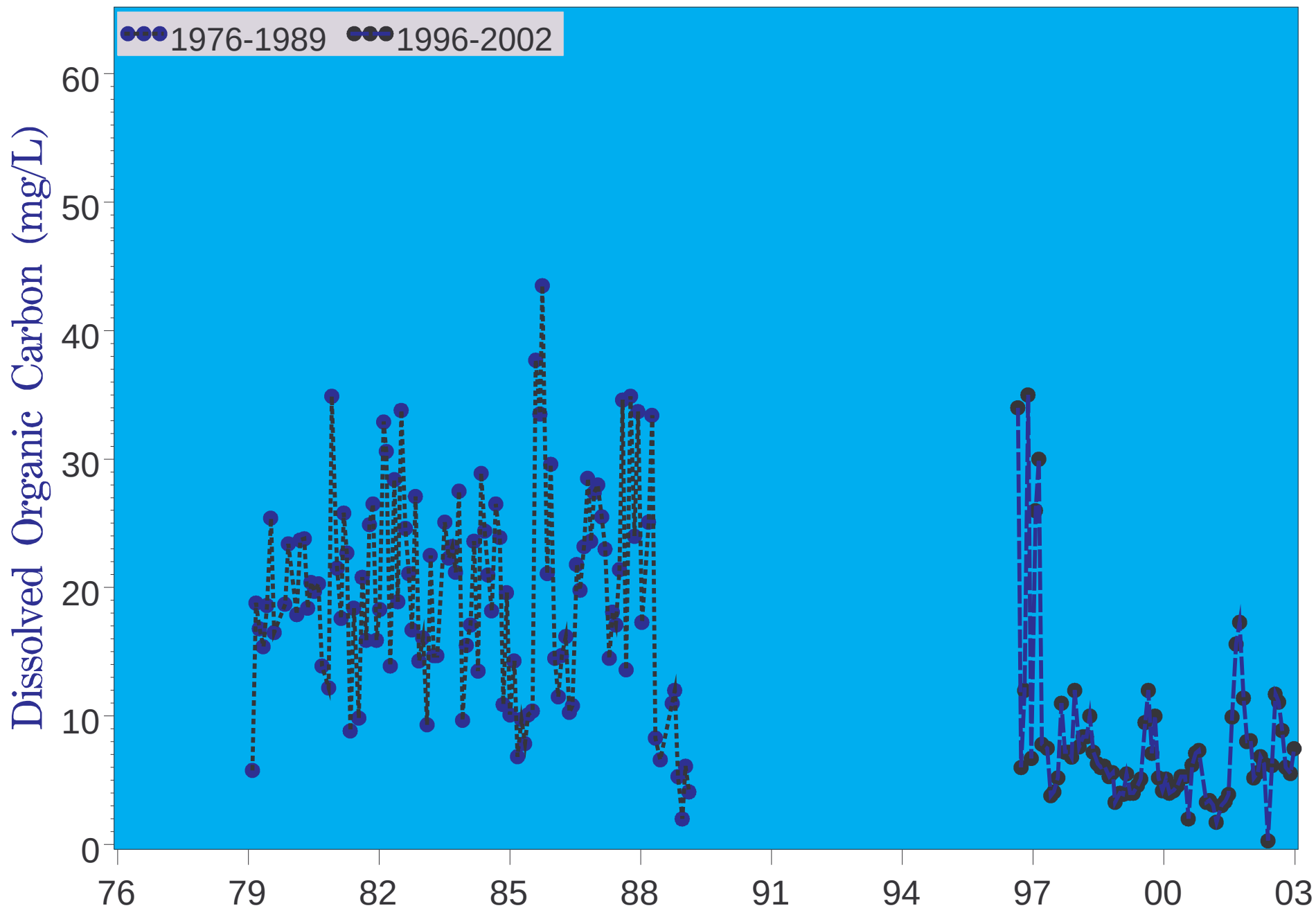


Figure 4.5.54 Long-term bottom dissolved organic carbon at river kilometer -2.4

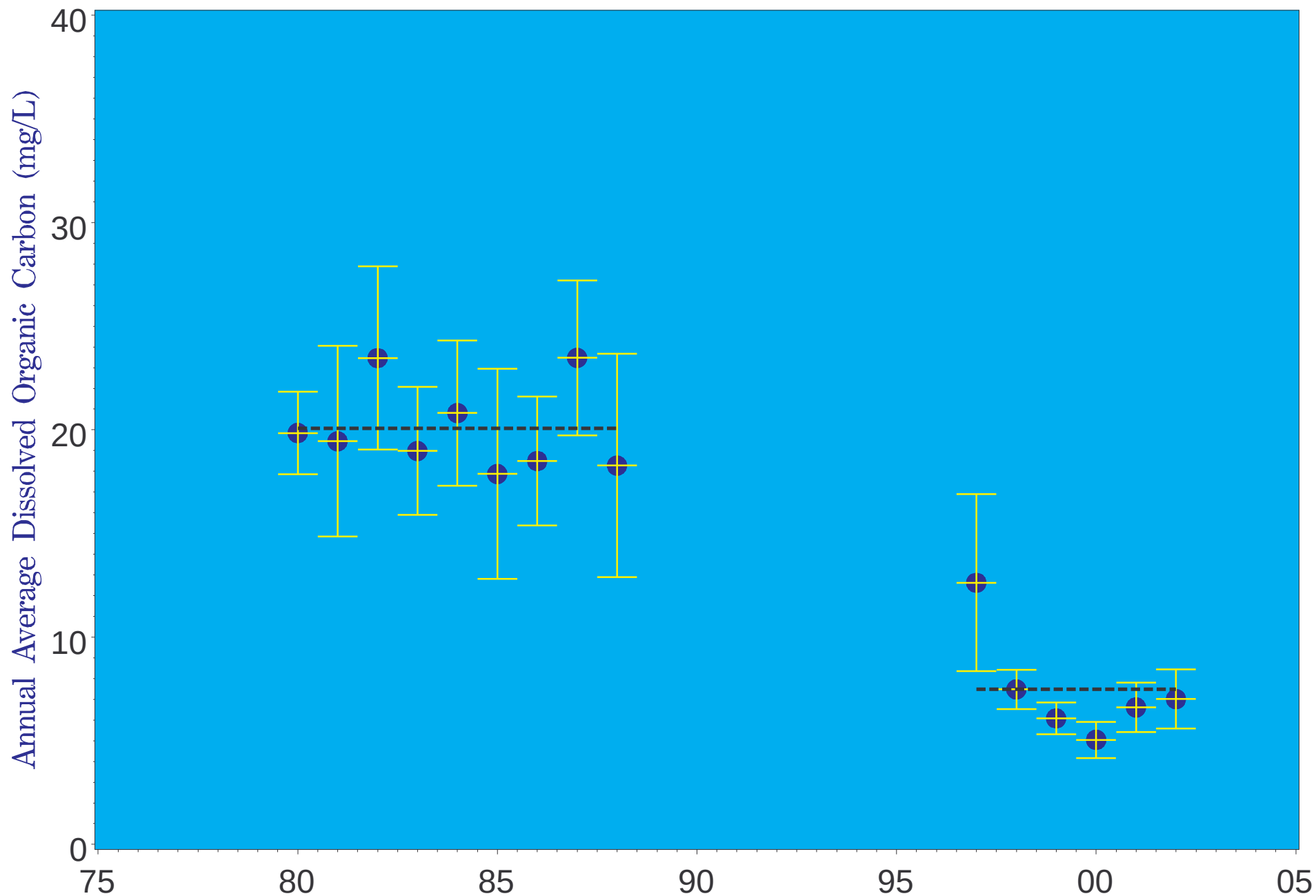


Figure 4.5.55 Long-term bottom dissolved organic carbon at river kilometer -2.4

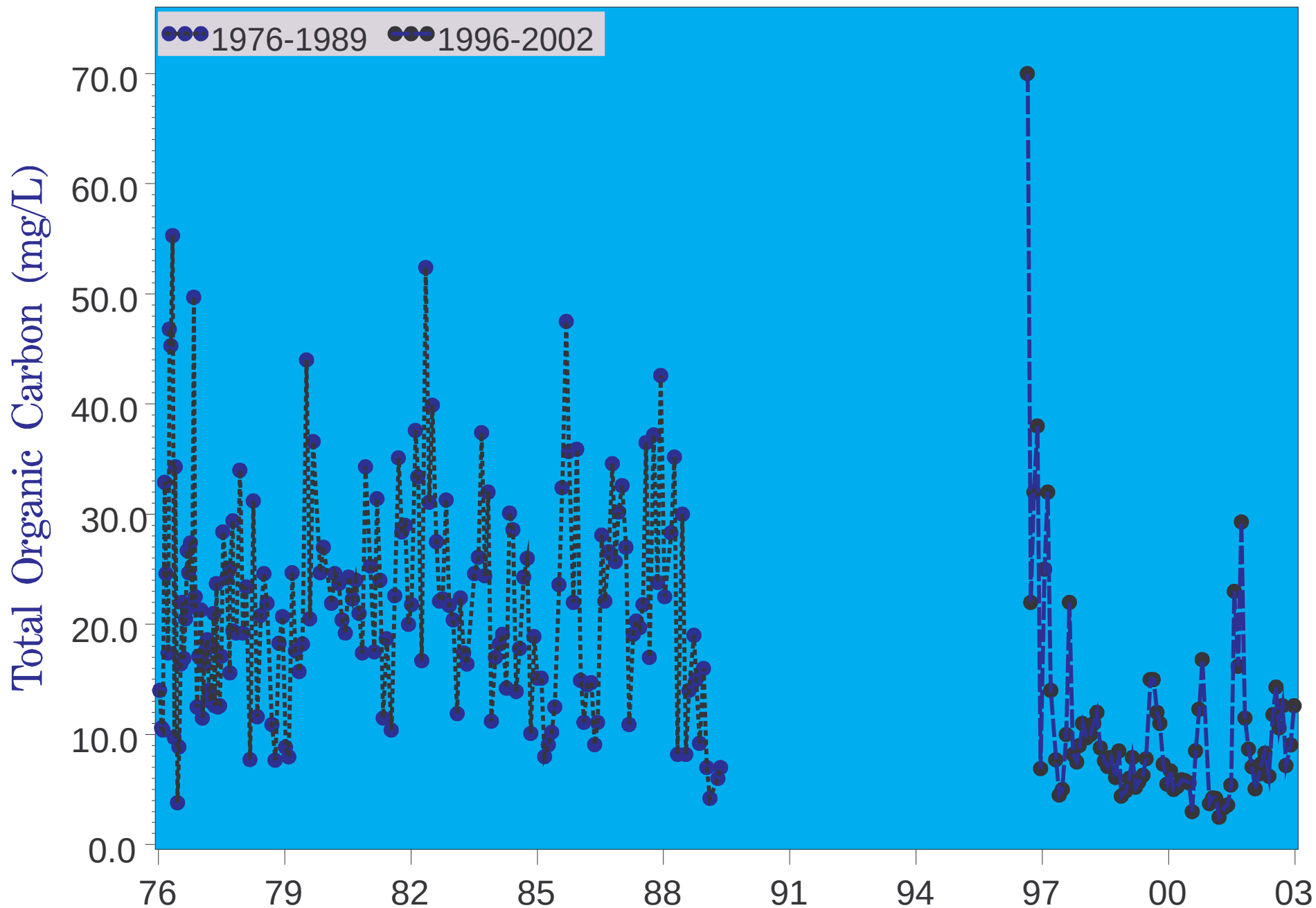


Figure 4.5.56 Long-term surface total organic carbon at river kilometer -2.4



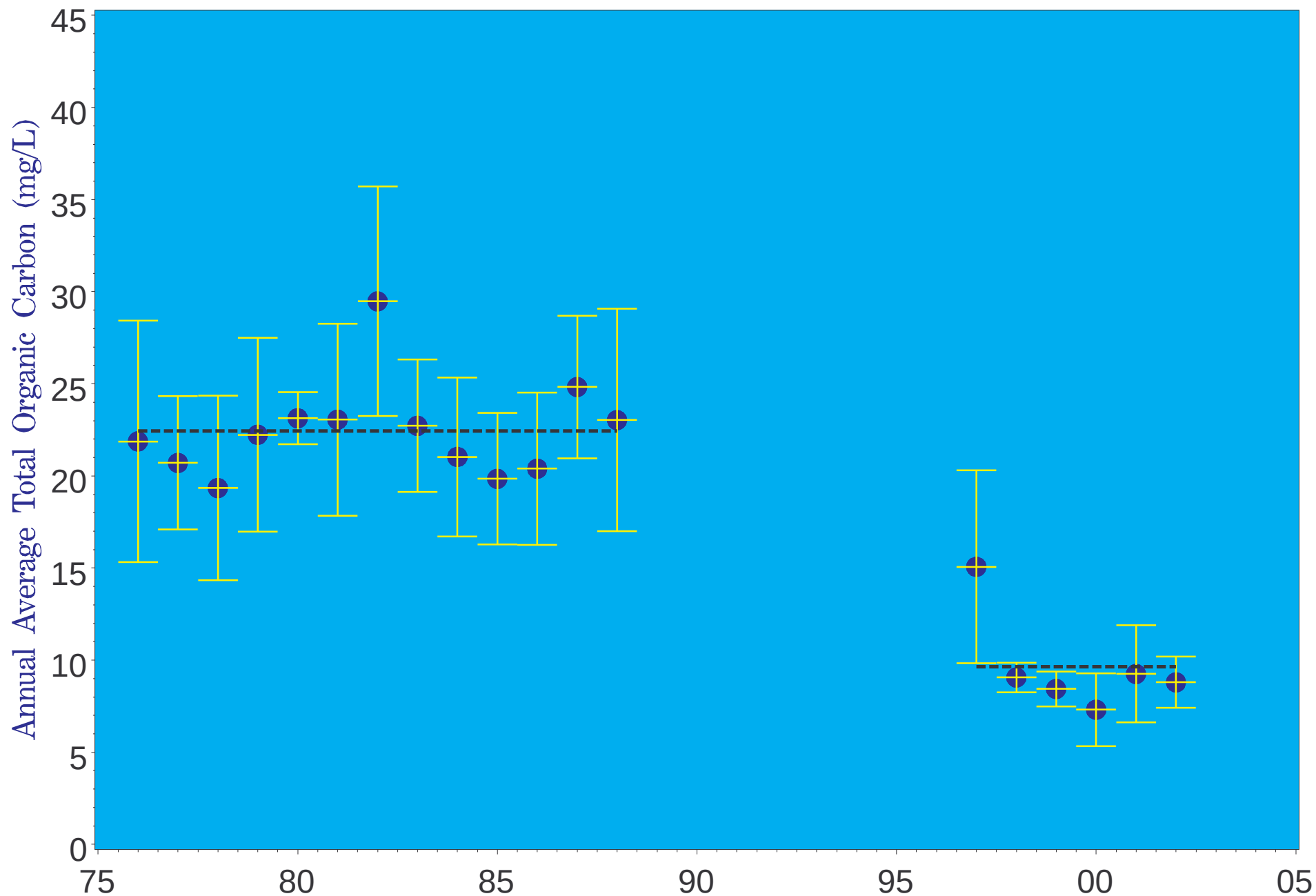


Figure 4.5.57 Long-term surface total organic carbon at river kilometer -2.4

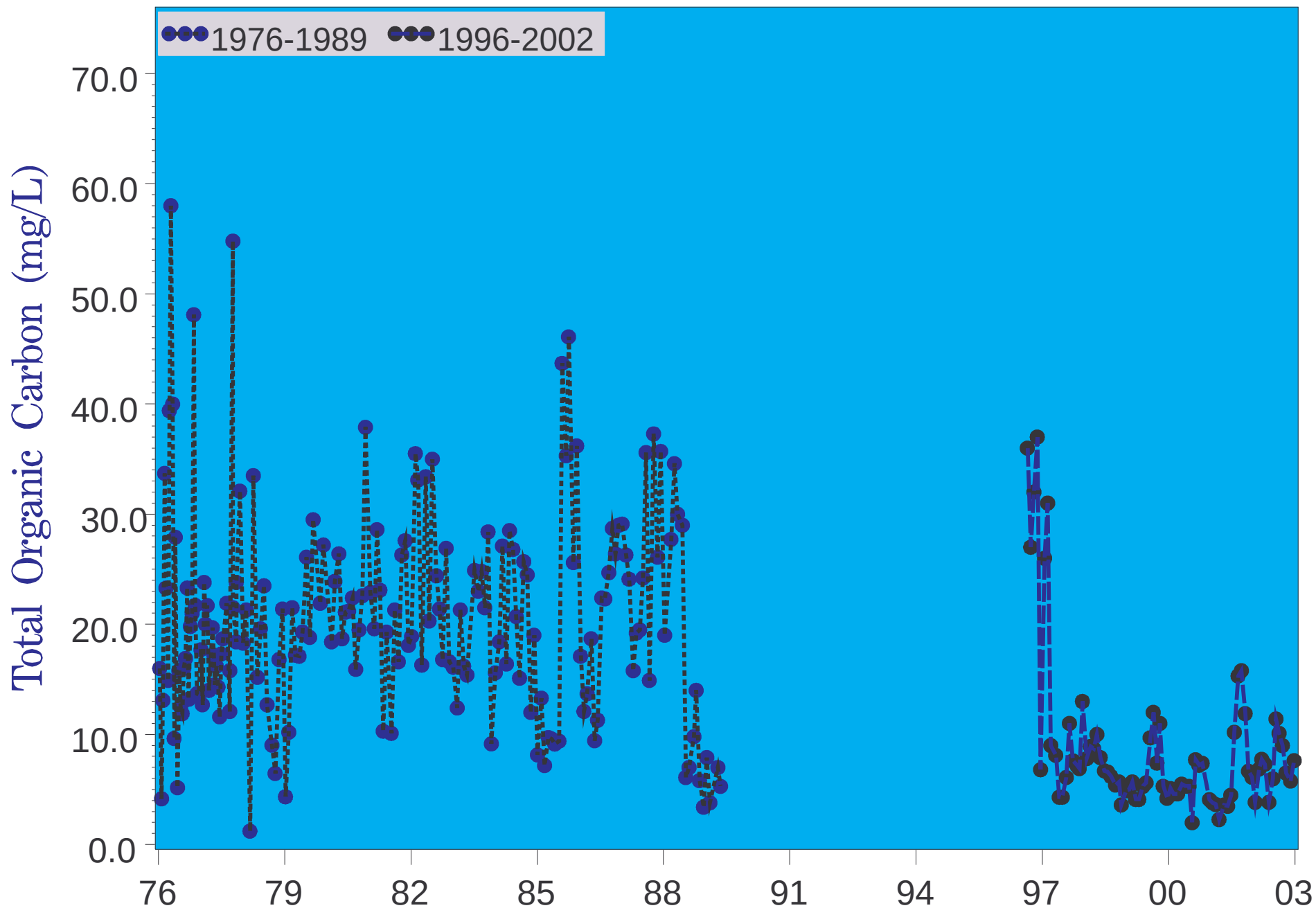


Figure 4.5.58 Long-term bottom total organic carbon at river kilometer -2.4

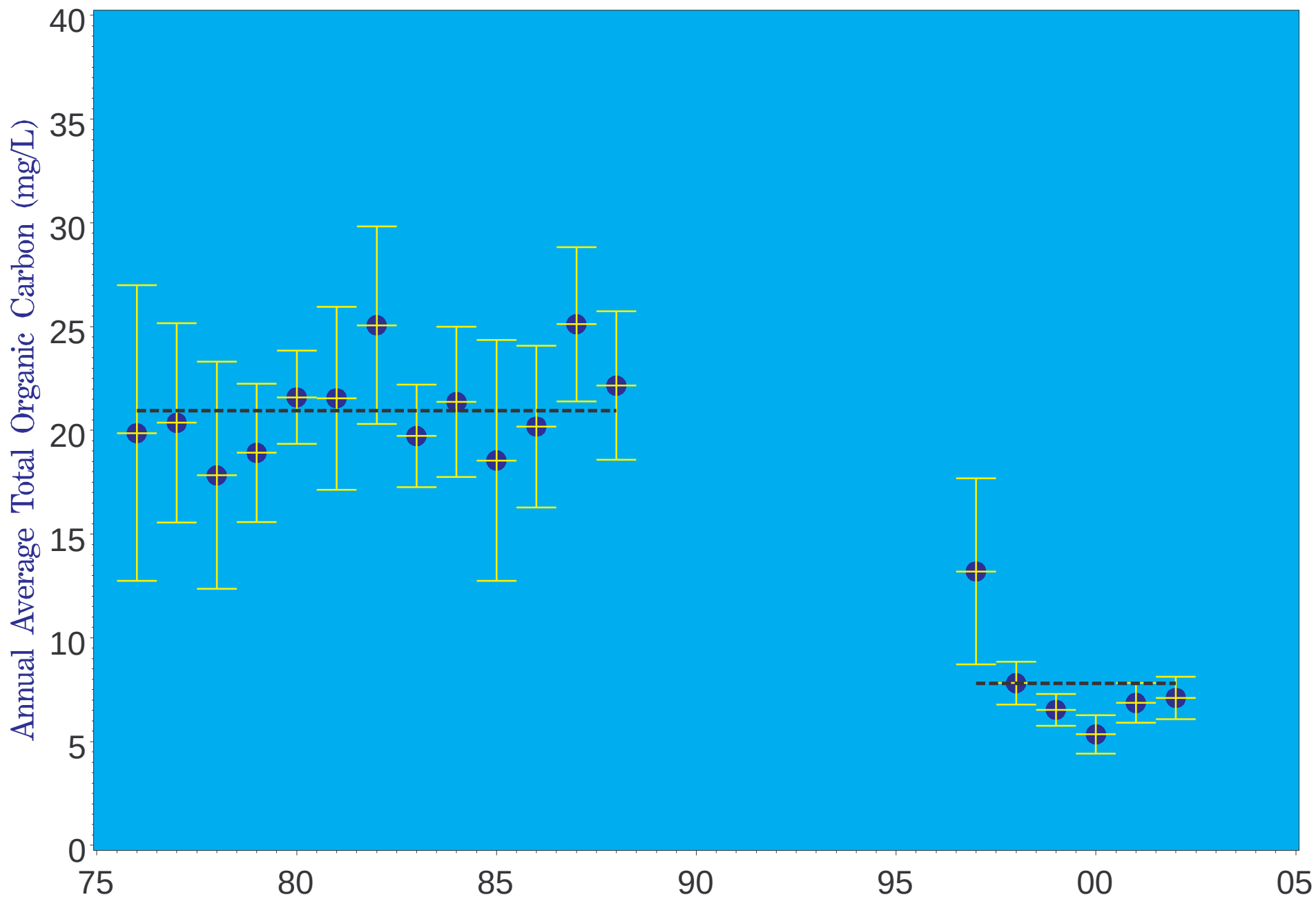


Figure 4.5.59 Long-term bottom total organic carbon at river kilometer -2.4

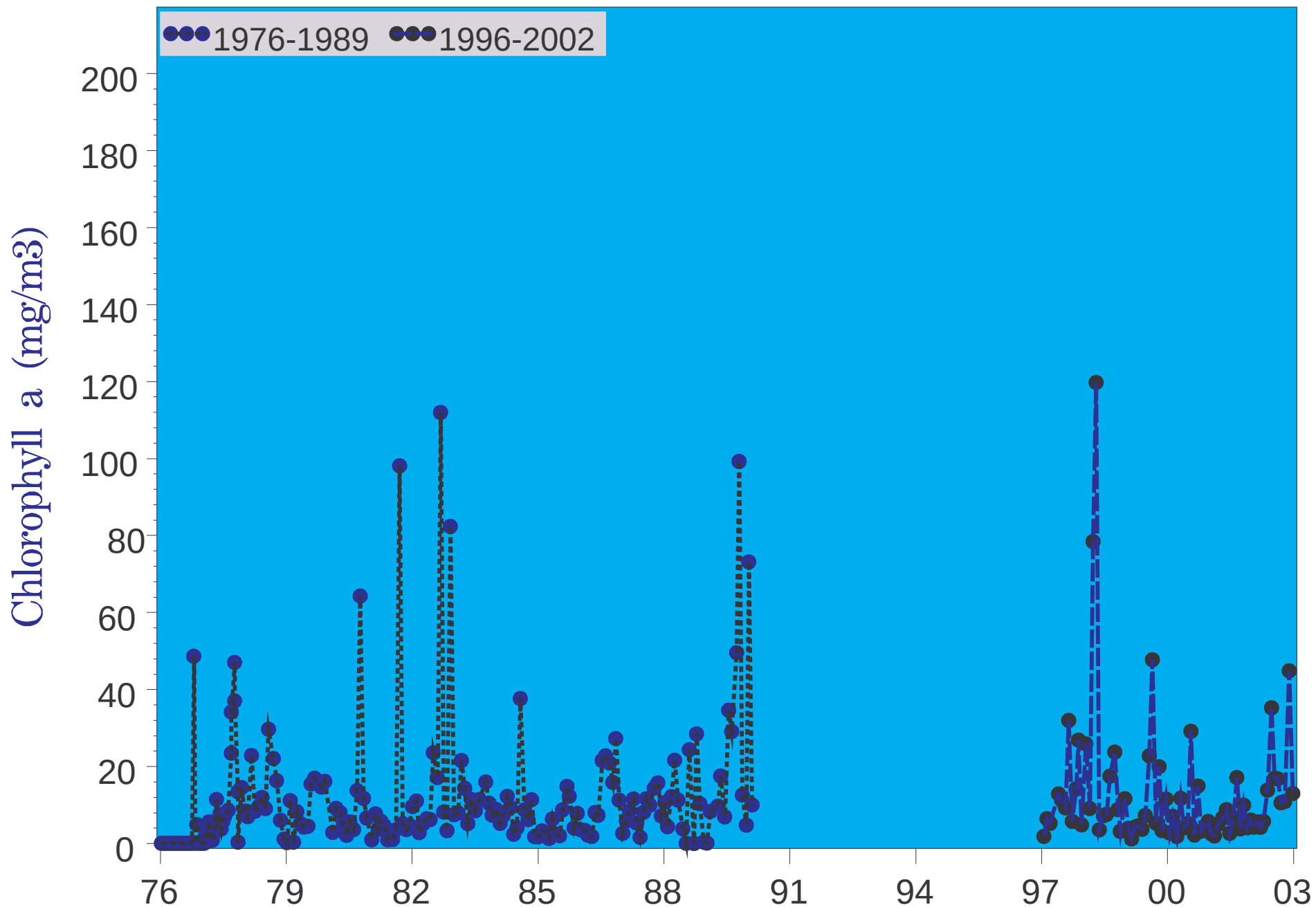


Figure 4.5.60 Long-term surface chlorophyll a at river kilometer -2.4

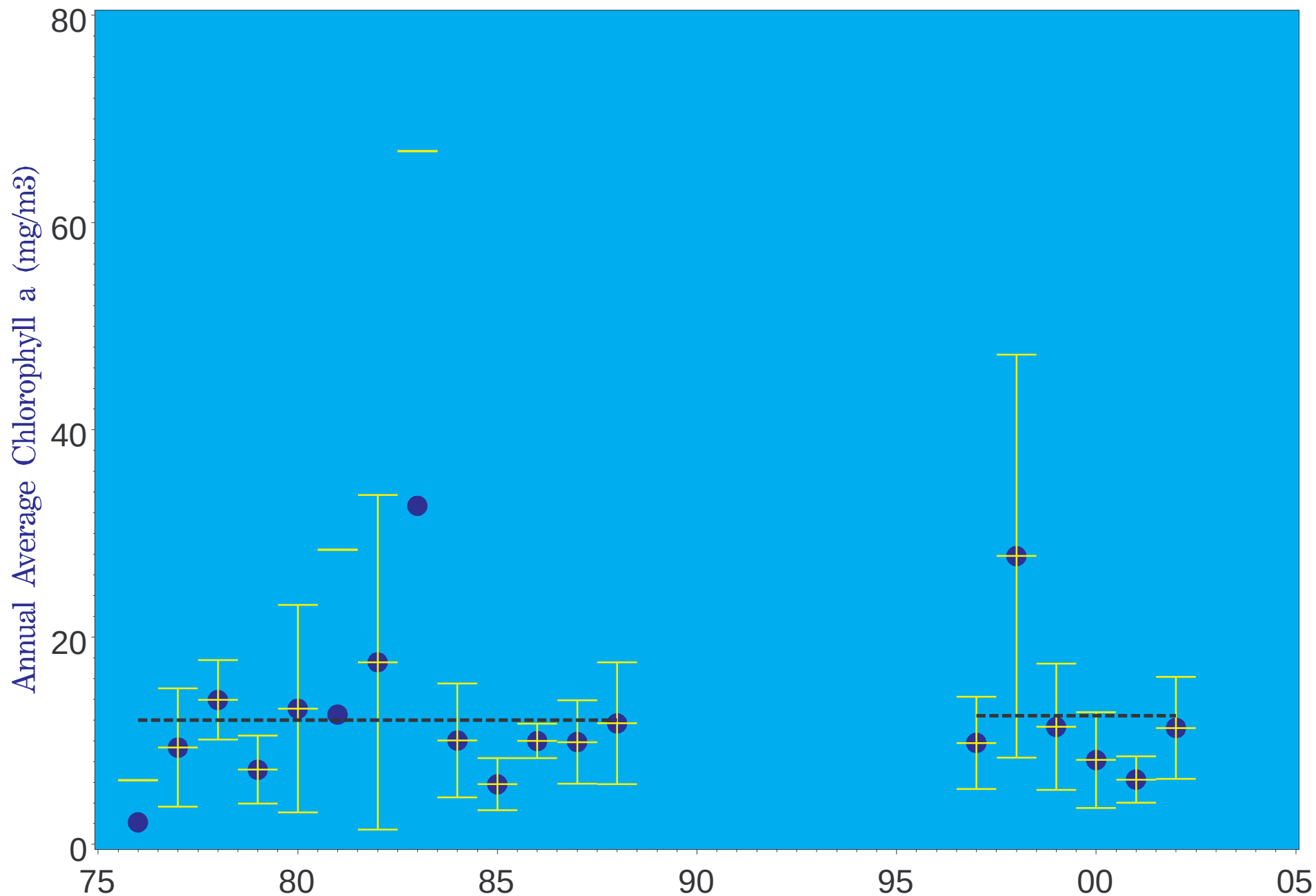


Figure 4.5.61 Long-term surface chlorophyll a at river kilometer -2.4

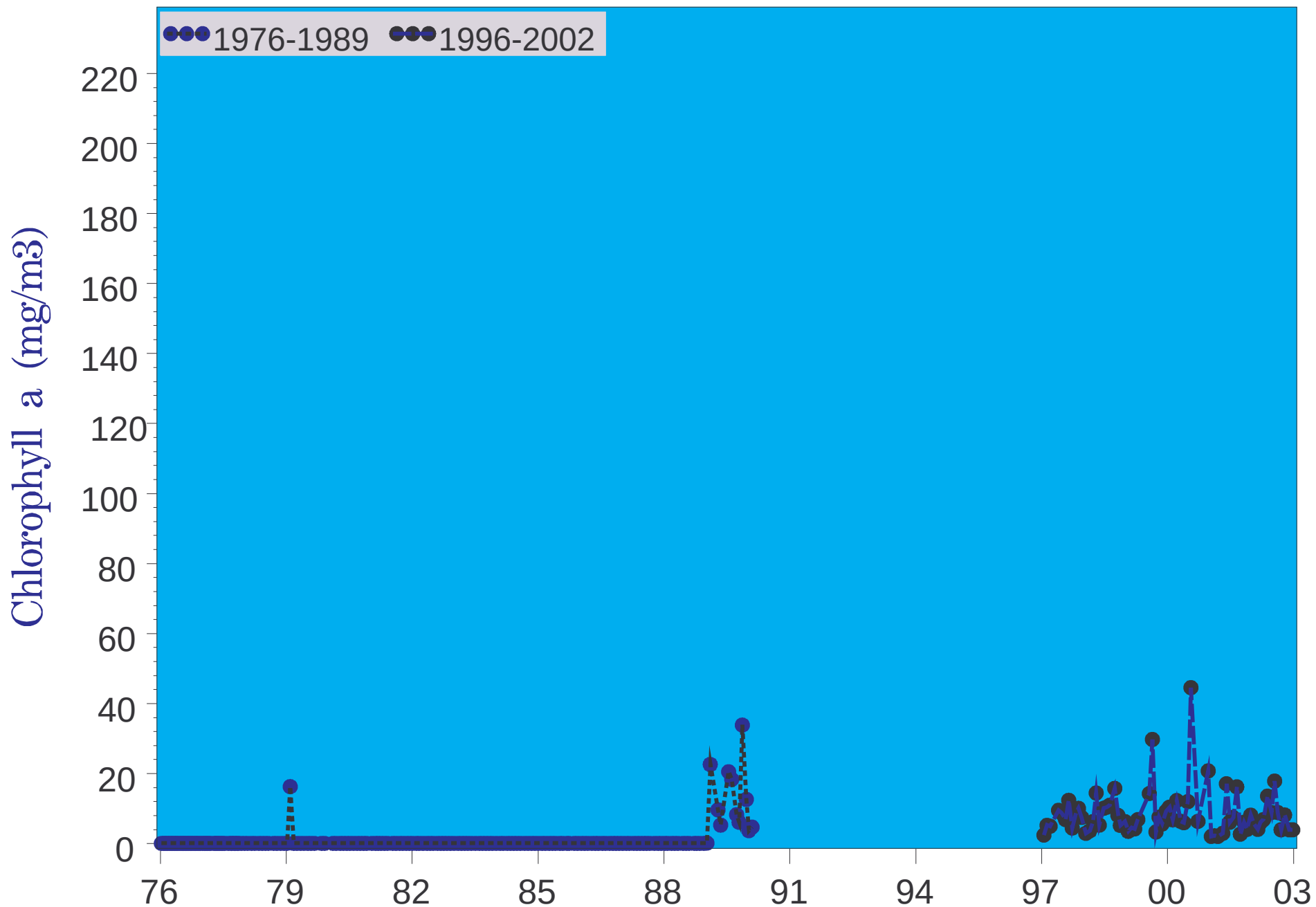


Figure 4.5.62 Long-term bottom chlorophyll a at river kilometer -2.4

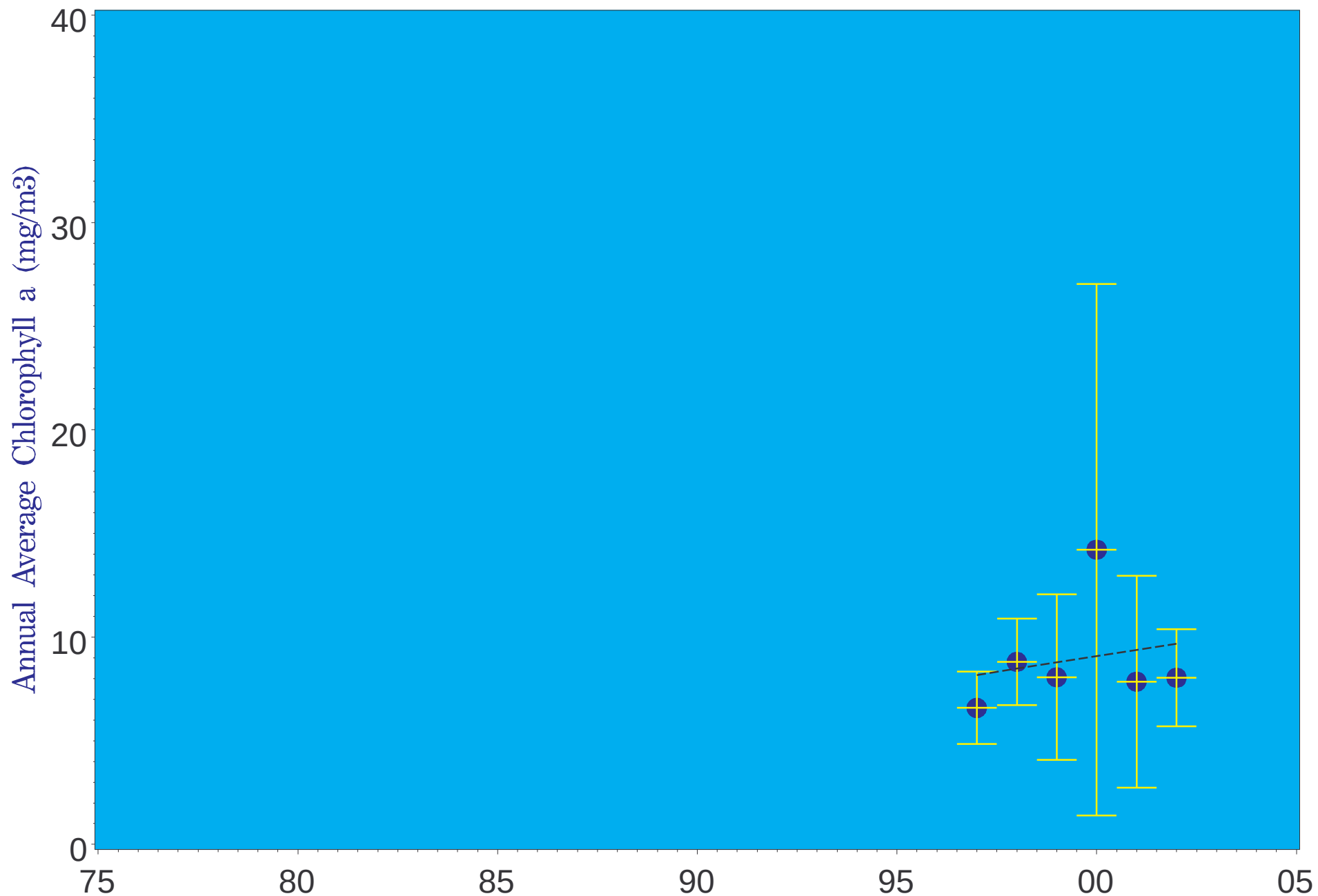


Figure 4.5.63 Long-term bottom chlorophyll a at river kilometer -2.4

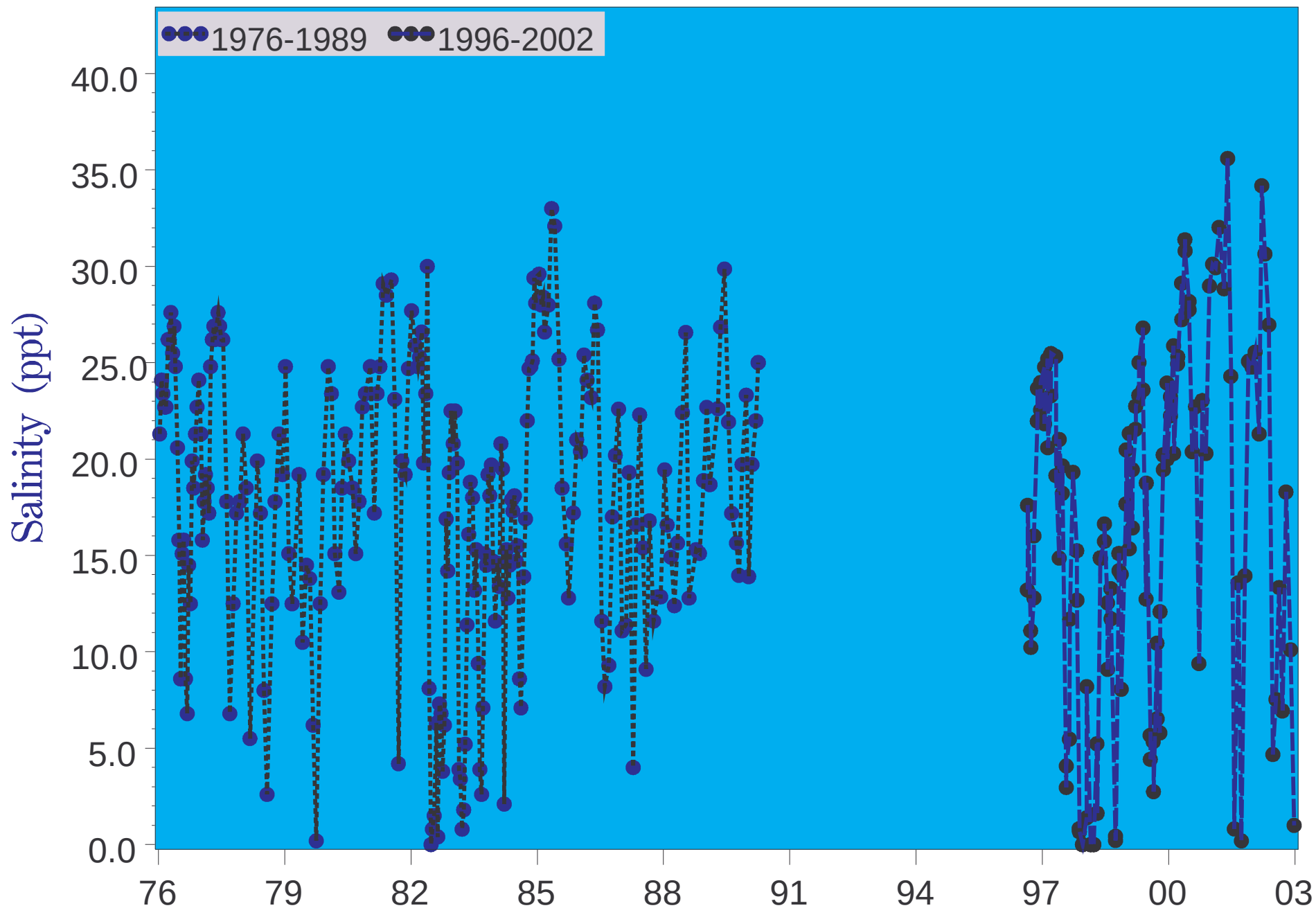


Figure 4.5.64 Long-term surface salinity at river kilometer 6.6



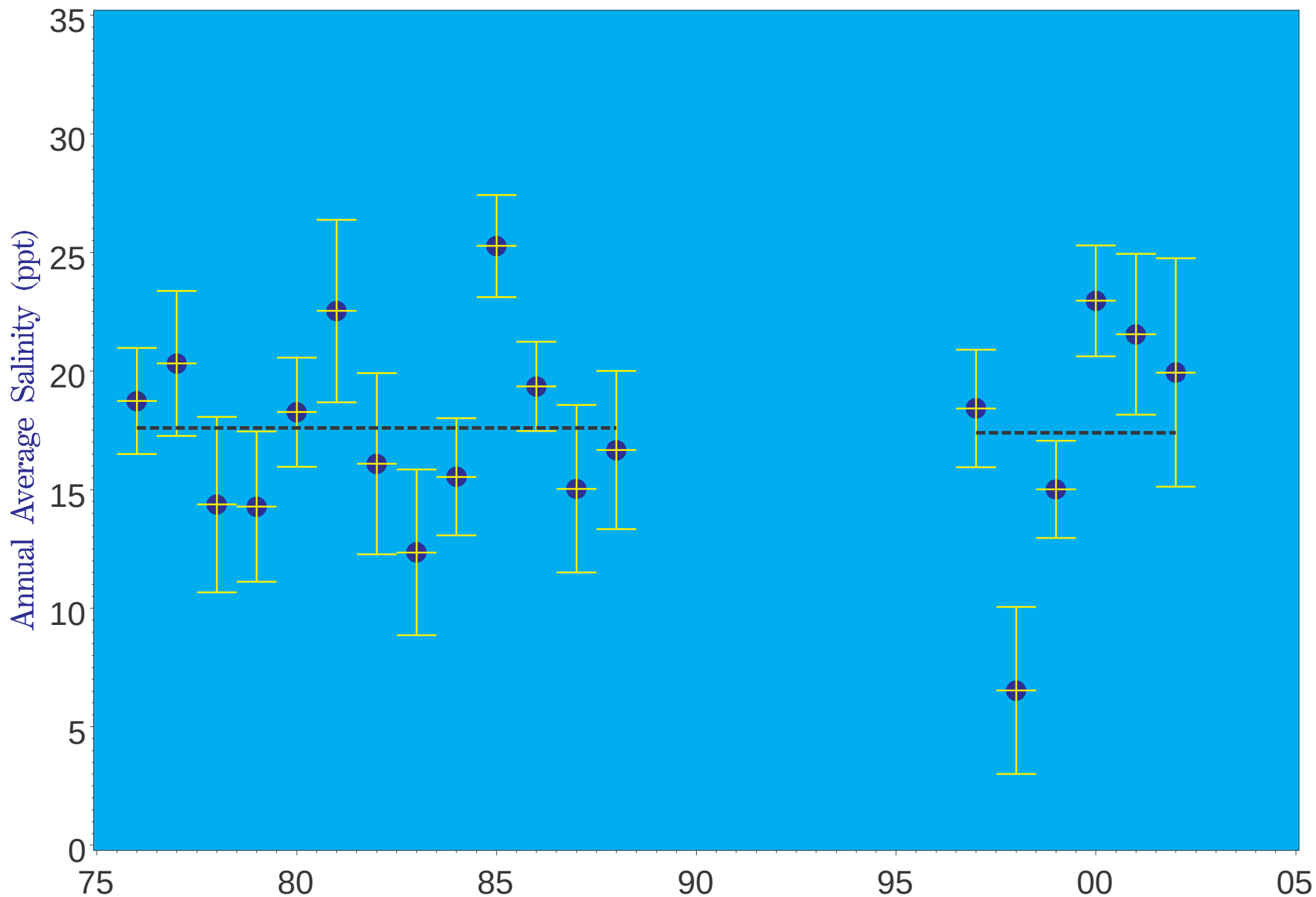


Figure 4.5.65 Long-term surface salinity at river kilometer 6.6

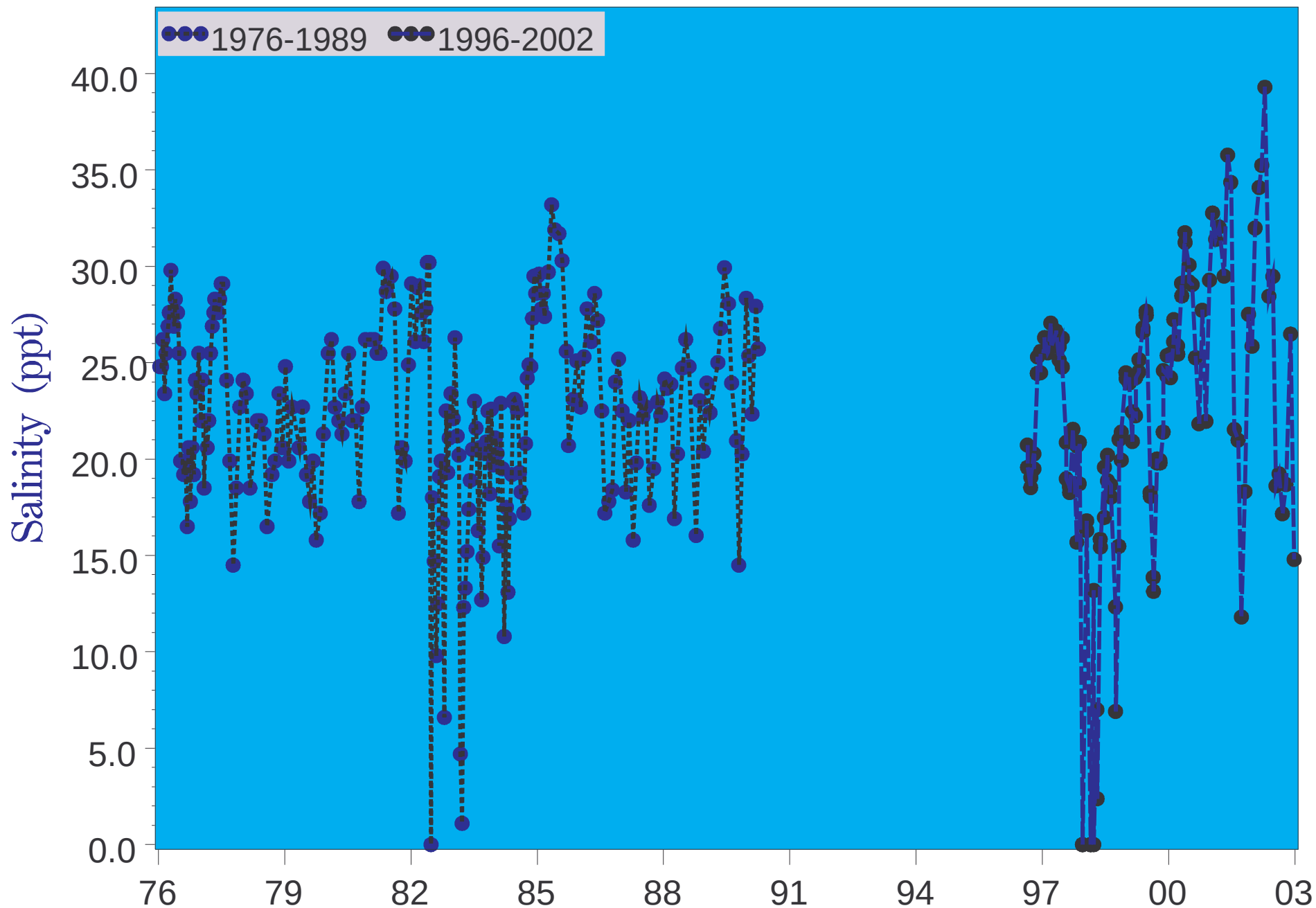


Figure 4.5.66 Long-term bottom salinity at river kilometer 6.6

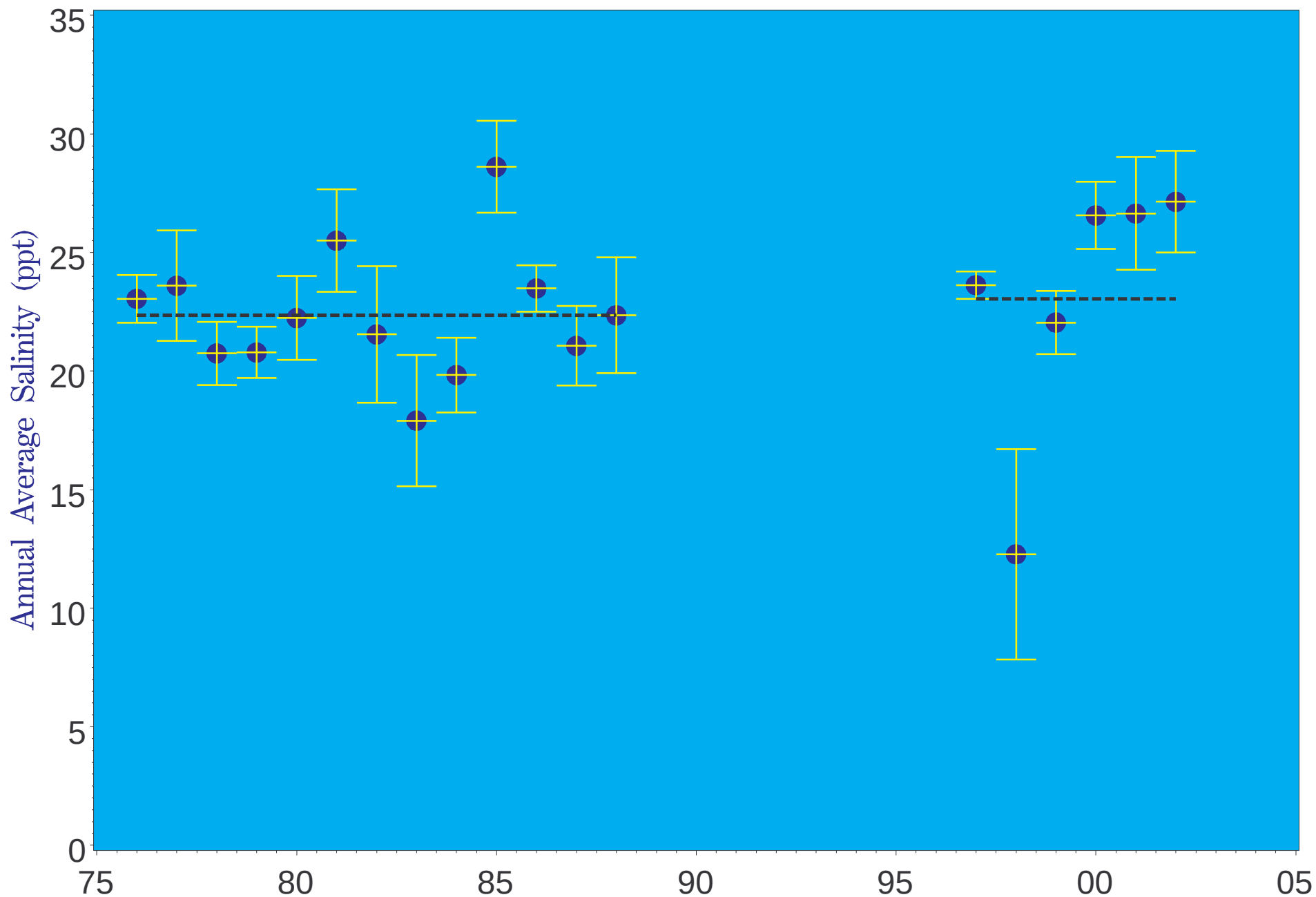


Figure 4.5.67 Long-term bottom salinity at river kilometer 6.6

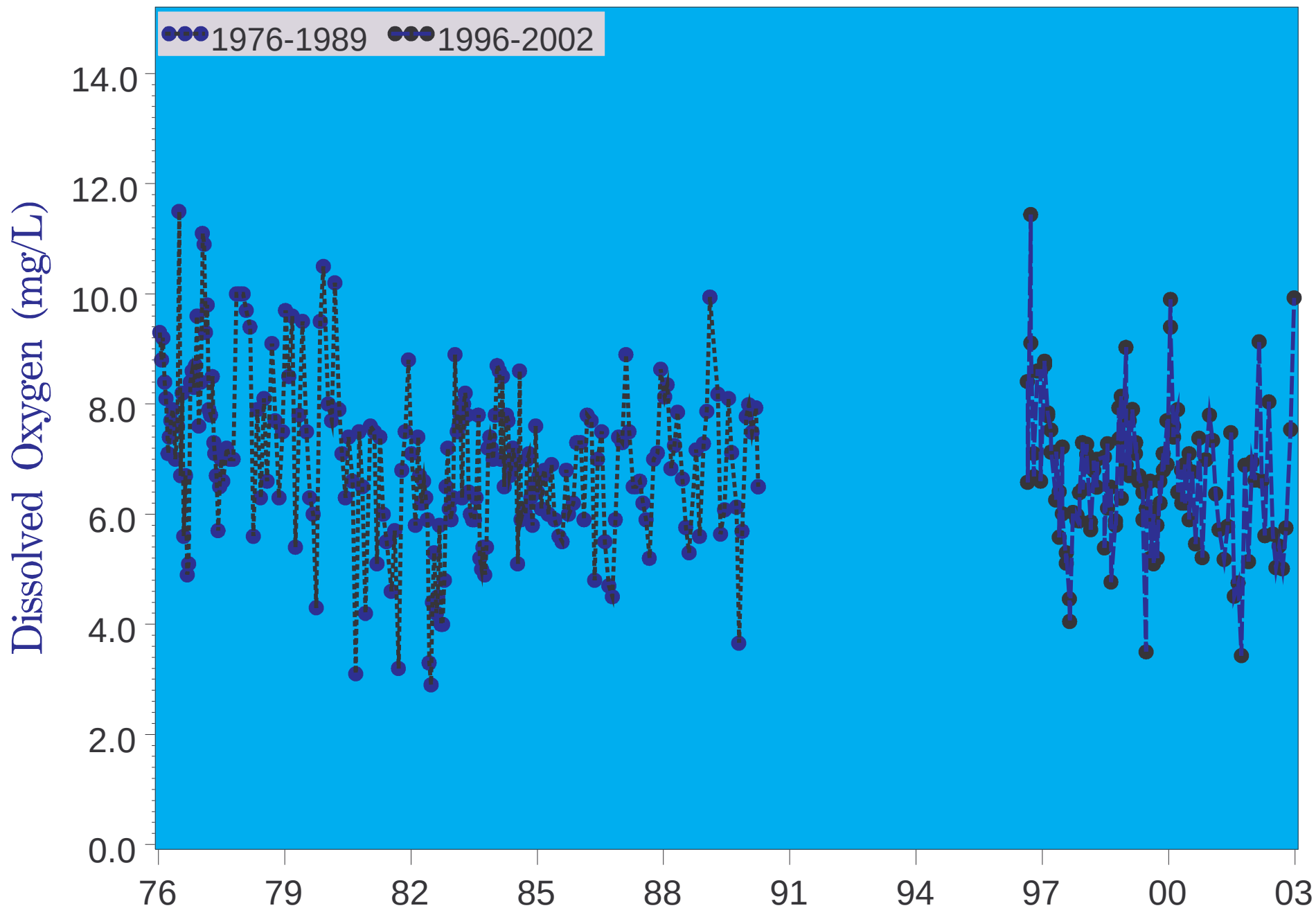


Figure 4.5.68 Long-term surface dissolved oxygen at river kilometer 6.6

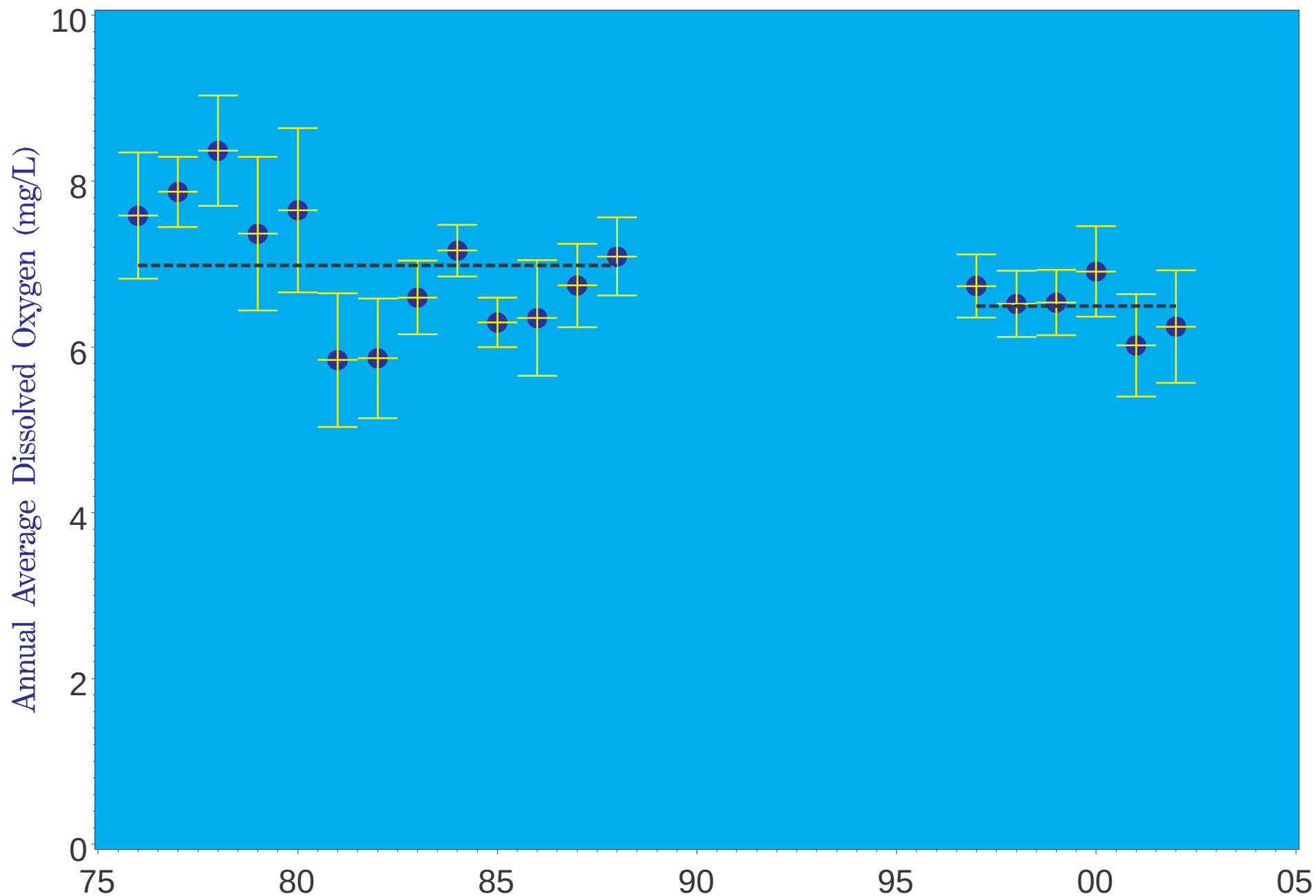


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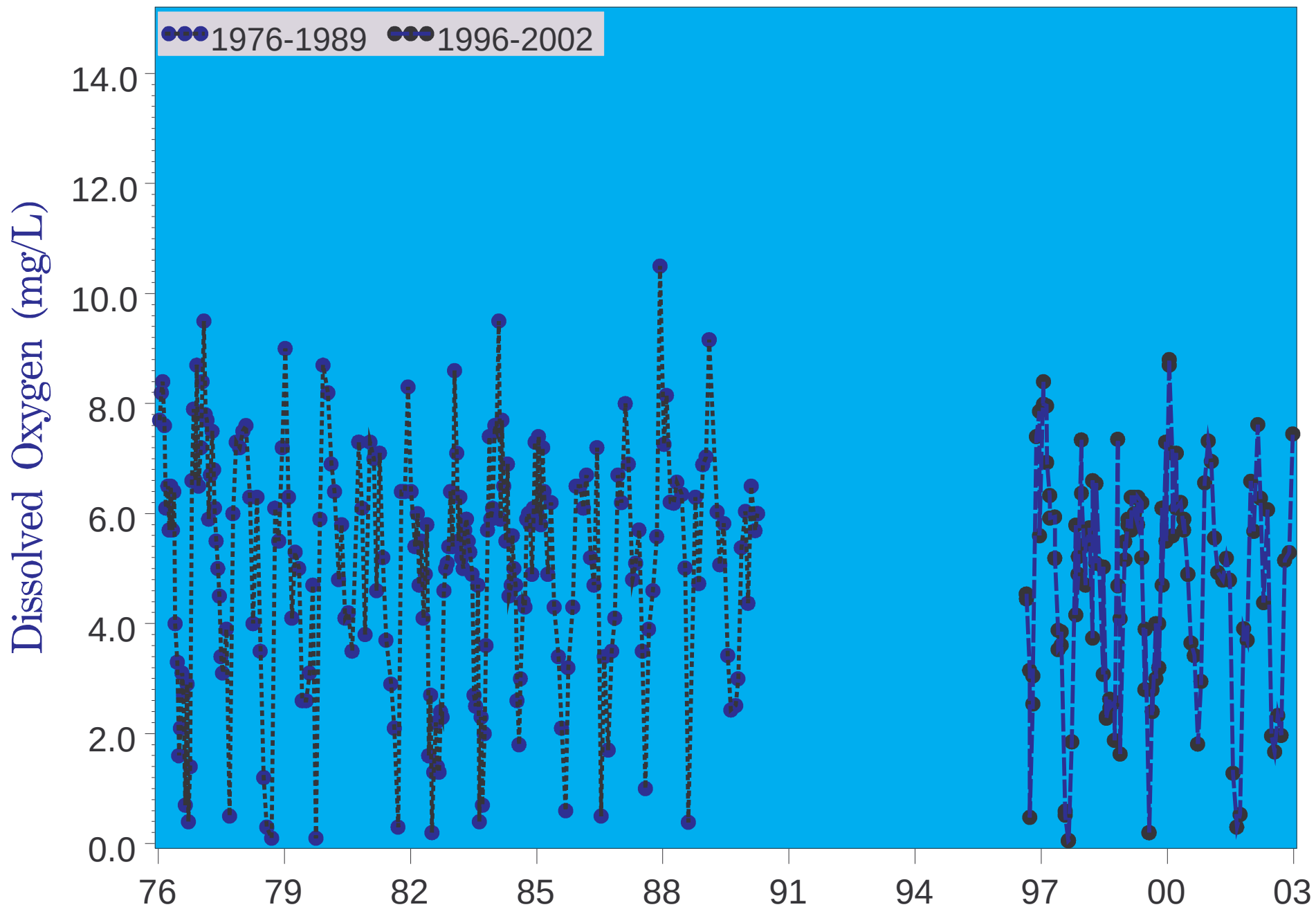


Figure 4.5.70 Long-term bottom dissolved oxygen at river kilometer 6.6

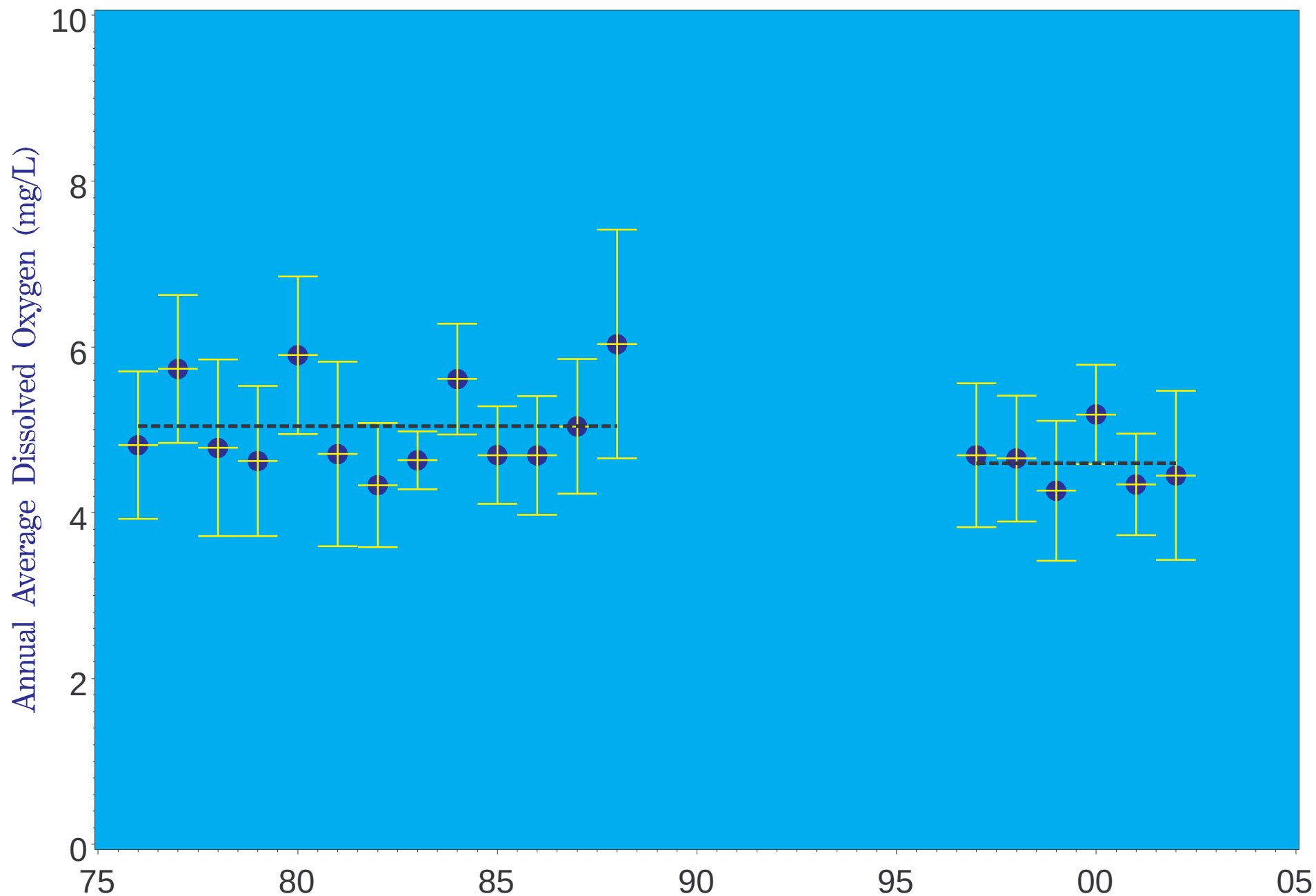


Figure 4.5.71 Long-term bottom dissolved oxygen at river kilometer 6.6

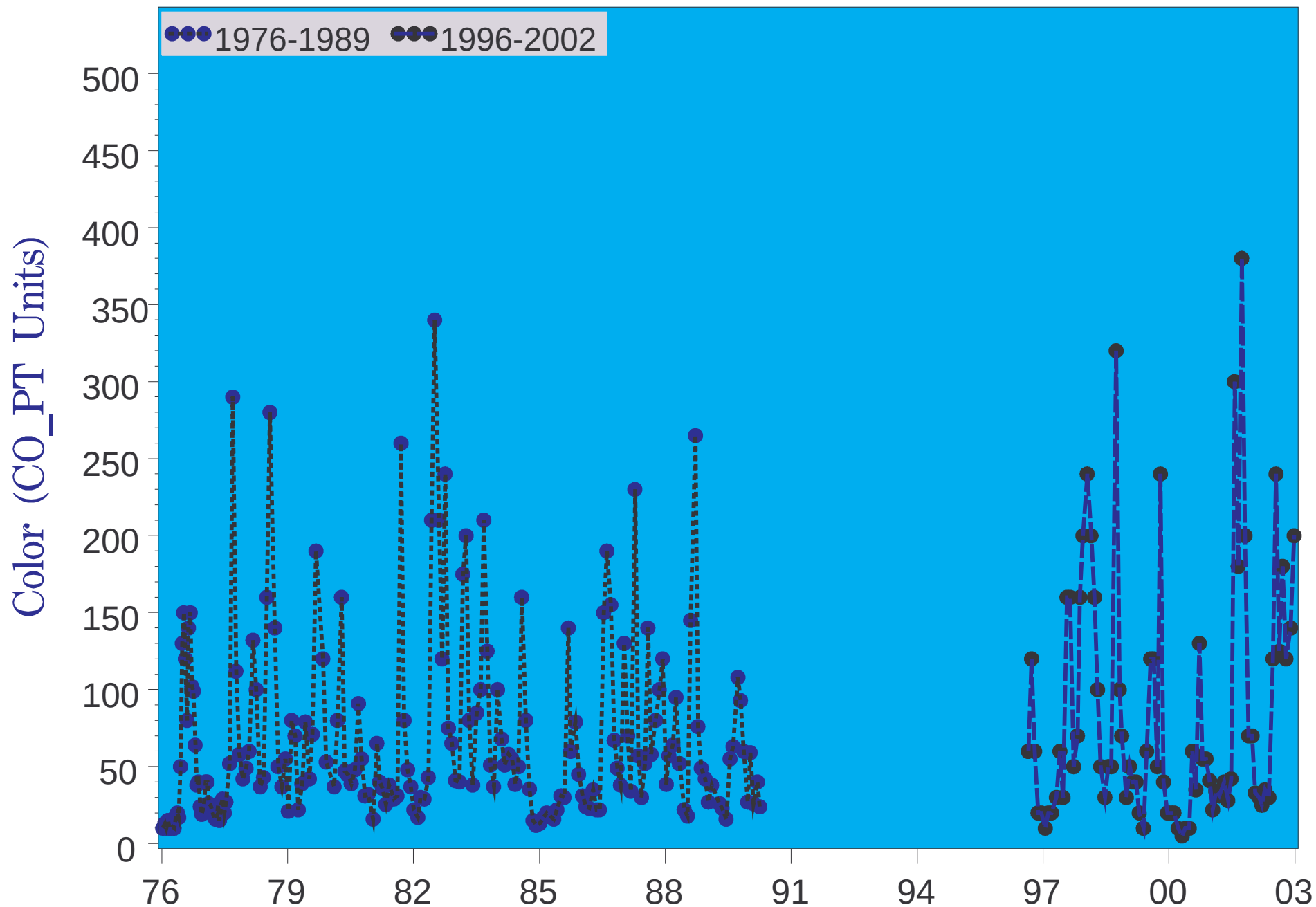


Figure 4.5.72 Long-term surface color at river kilometer 6.6



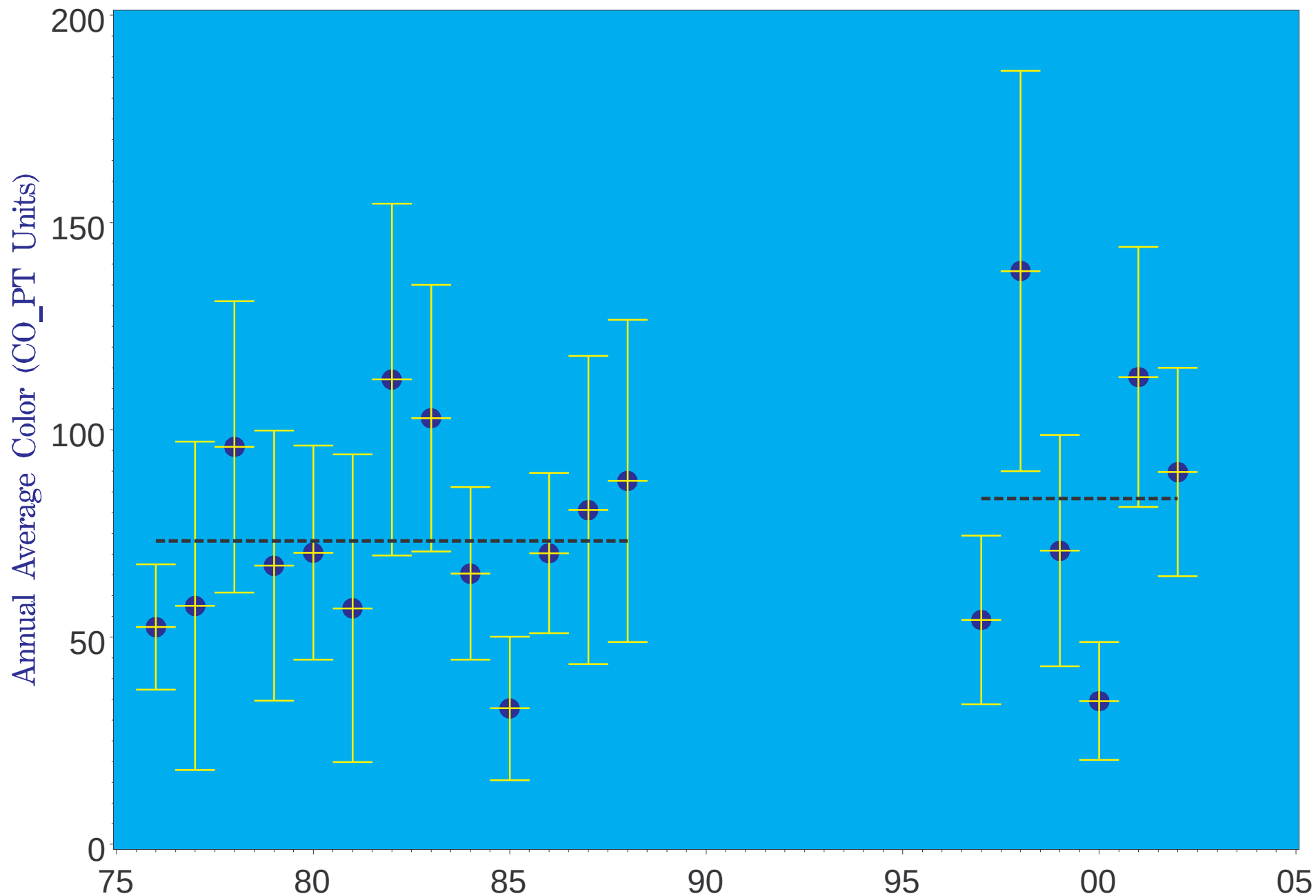


Figure 4.5.73 Long-term surface color at river kilometer 6.6

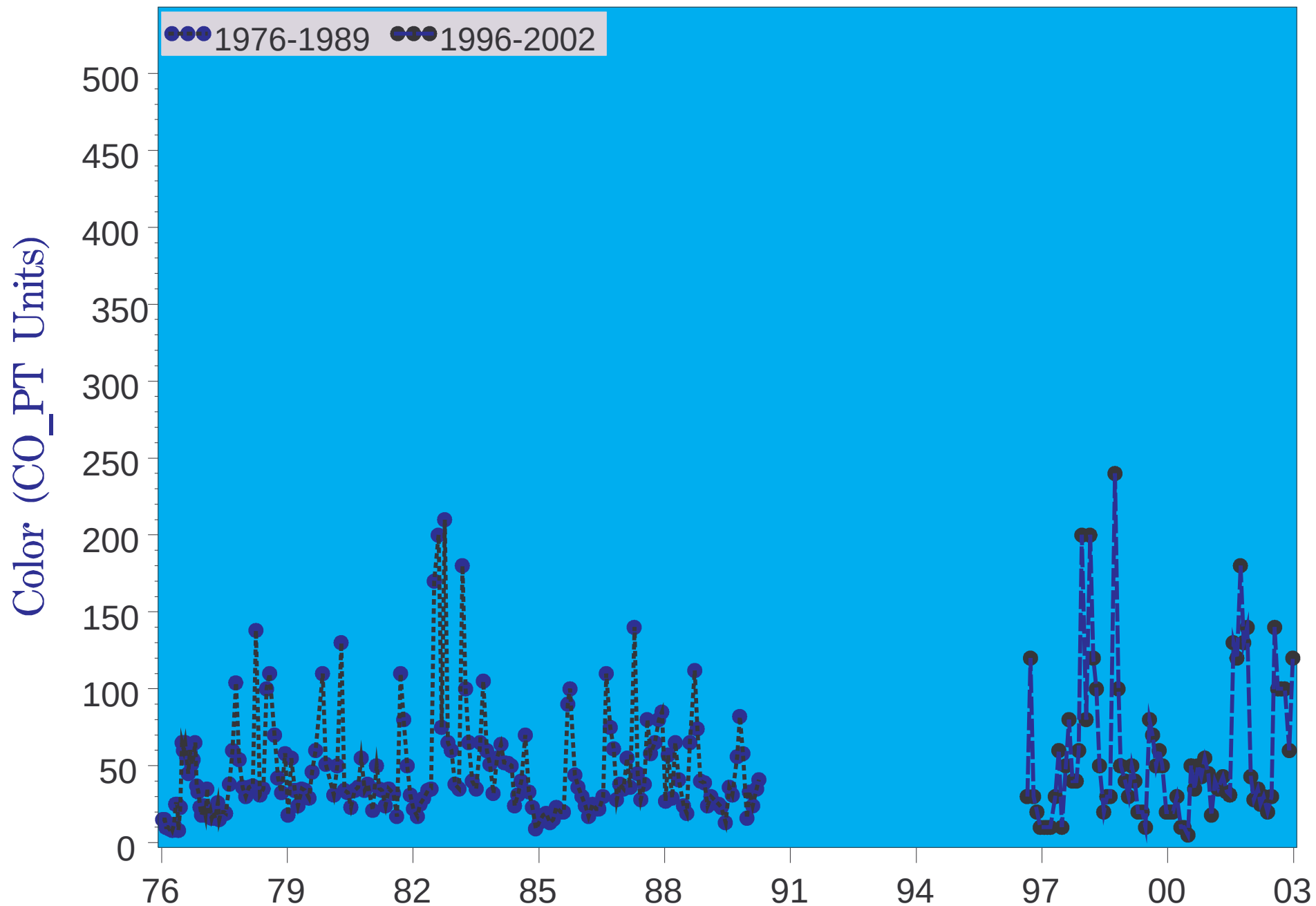


Figure 4.5.74 Long-term bottom color at river kilometer 6.6

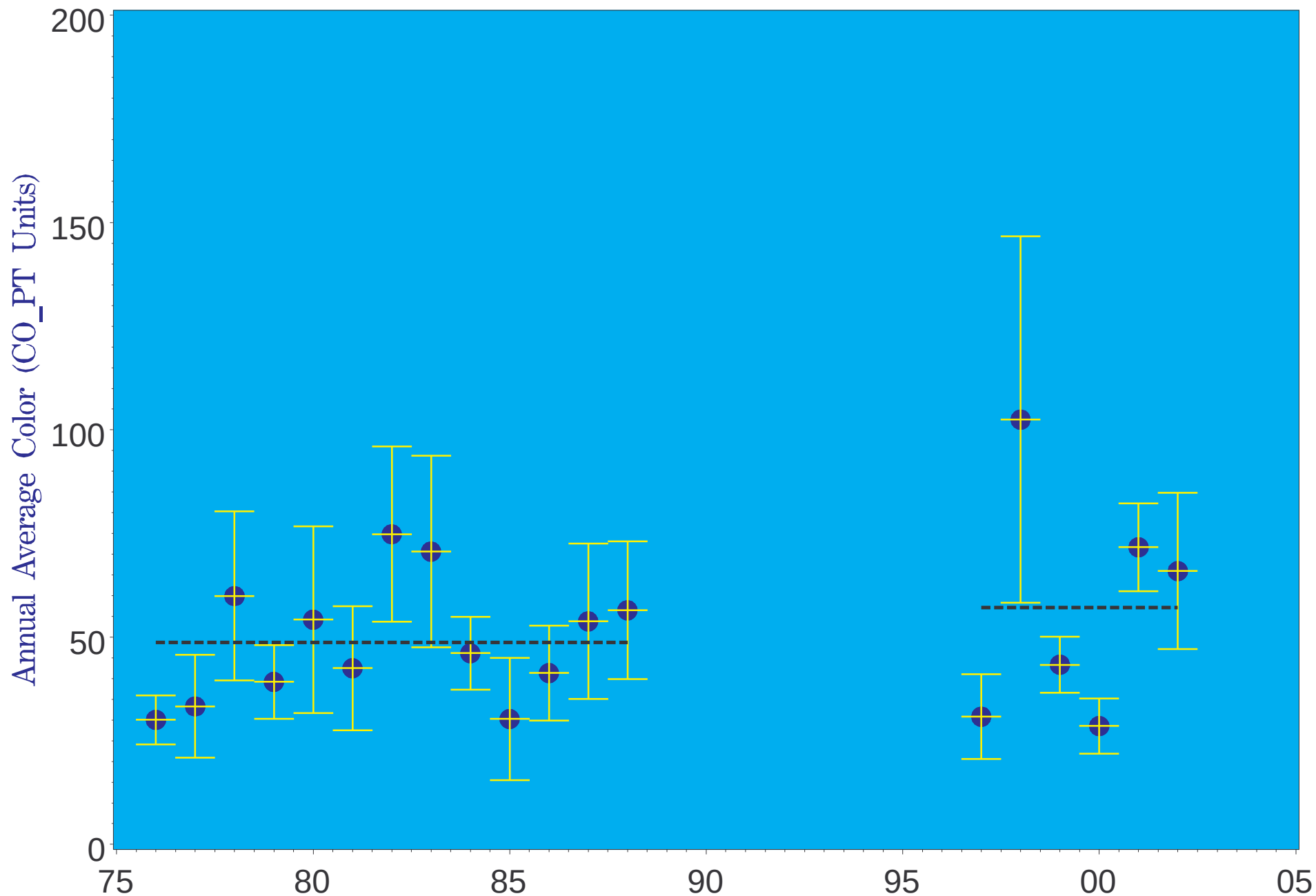


Figure 4.5.75 Long-term bottom color at river kilometer 6.6

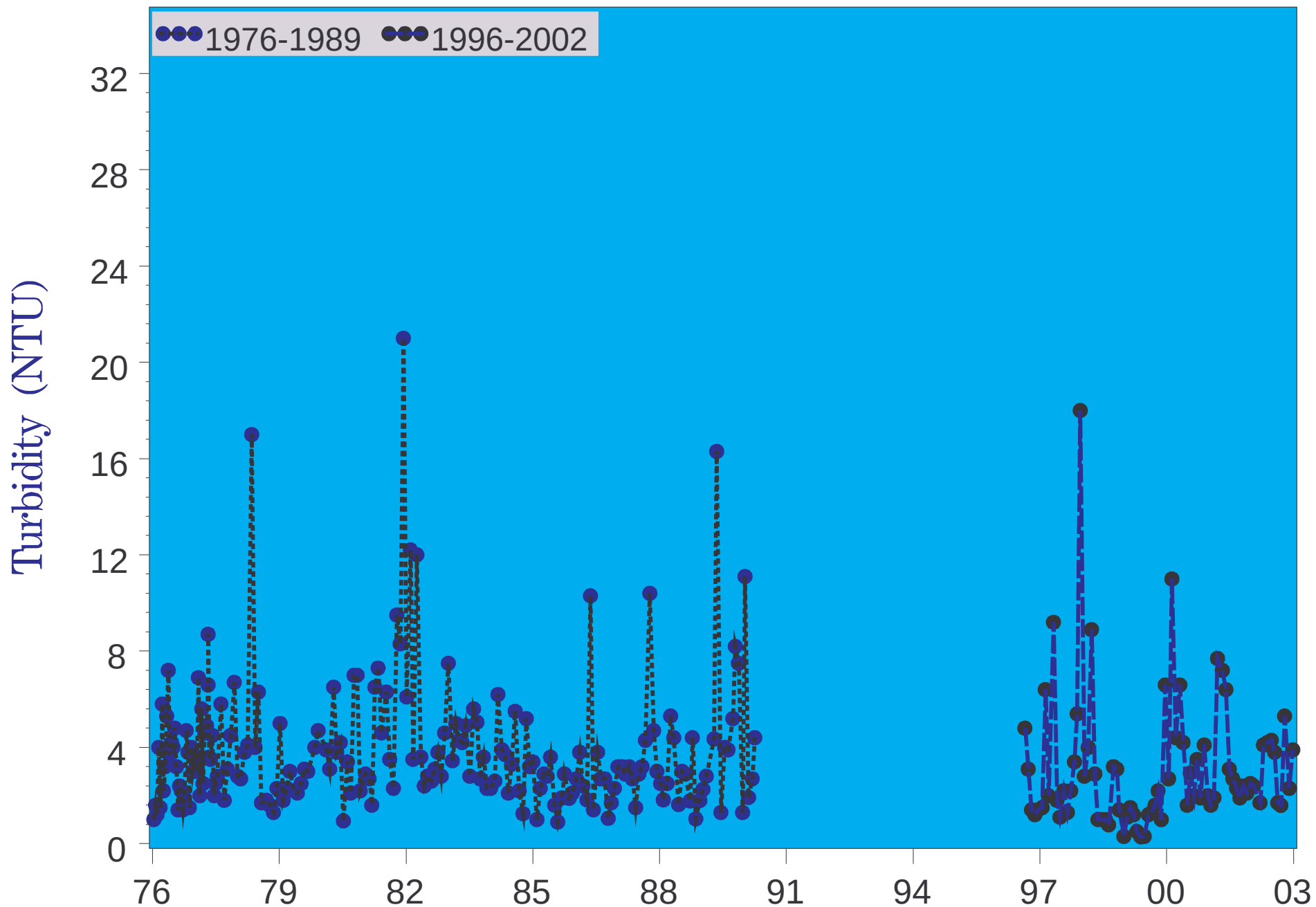


Figure 4.5.76 Long-term surface turbidity at river kilometer 6.6

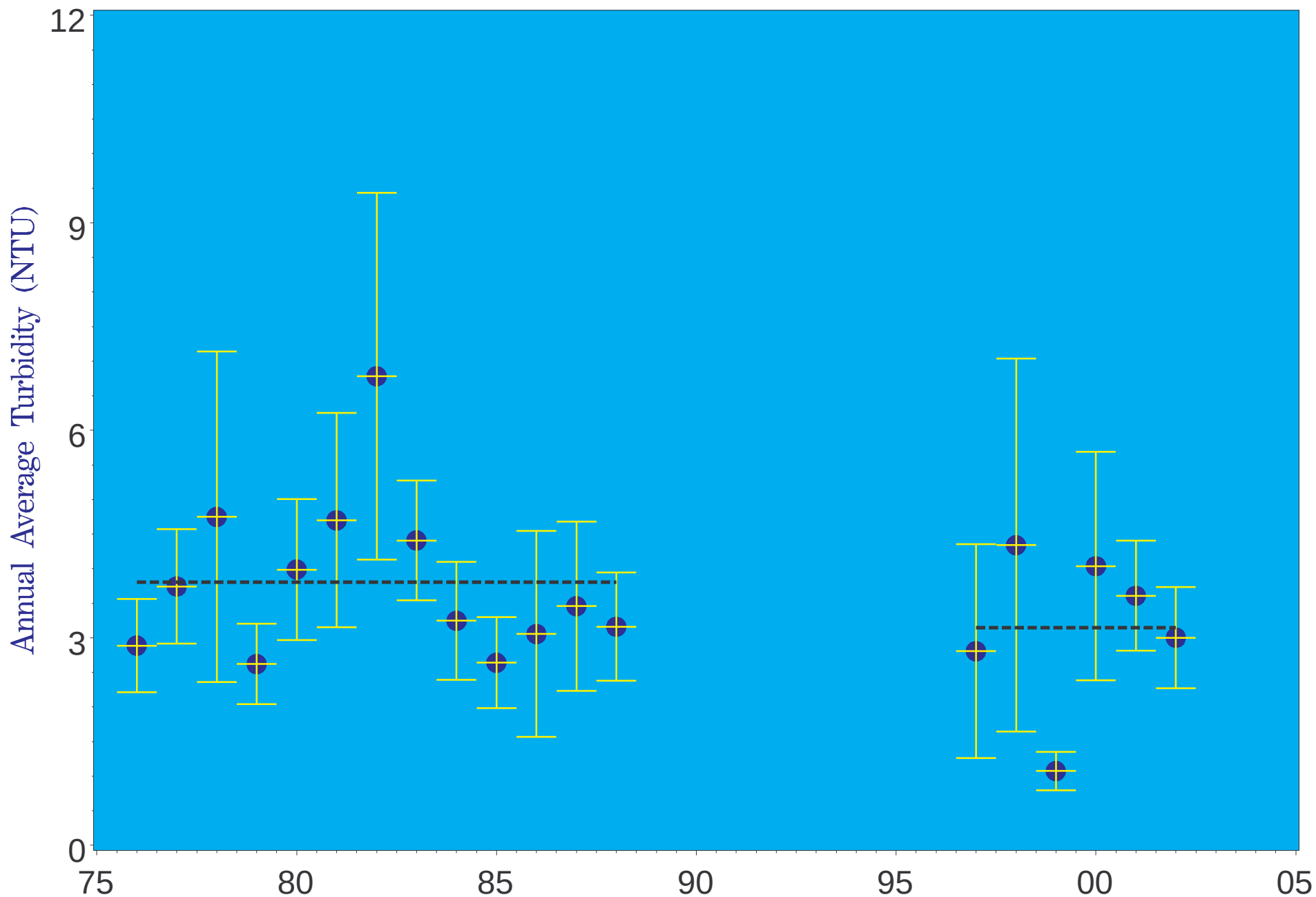


Figure 4.5.77 Long-term surface turbidity at river kilometer 6.6

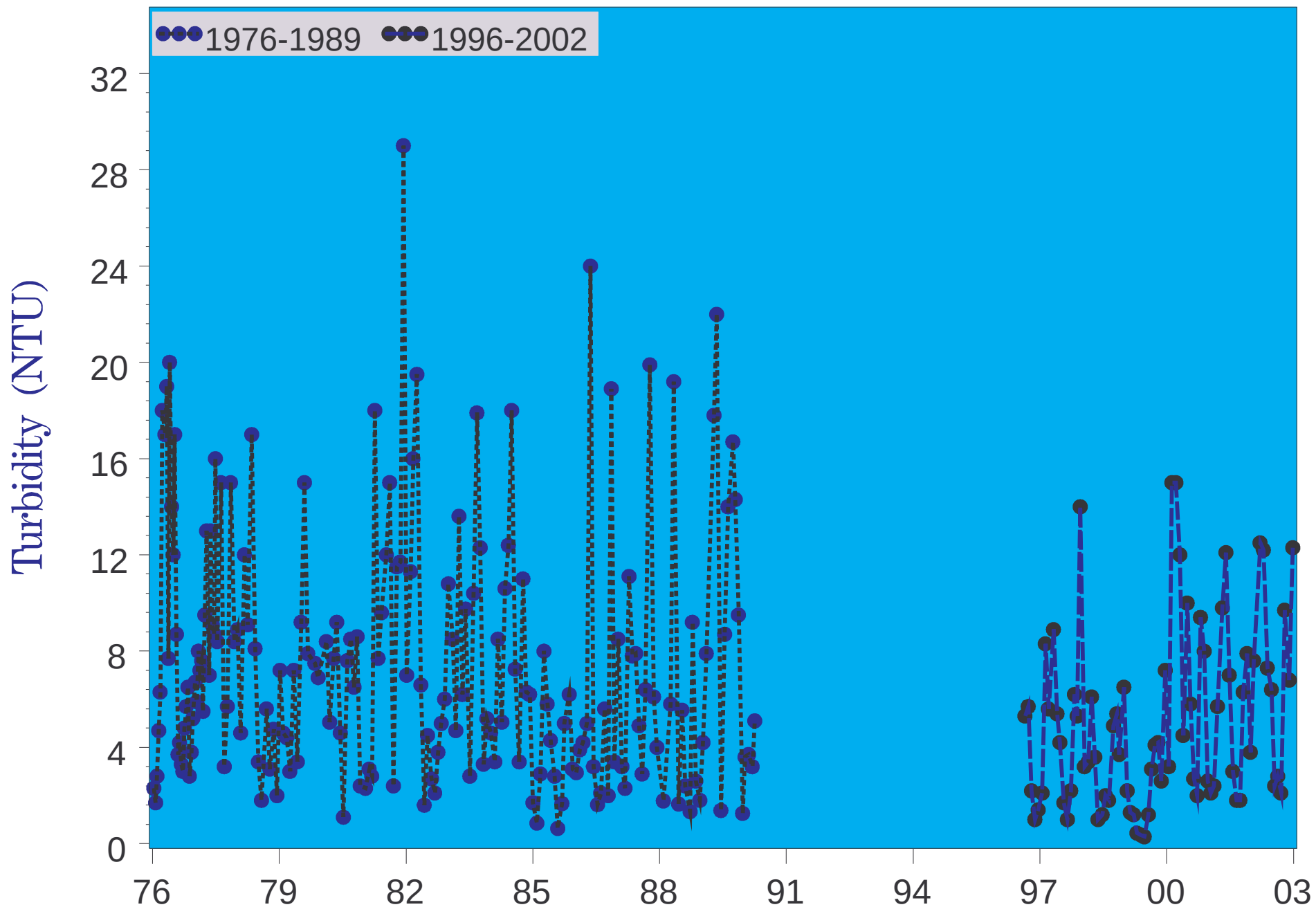


Figure 4.5.78 Long-term bottom turbidity at river kilometer 6.6

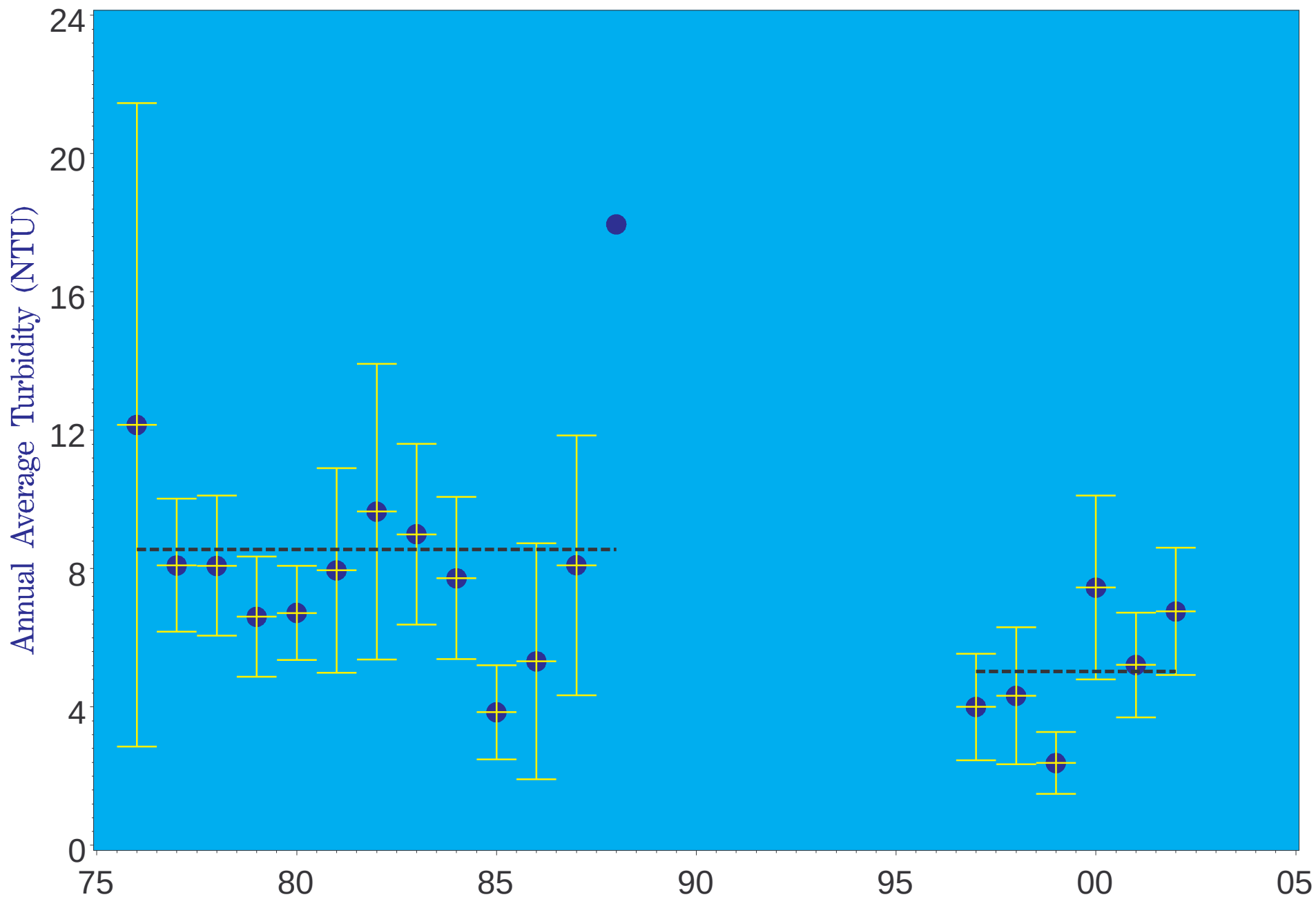


Figure 4.5.79 Long-term bottom turbidity at river kilometer 6.6

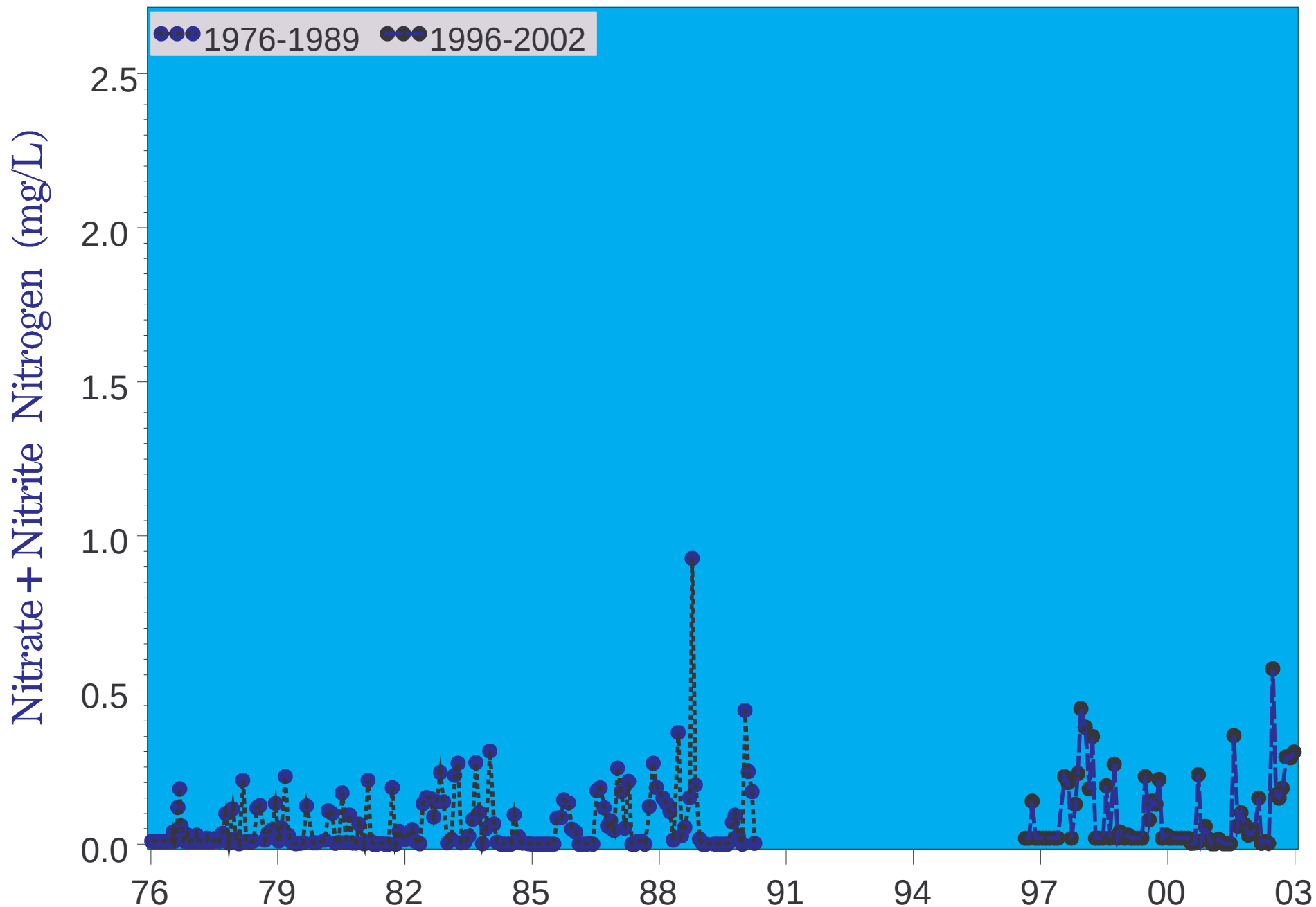


Figure 4.5.80 Long-term surface nitrate/nitrite nitrogen at river kilometer 6.6



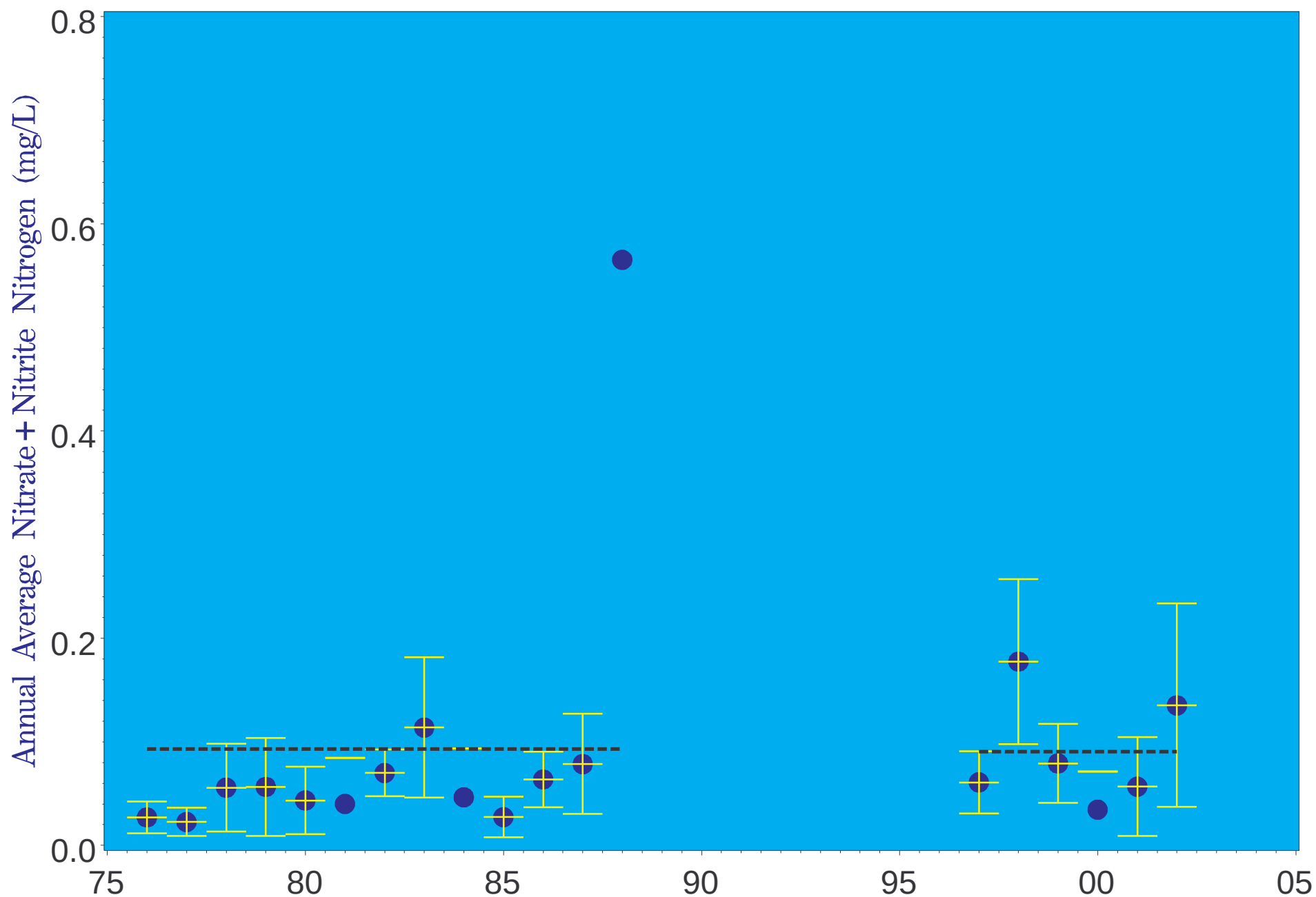


Figure 4.5.81 Long-term surface nitrate/nitrite nitrogen at river kilometer 6.6

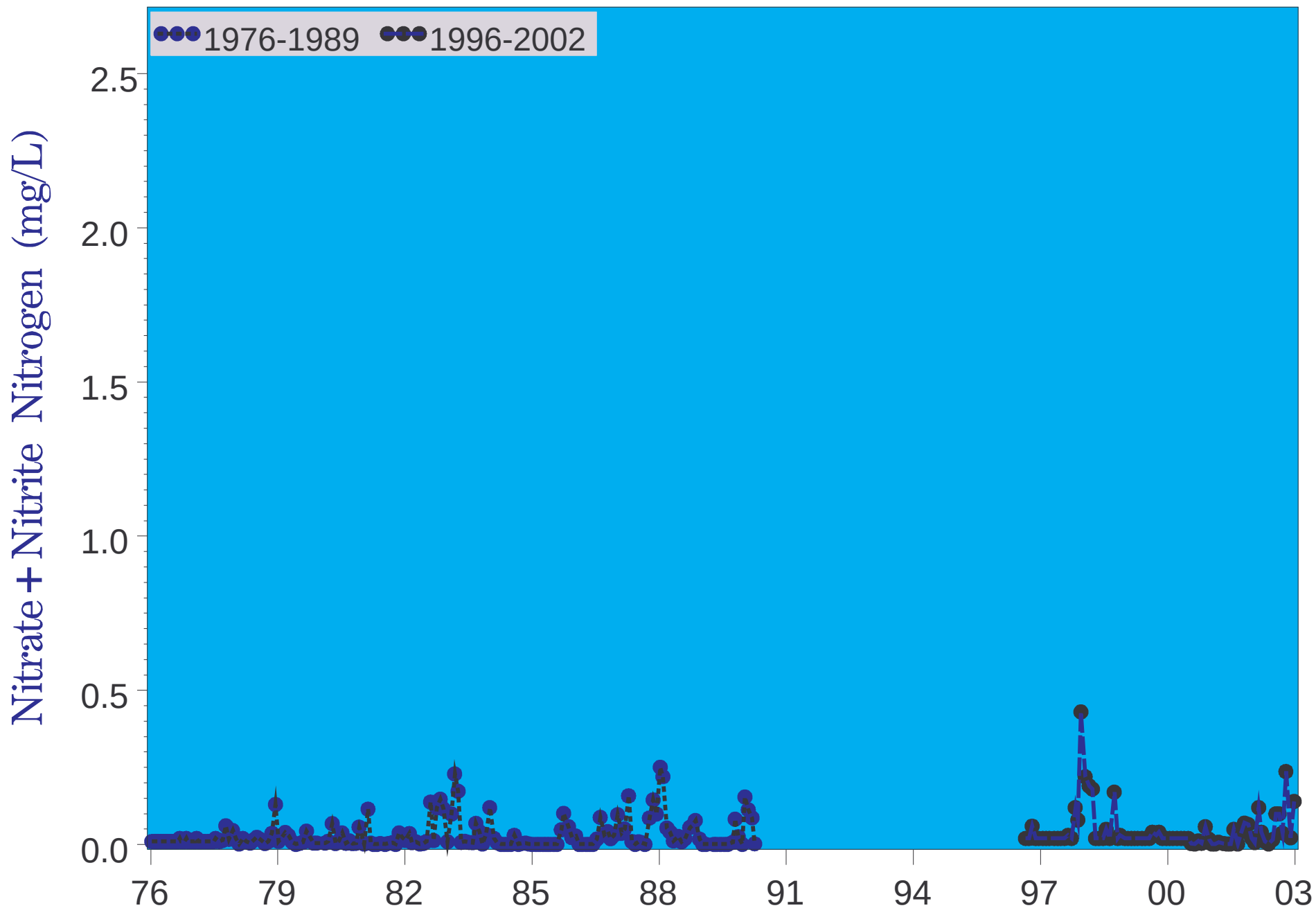


Figure 4.5.82 Long-term bottom nitrate/nitrite nitrogen at river kilometer 6.6

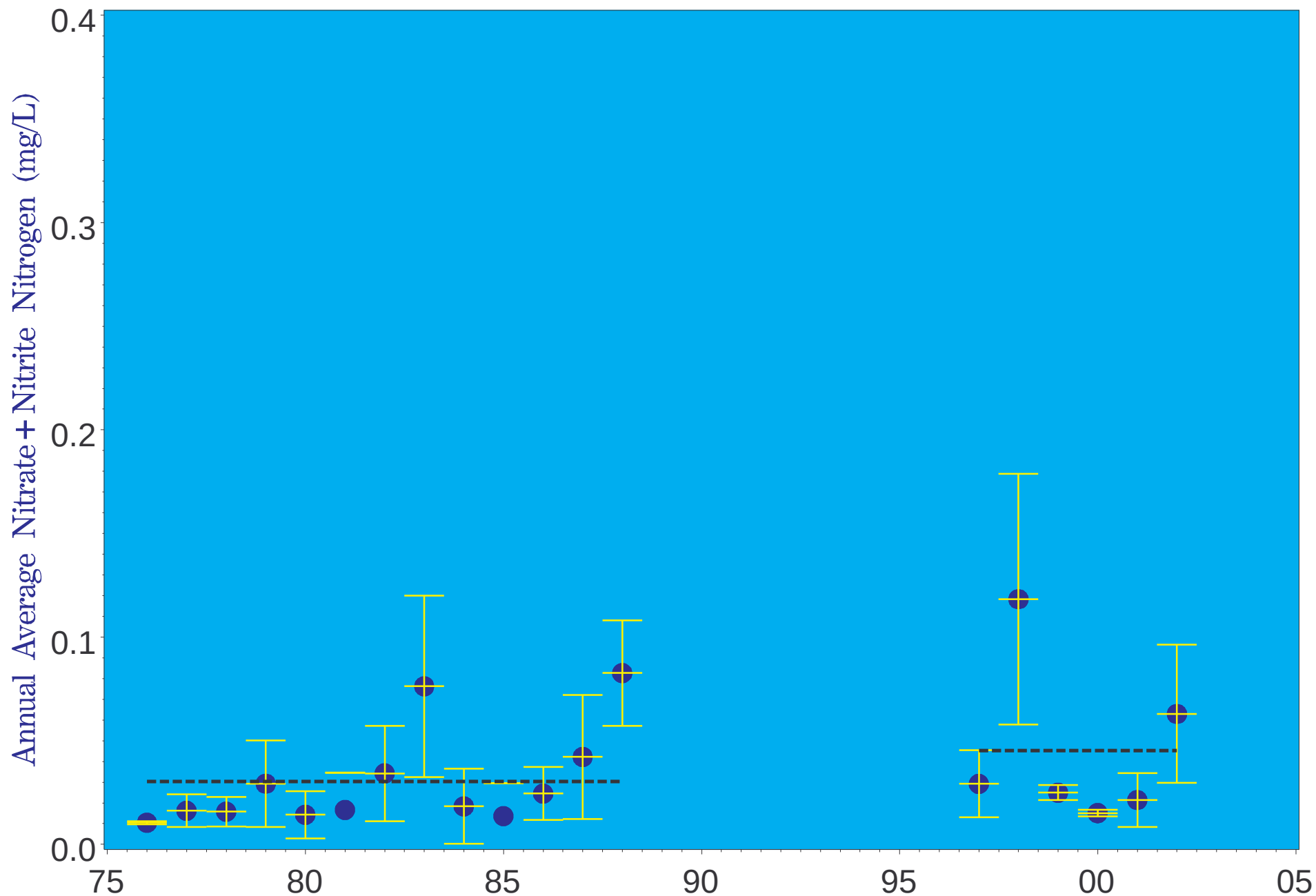


Figure 4.5.83 Long-term bottom nitrate/nitrite nitrogen at river kilometer 6.6

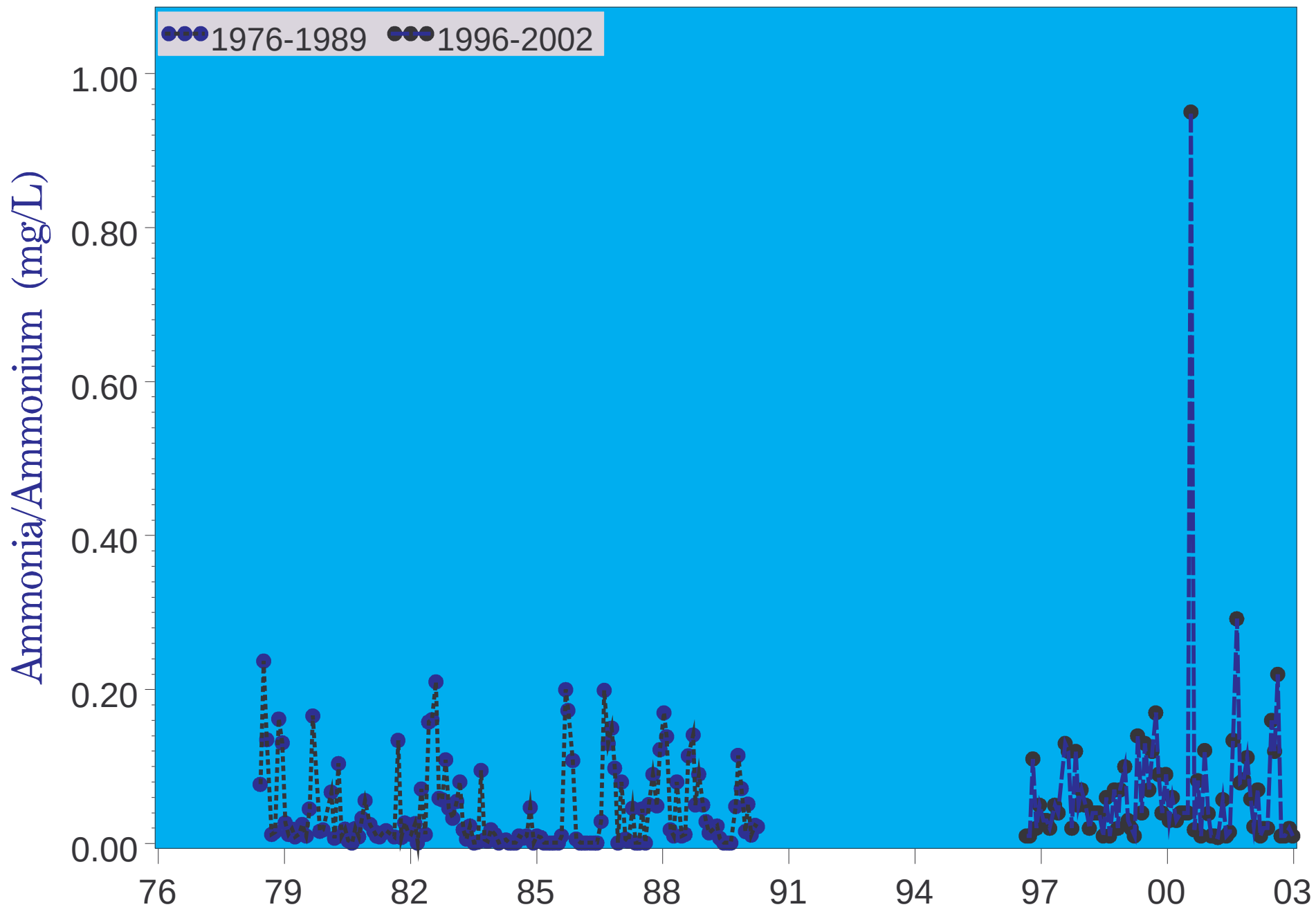


Figure 4.5.84 Long-term surface ammonia/ammonium at river kilometer 6.6

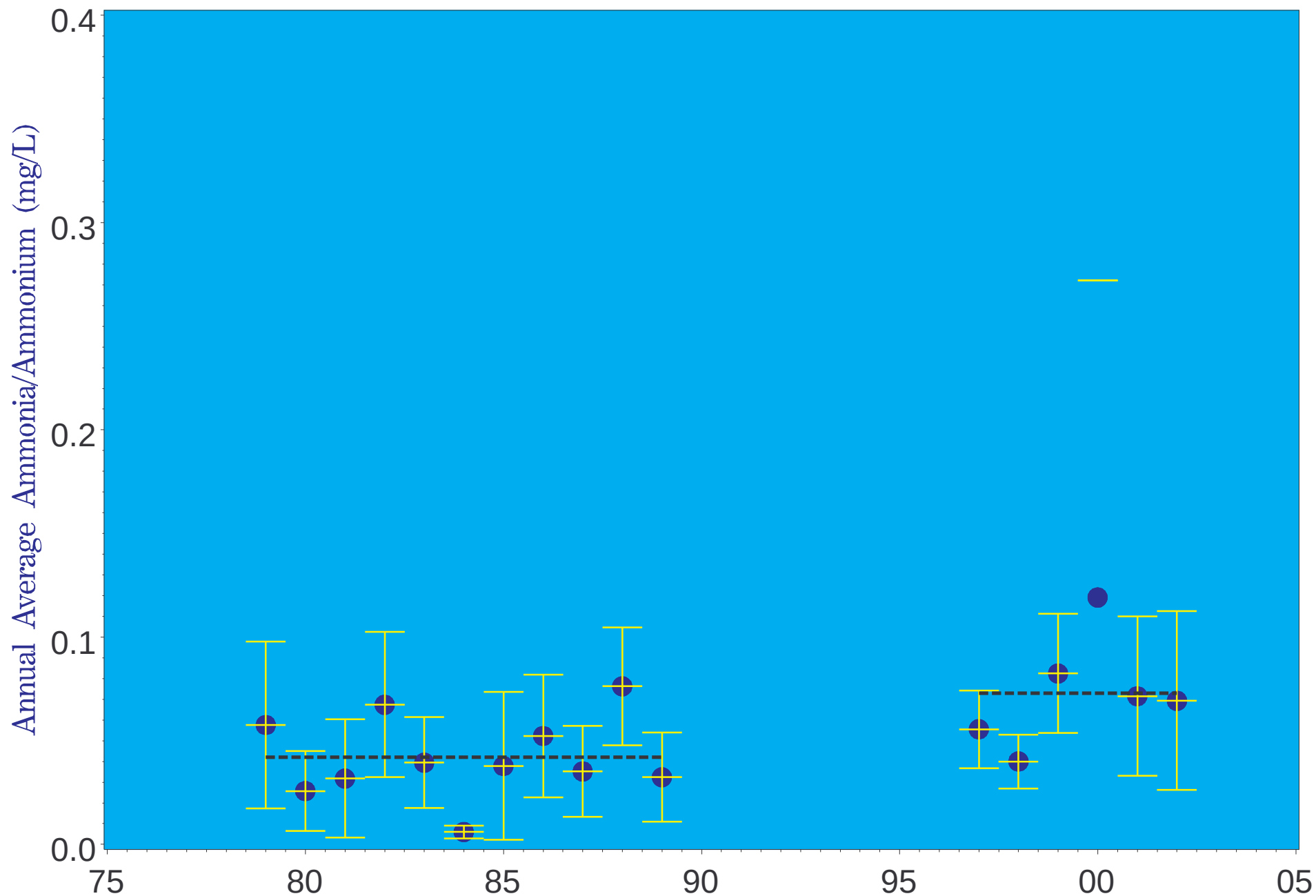


Figure 4.5.85 Long-term surface ammonia/ammonium at river kilometer 6.6

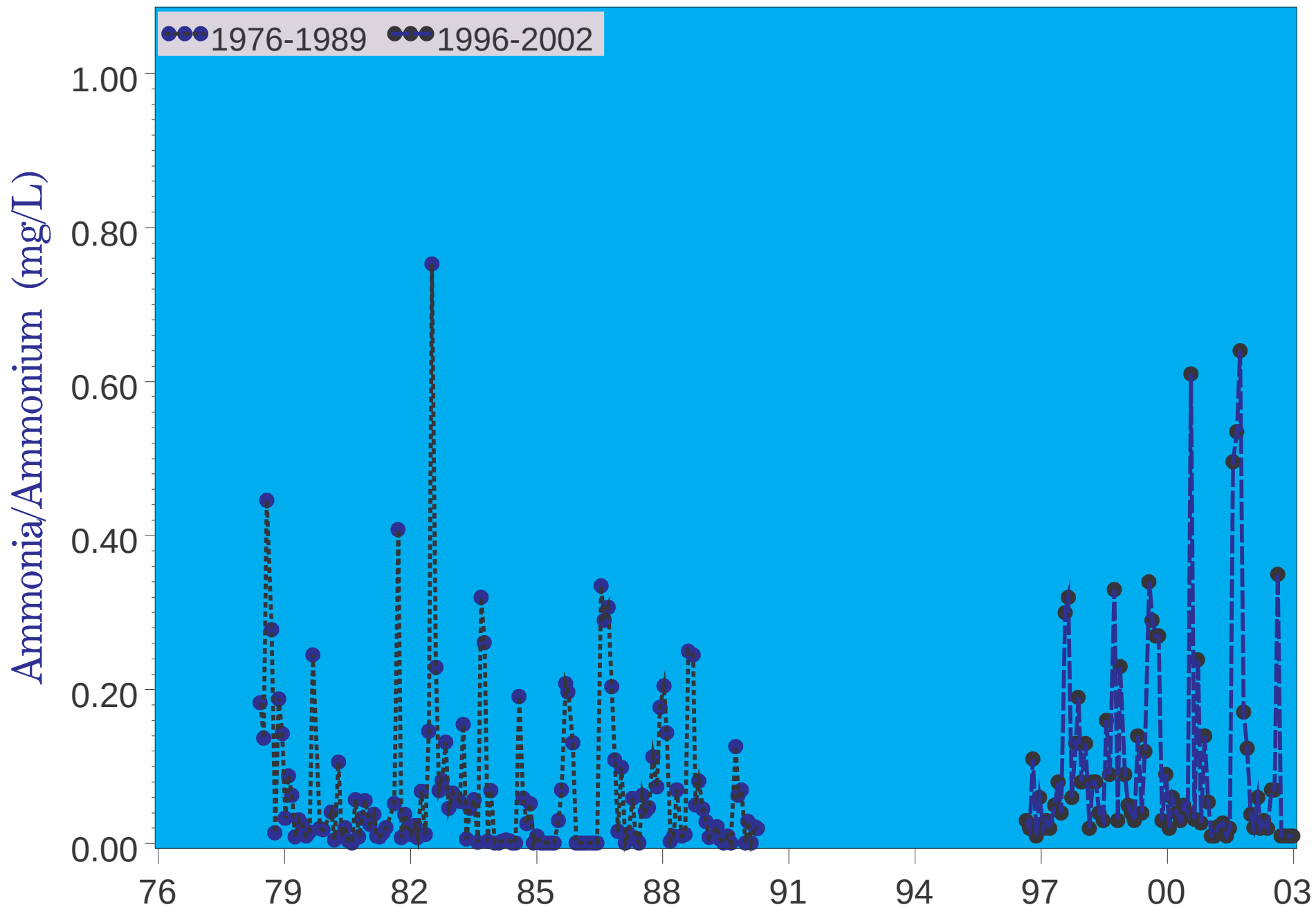


Figure 4.5.86 Long-term bottom ammonia/ammonium at river kilometer 6.6

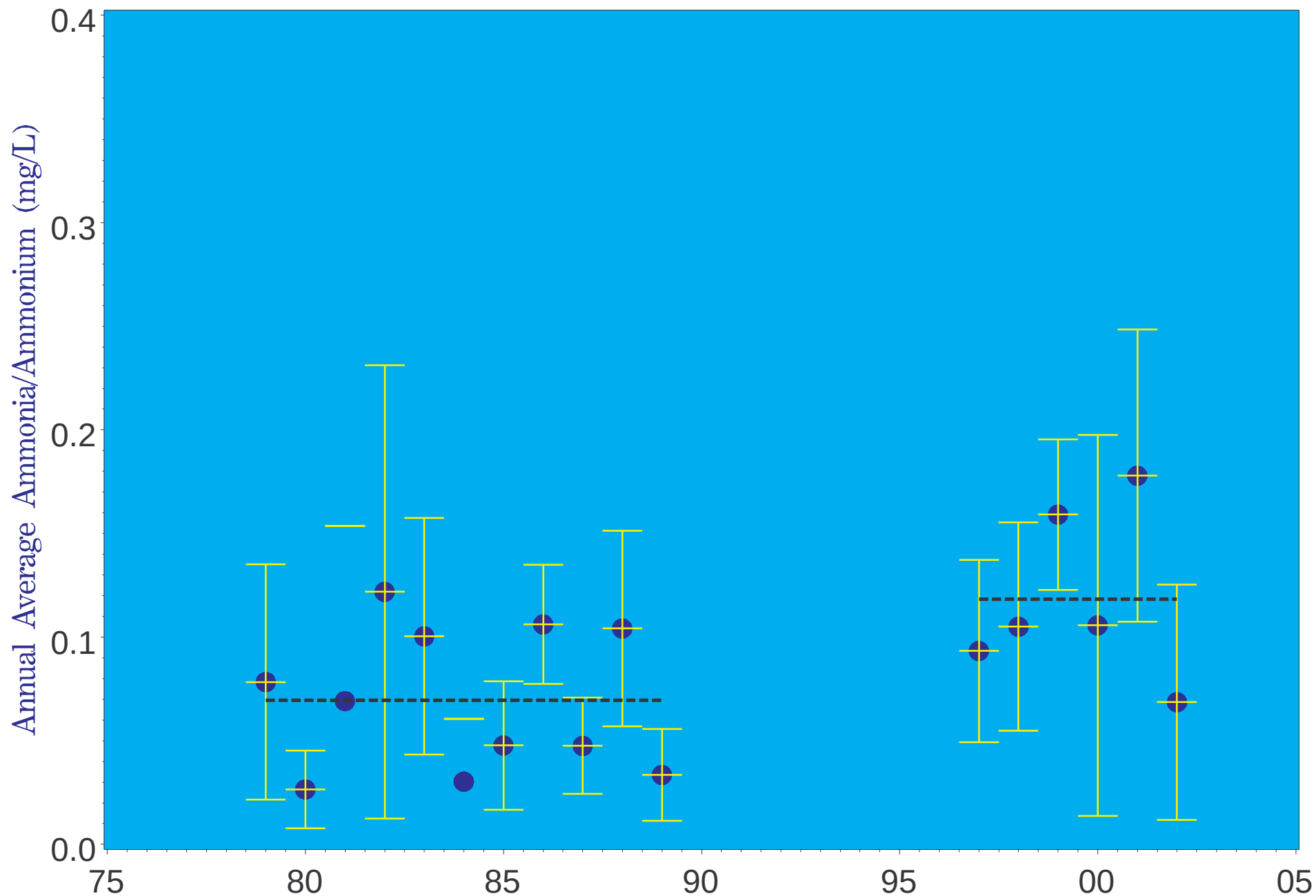


Figure 4.5.87 Long-term bottom ammonia/ammonium at river kilometer 6.6

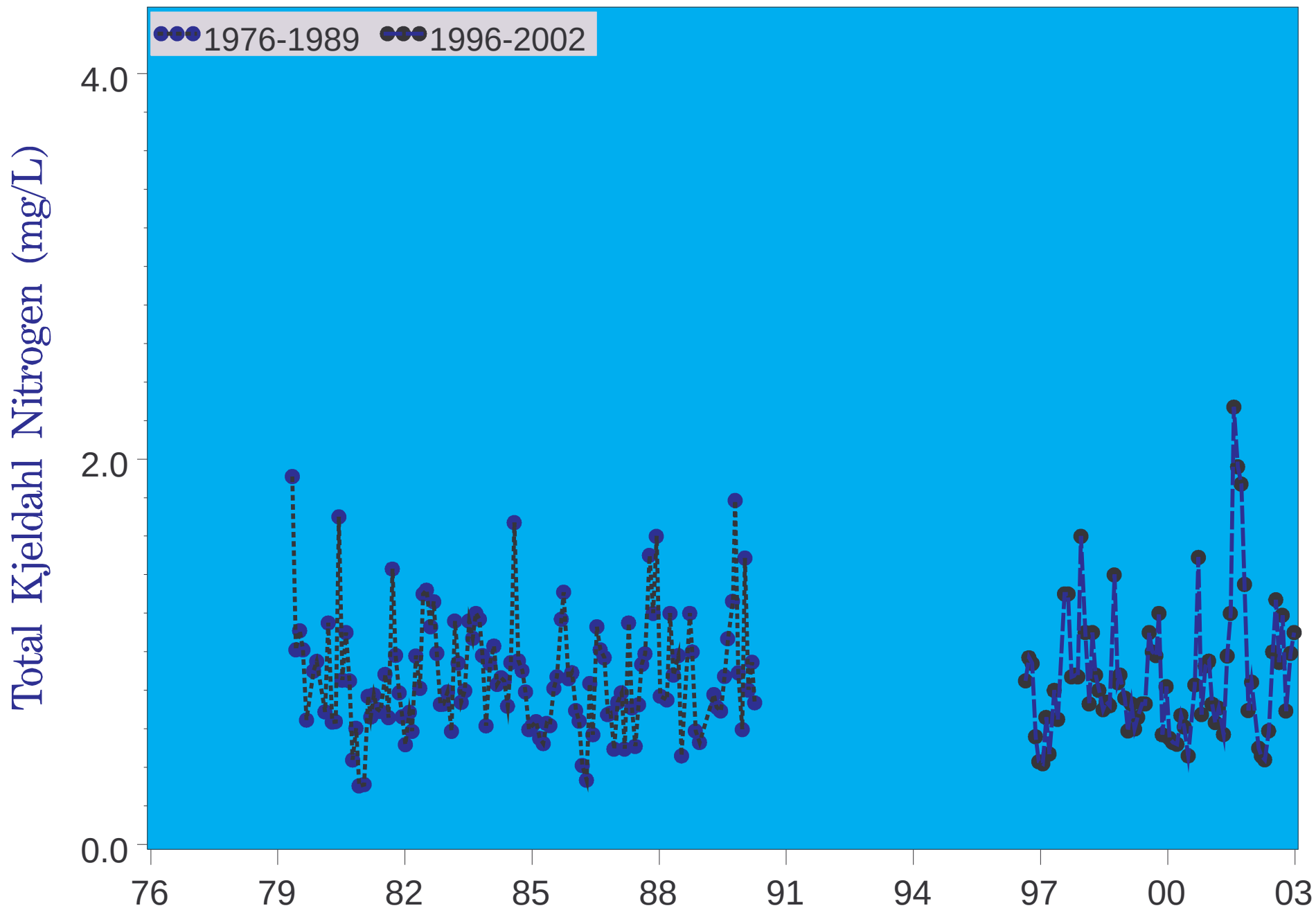


Figure 4.5.88 Long-term surface total Kjeldahl nitrogen at river kilometer 6.6



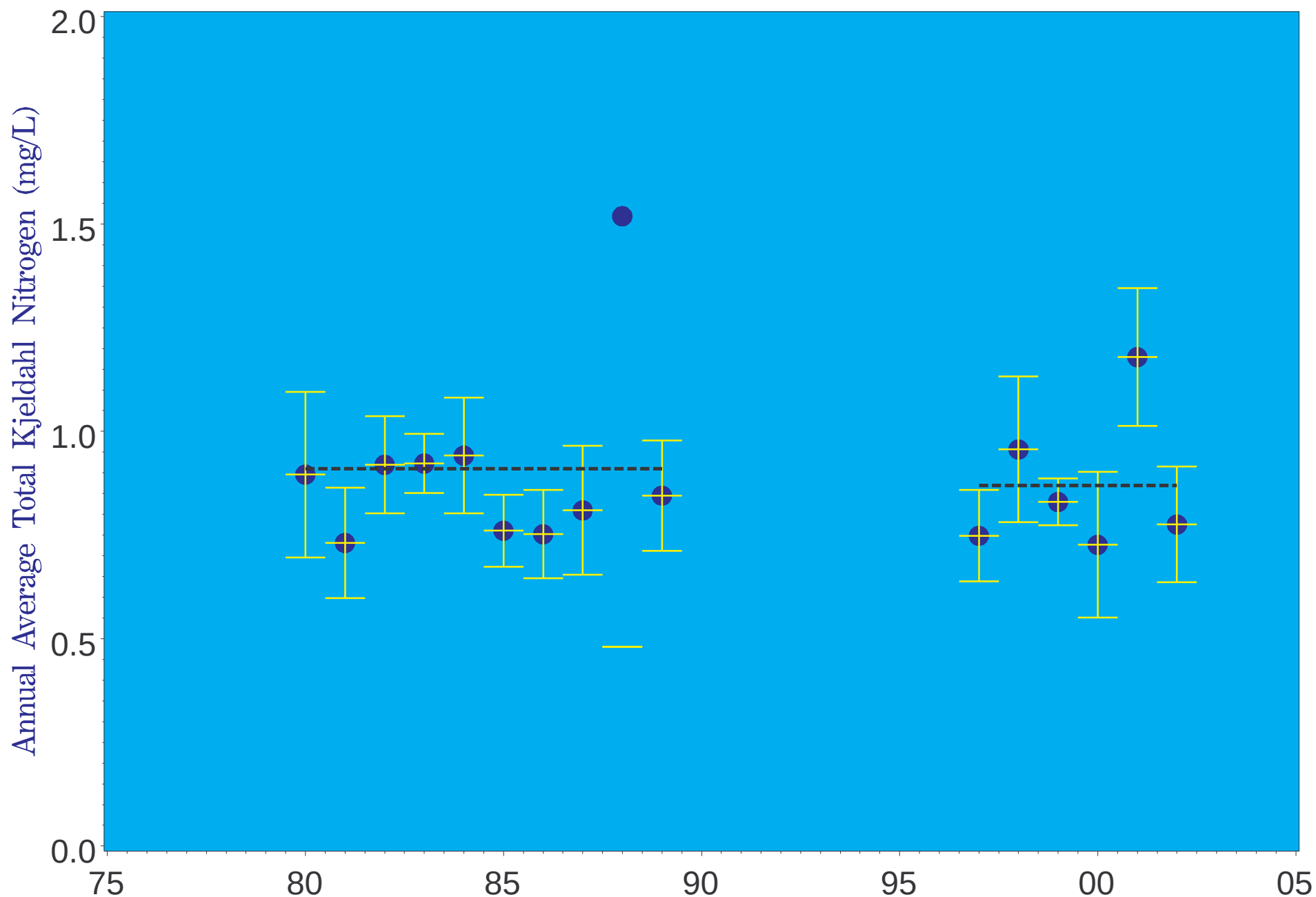


Figure 4.5.89 Long-term surface total Kjeldahl nitrogen at river kilometer 6.6

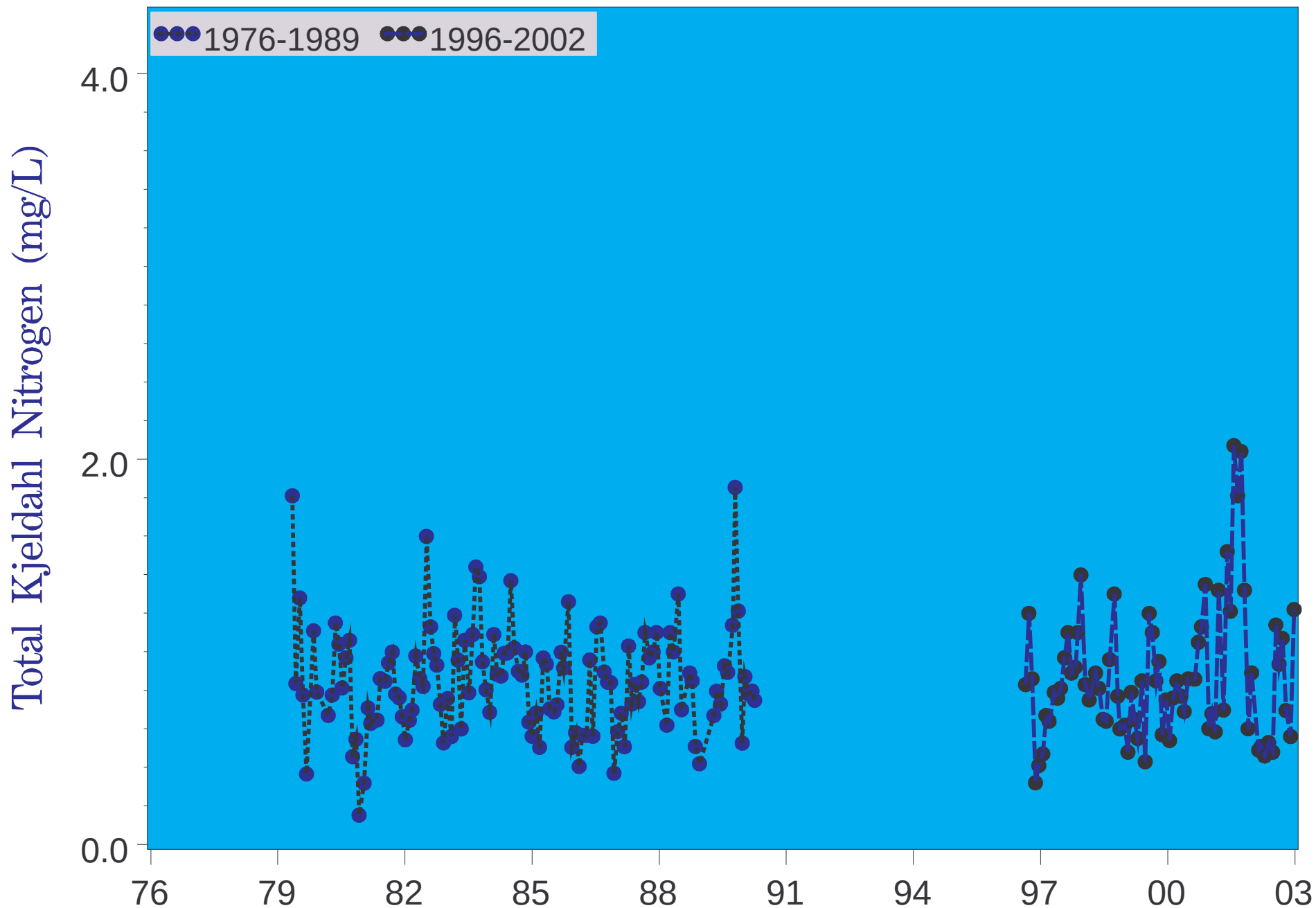


Figure 4.5.90 Long-term bottom total Kjeldhal nitrogen at river kilometer 6.6

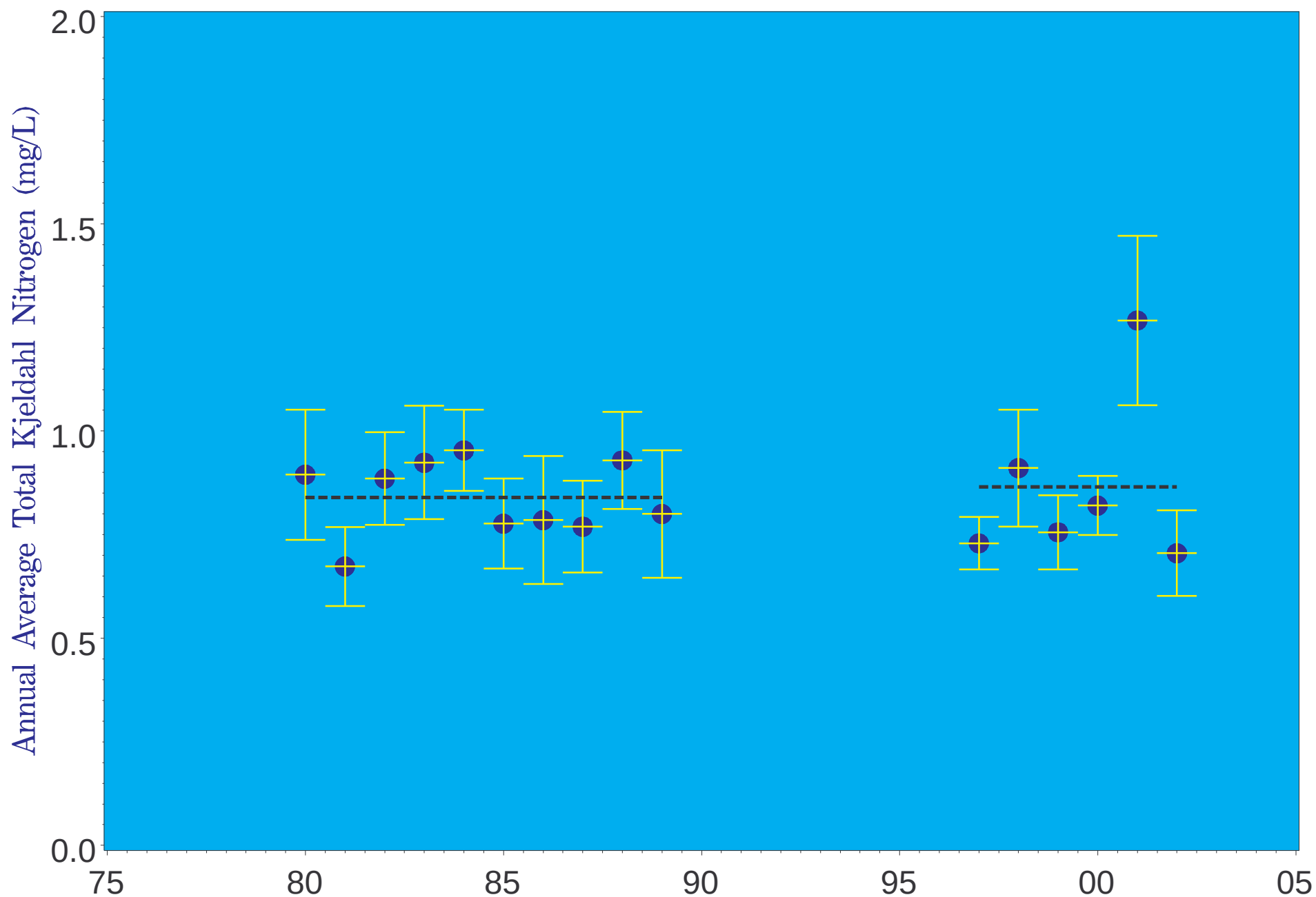


Figure 4.5.91 Long-term bottom total Kjeldhal nitrogen at river kilometer 6.6

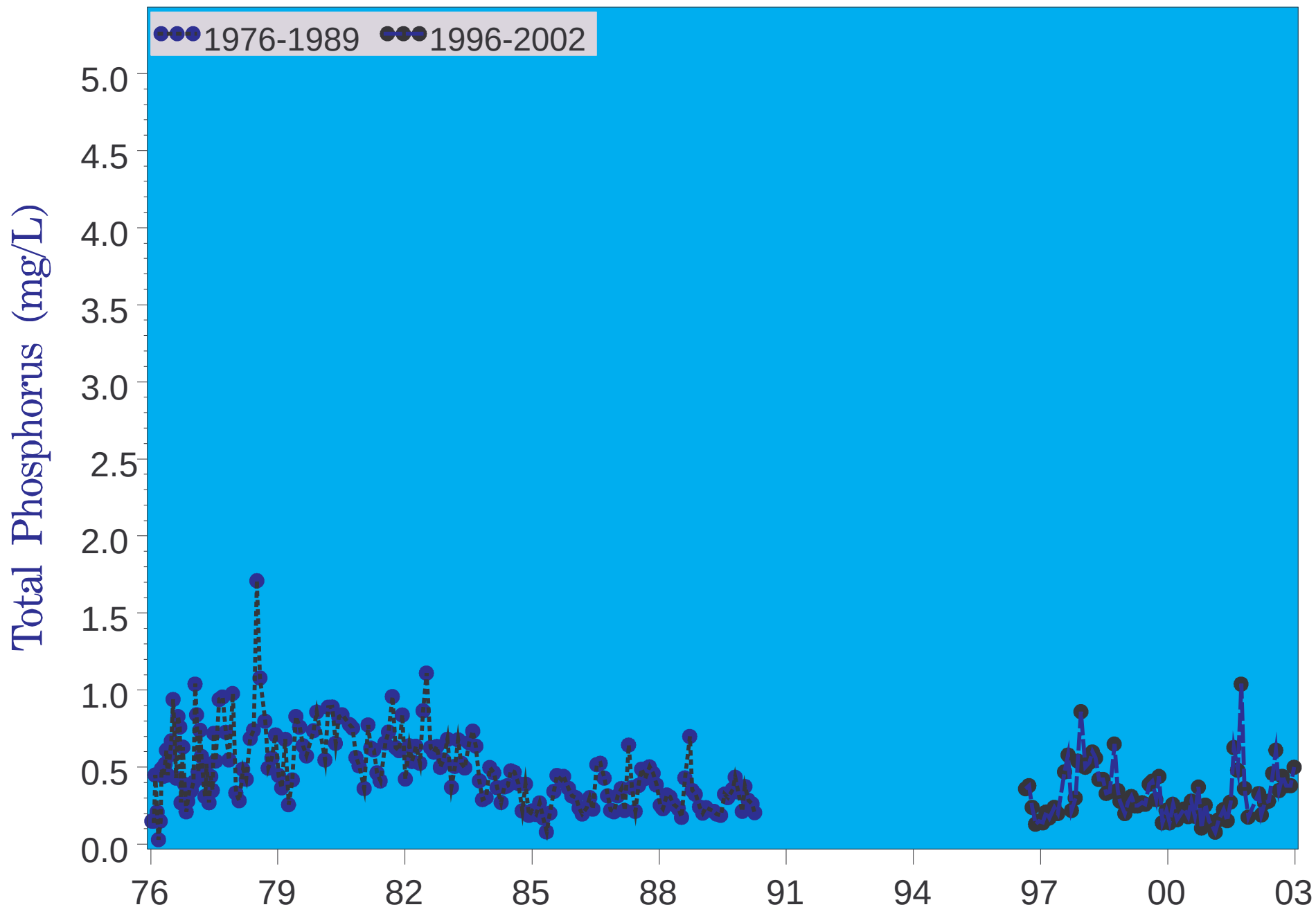


Figure 4.5.92 Long-term surface total phosphorus at river kilometer 6.6

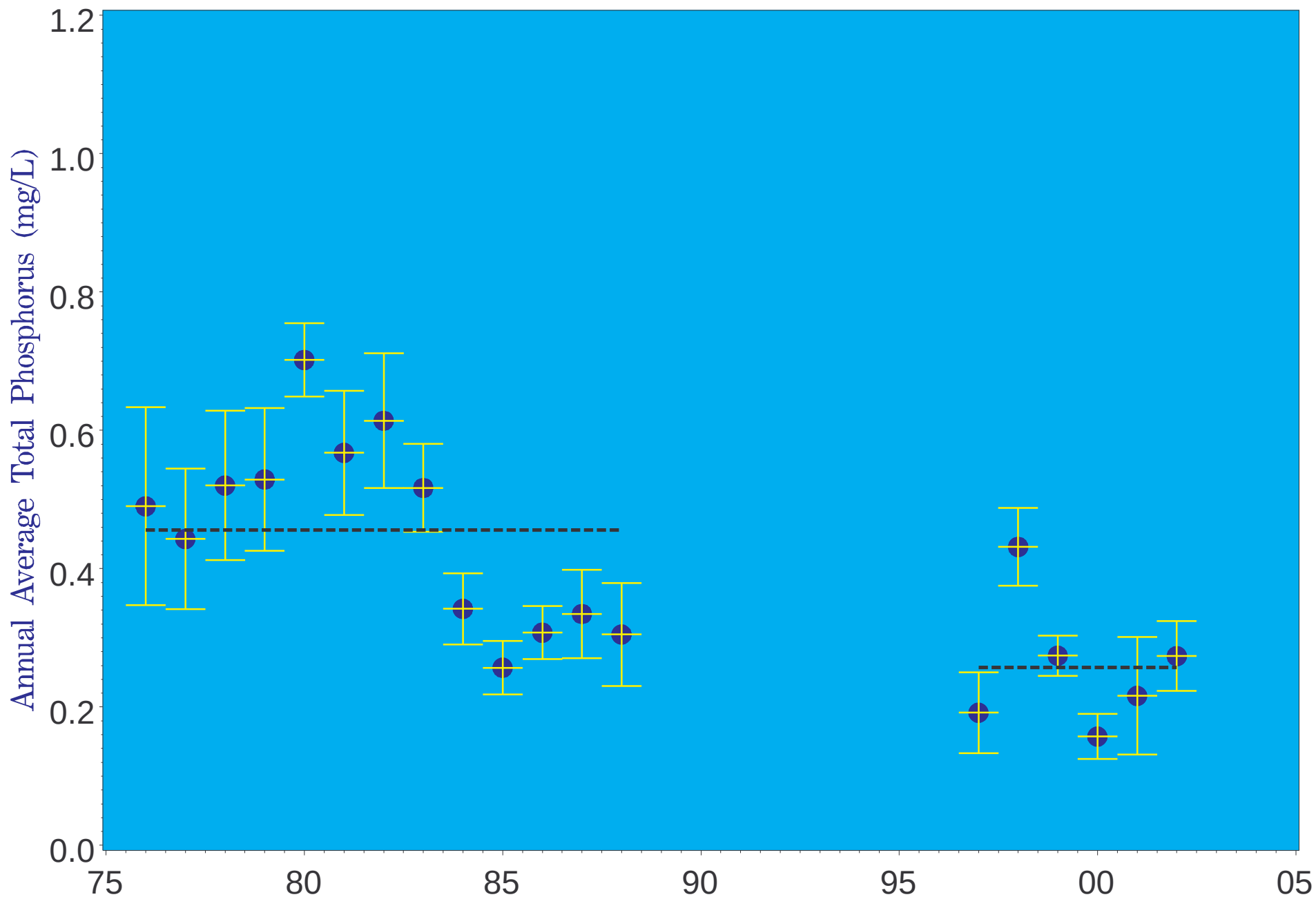


Figure 4.5.93 Long-term surface total phosphorus at river kilometer 6.6

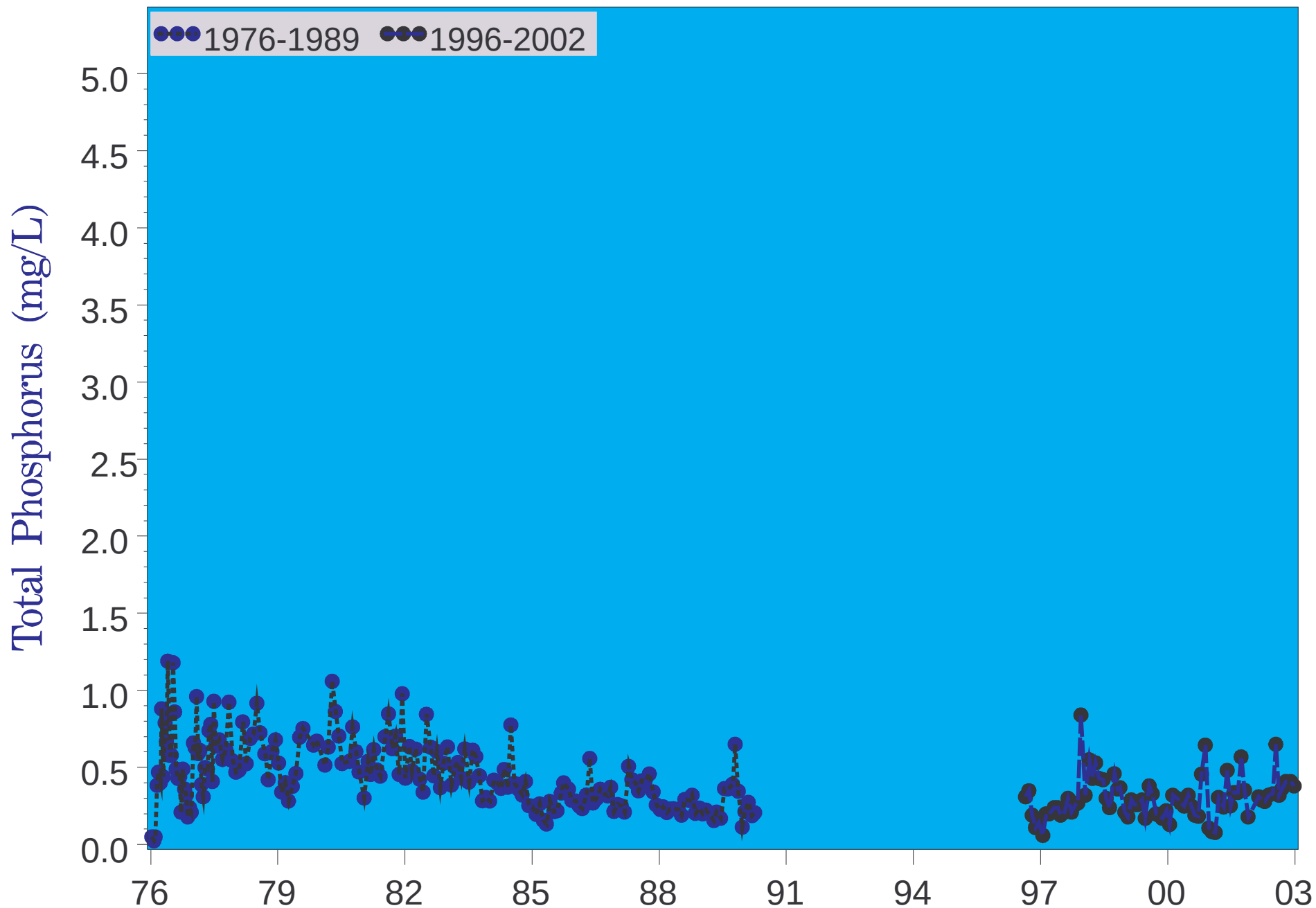


Figure 4.5.94 Long-term bottom total phosphorus at river kilometer 6.6

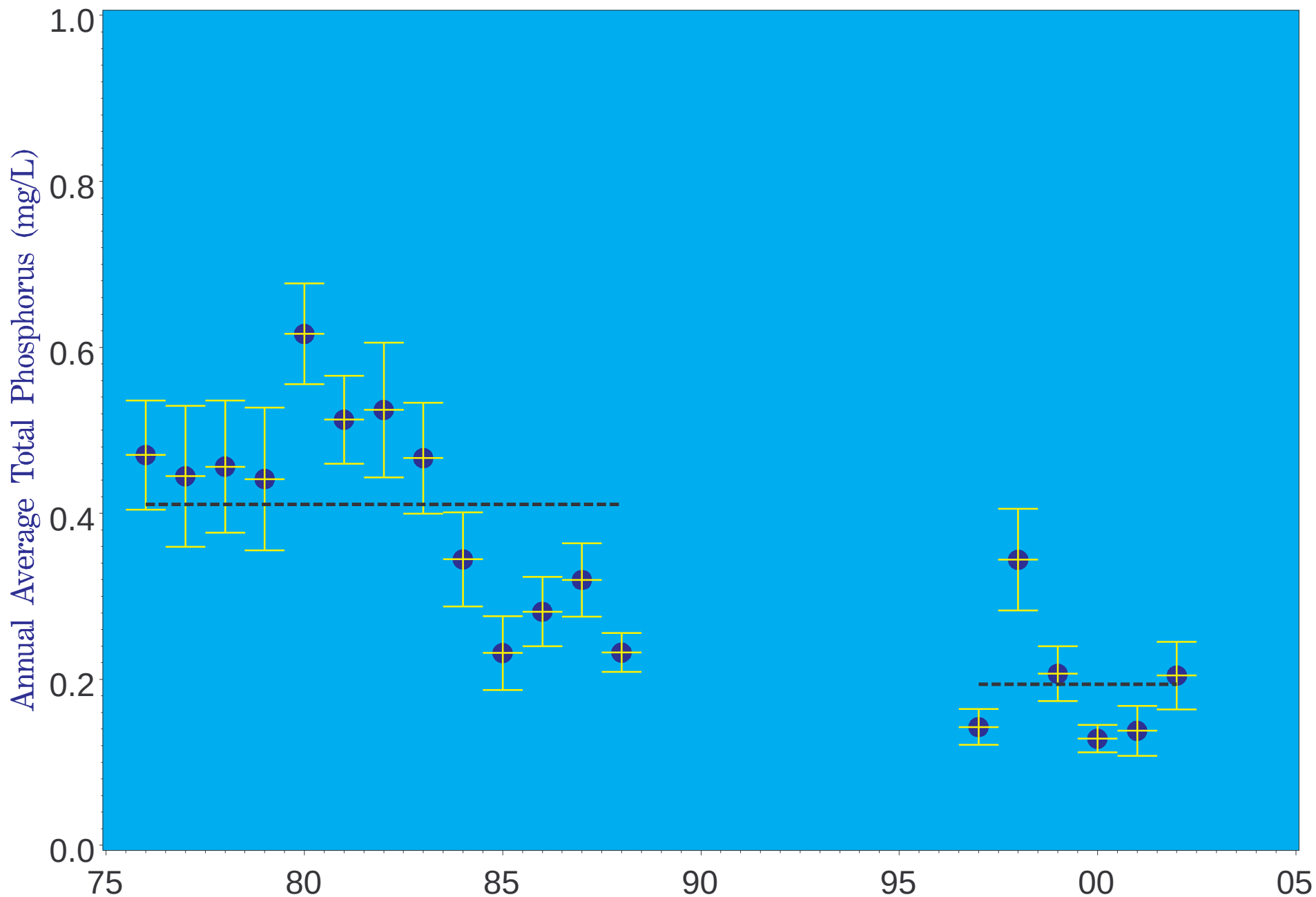


Figure 4.5.95 Long-term bottom total phosphorus at river kilometer 6.6

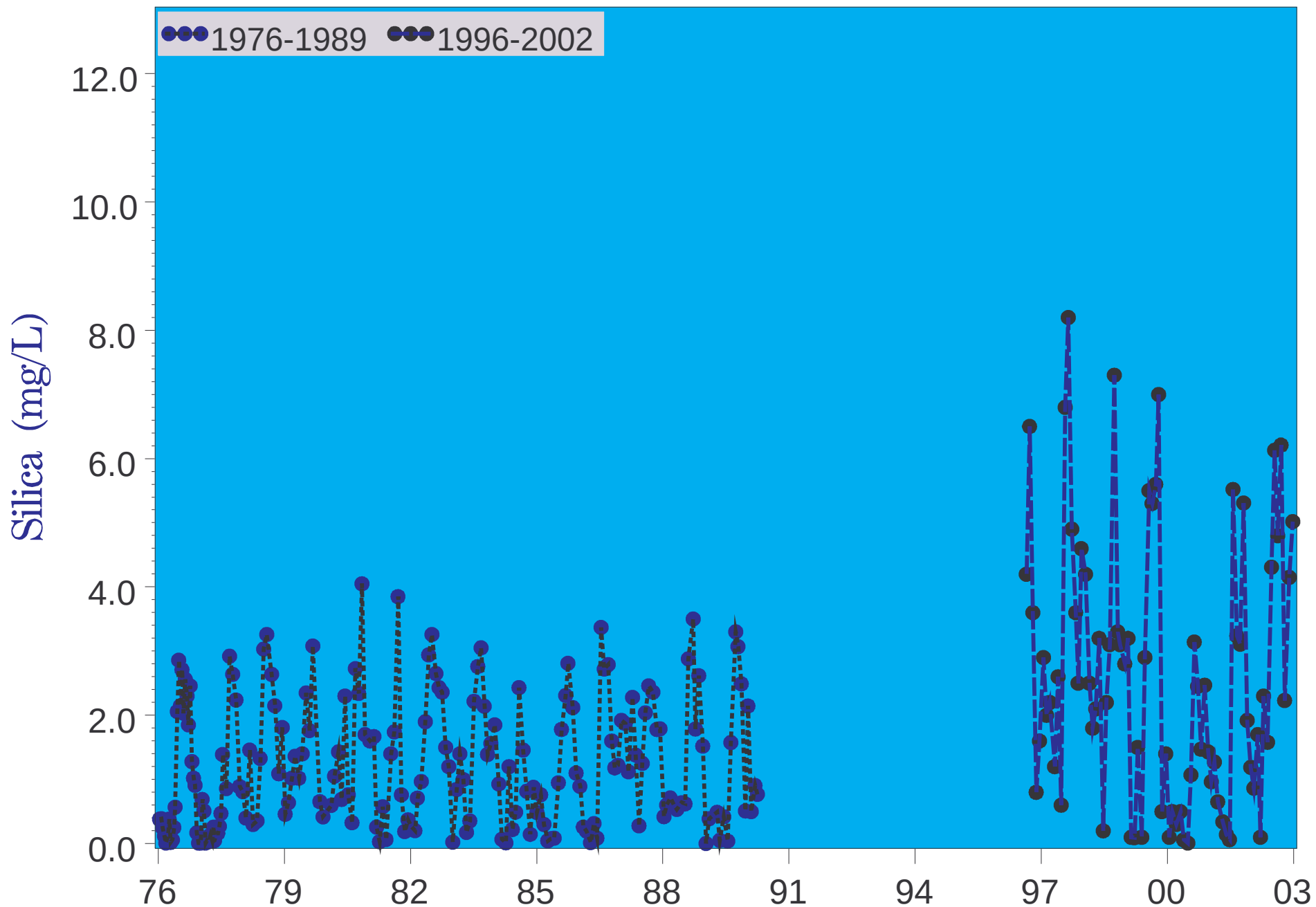


Figure 4.5.96 Long-term surface silica at river kilometer 6.6



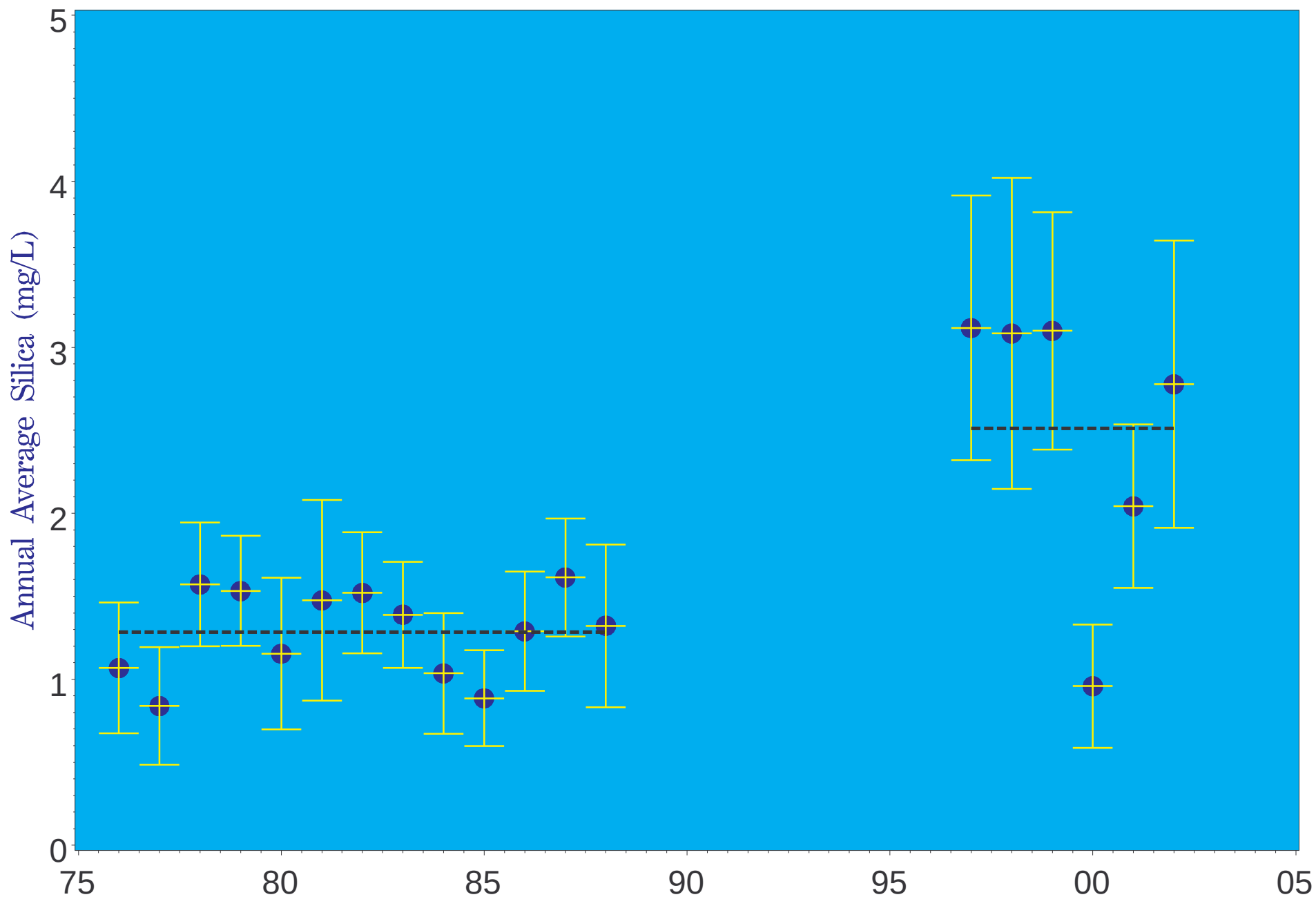


Figure 4.5.97 Long-term surface silica at river kilometer 6.6

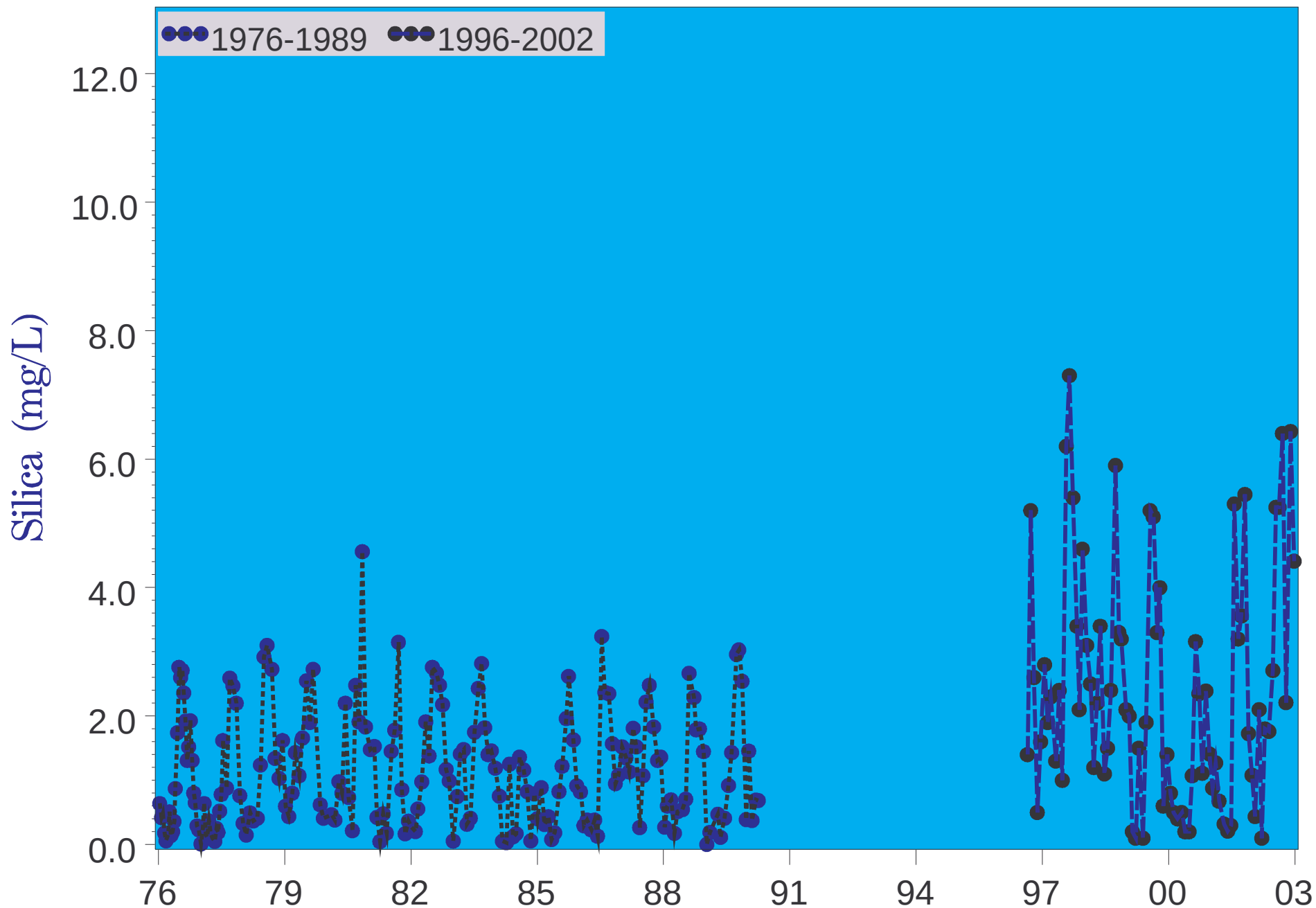


Figure 4.5.98 Long-term bottom silica at river kilometer 6.6

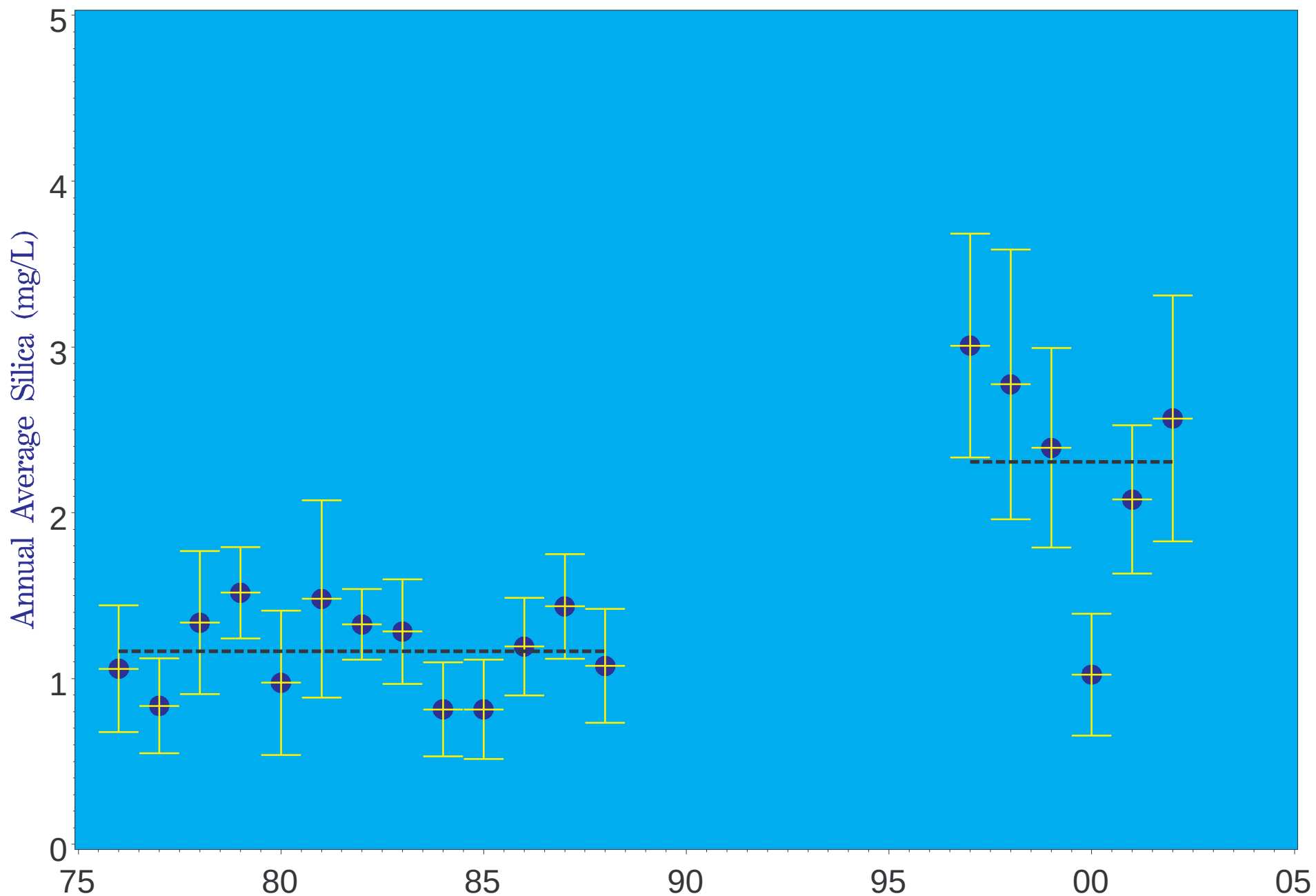
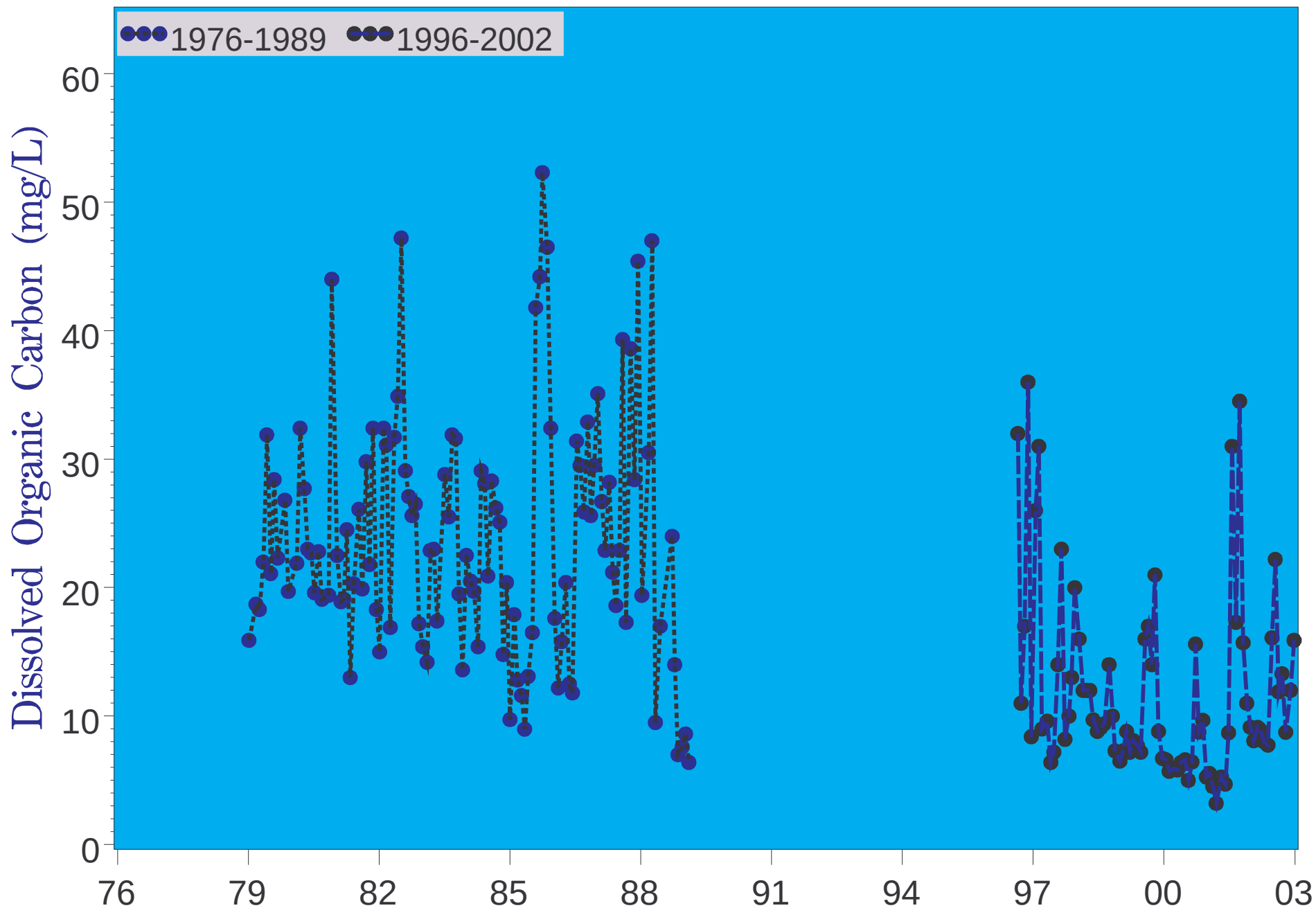


Figure 4.5.99 Long-term bottom silica at river kilometer 6.6



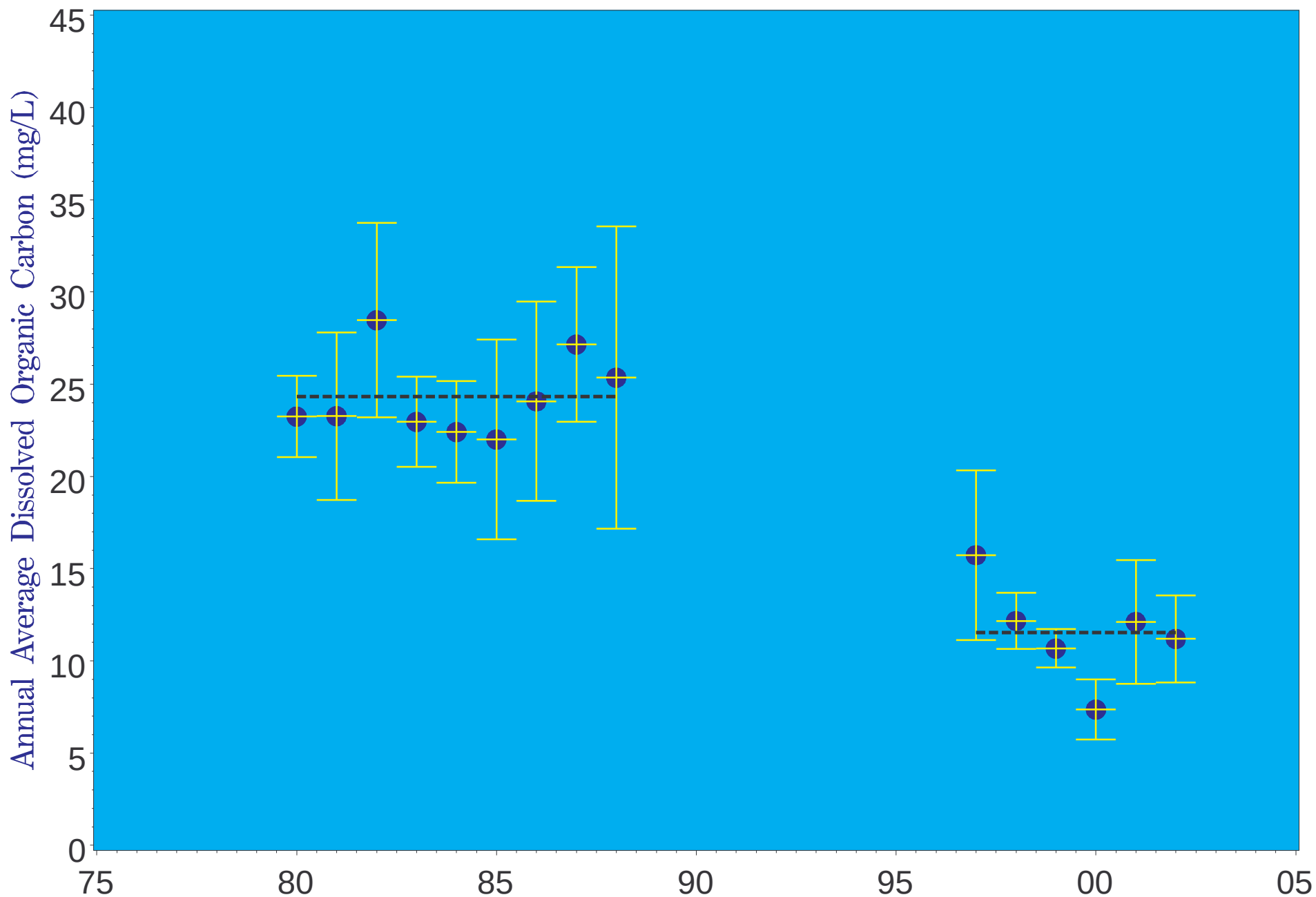


Figure 4.5.101 Long-term surface dissolved organic carbon at river kilometer 6.6

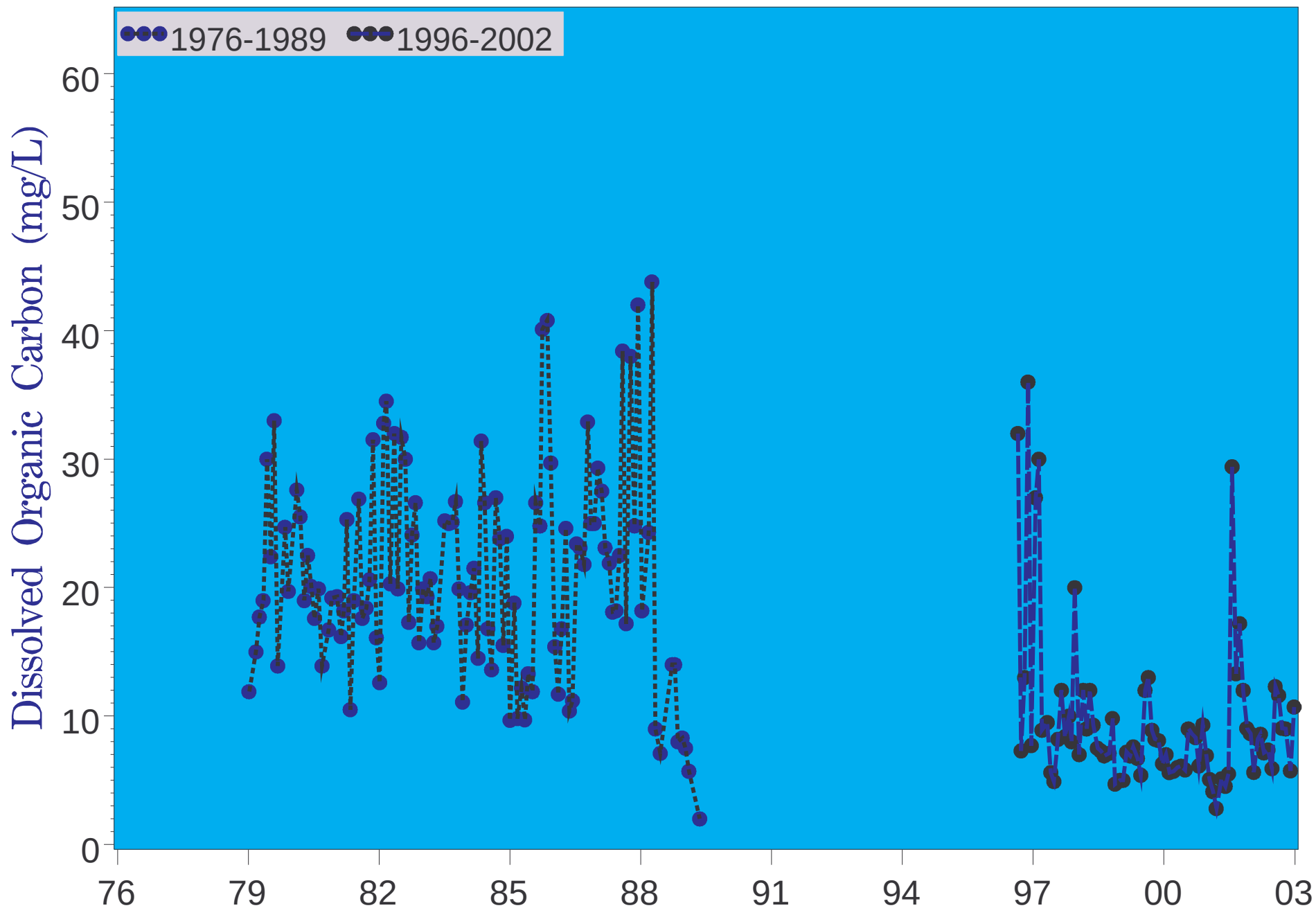


Figure 4.5.102 Long-term bottom dissolved organic carbon at river kilometer 6.6

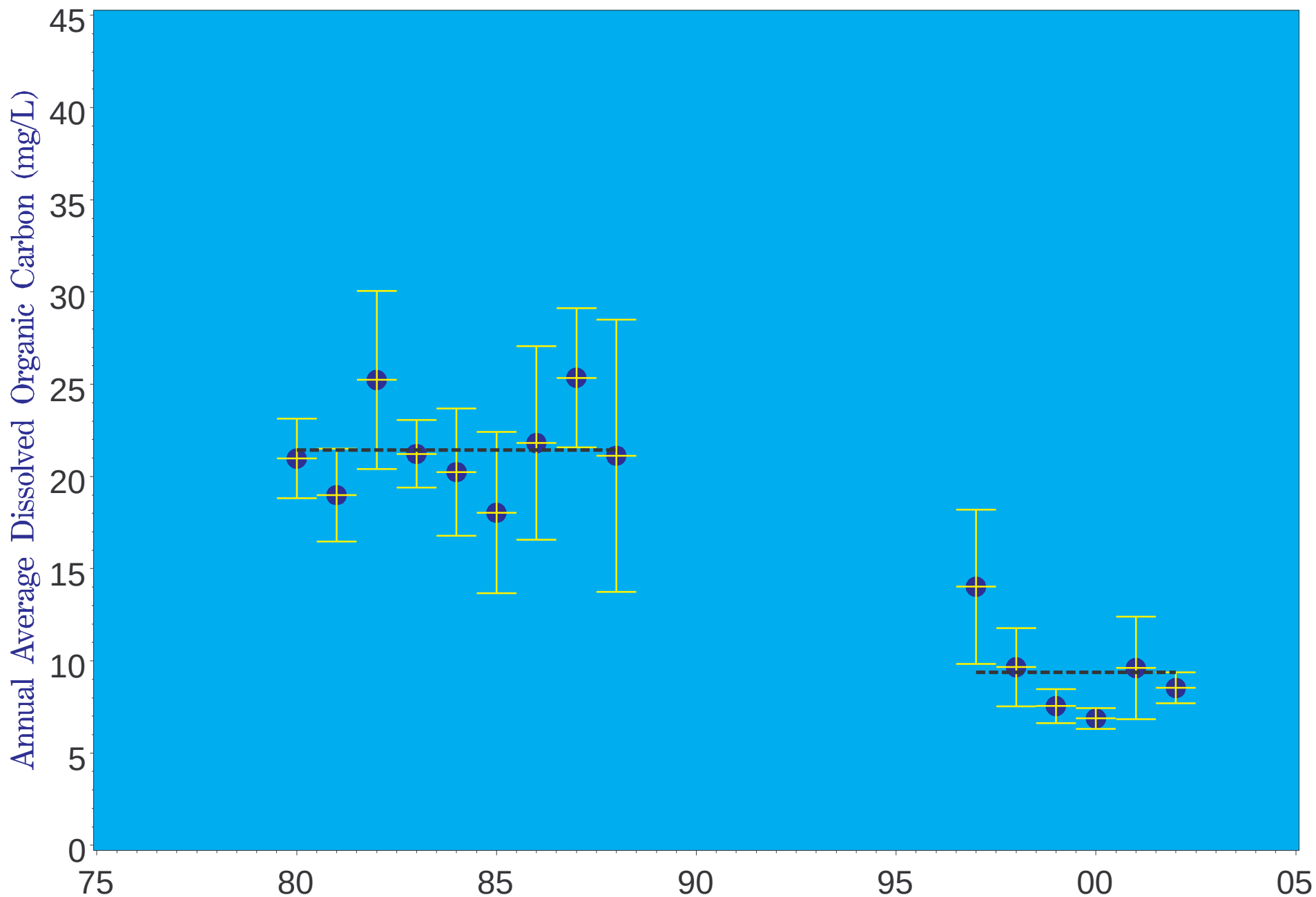


Figure 4.5.103 Long-term bottom dissolved organic carbon at river kilometer 6.6

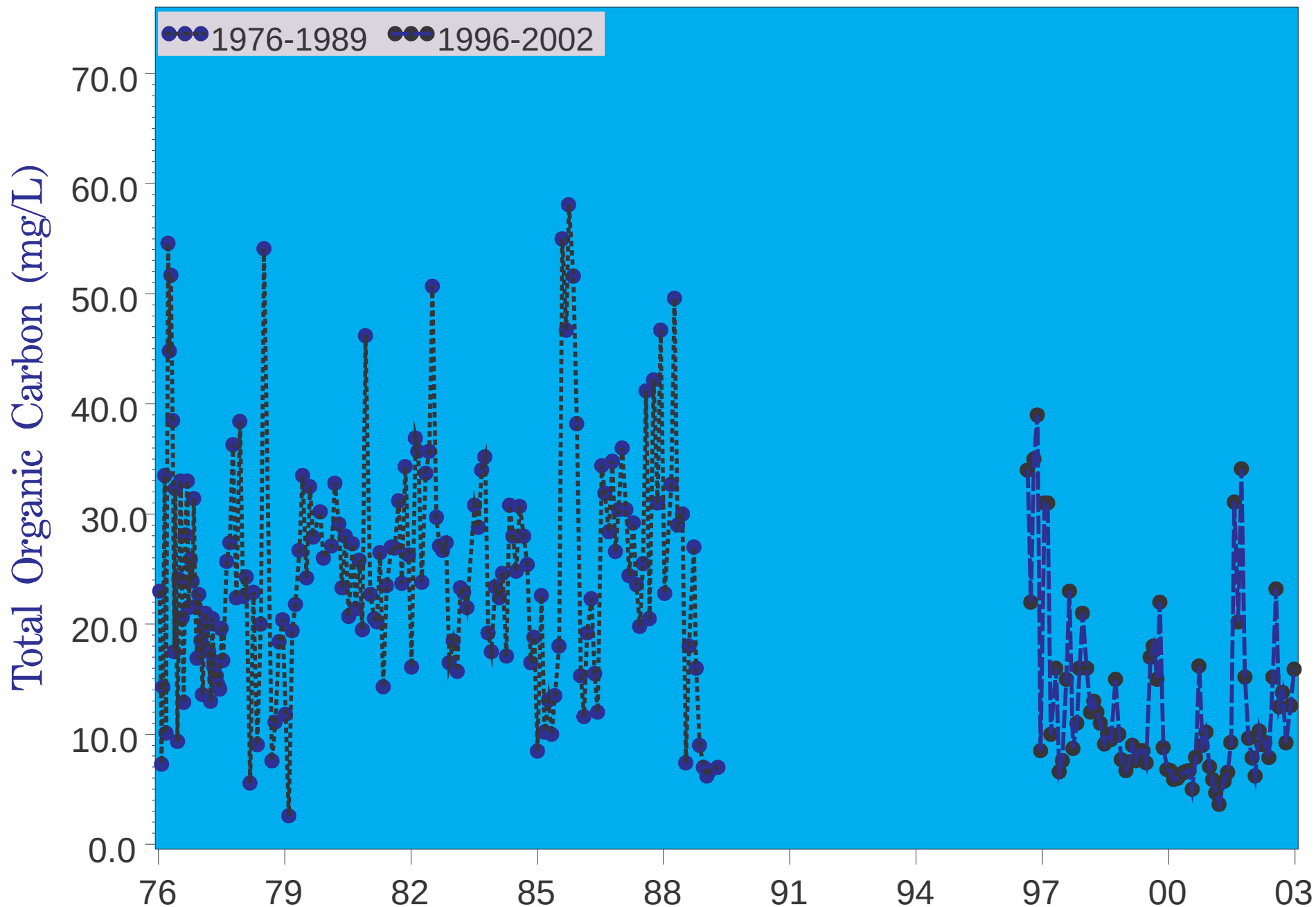


Figure 4.5.104 Long-term surface total organic carbon at river kilometer 6.6



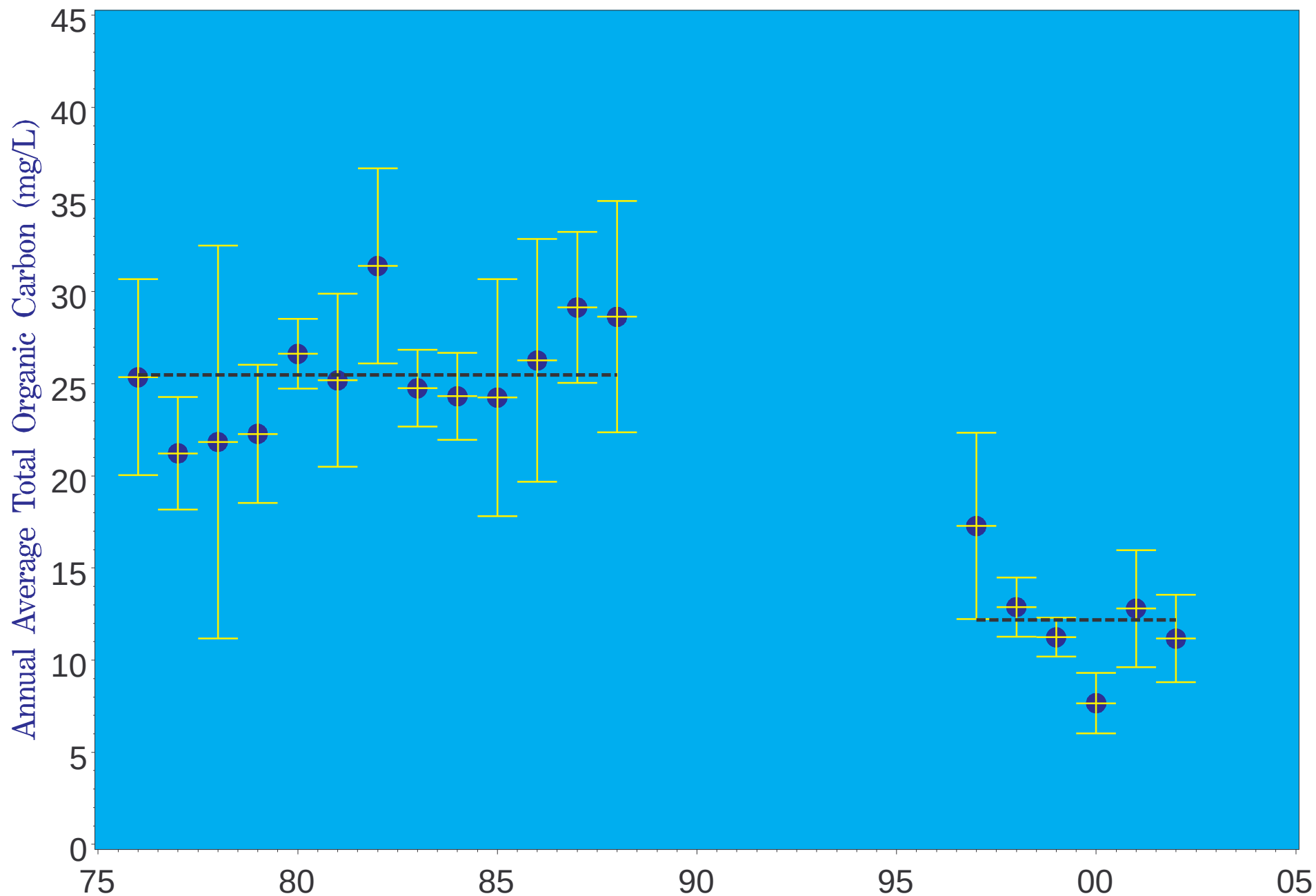


Figure 4.5.105 Long-term surface total organic carbon at river kilometer 6.6

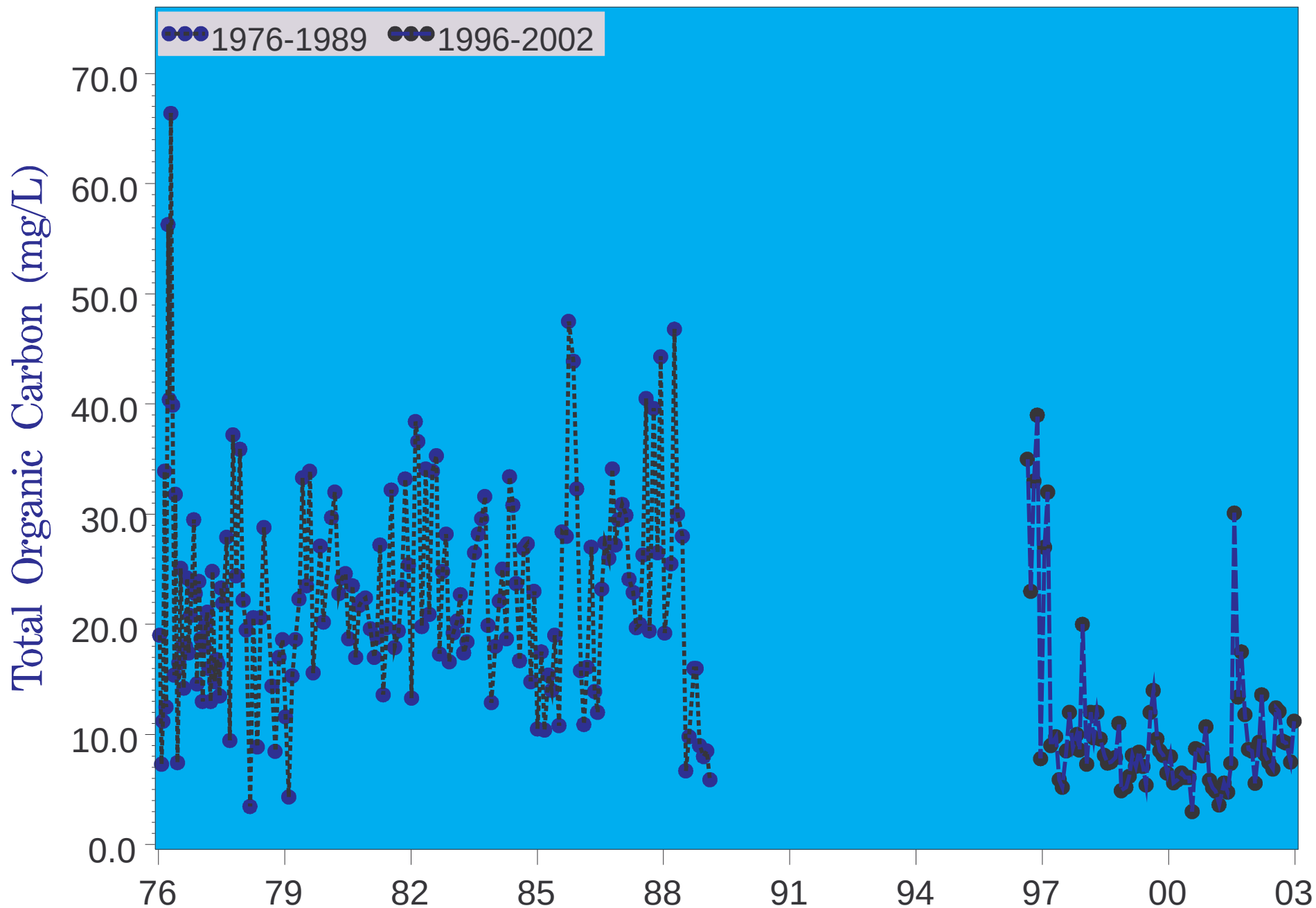


Figure 4.5.106 Long-term bottom total organic carbon at river kilometer 6.6

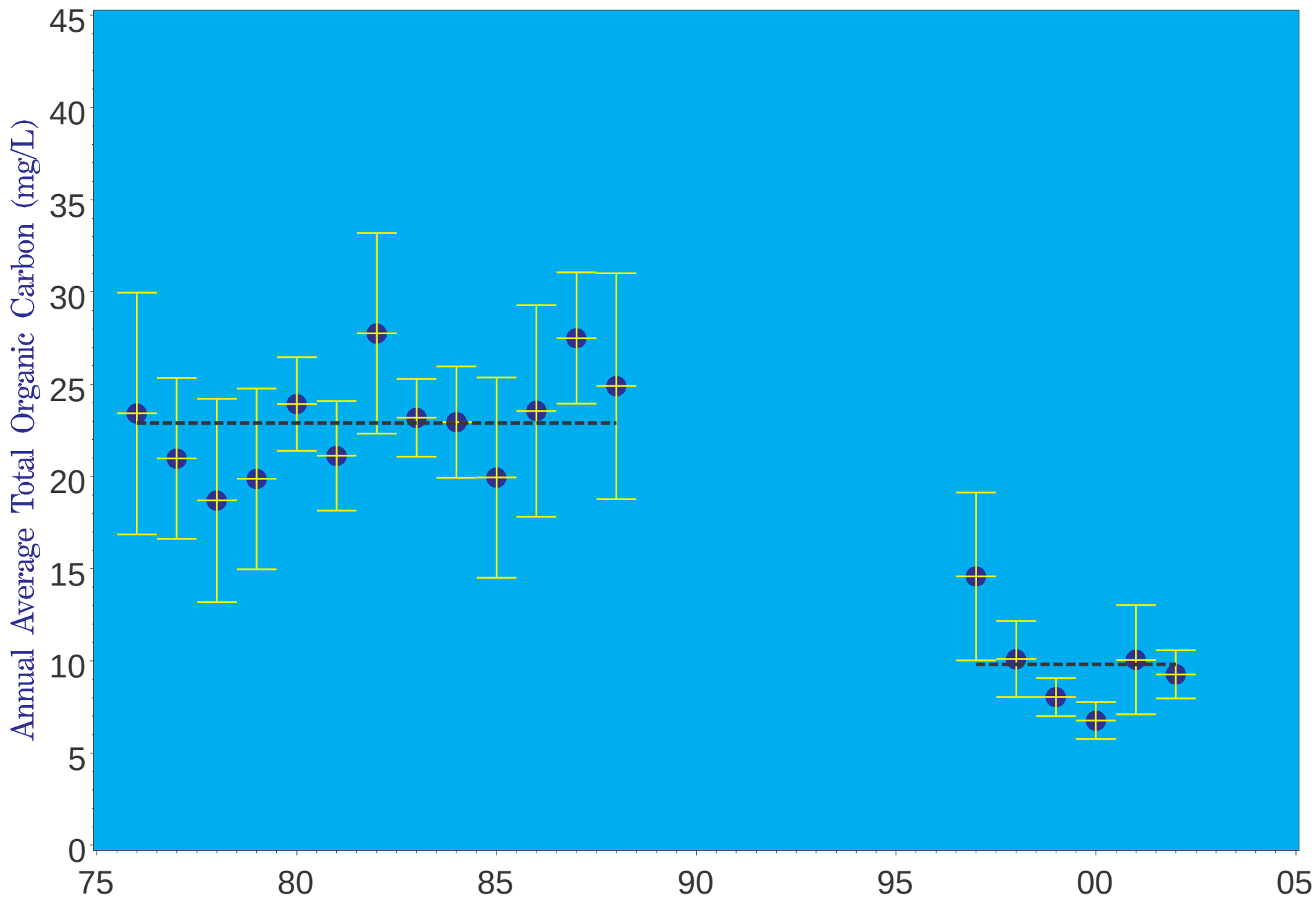


Figure 4.5.107 Long-term bottom total organic carbon at river kilometer 6.6

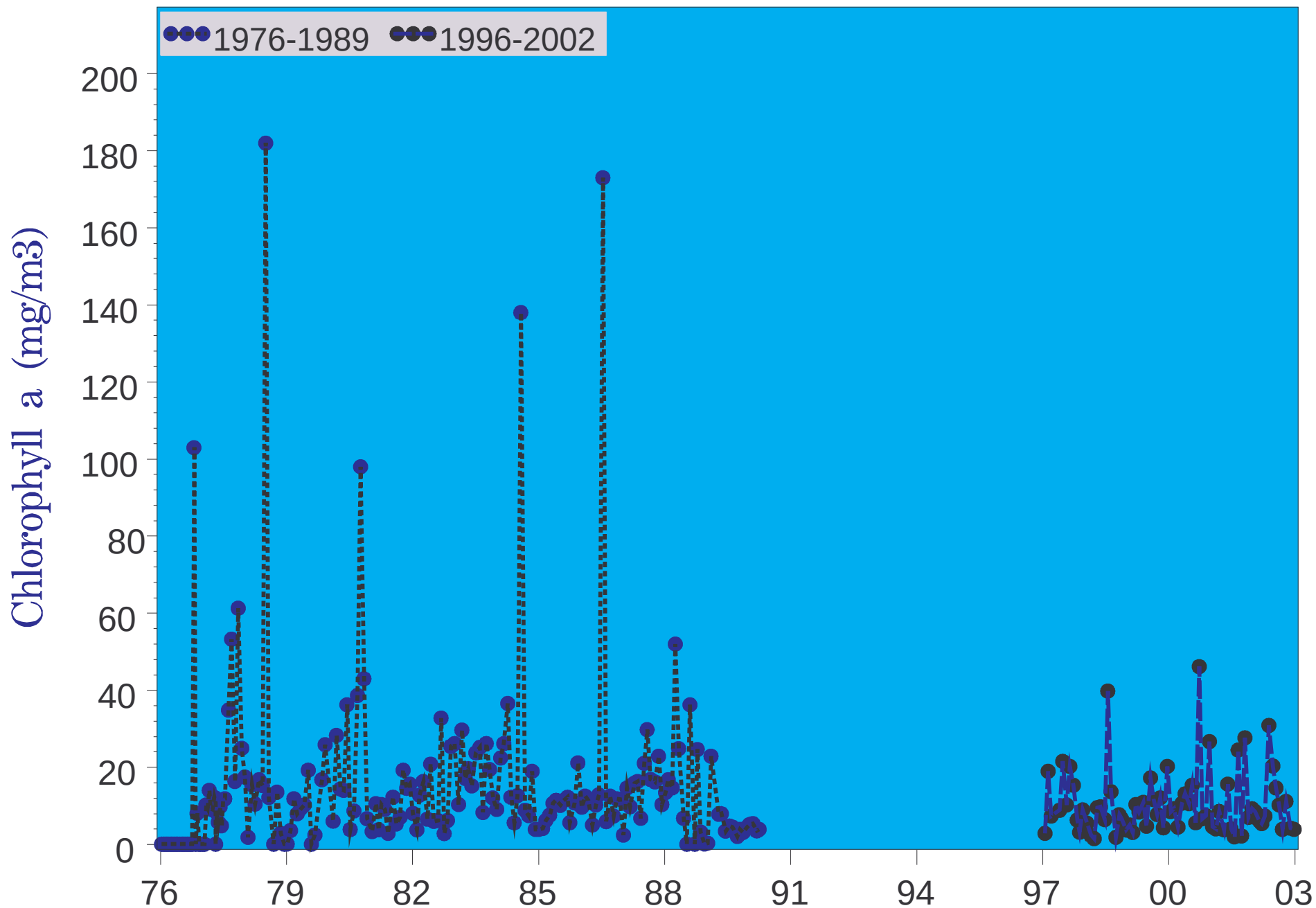


Figure 4.5.108 Long-term surface chlorophyll a at river kilometer 6.6

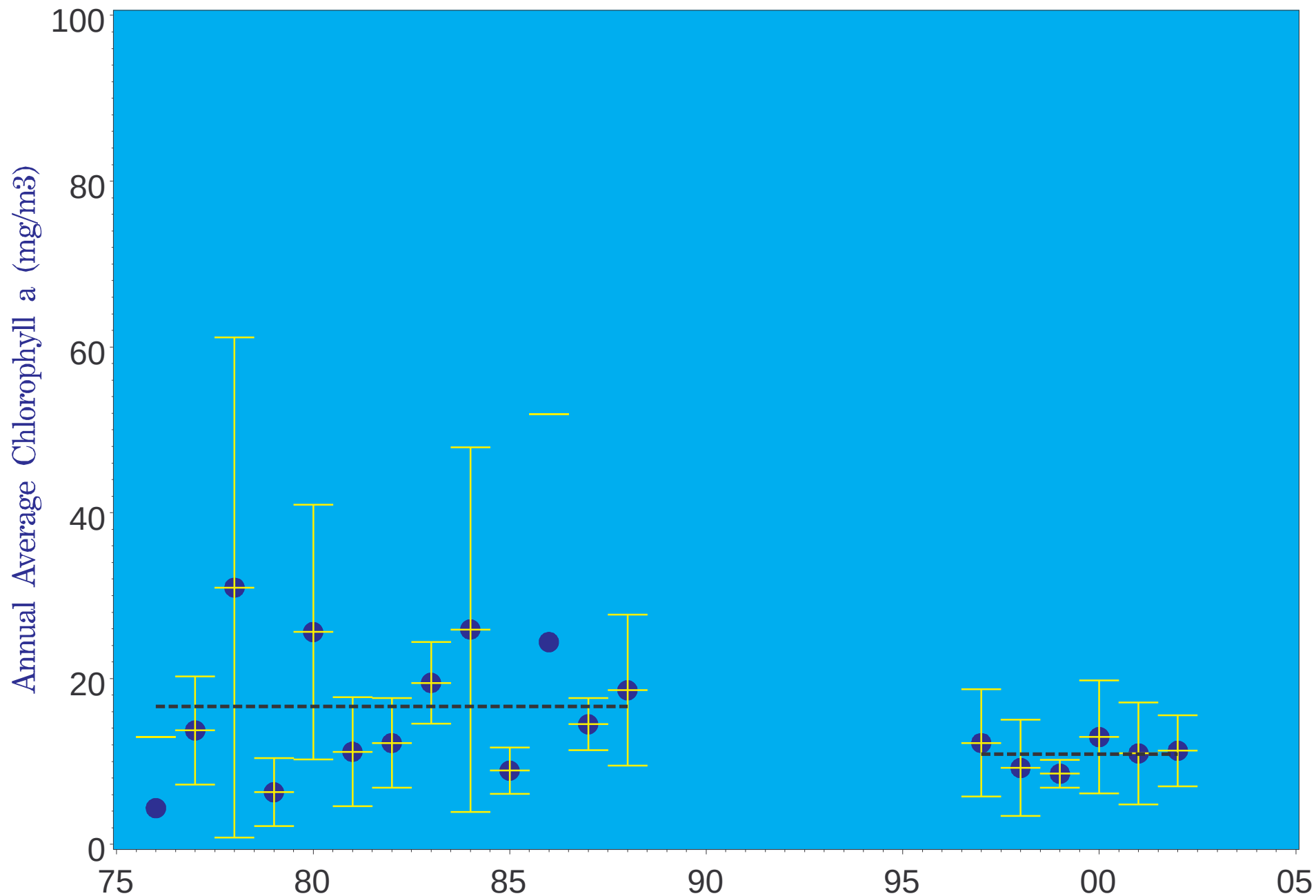


Figure 4.5.109 Long-term surface chlorophyll a at river kilometer 6.6

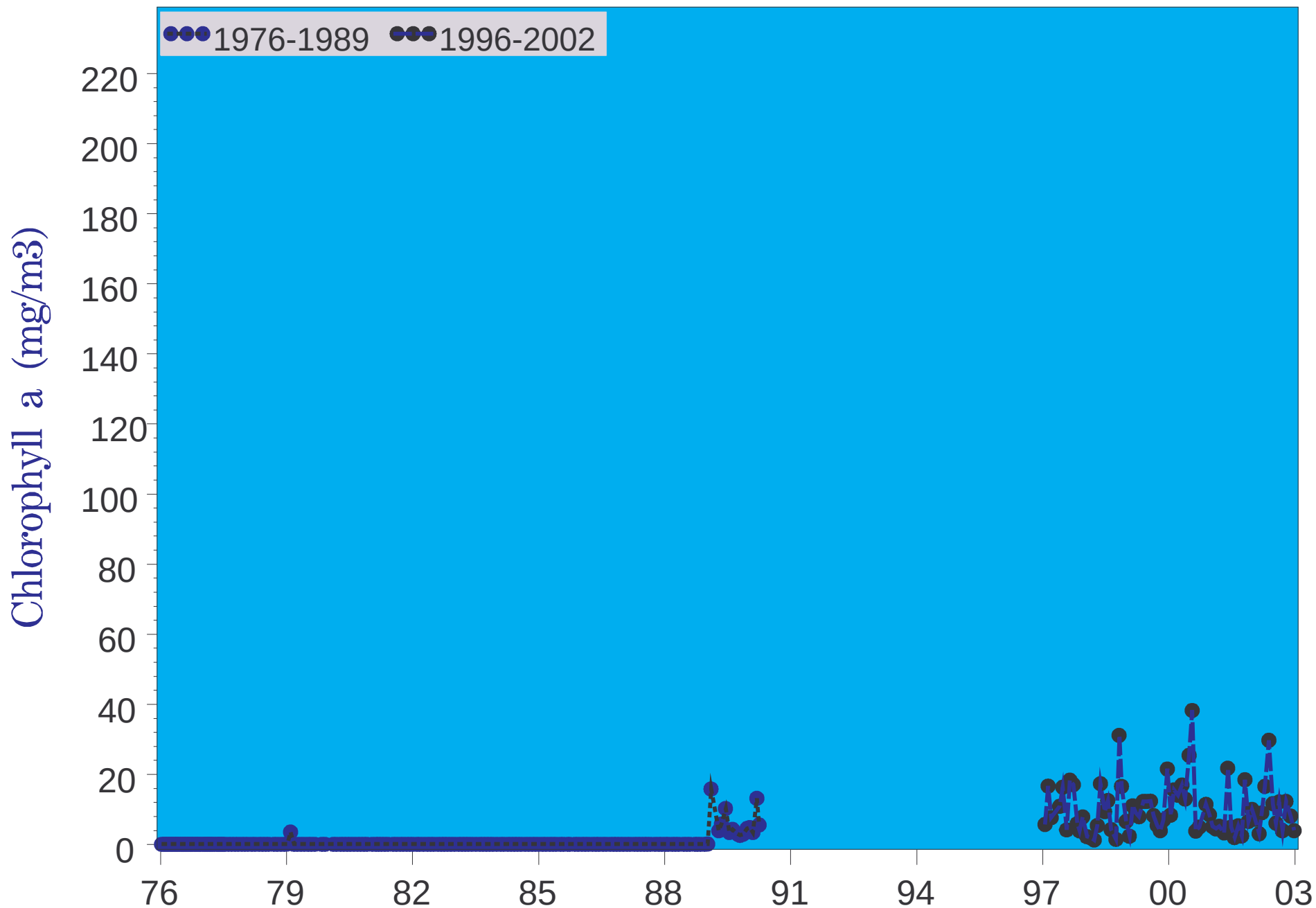


Figure 4.5.110 Long-term bottom chlorophyll a at river kilometer 6.6

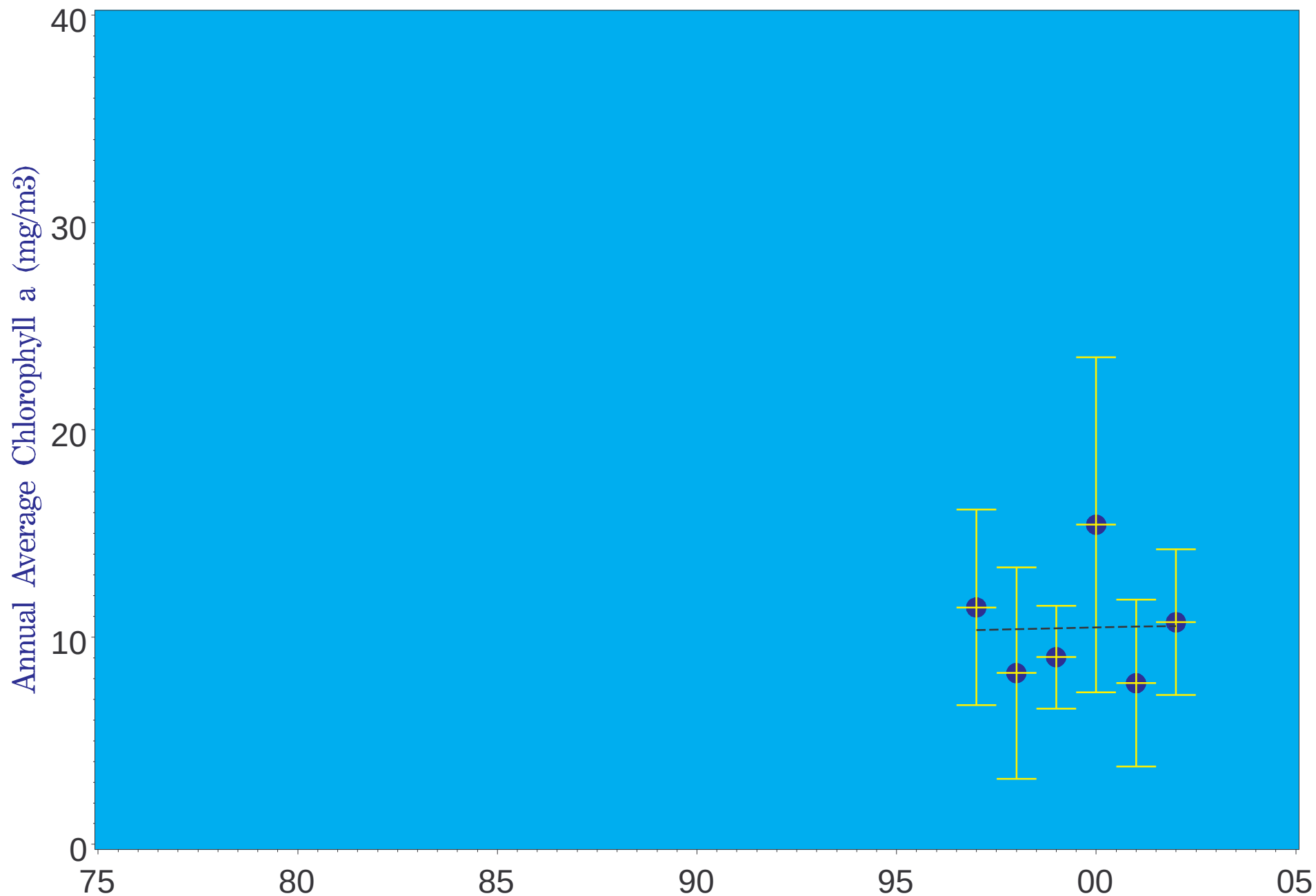


Figure 4.5.111 Long-term bottom chlorophyll a at river kilometer 6.6

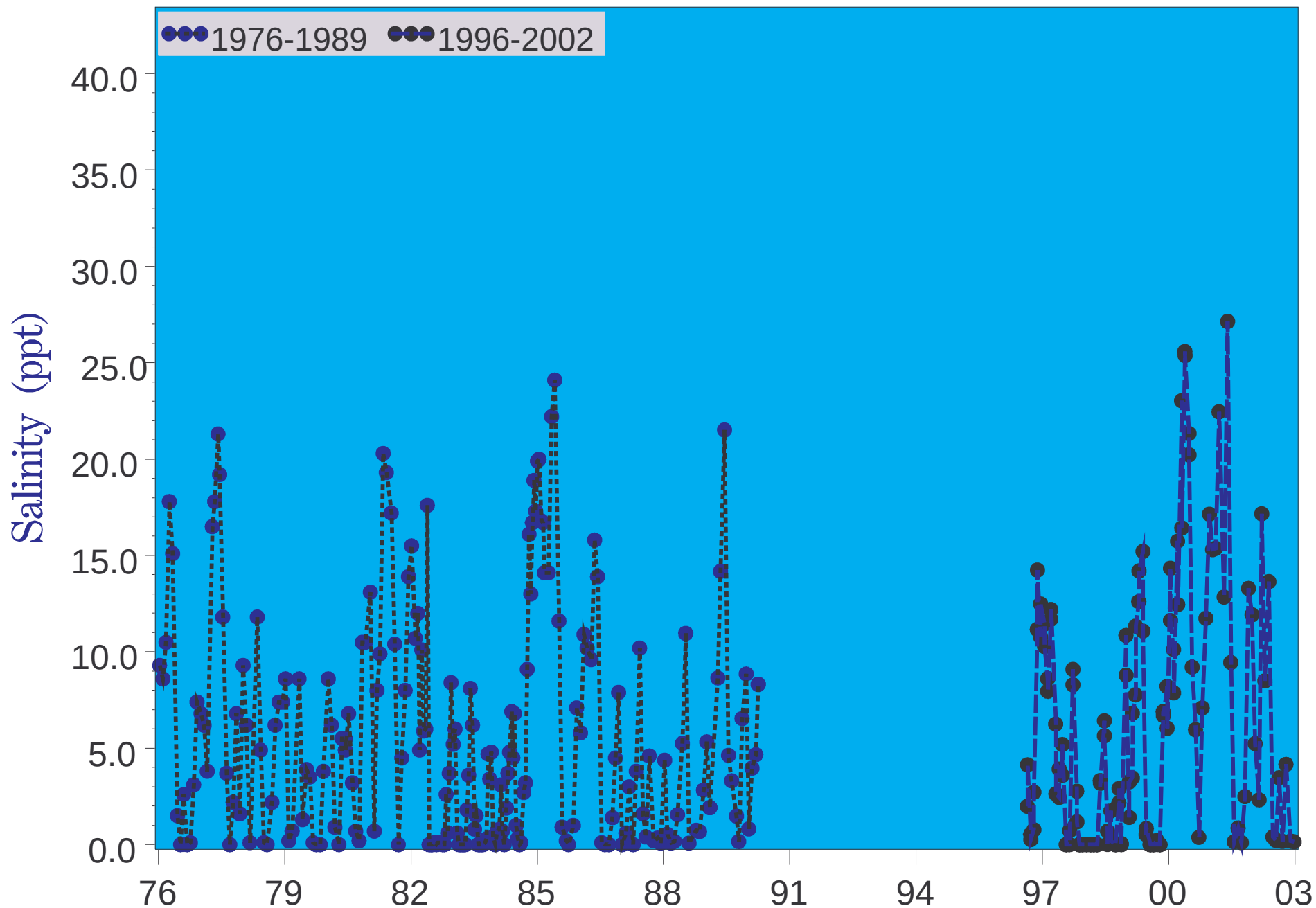


Figure 4.5.112 Long-term surface salinity at river kilometer 15.5



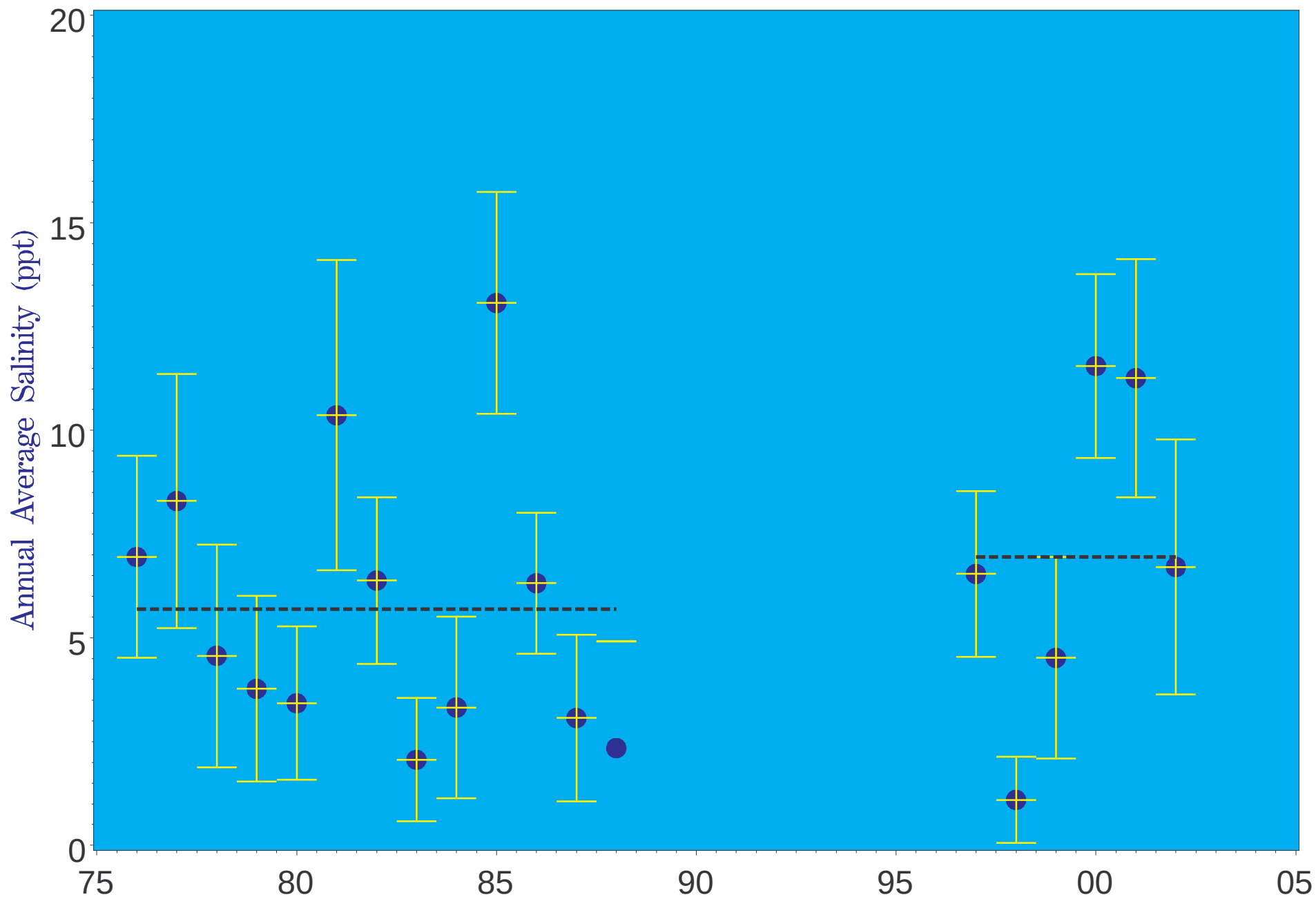


Figure 4.5.113 Long-term surface salinity at river kilometer 15.5

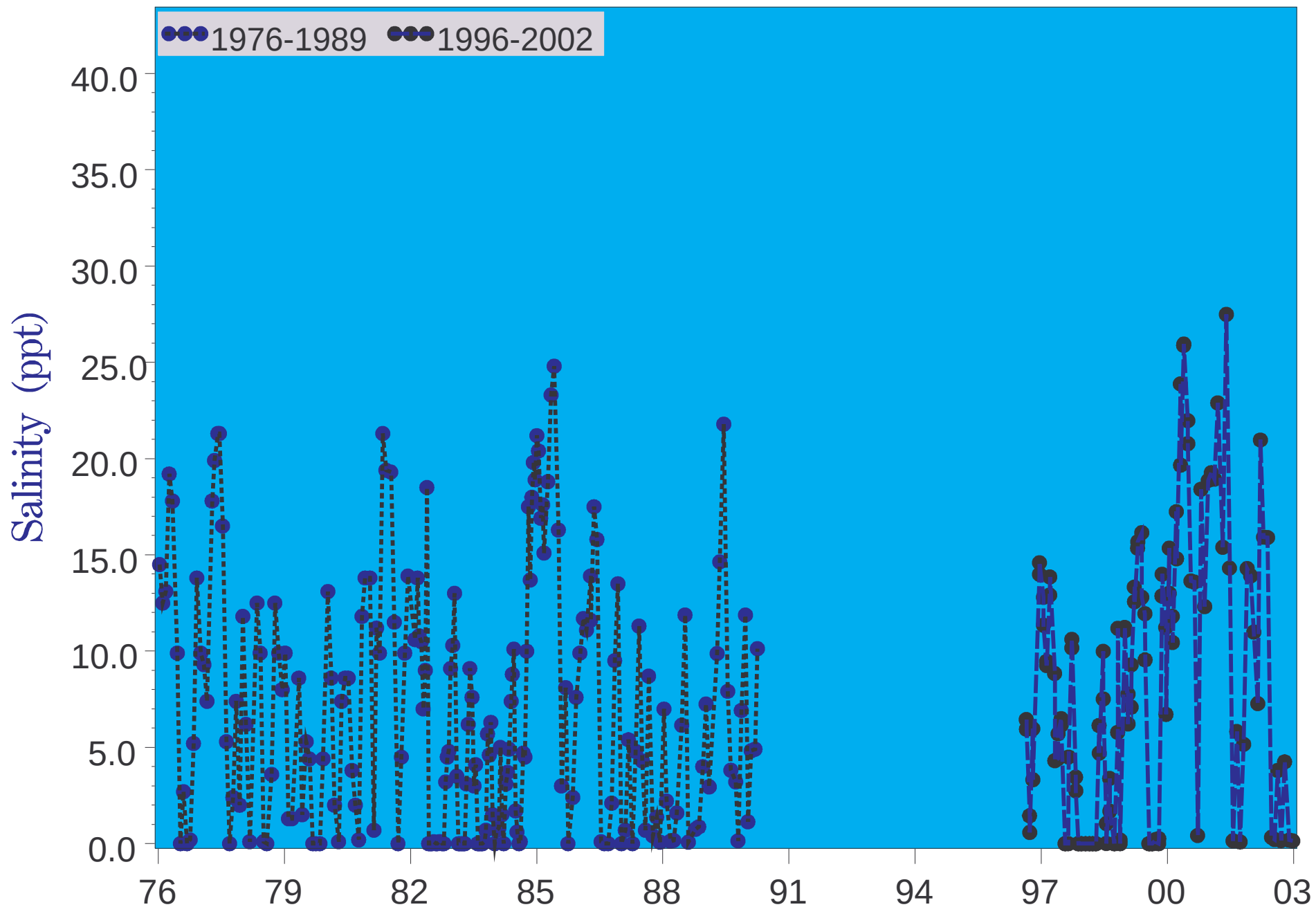


Figure 4.5.114 Long-term bottom salinity at river kilometer 15.5

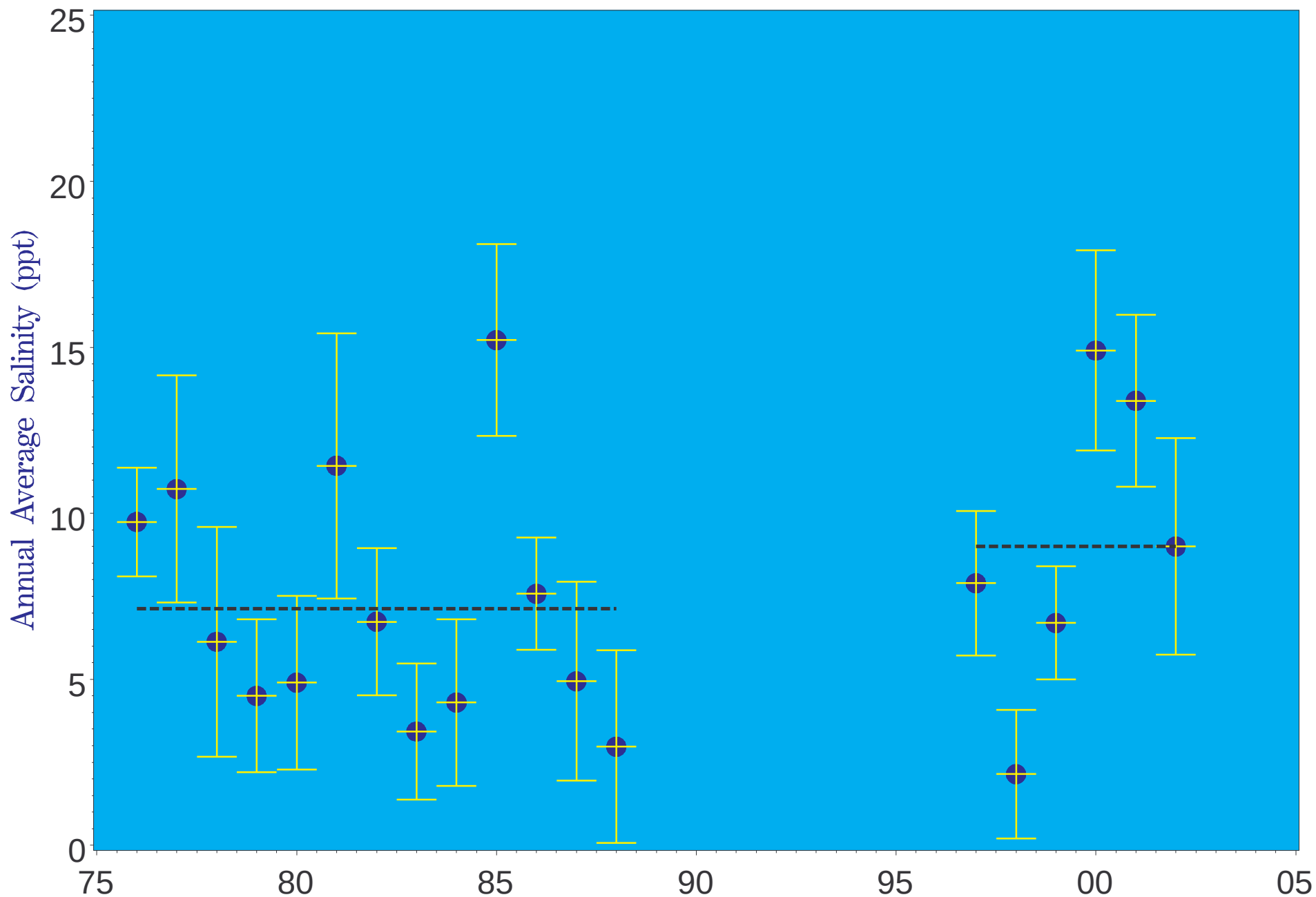


Figure 4.5.115 Long-term bottom salinity at river kilometer 15.5

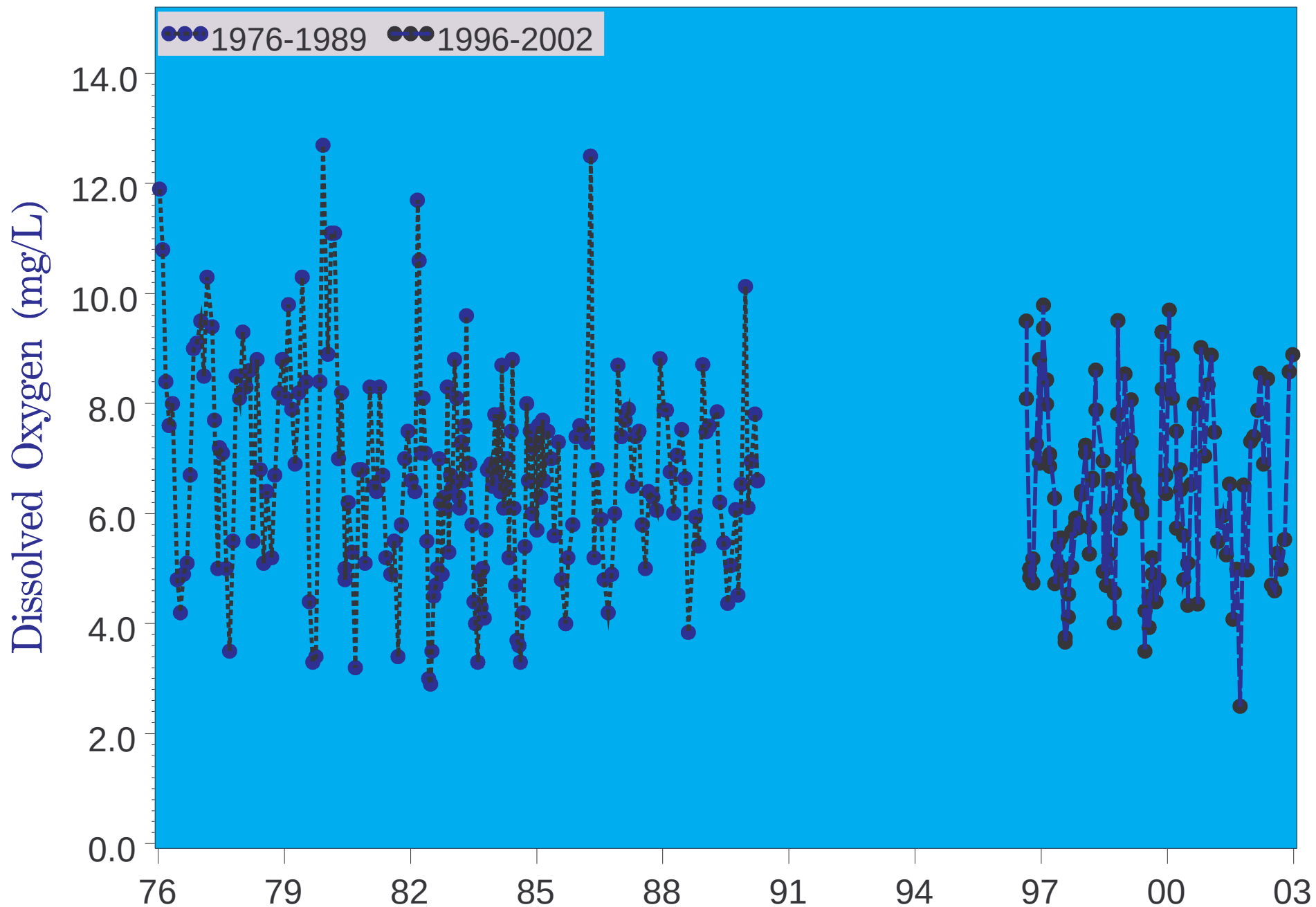


Figure 4.5.116 Long-term surface dissolved oxygen at river kilometer 15.5

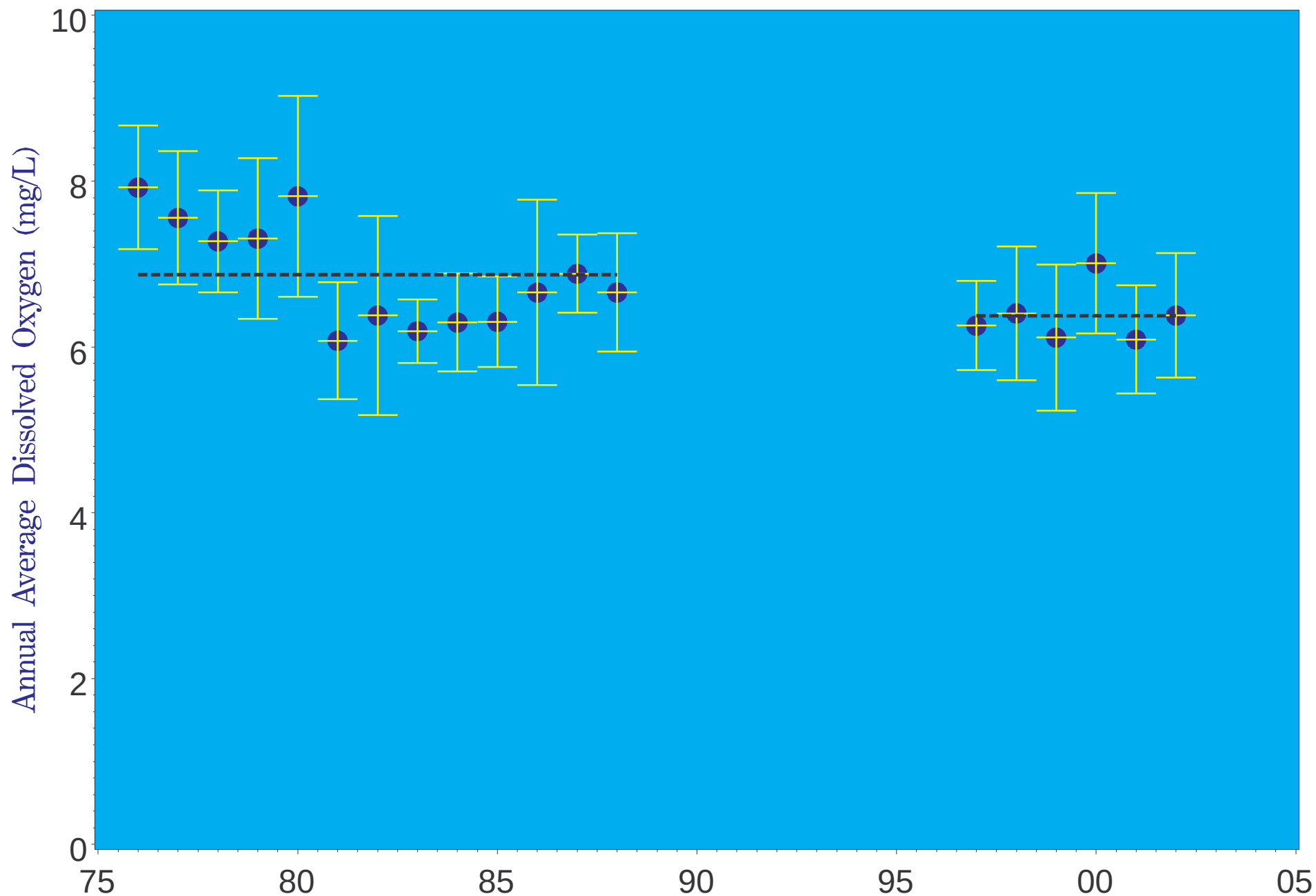


Figure 4.5.117 Long-term surface dissolved oxygen at river kilometer 15.5

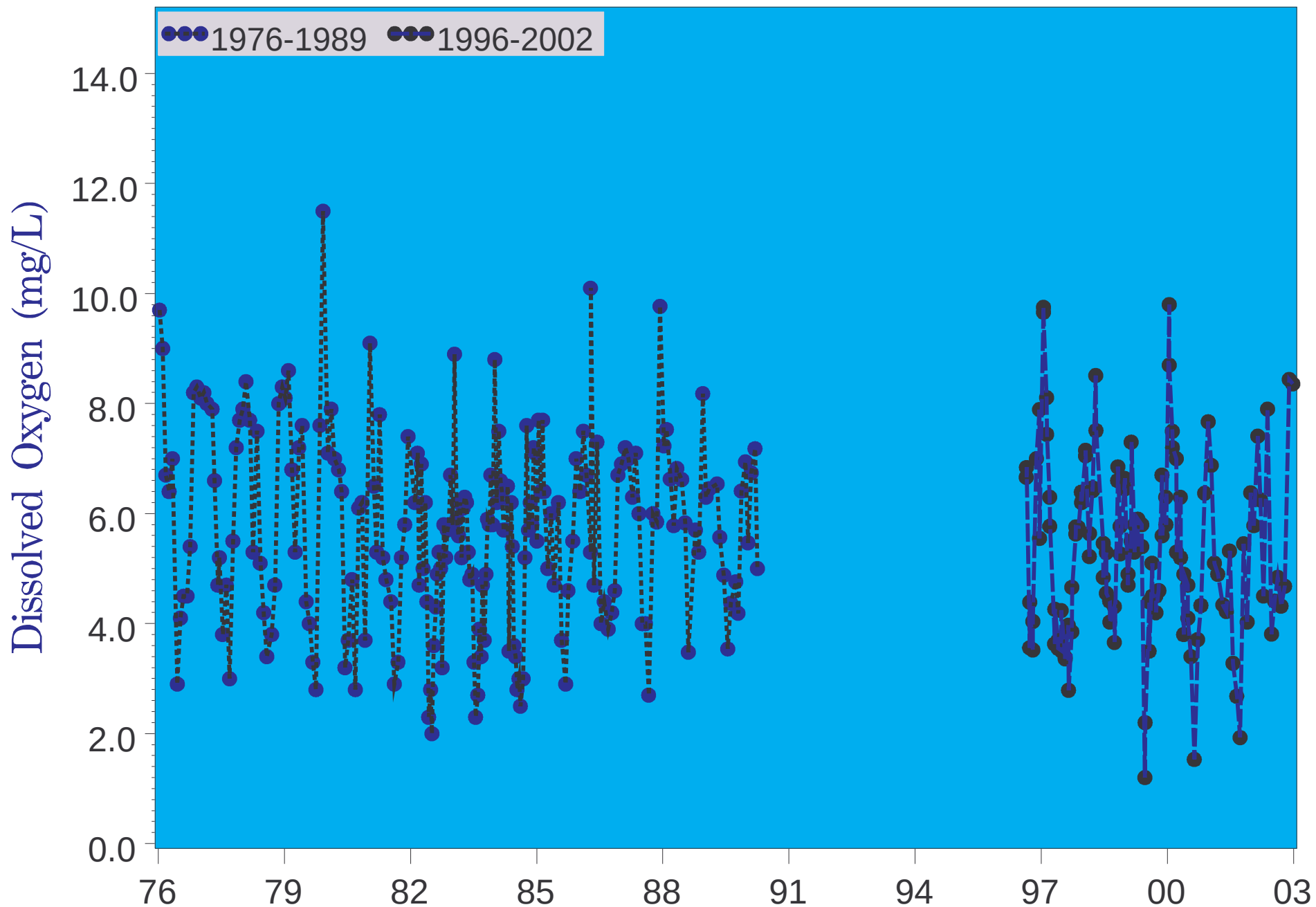


Figure 4.5.118 Long-term bottom dissolved oxygen at river kilometer 15.5

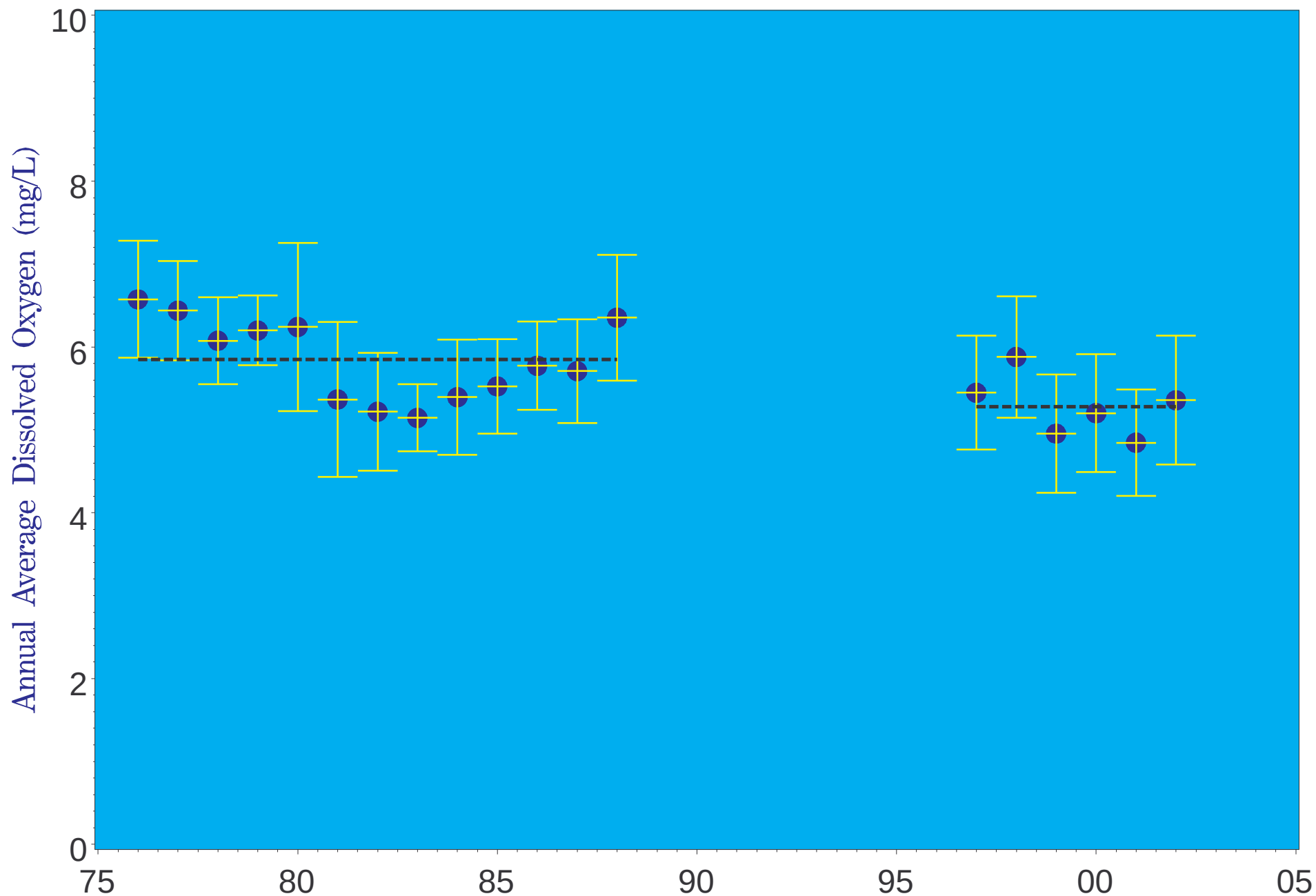


Figure 4.5.119 Long-term bottom dissolved oxygen at river kilometer 15.5

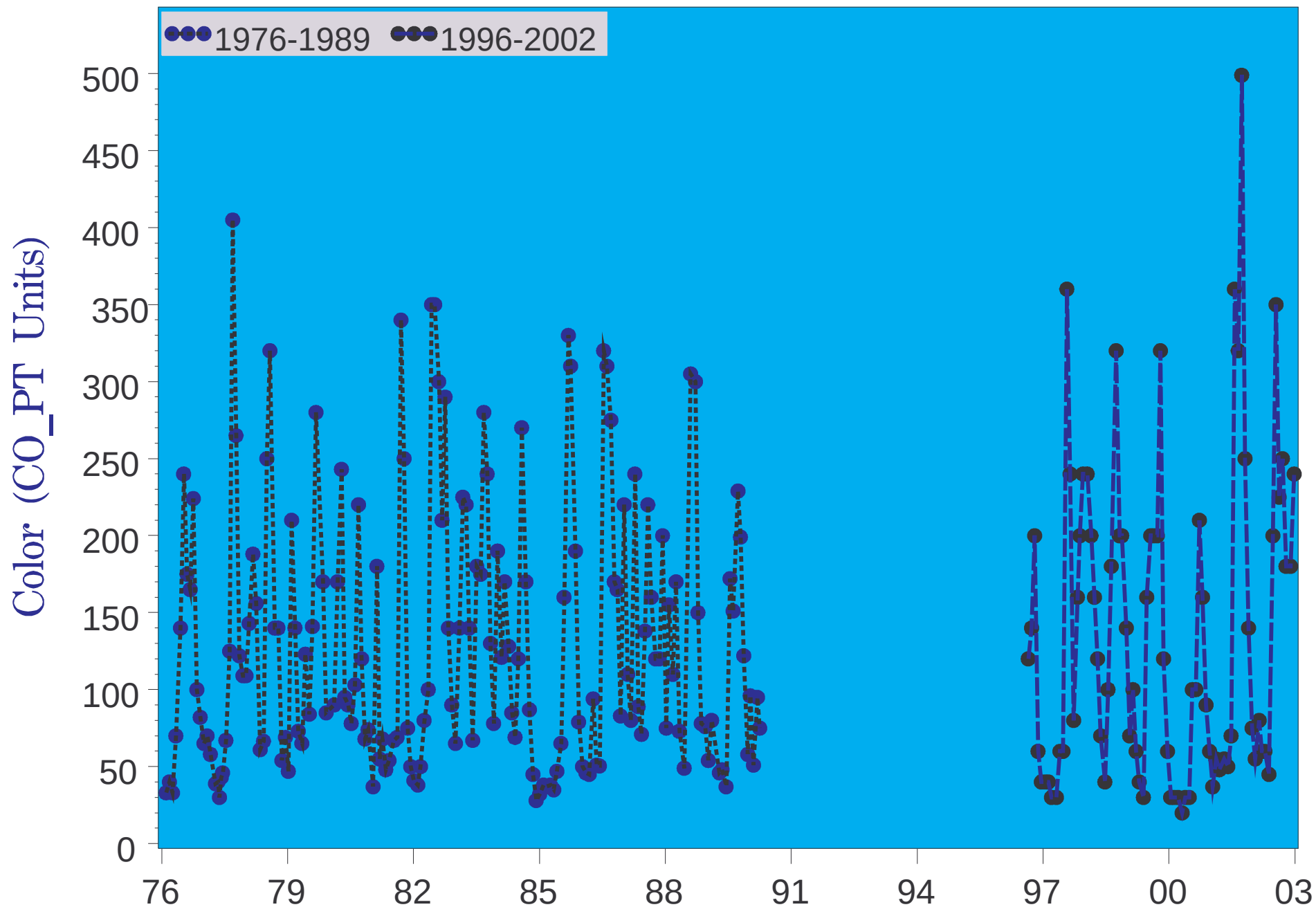


Figure 4.5.120 Long-term surface color at river kilometer 15.5



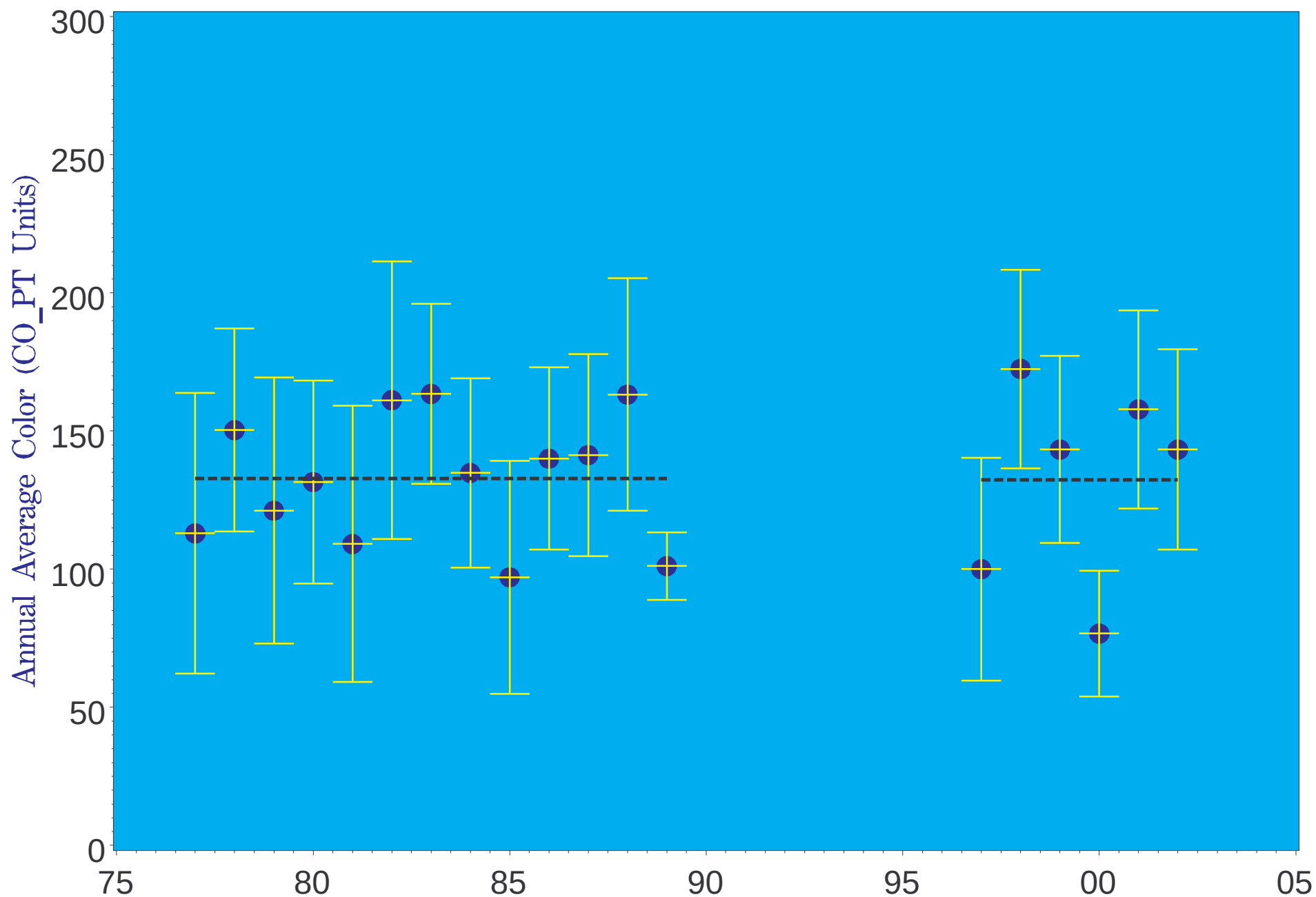


Figure 4.5.121 Long-term surface color at river kilometer 15.5

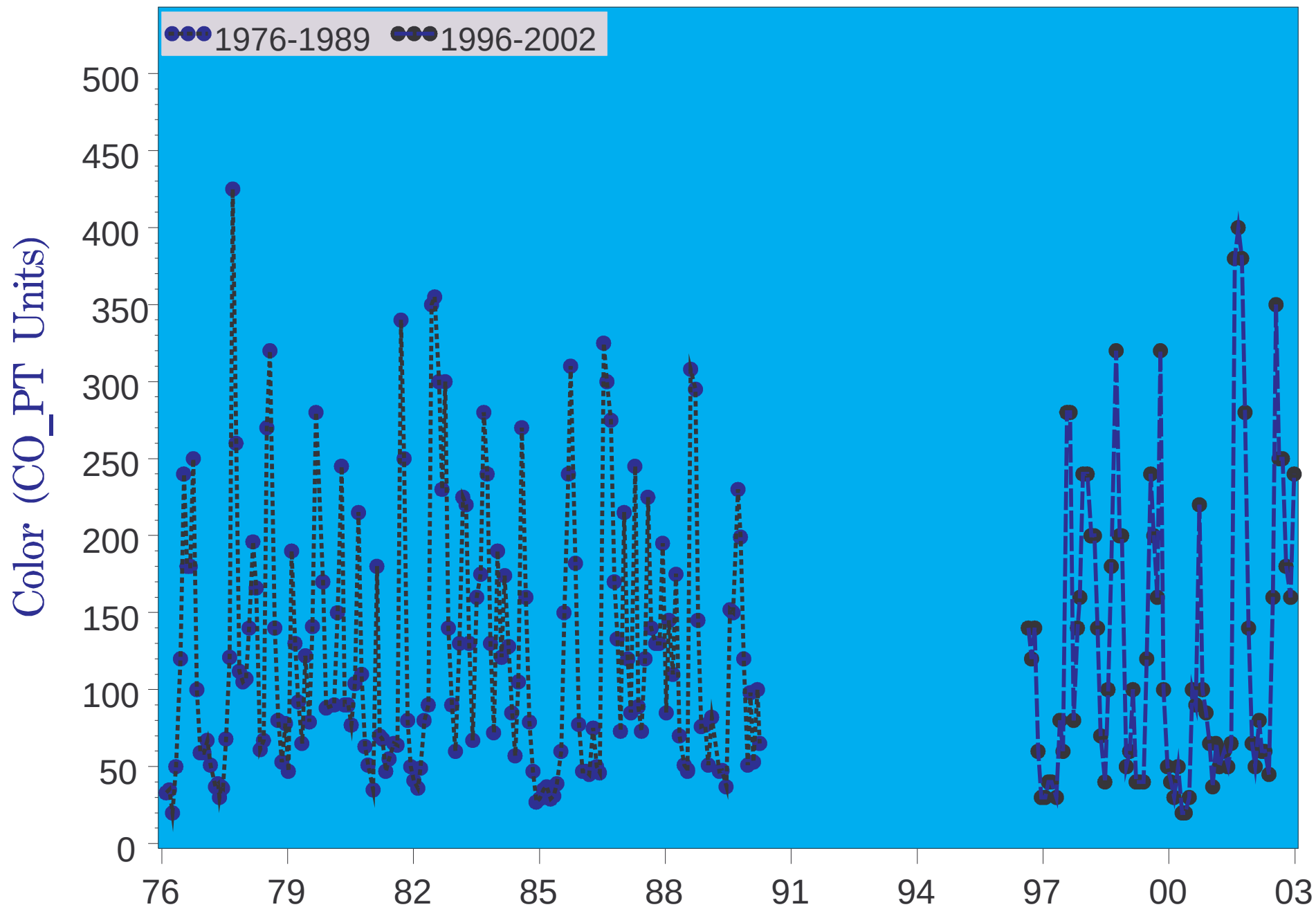


Figure 4.5.122 Long-term bottom color at river kilometer 15.5

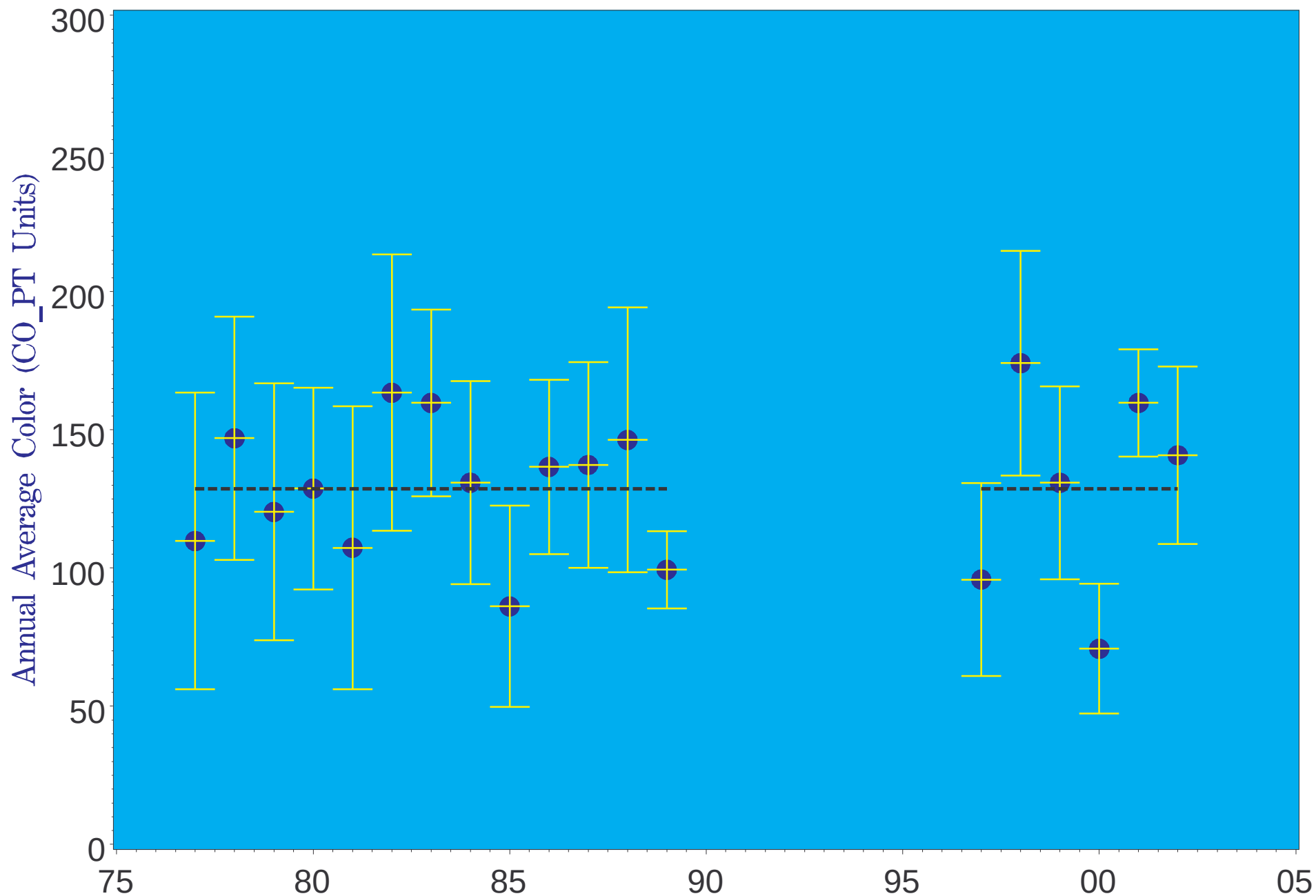


Figure 4.5.123 Long-term bottom color at river kilometer 15.5

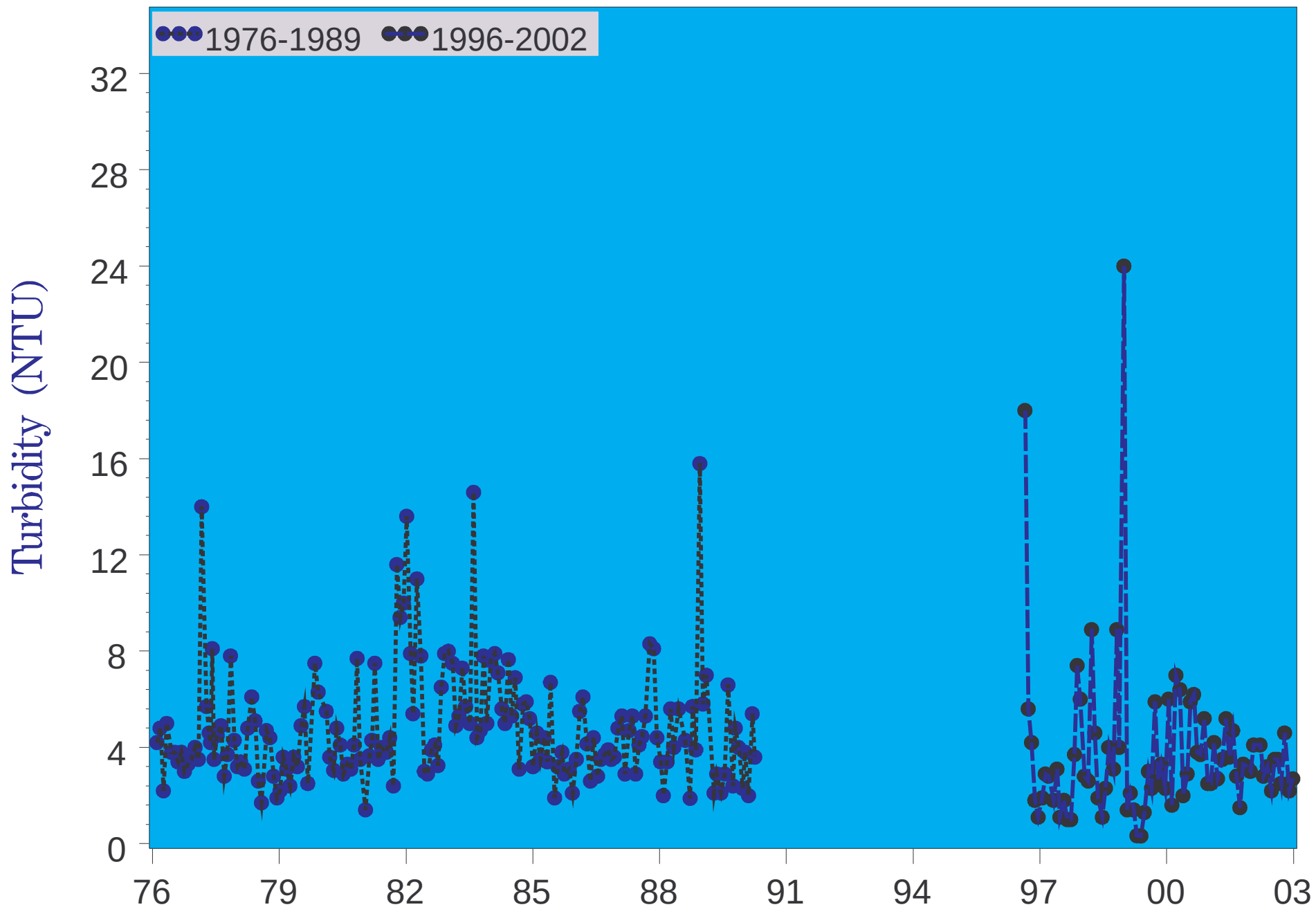


Figure 4.5.124 Long-term surface turbidity at river kilometer 15.5

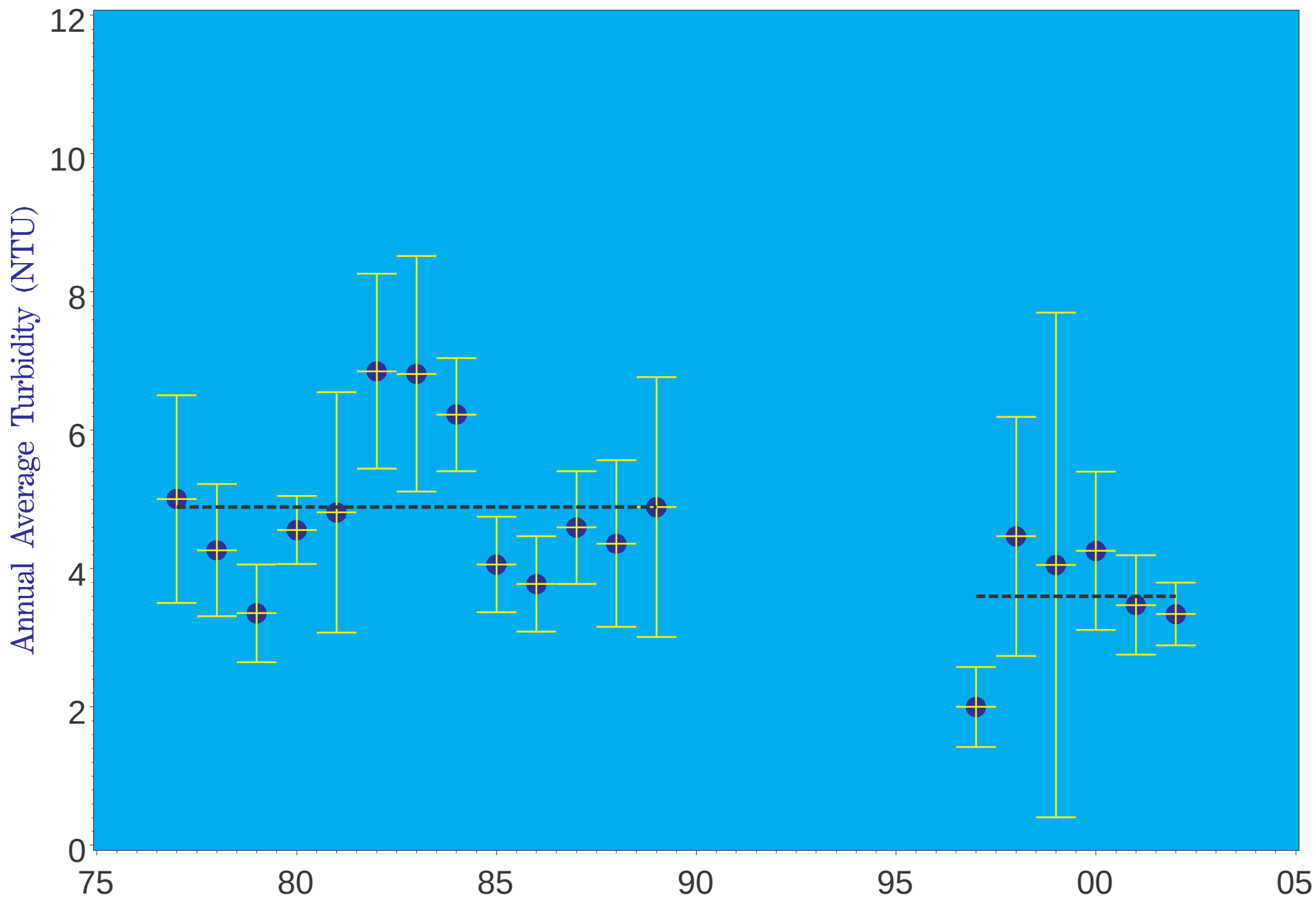


Figure 4.5.125 Long-term surface turbidity at river kilometer 15.5

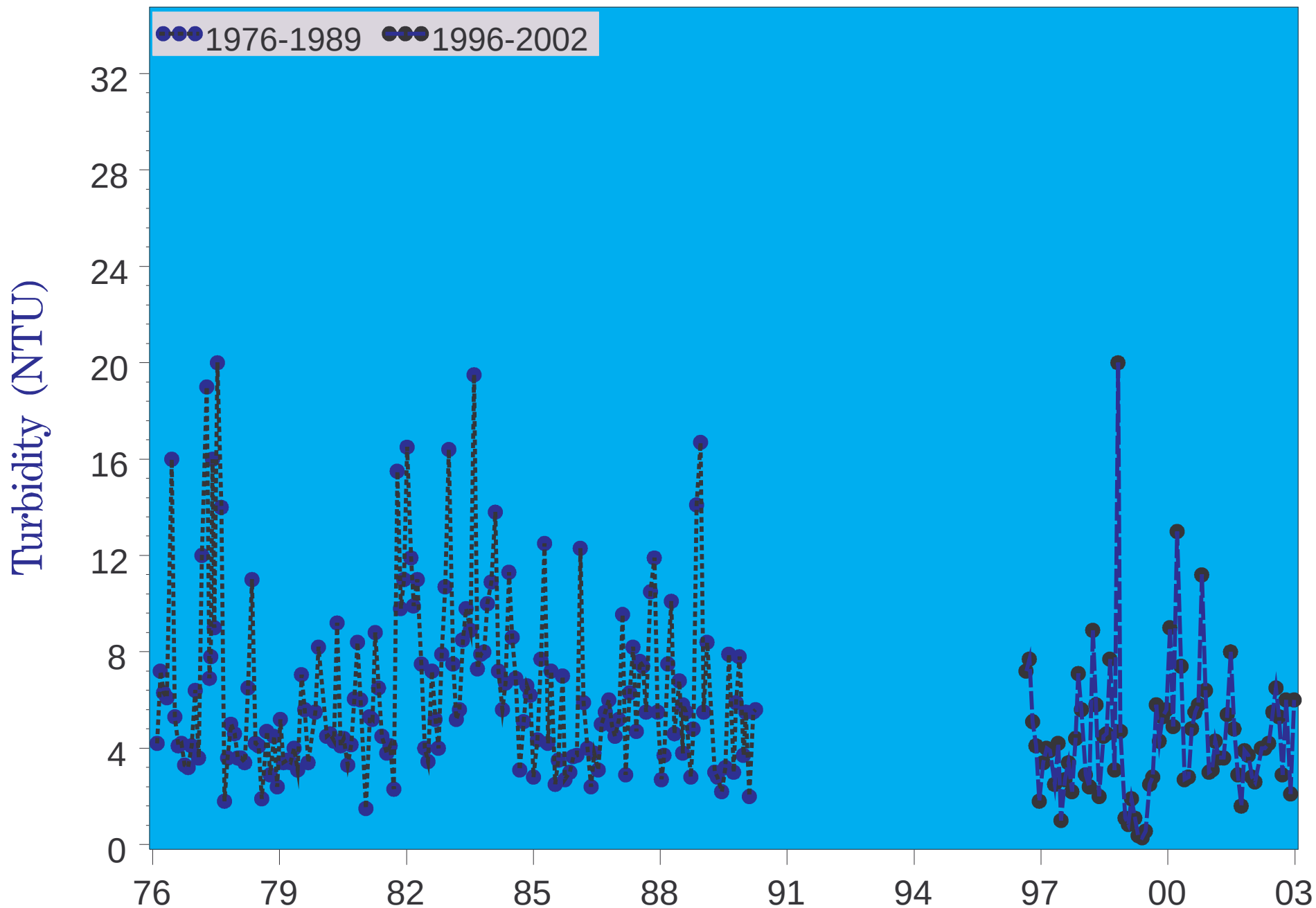


Figure 4.5.126 Long-term bottom turbidity at river kilometer 15.5

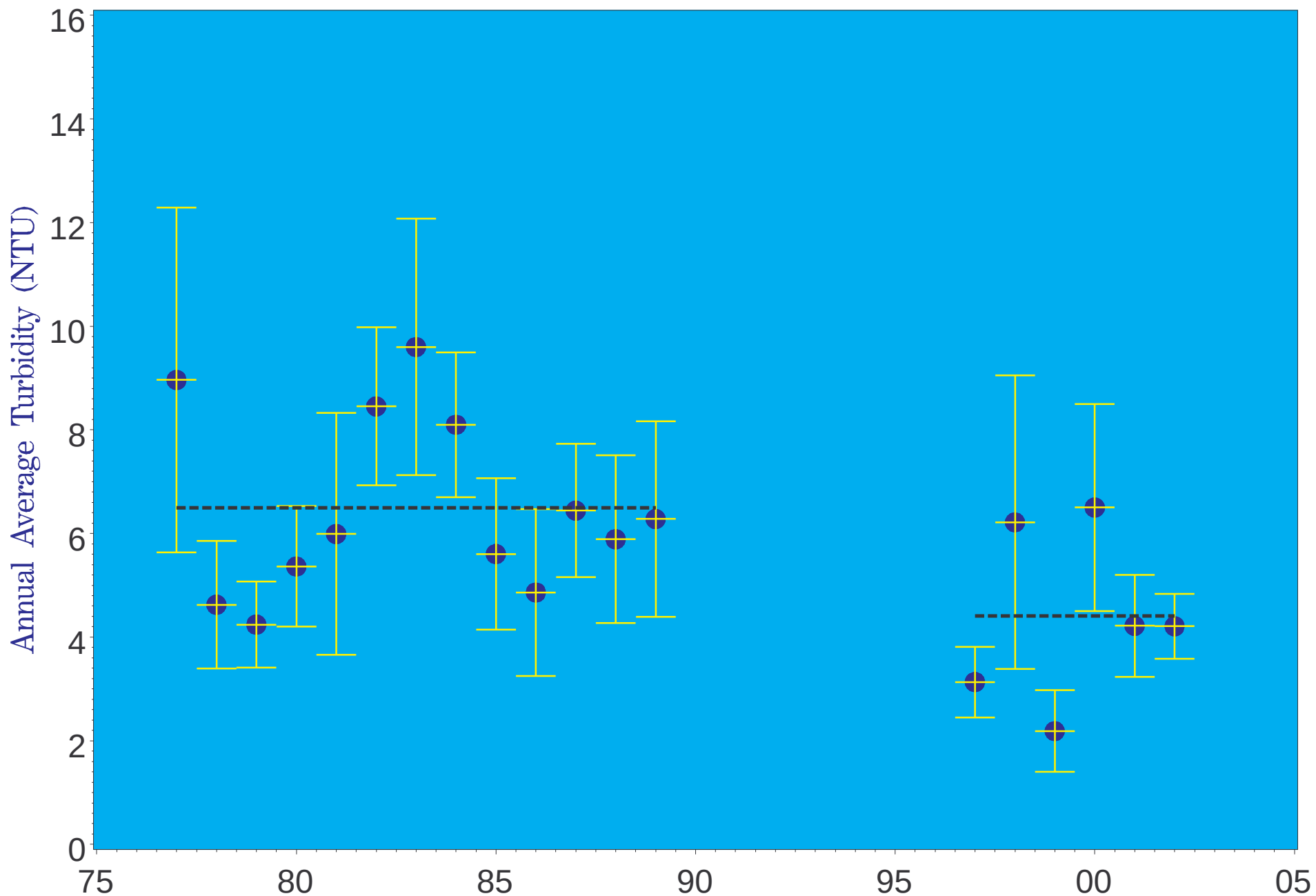


Figure 4.5.127 Long-term bottom turbidity at river kilometer 15.5

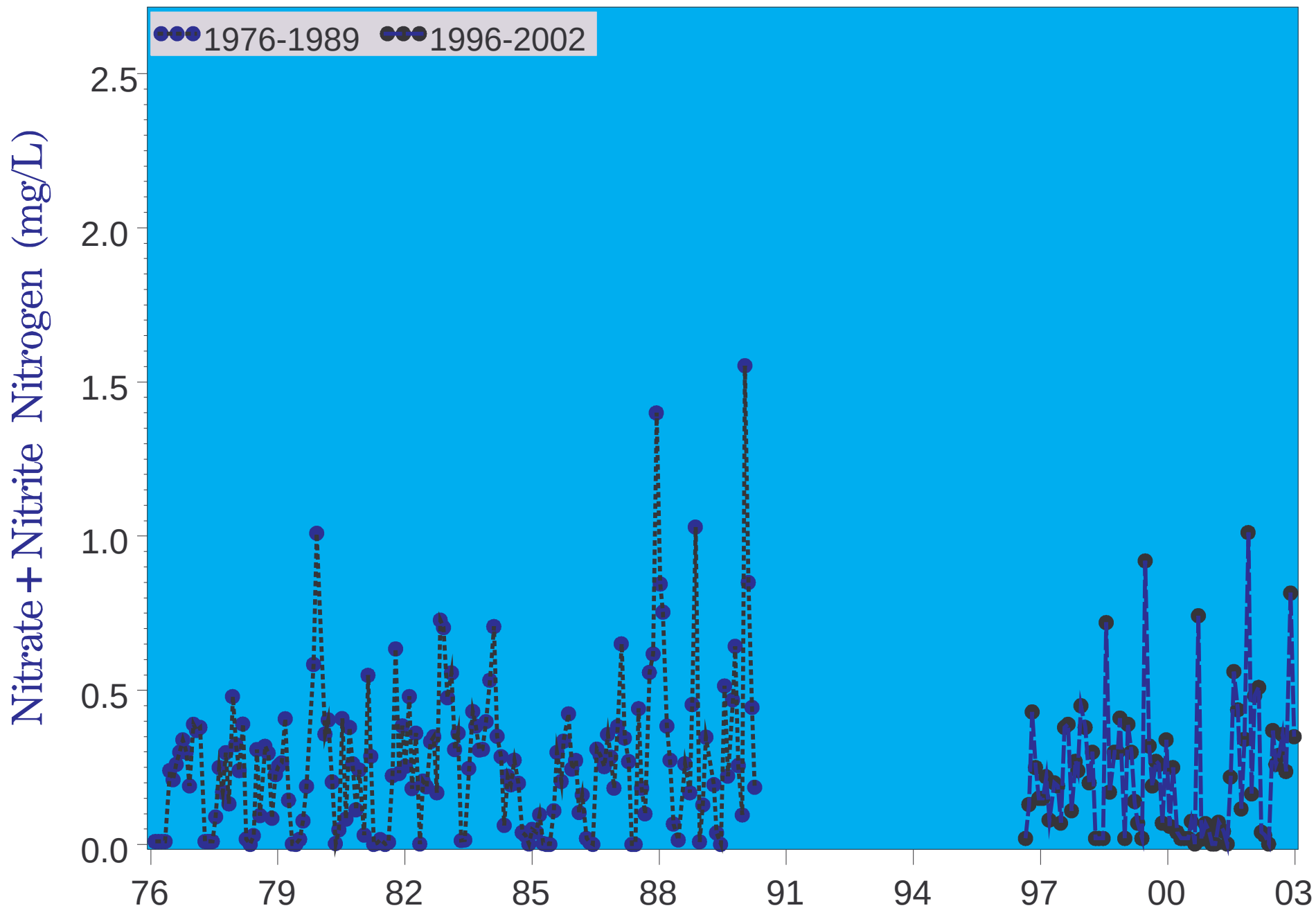


Figure 4.5.128 Long-term surface nitrate/nitrite nitrogen at river kilometer 15.5



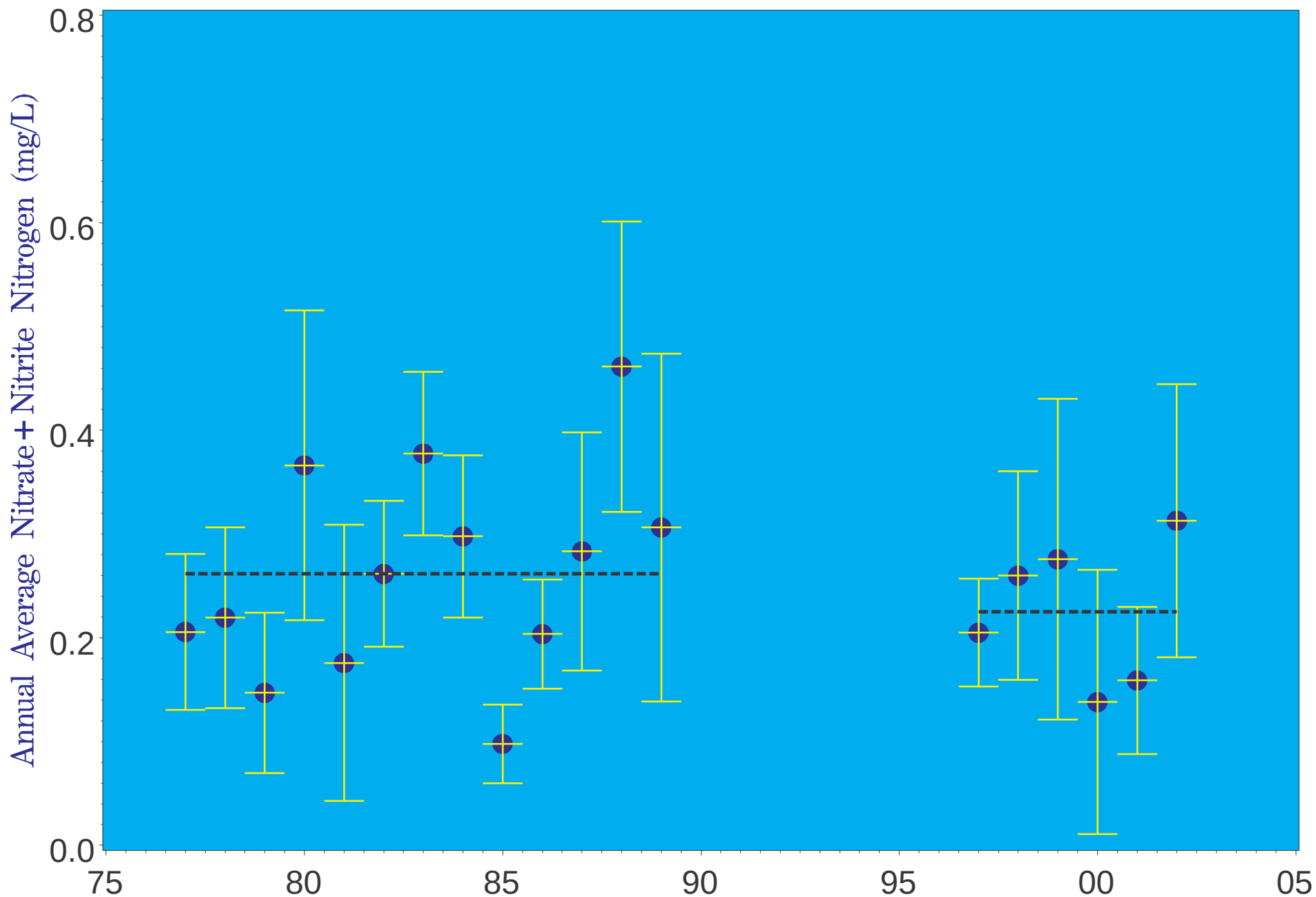


Figure 4.5.129 Long-term surface nitrate/nitrite nitrogen at river kilometer 15.5

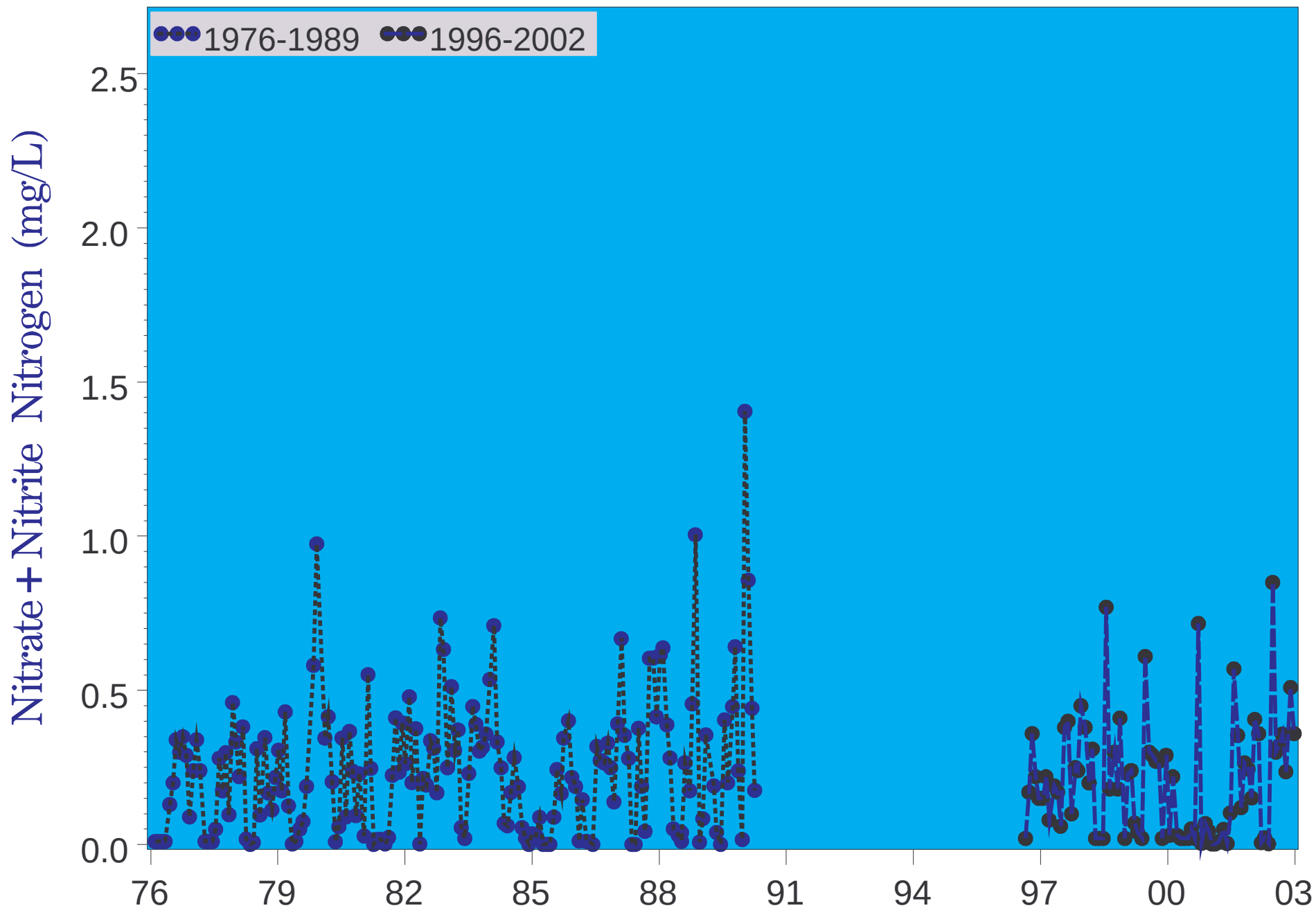


Figure 4.5.130 Long-term bottom nitrate/nitrite nitrogen at river kilometer 15.5

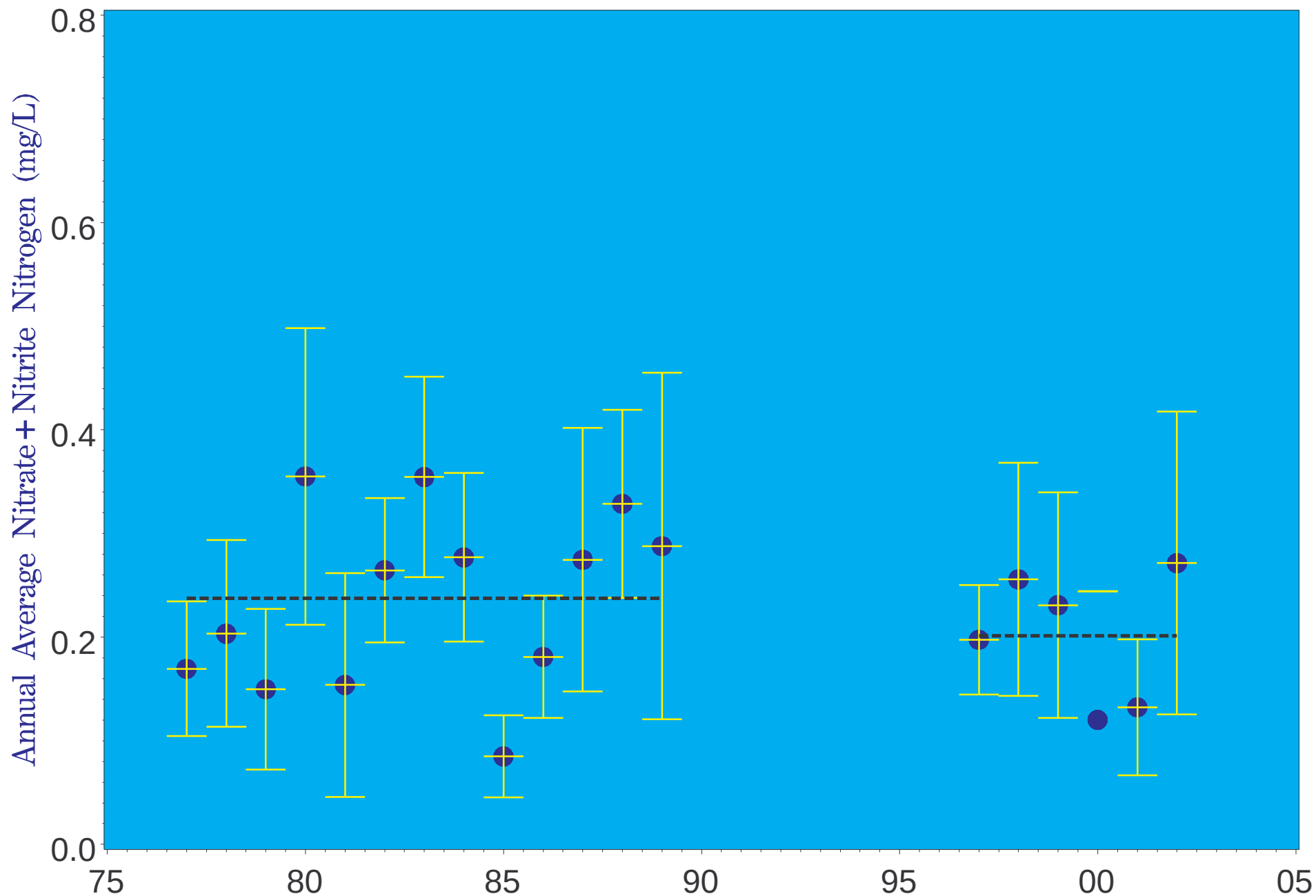


Figure 4.5.131 Long-term bottom nitrate/nitrite nitrogen at river kilometer 15.5

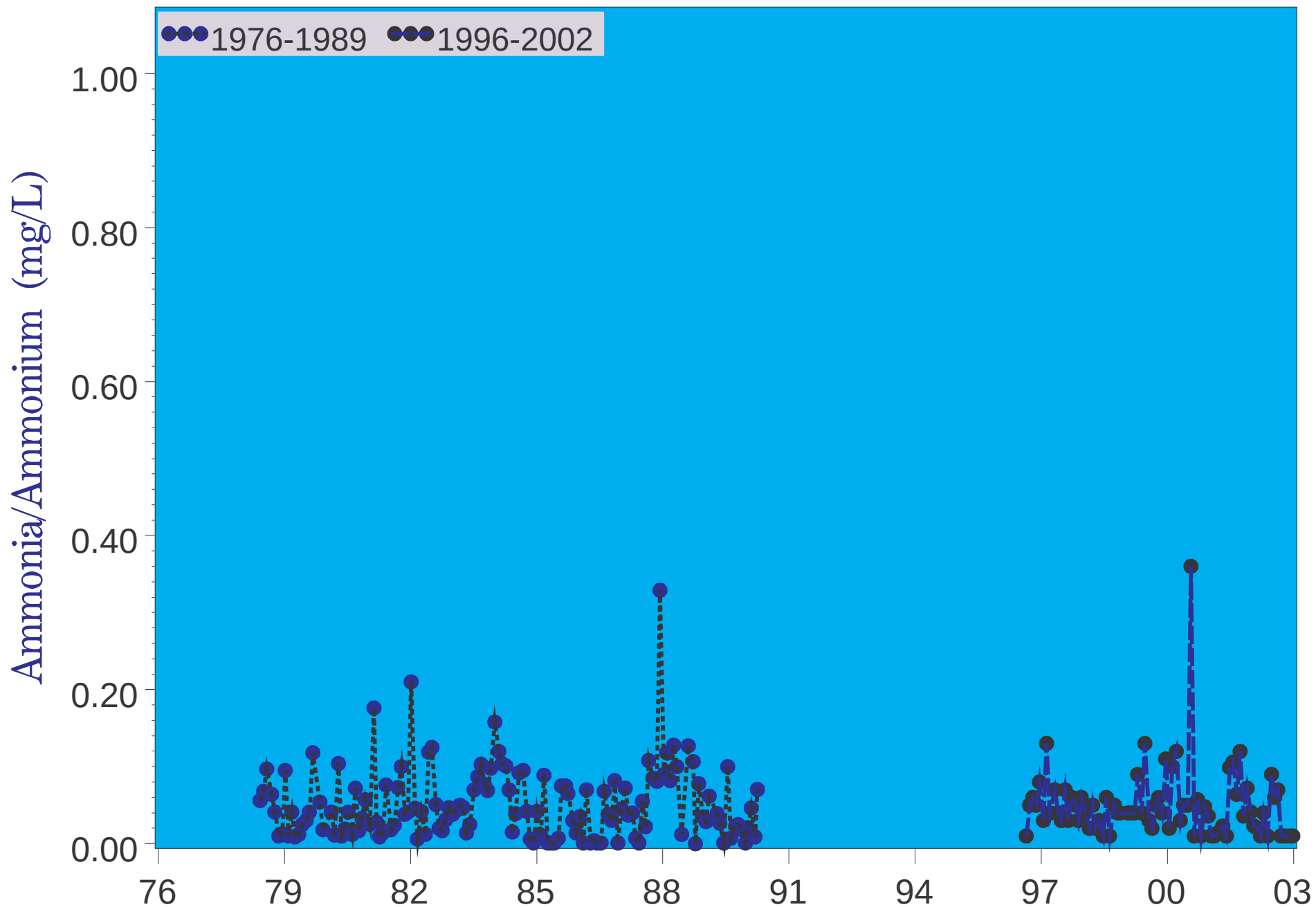


Figure 4.5.132 Long-term surface ammonia/ammonium at river kilometer 15.5

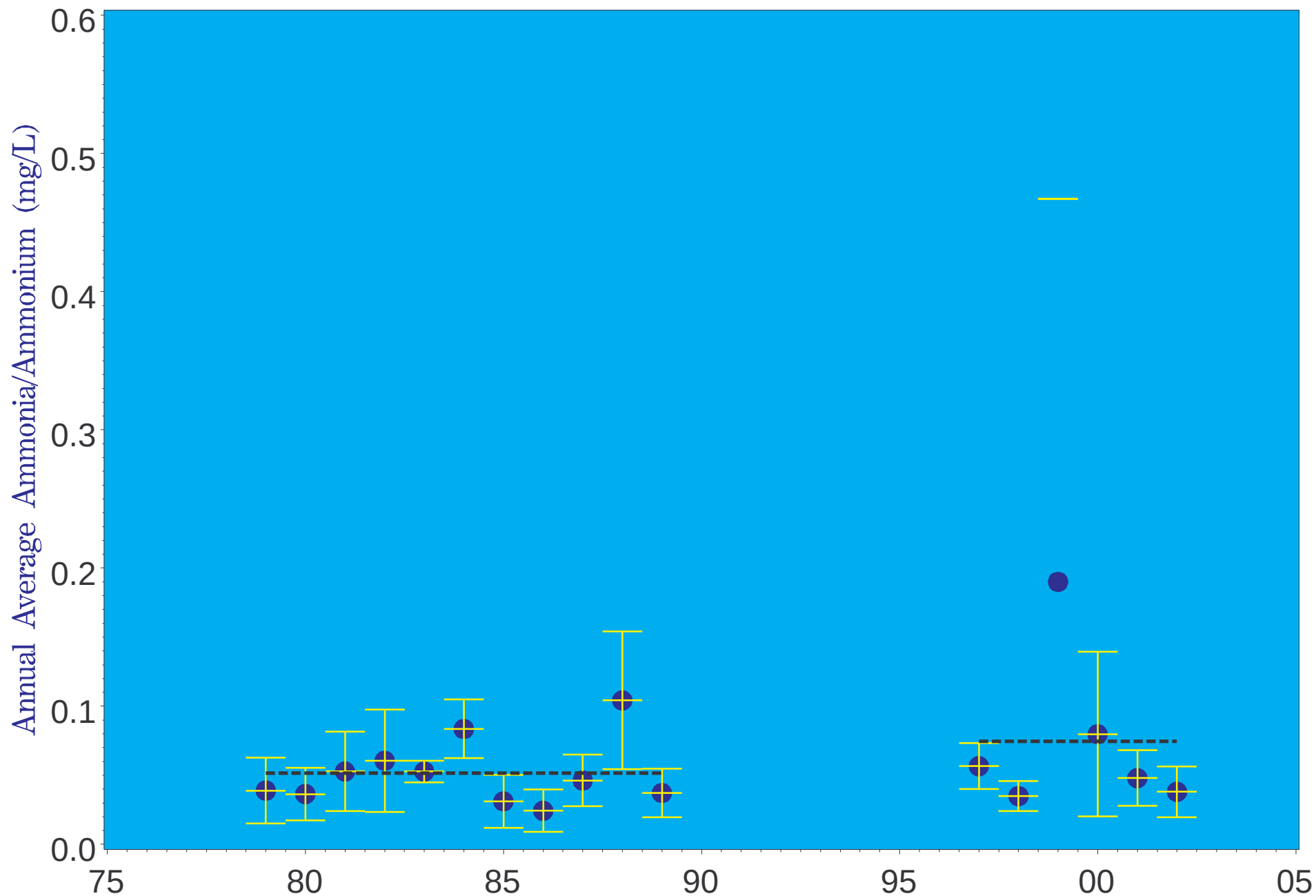


Figure 4.5.133 Long-term surface ammonia/ammonium at river kilometer 15.5

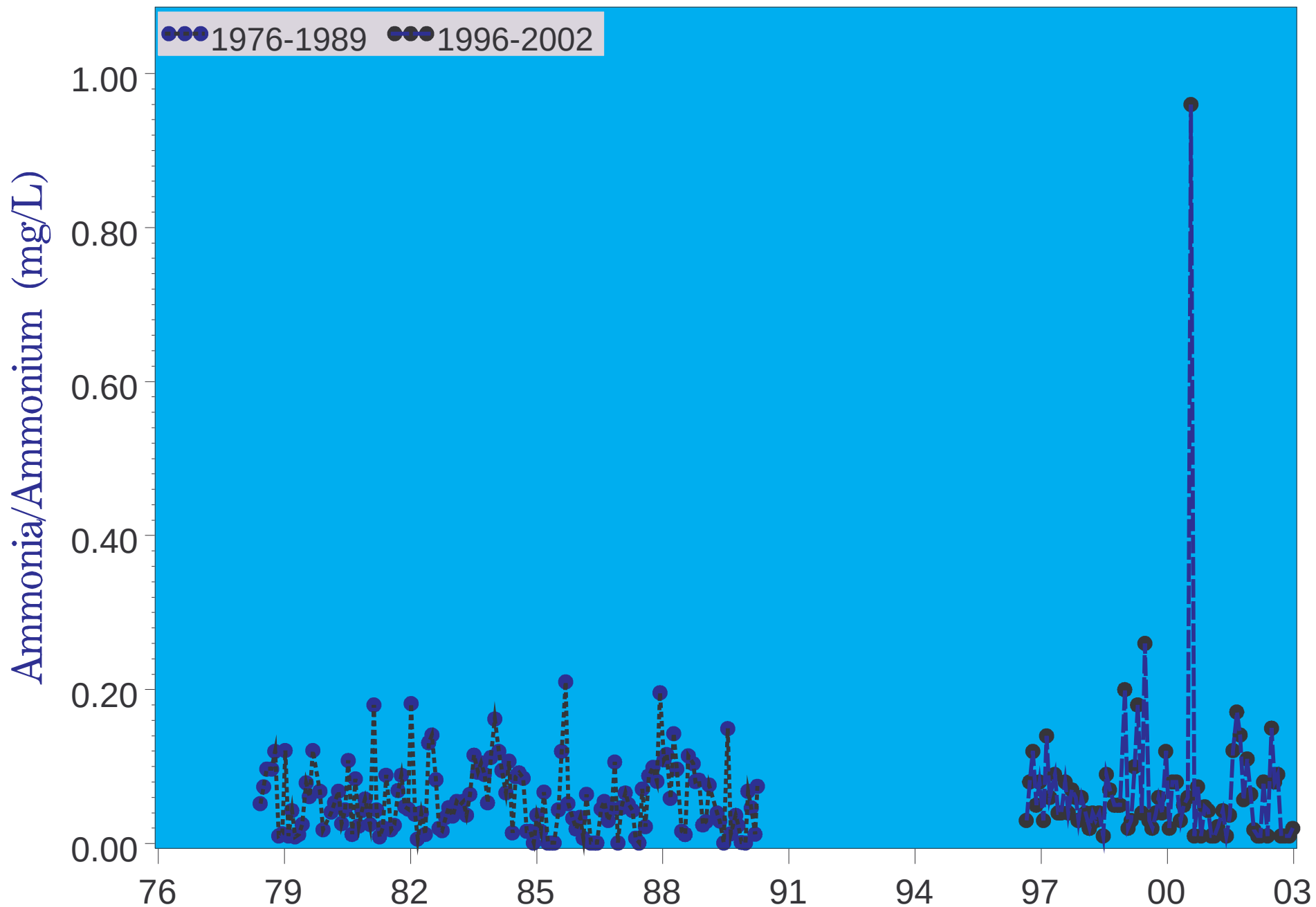


Figure 4.5.134 Long-term bottom ammonia/ammonium at river kilometer 15.5

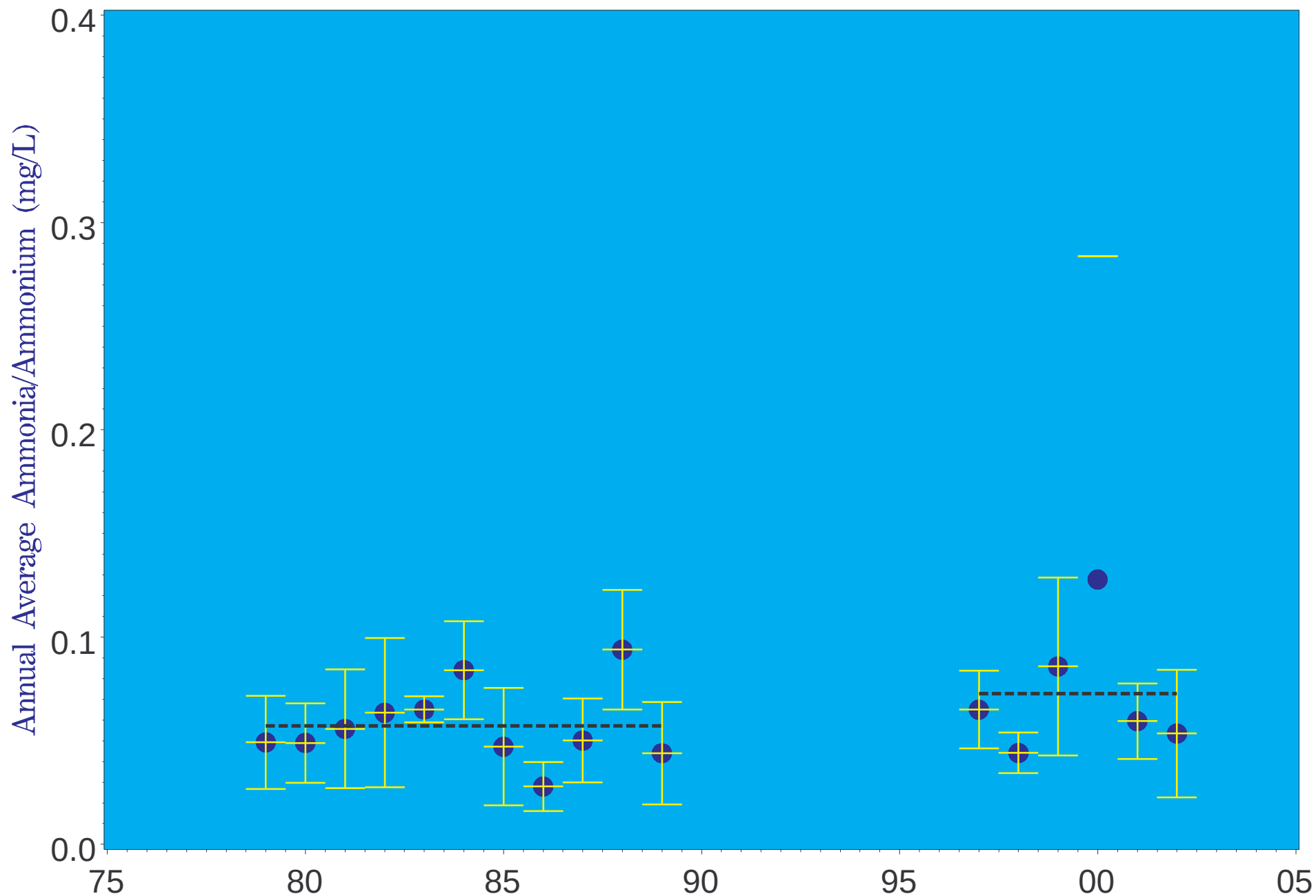


Figure 4.5.135 Long-term bottom ammonia/ammonium at river kilometer 15.5

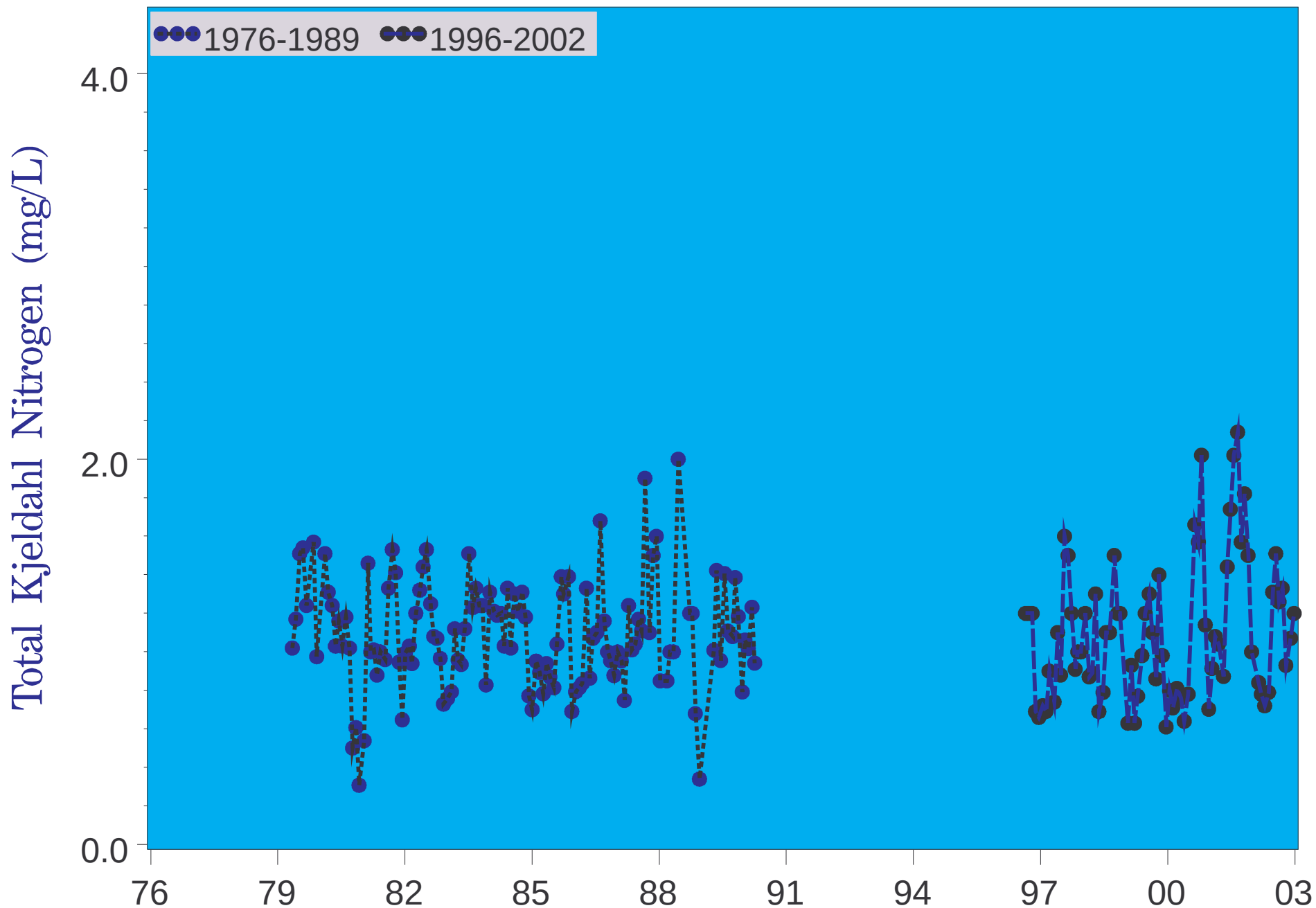


Figure 4.5.136 Long-term surface total Kjeldahl nitrogen at river kilometer 15.5



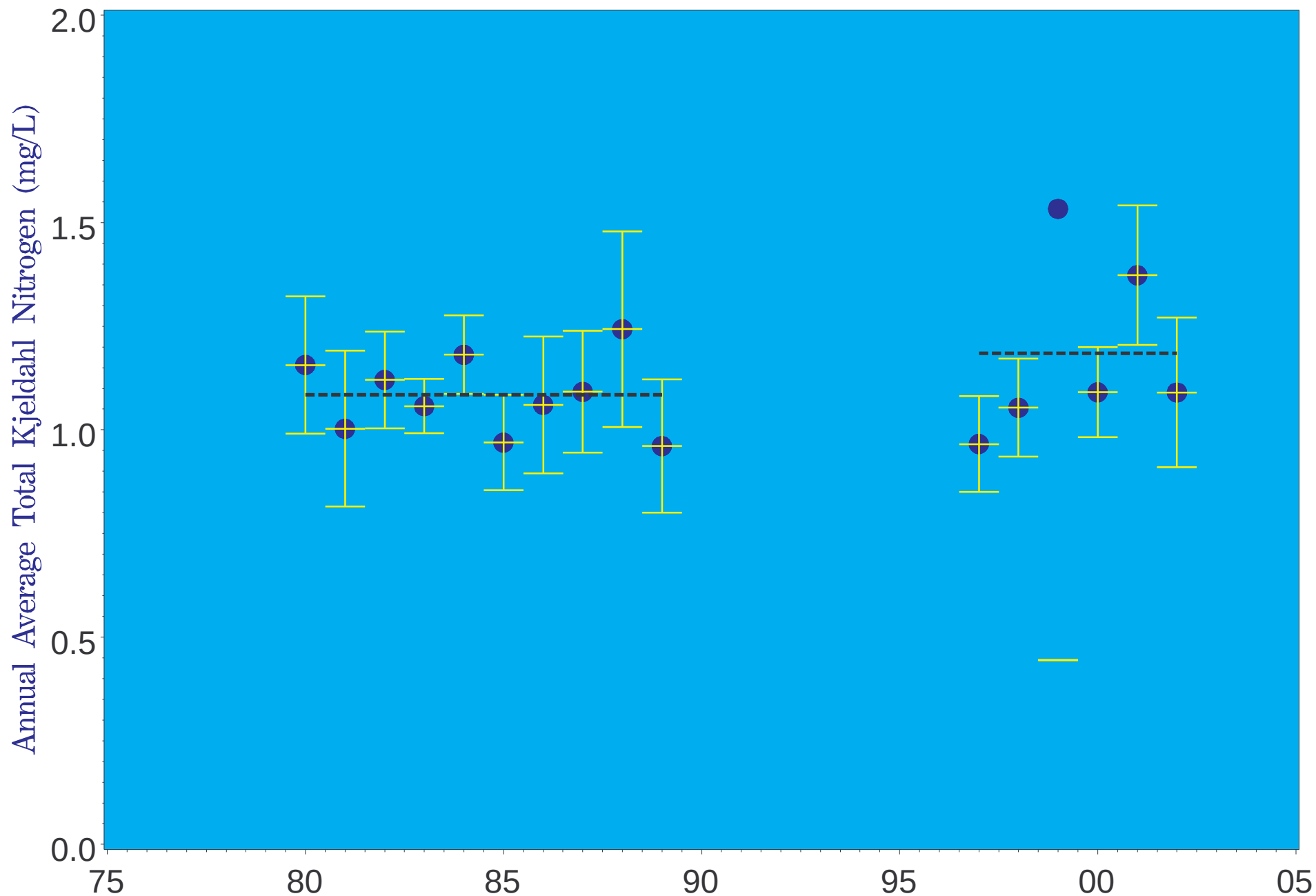


Figure 4.5.137 Long-term surface total Kjeldahl nitrogen at river kilometer 15.5

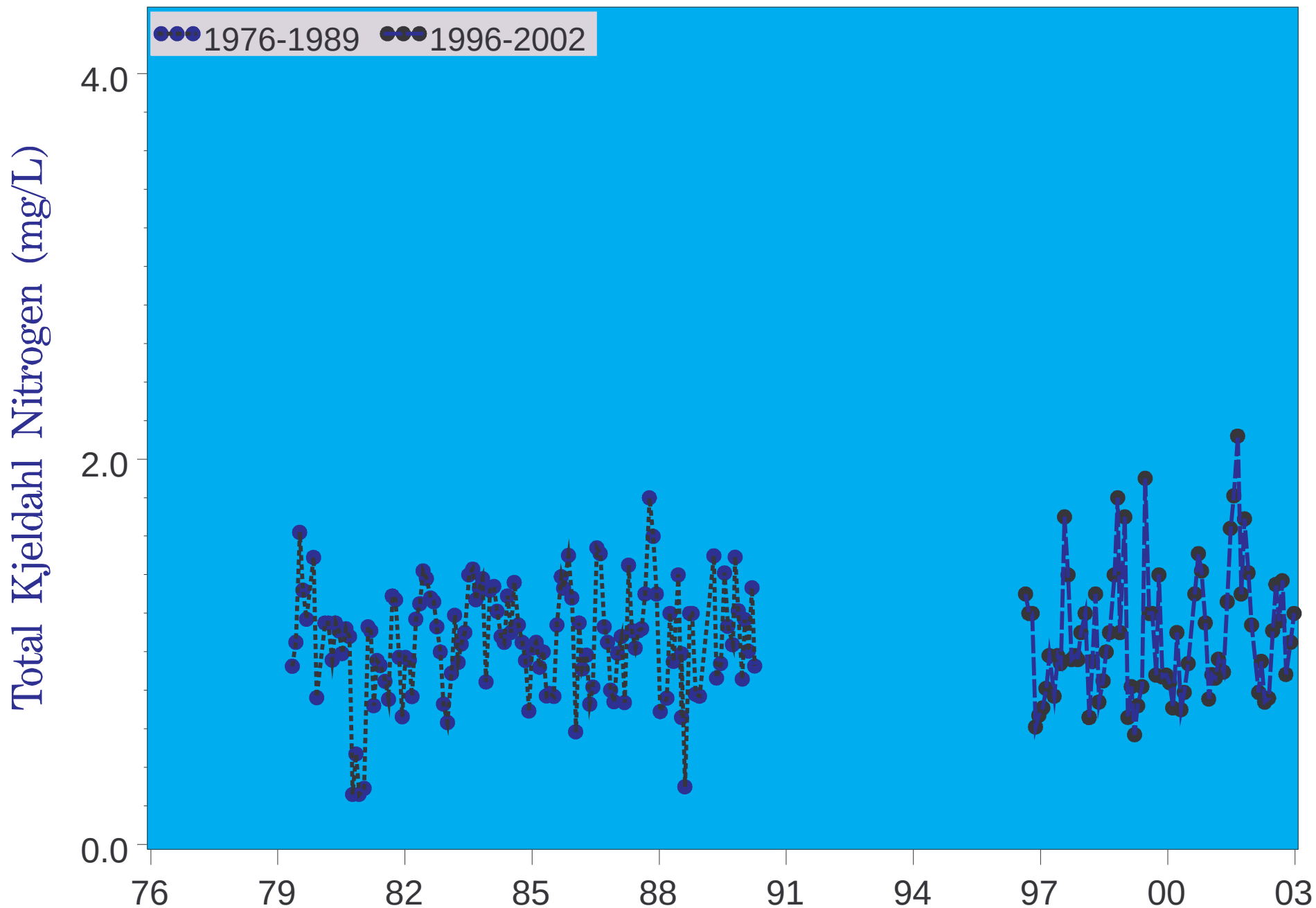


Figure 4.5.138 Long-term bottom total Kjeldhal nitrogen at river kilometer 15.5

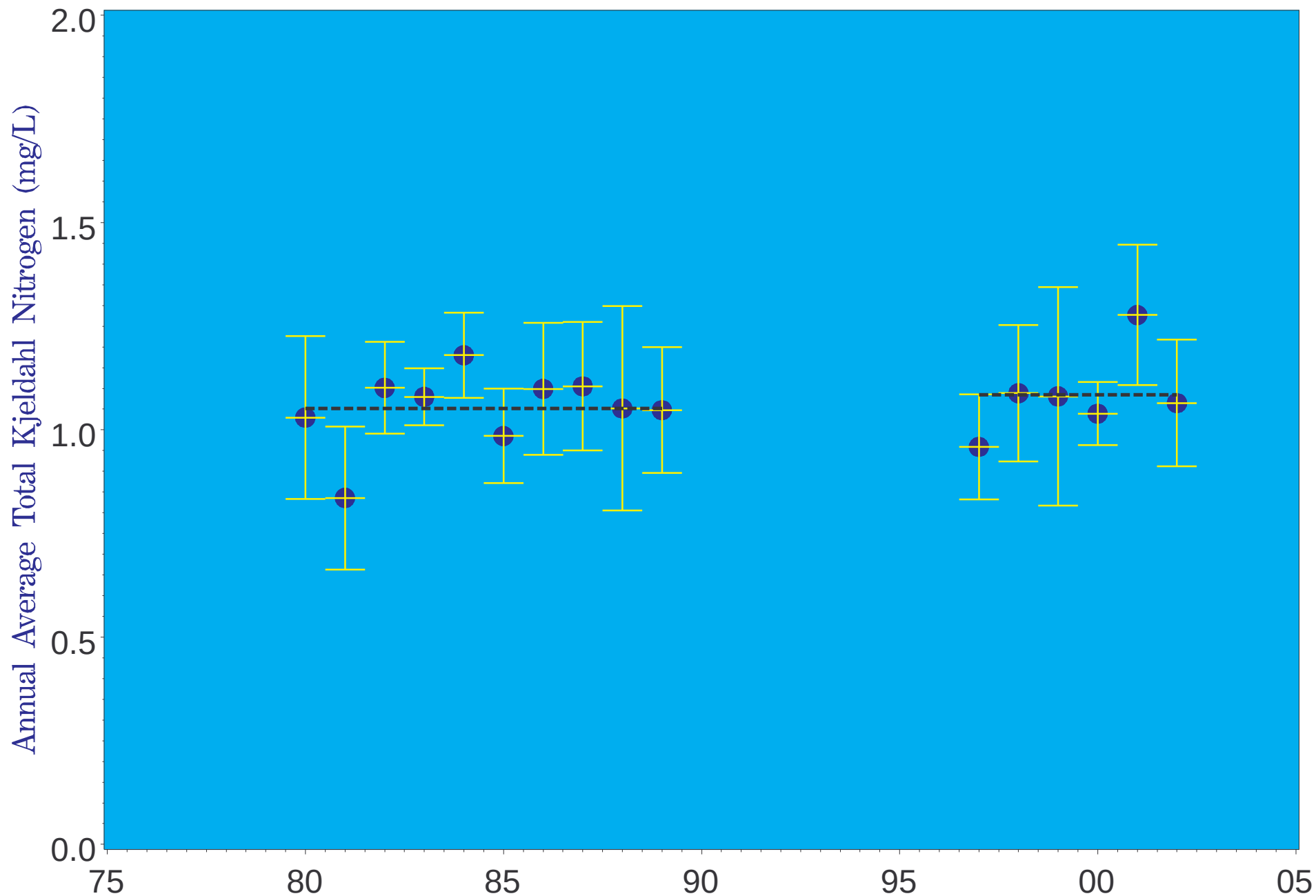


Figure 4.5.139 Long-term bottom total Kjeldhal nitrogen at river kilometer 15.5

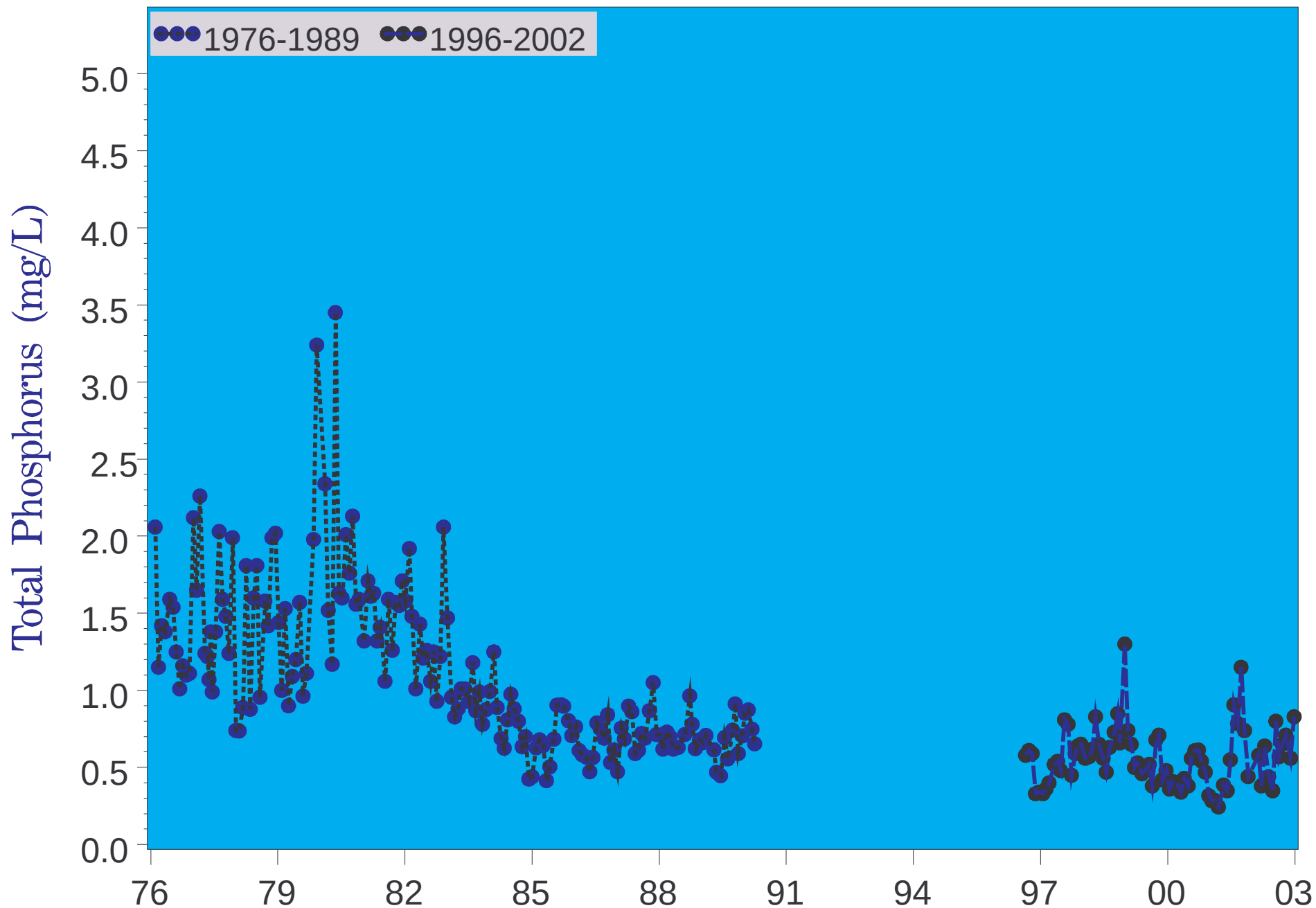


Figure 4.5.140 Long-term surface total phosphorus at river kilometer 15.5

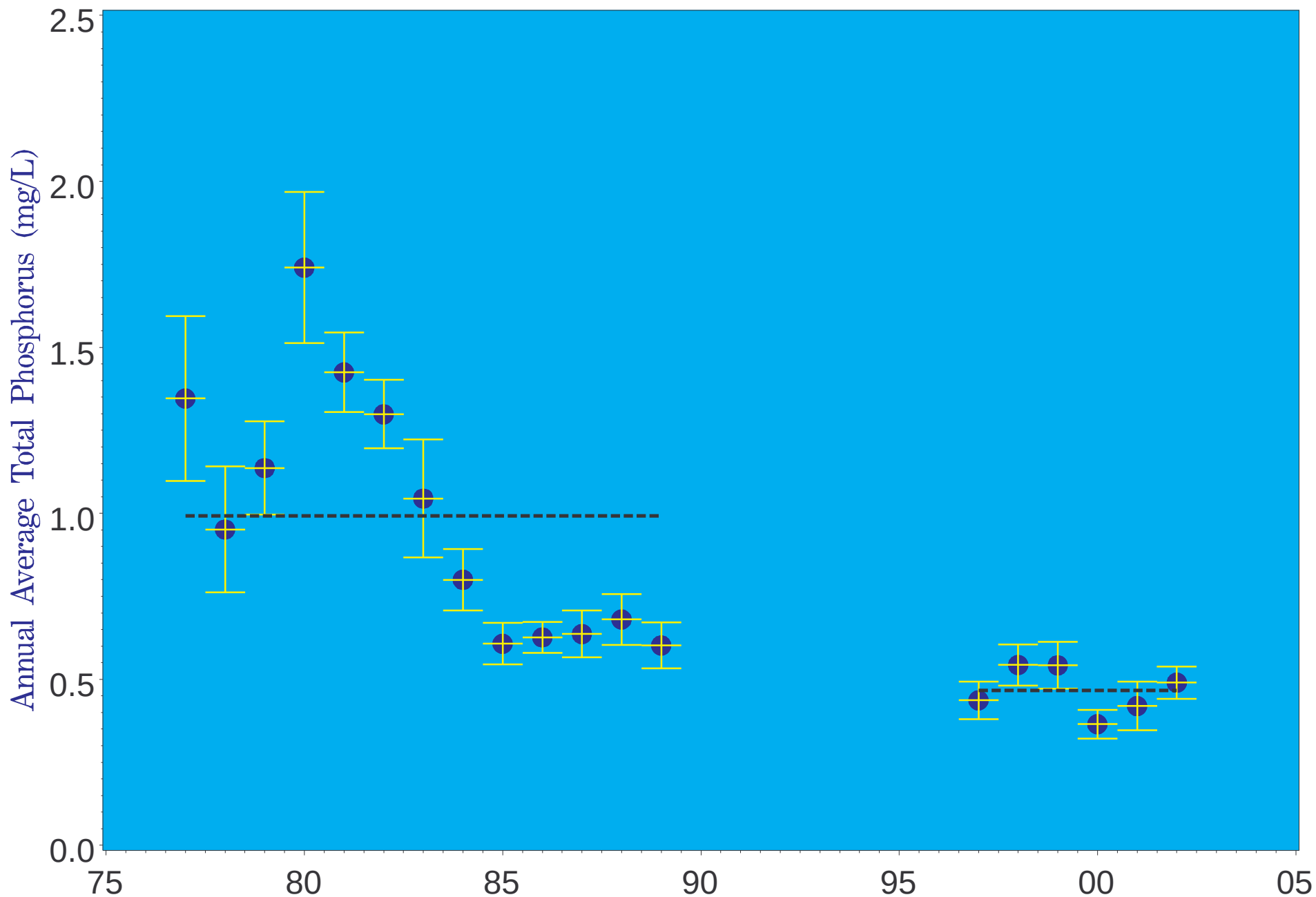


Figure 4.5.141 Long-term surface total phosphorus at river kilometer 15.5

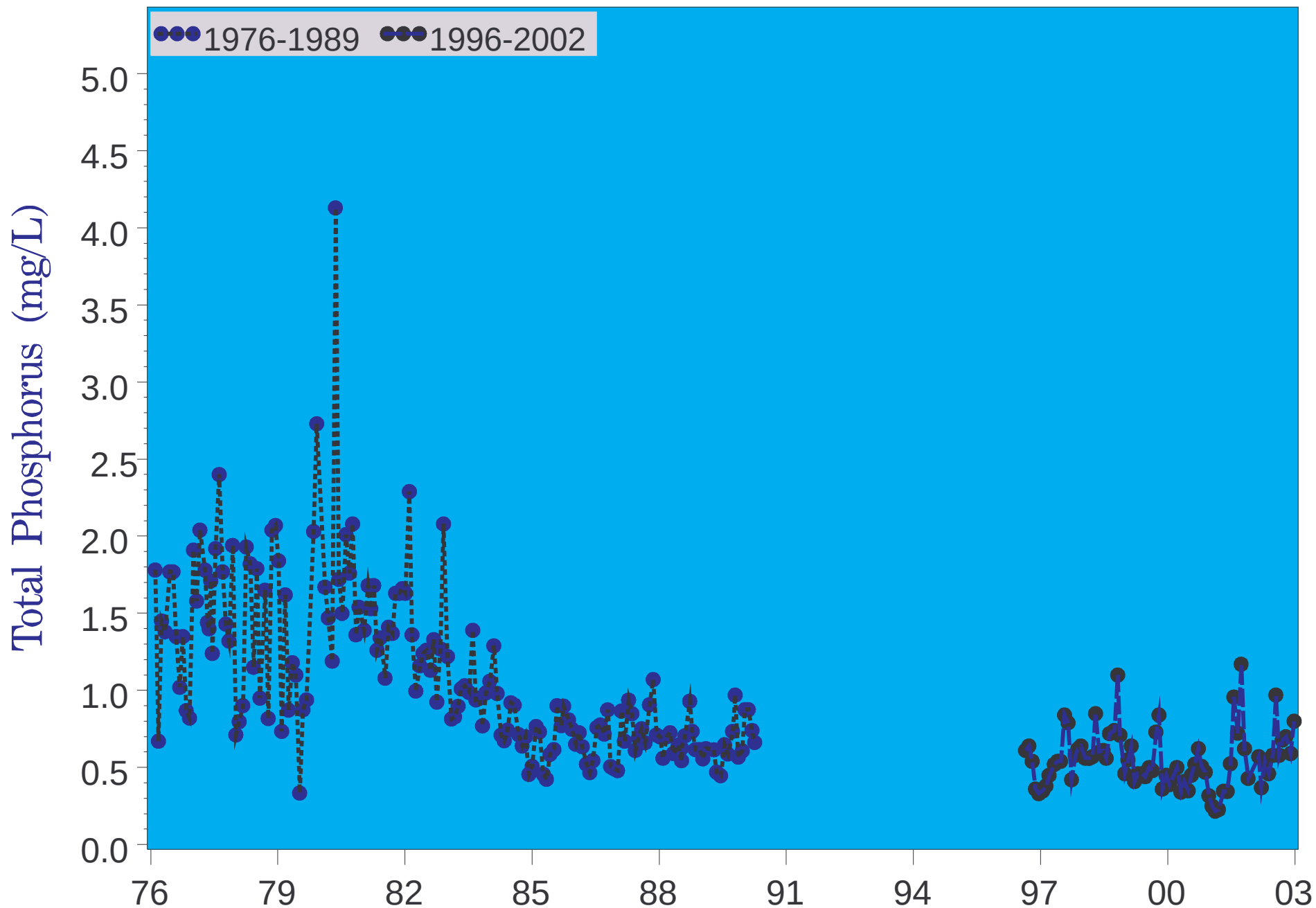


Figure 4.5.142 Long-term bottom total phosphorus at river kilometer 15.5

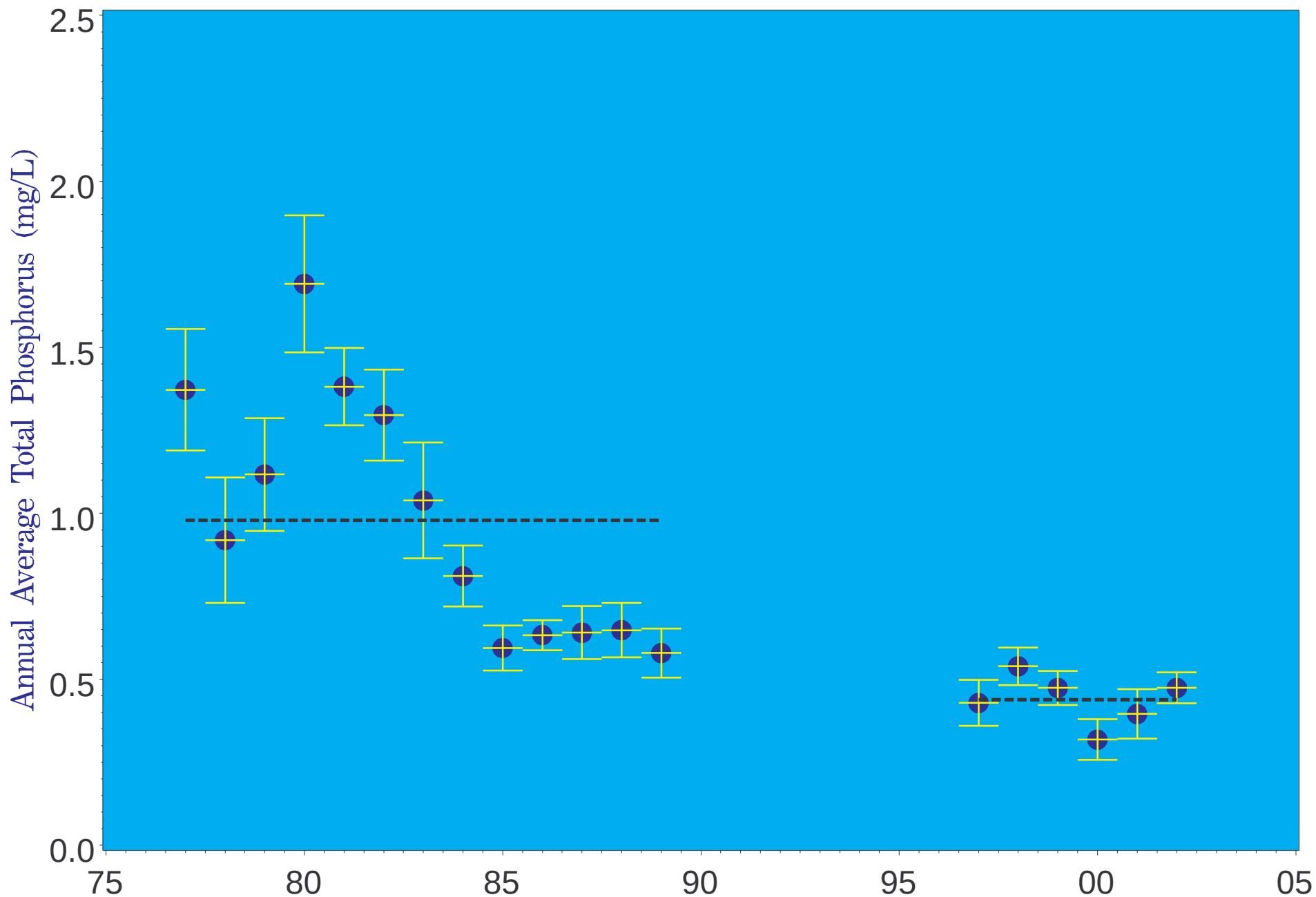


Figure 4.5.143 Long-term bottom total phosphorus at river kilometer 15.5

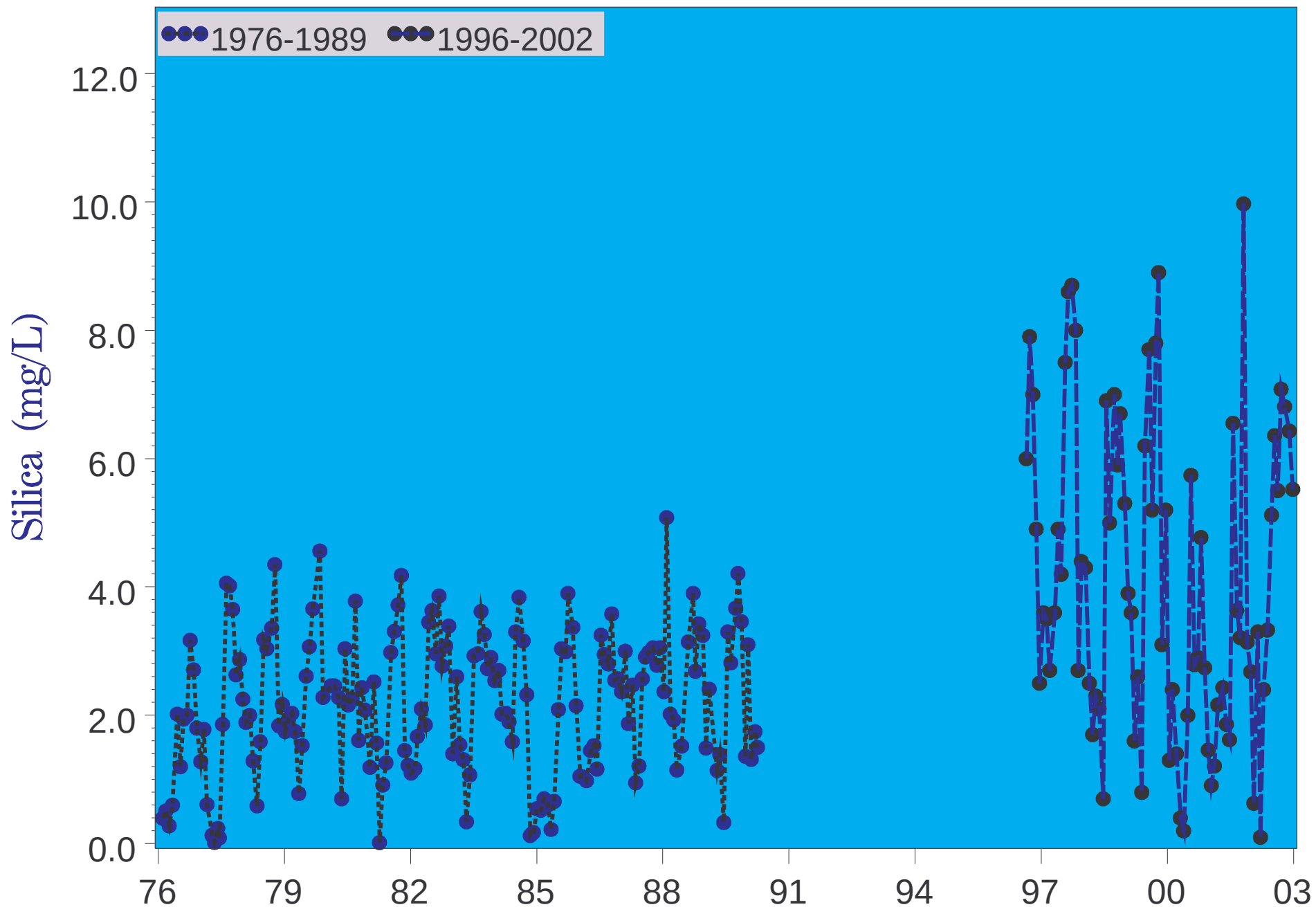


Figure 4.5.144 Long-term surface silica at river kilometer 15.5



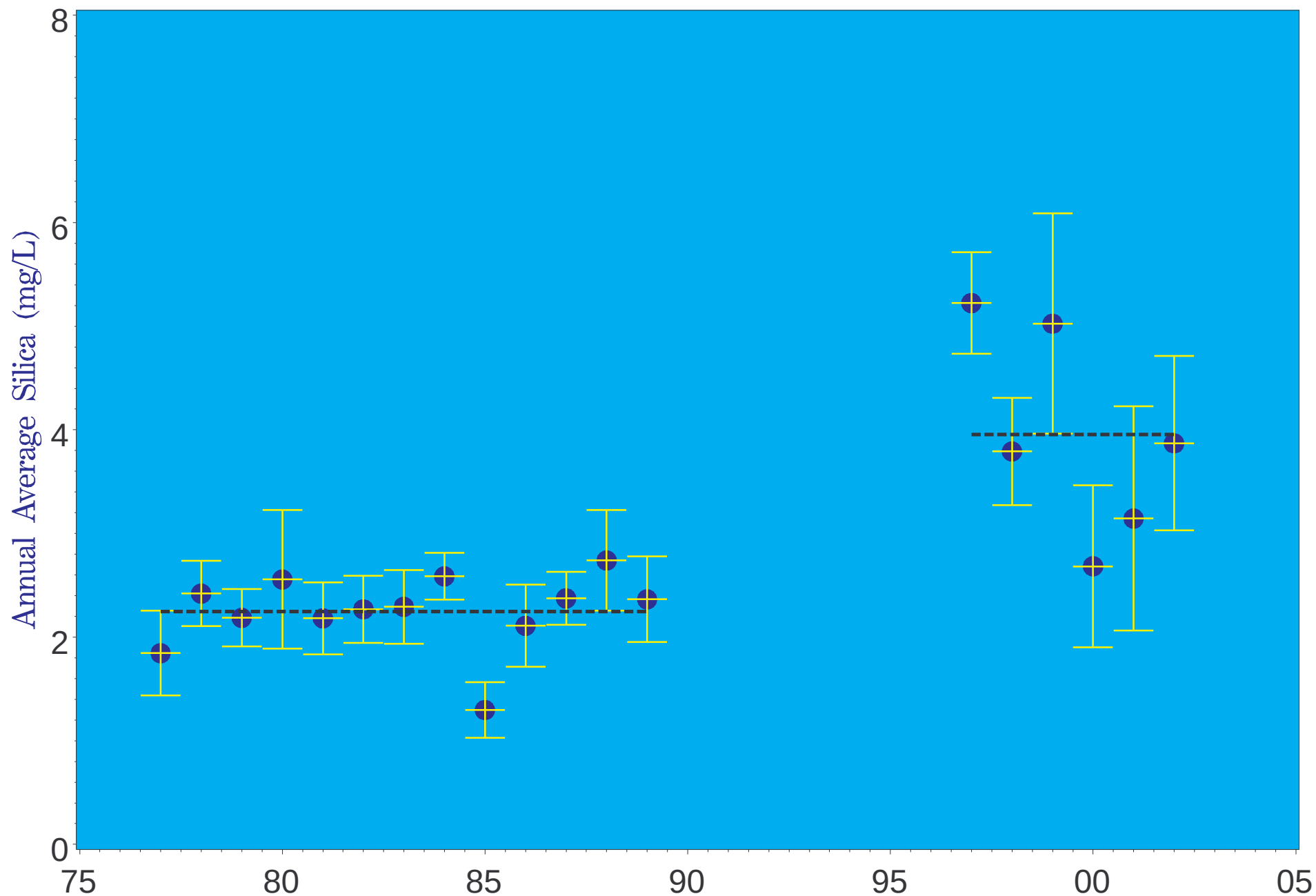


Figure 4.5.145 Long-term surface silica at river kilometer 15.5

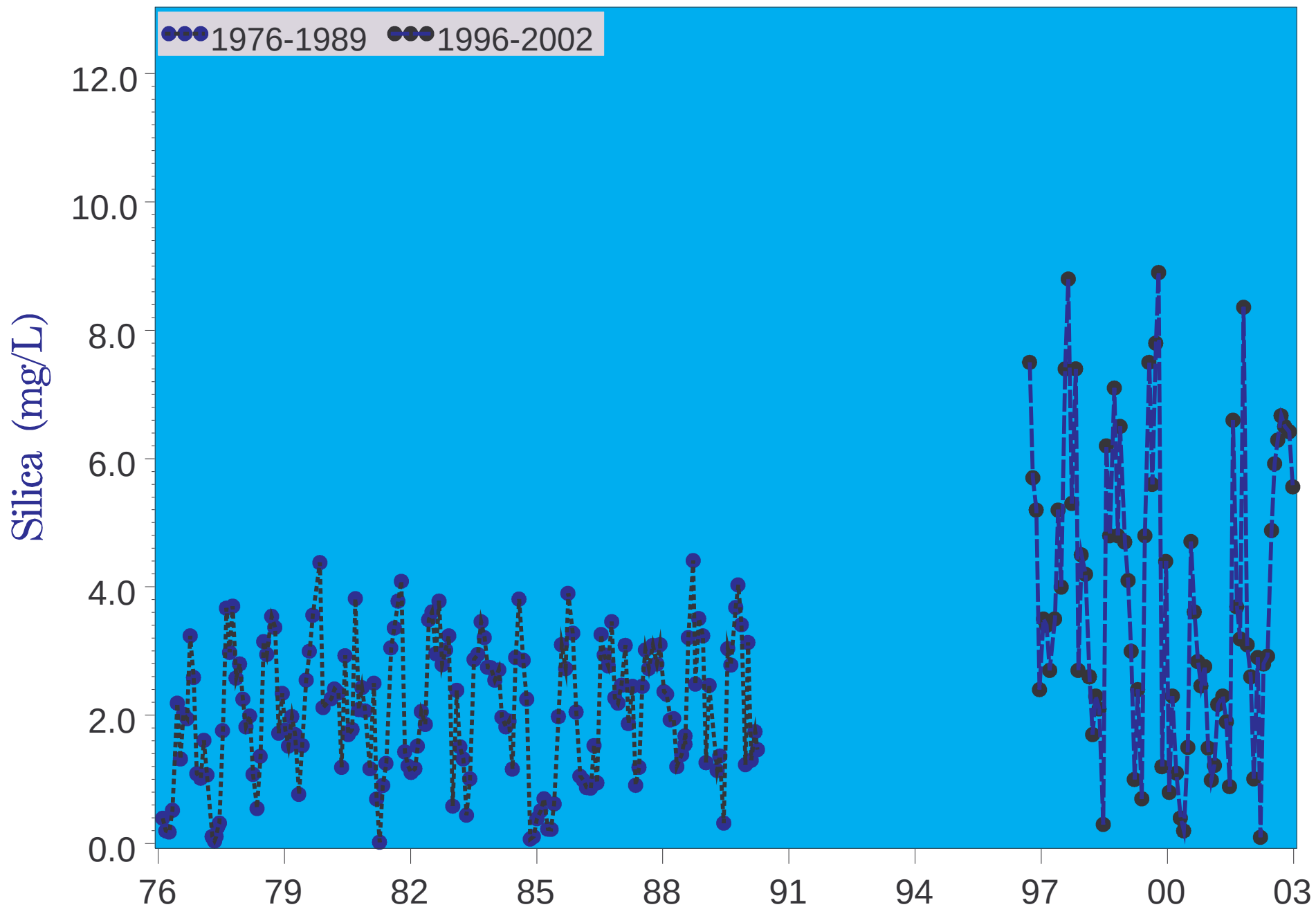


Figure 4.5.146 Long-term bottom silica at river kilometer 15.5

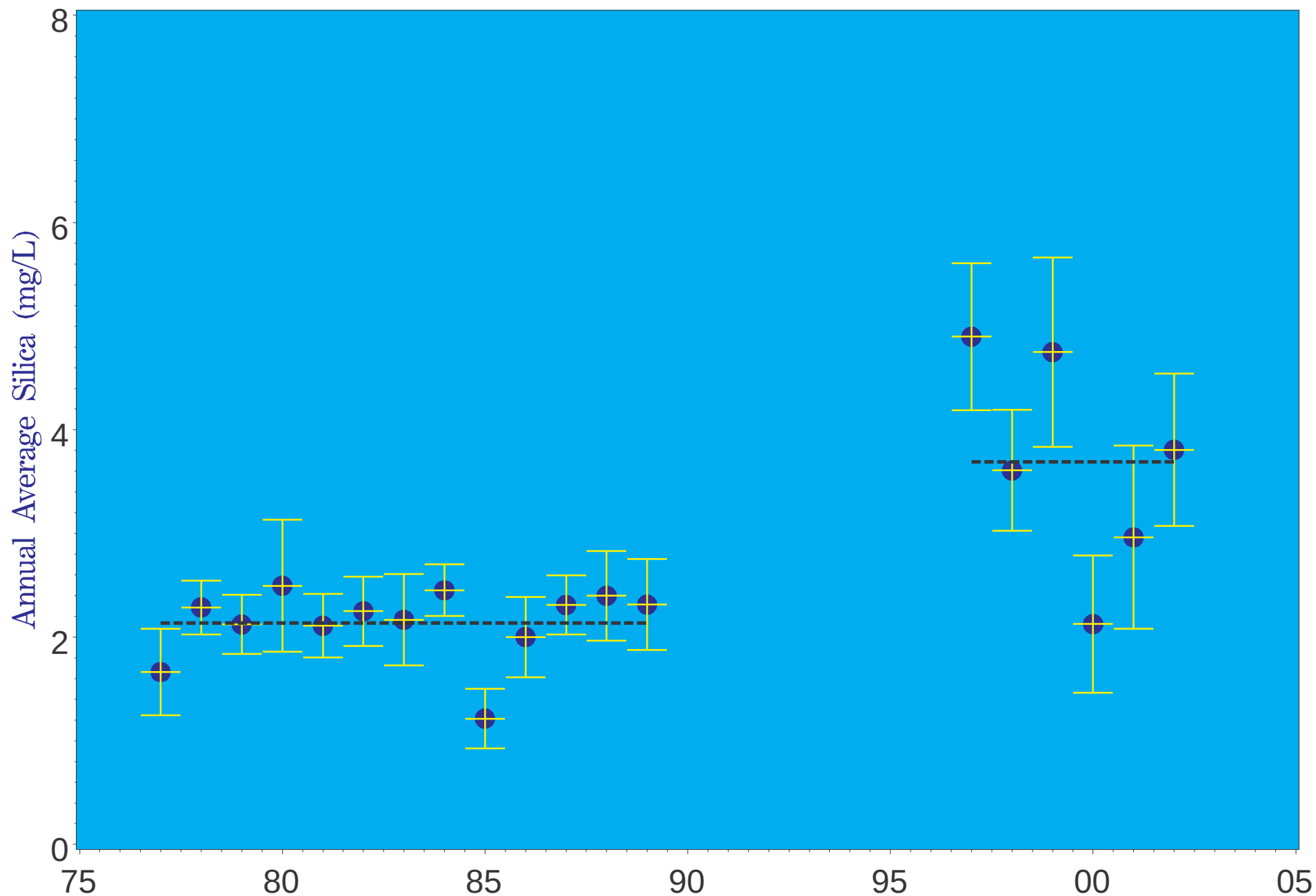


Figure 4.5.147 Long-term bottom silica at river kilometer 15.5

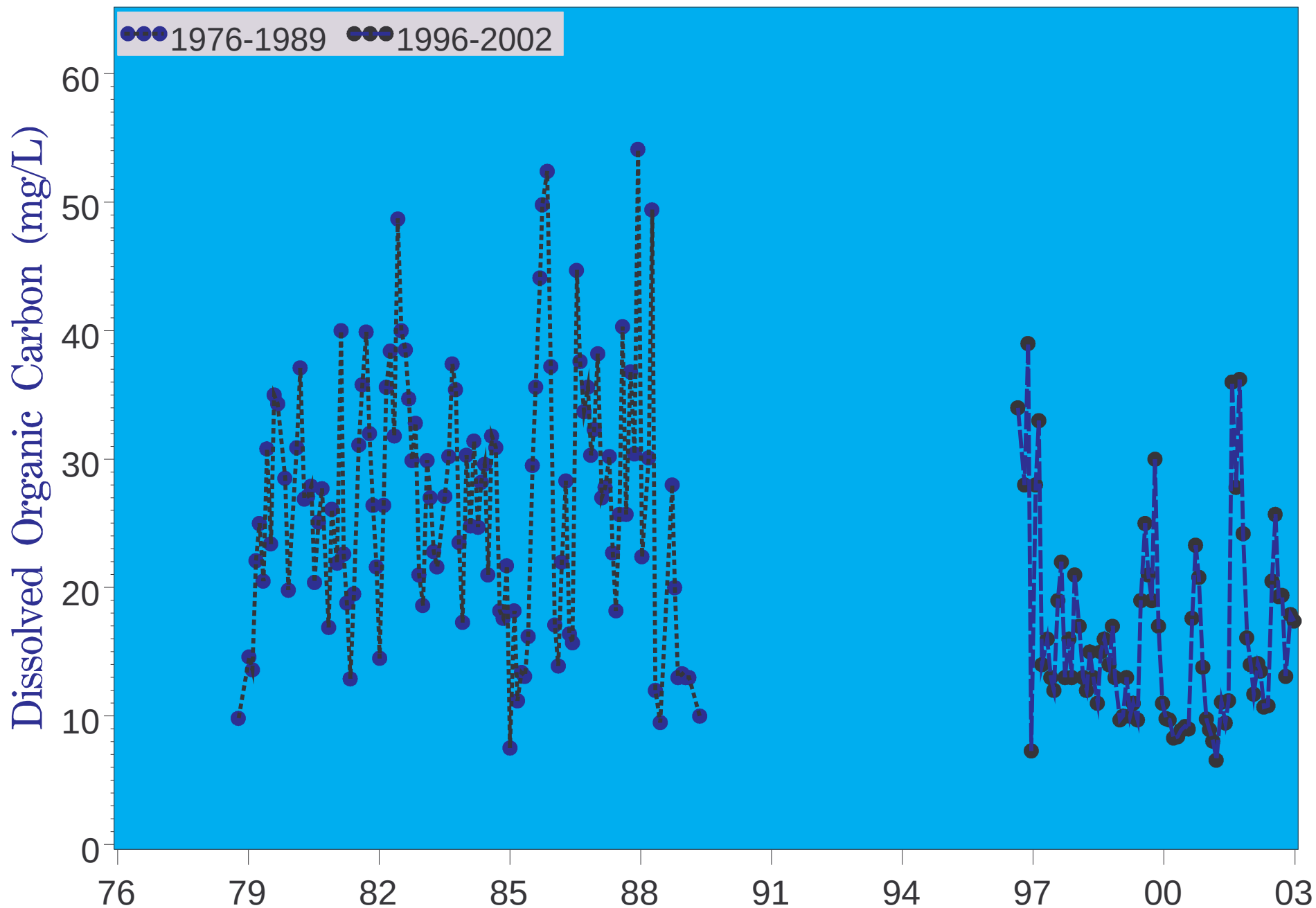


Figure 4.5.148 Long-term surface dissolved organic carbon at river kilometer 15.5

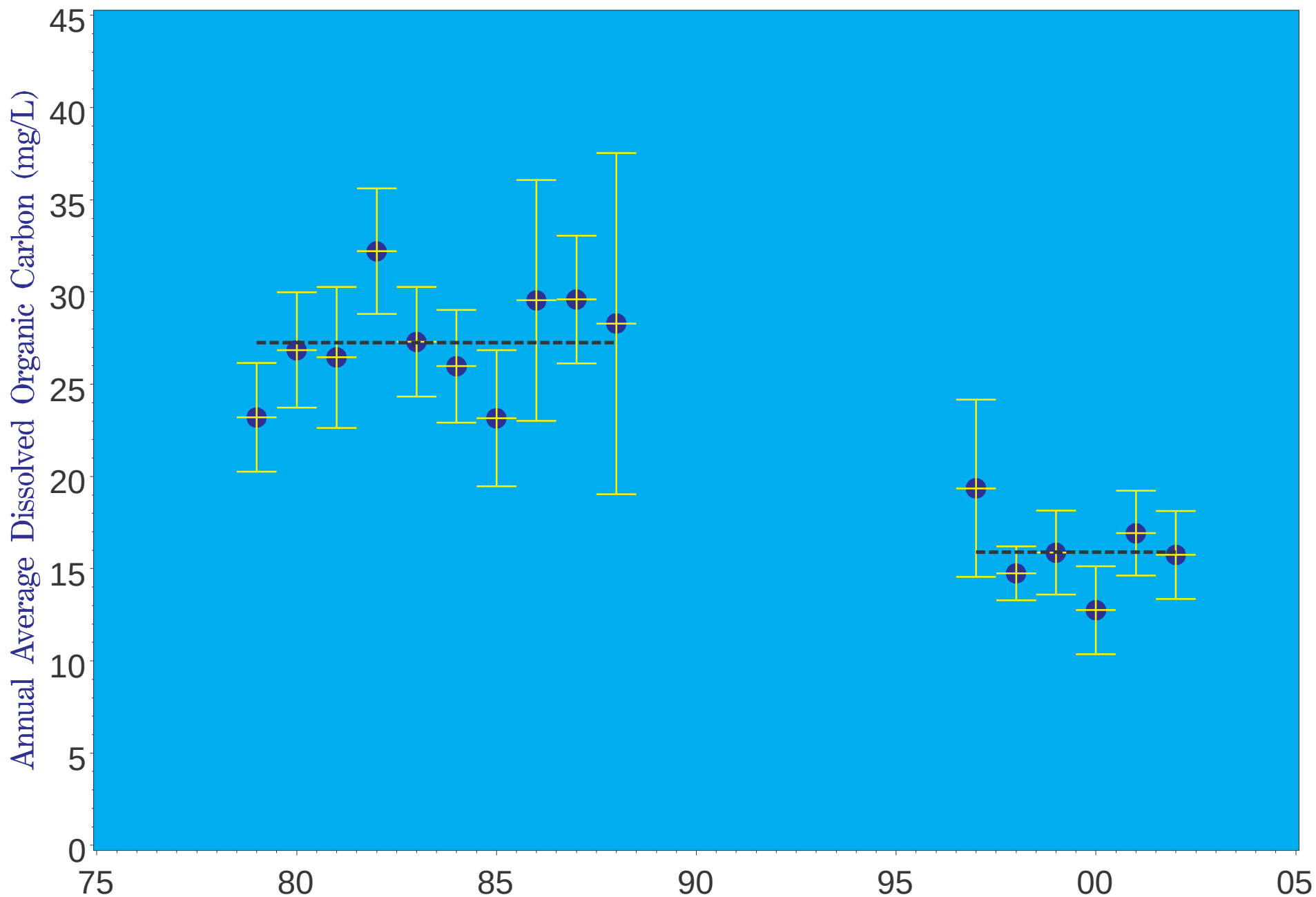


Figure 4.5.149 Long-term surface dissolved organic carbon at river kilometer 15.5

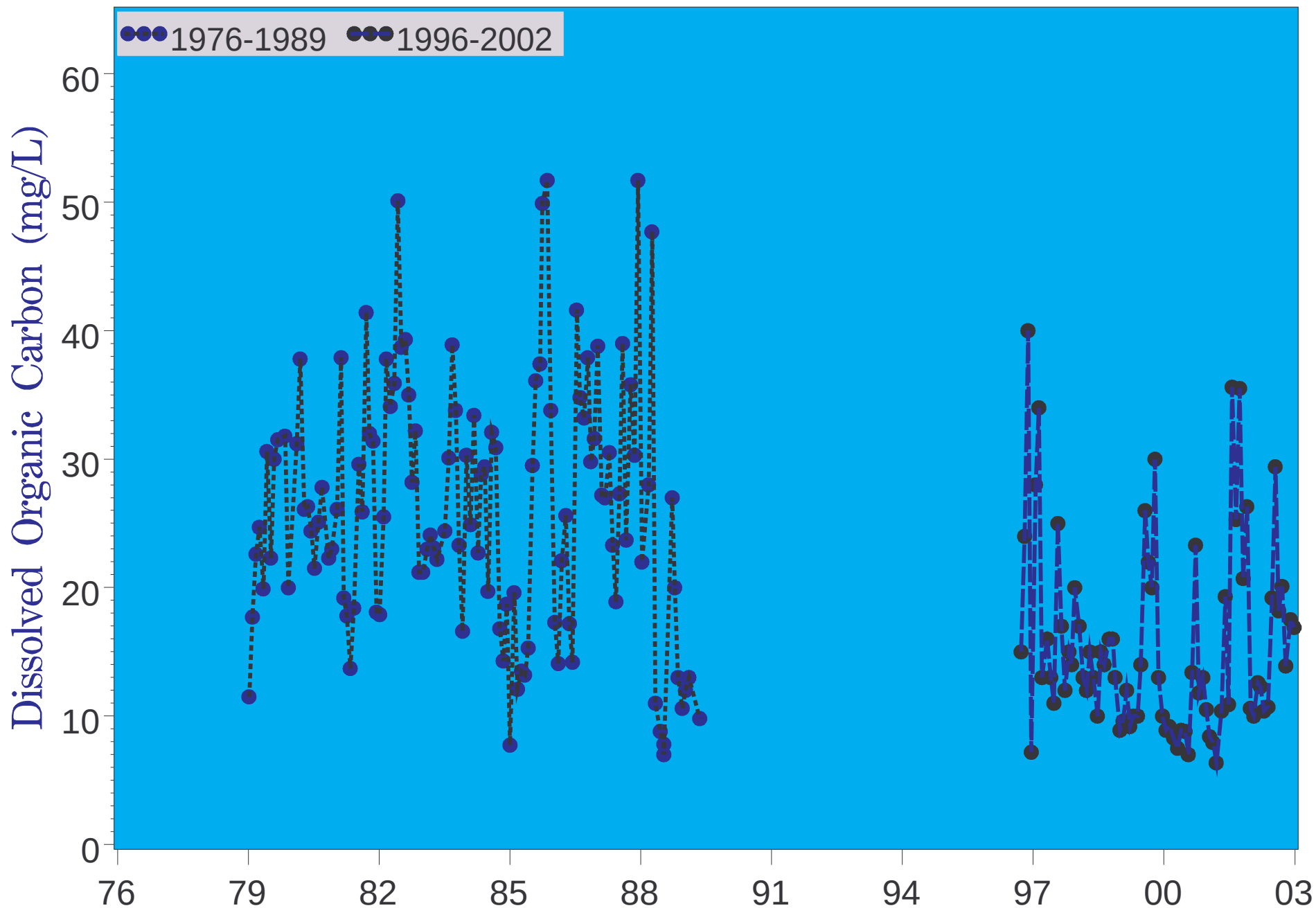


Figure 4.5.150 Long-term bottom dissolved organic carbon at river kilometer 15.5

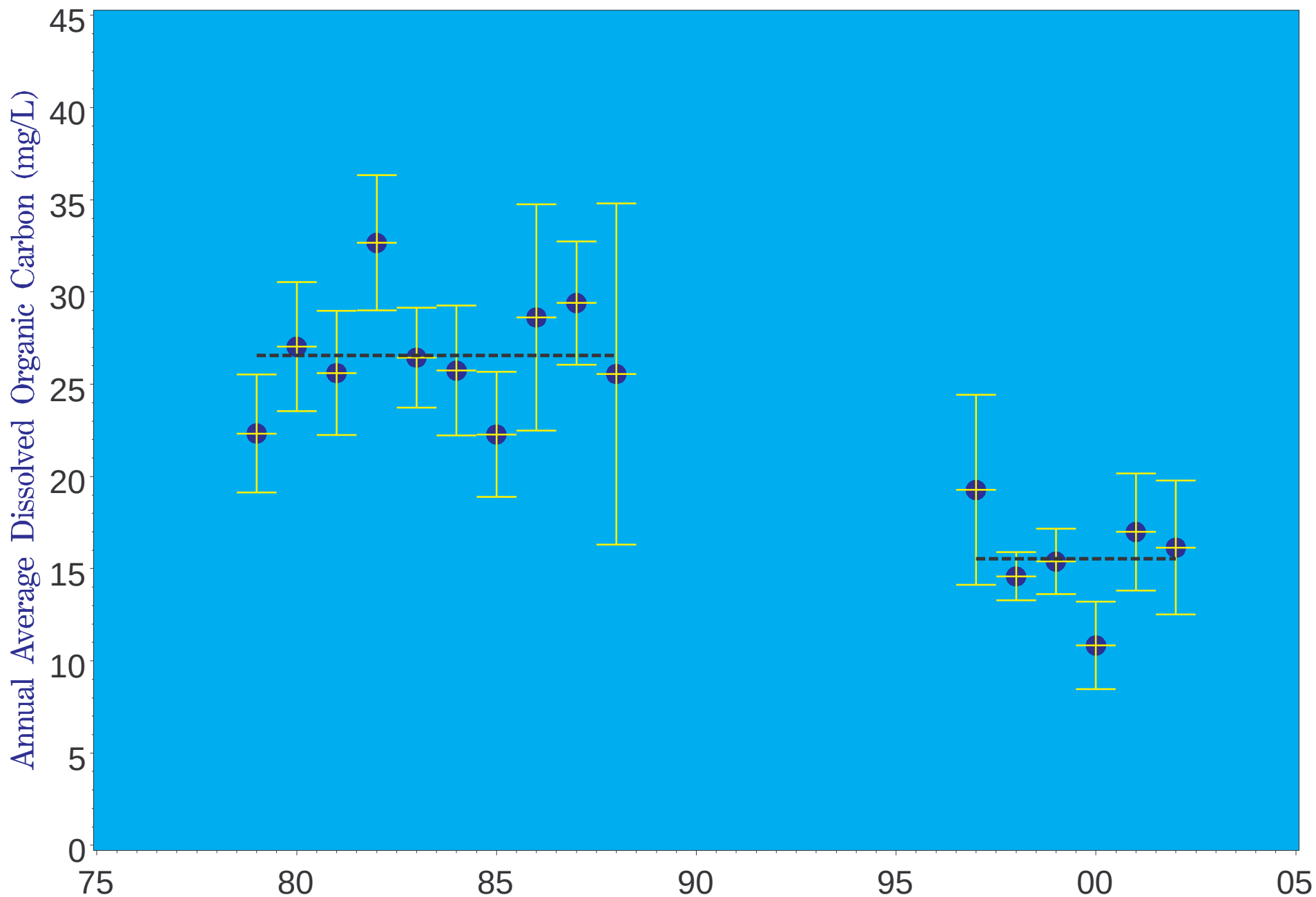


Figure 4.5.151 Long-term bottom dissolved organic carbon at river kilometer 15.5

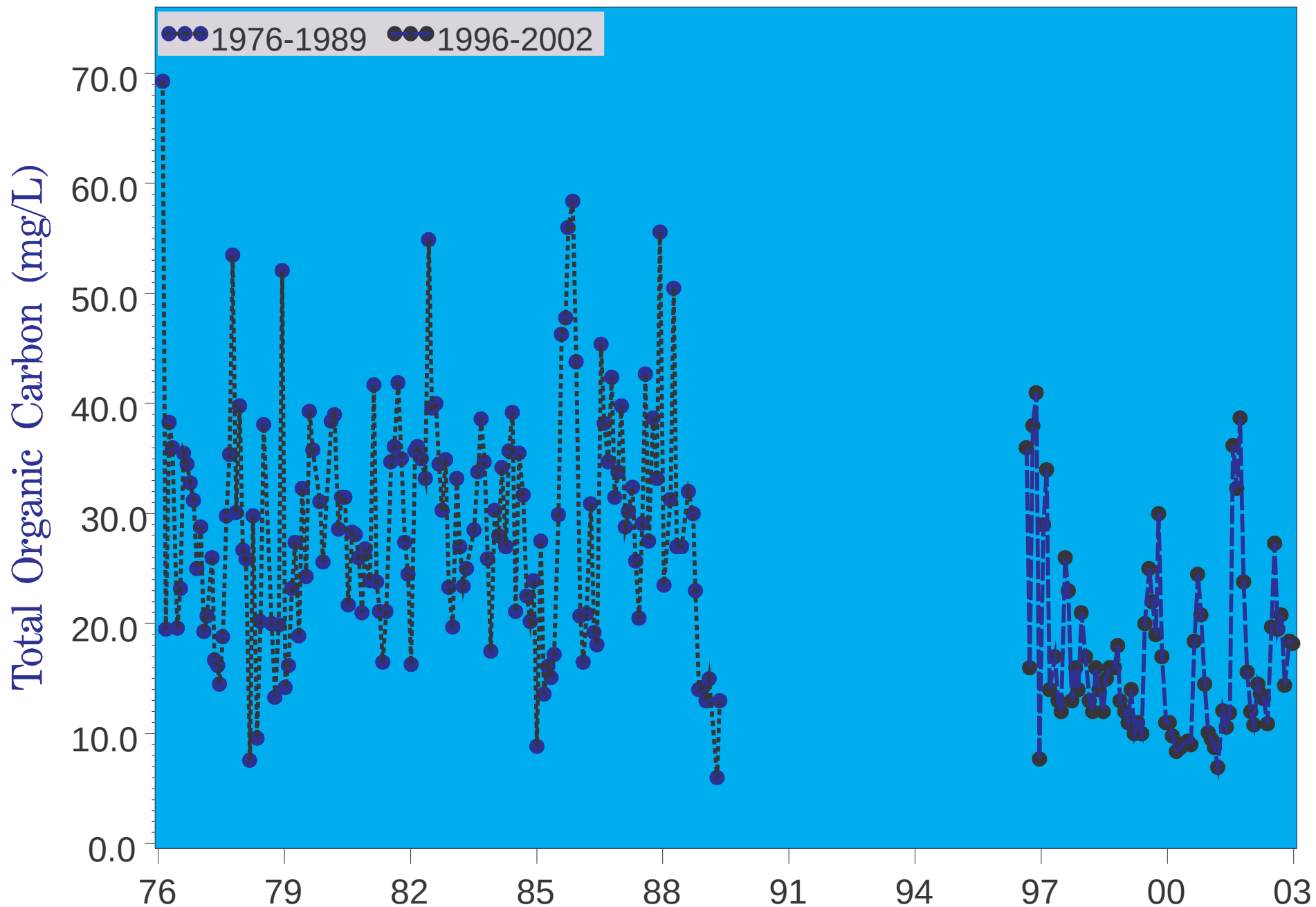


Figure 4.5.152 Long-term surface total organic carbon at river kilometer 15.5



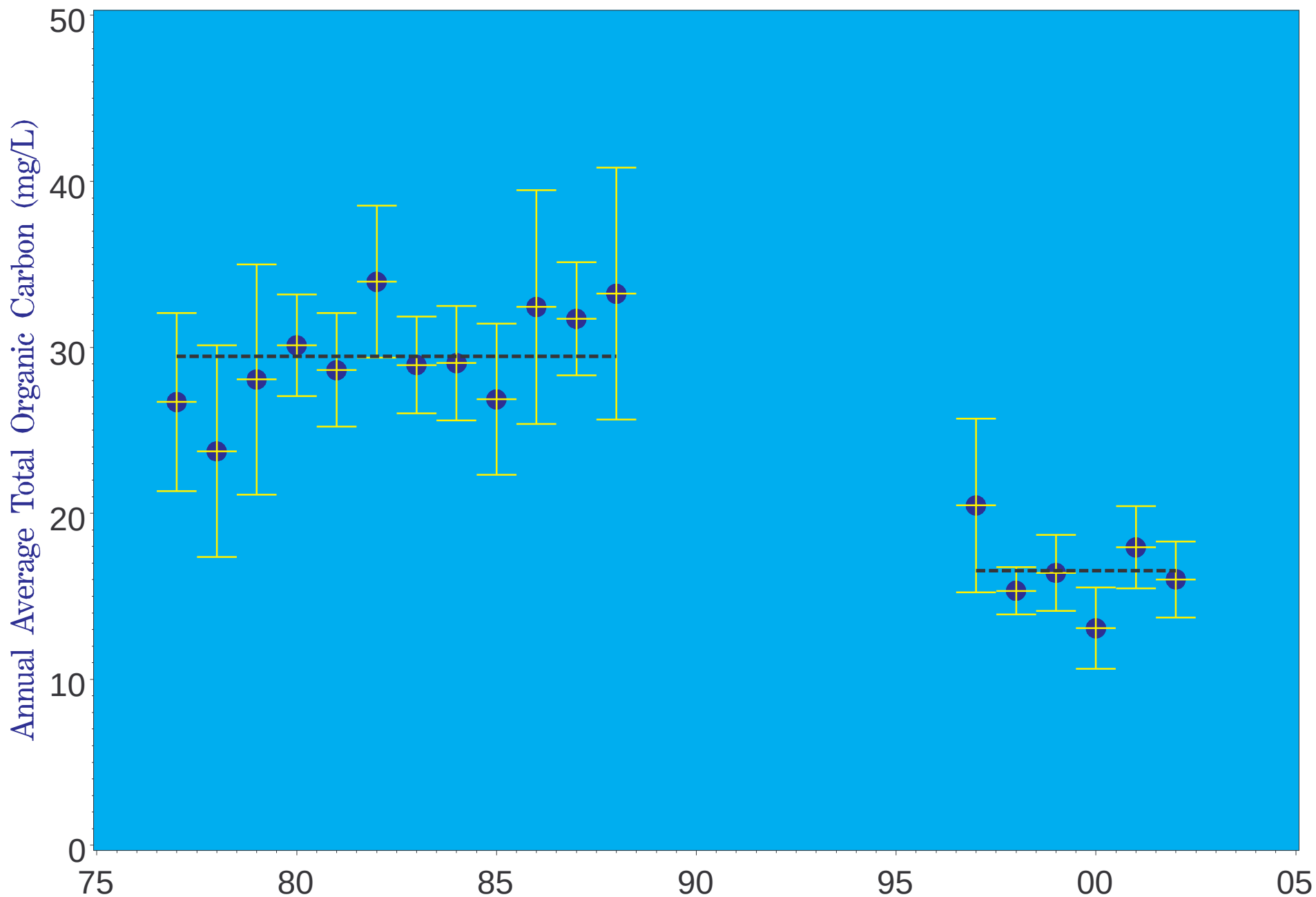
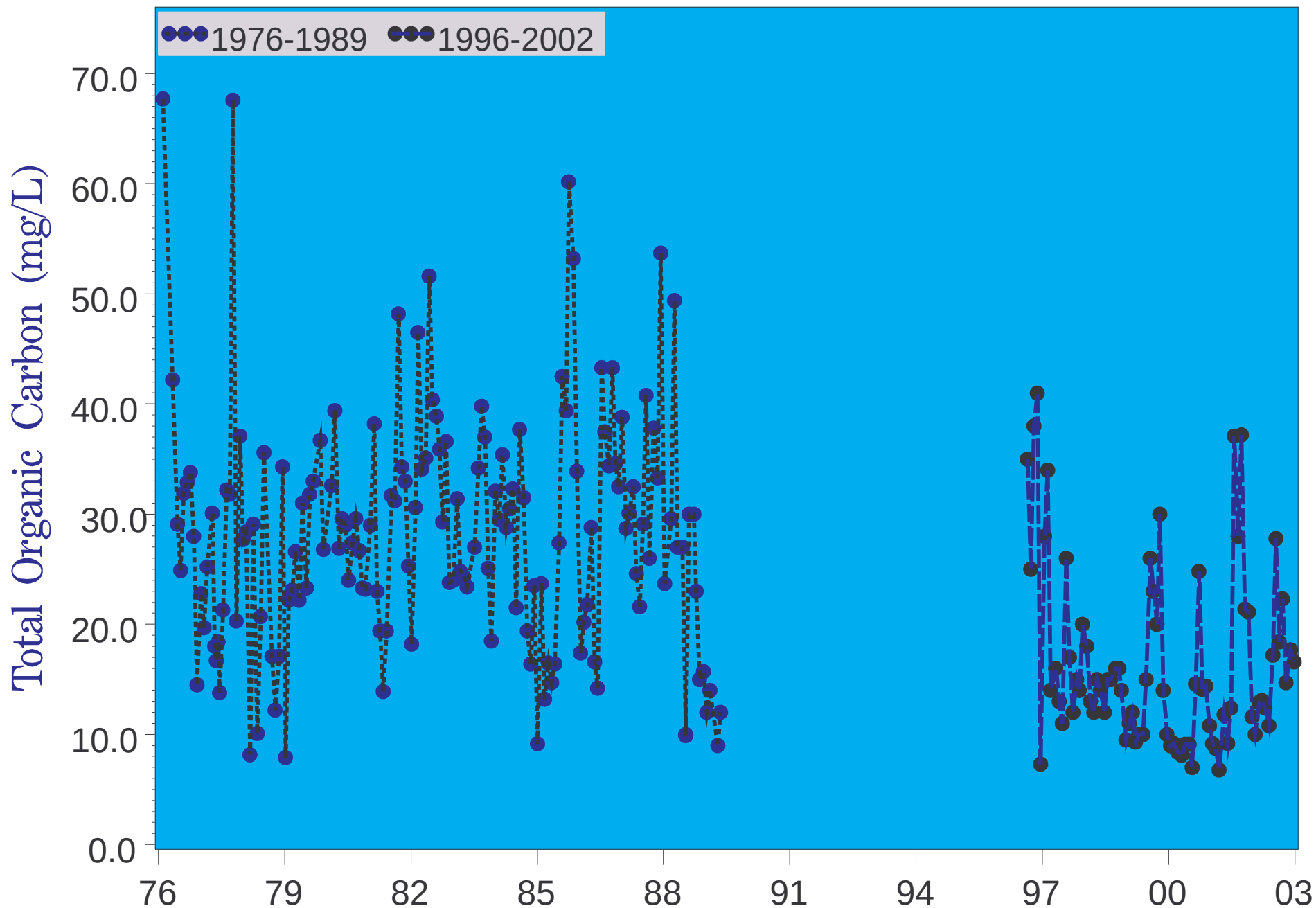


Figure 4.5.153 Long-term surface total organic carbon at river kilometer 15.5



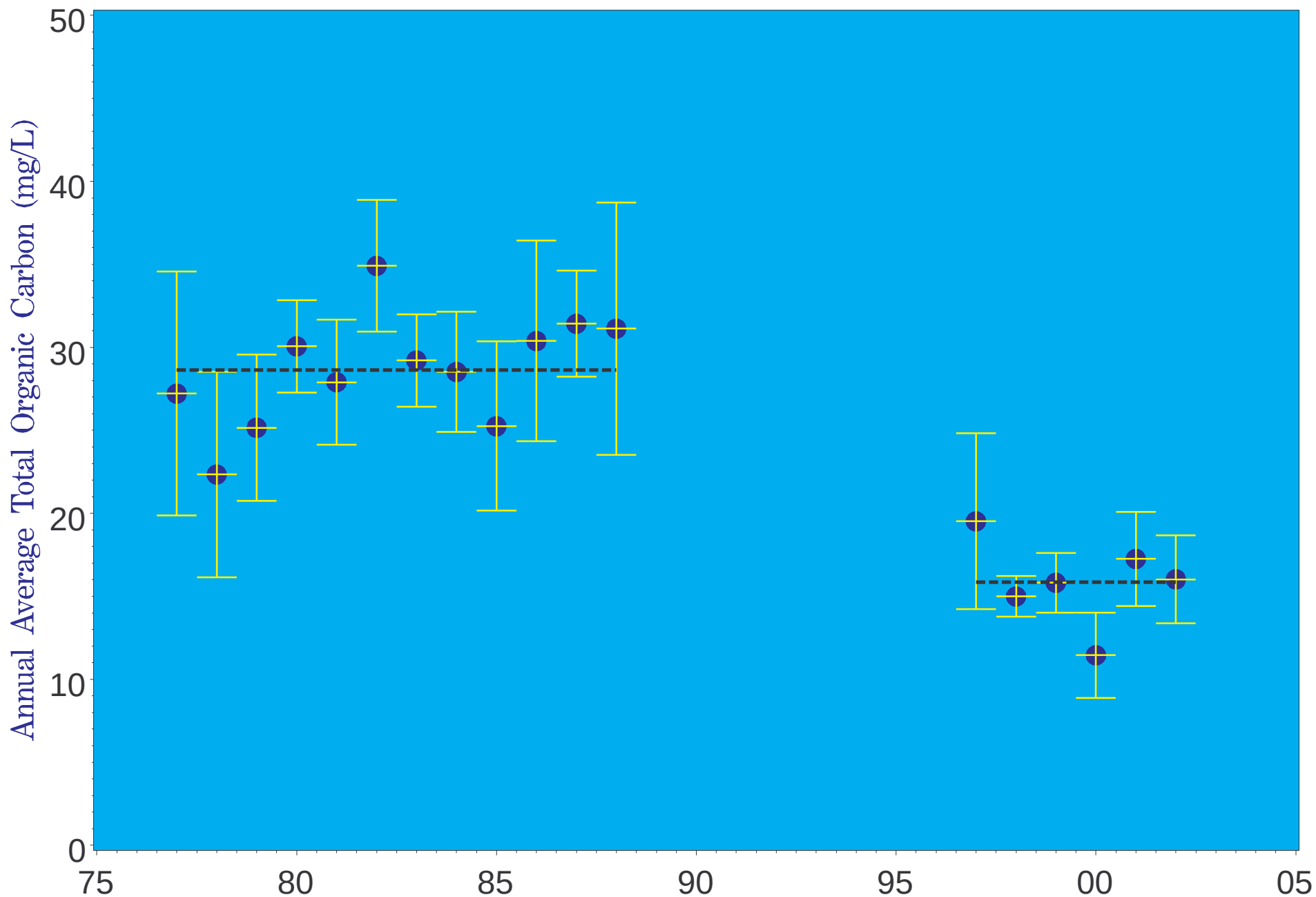


Figure 4.5.155 Long-term bottom total organic carbon at river kilometer 15.5

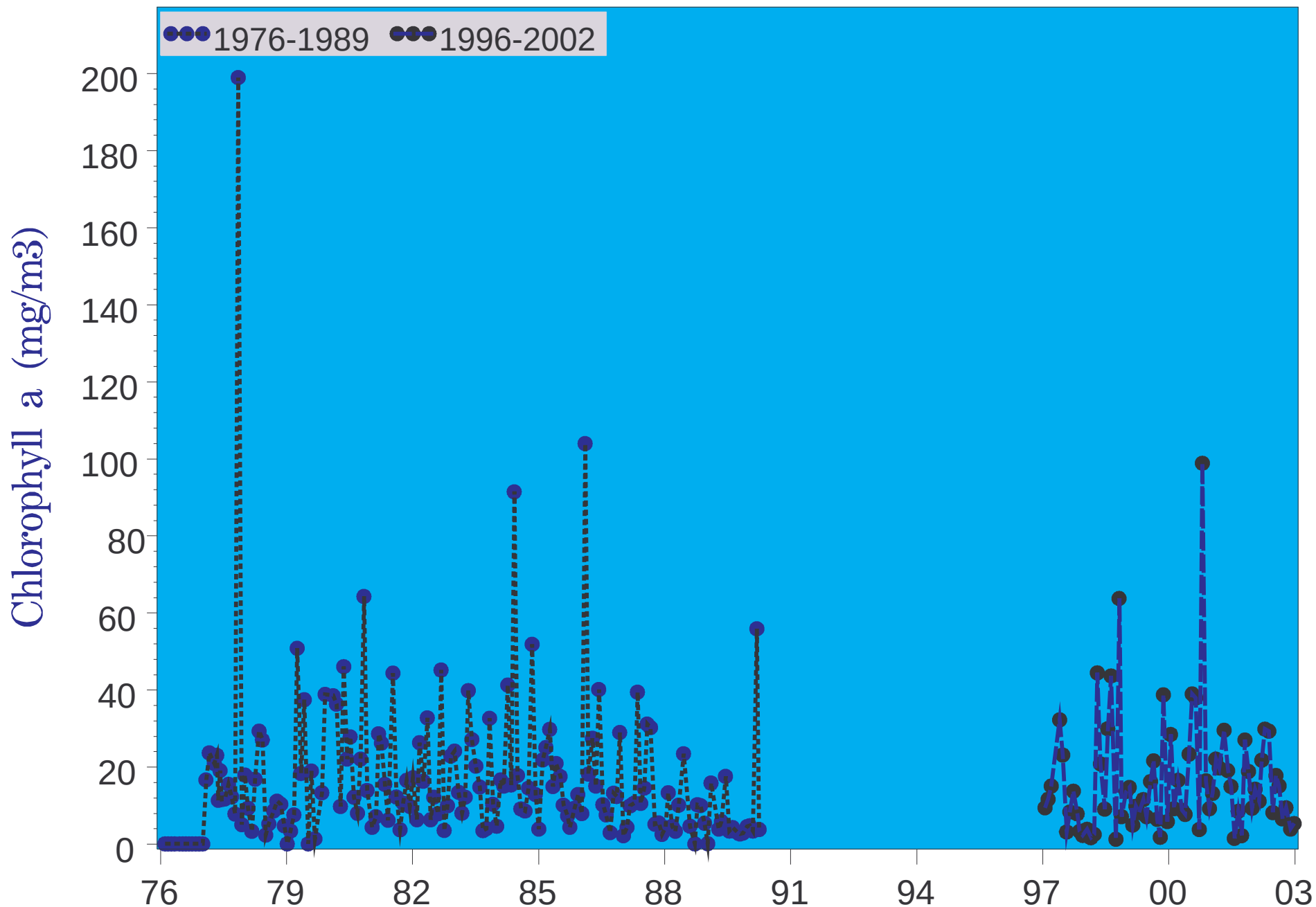


Figure 4.5.156 Long-term surface chlorophyll a at river kilometer 15.5

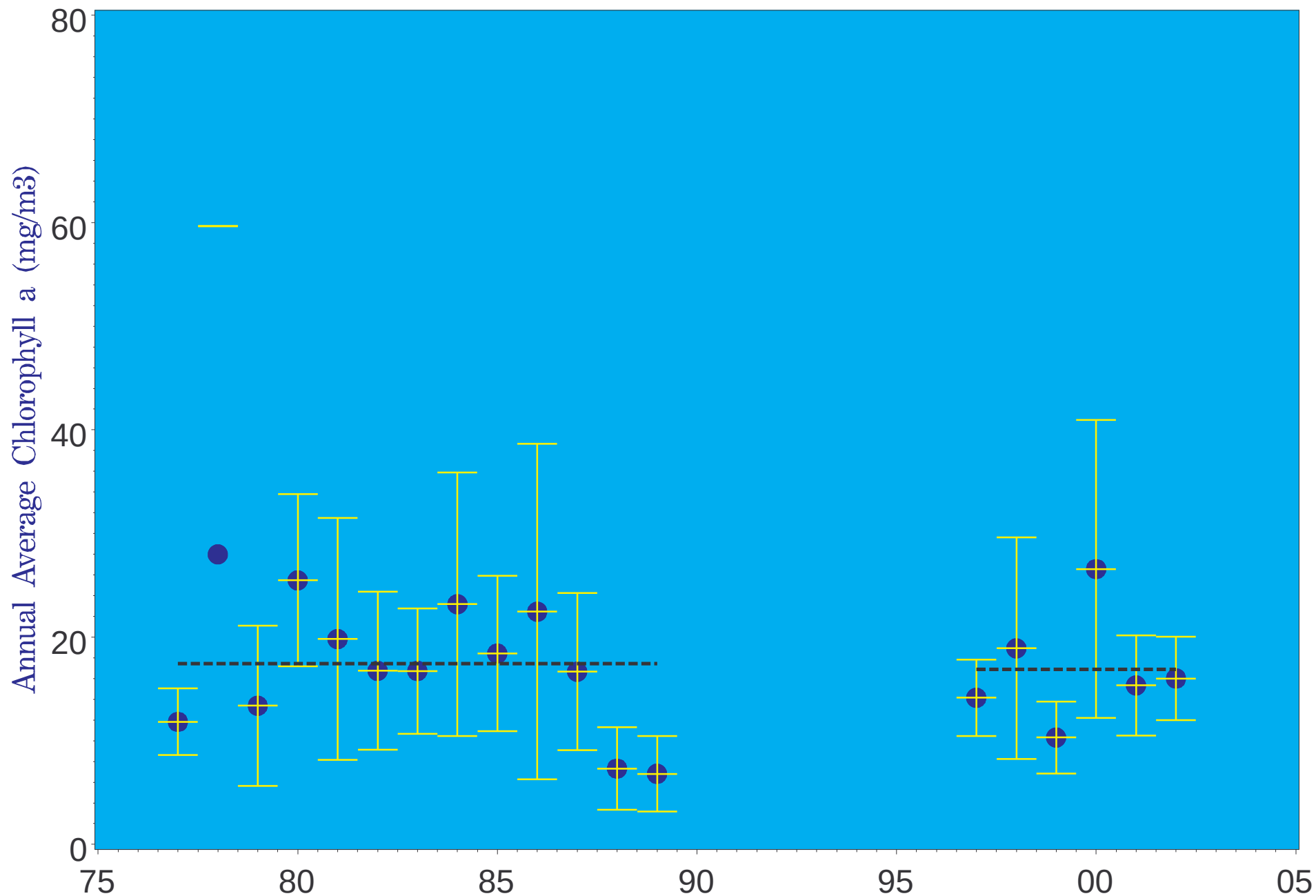


Figure 4.5.157 Long-term surface chlorophyll a at river kilometer 15.5

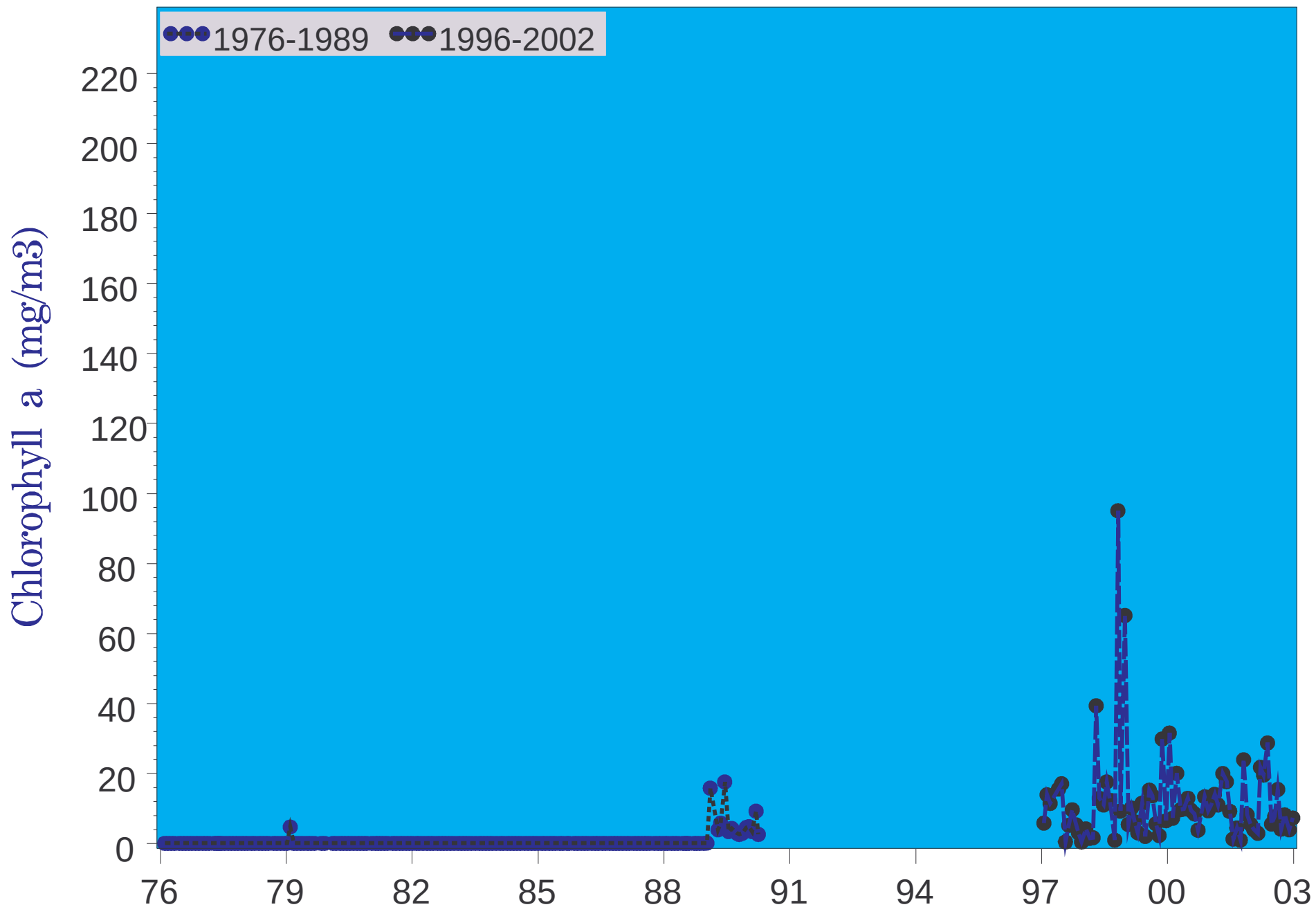


Figure 4.5.158 Long-term bottom chlorophyll a at river kilometer 15.5

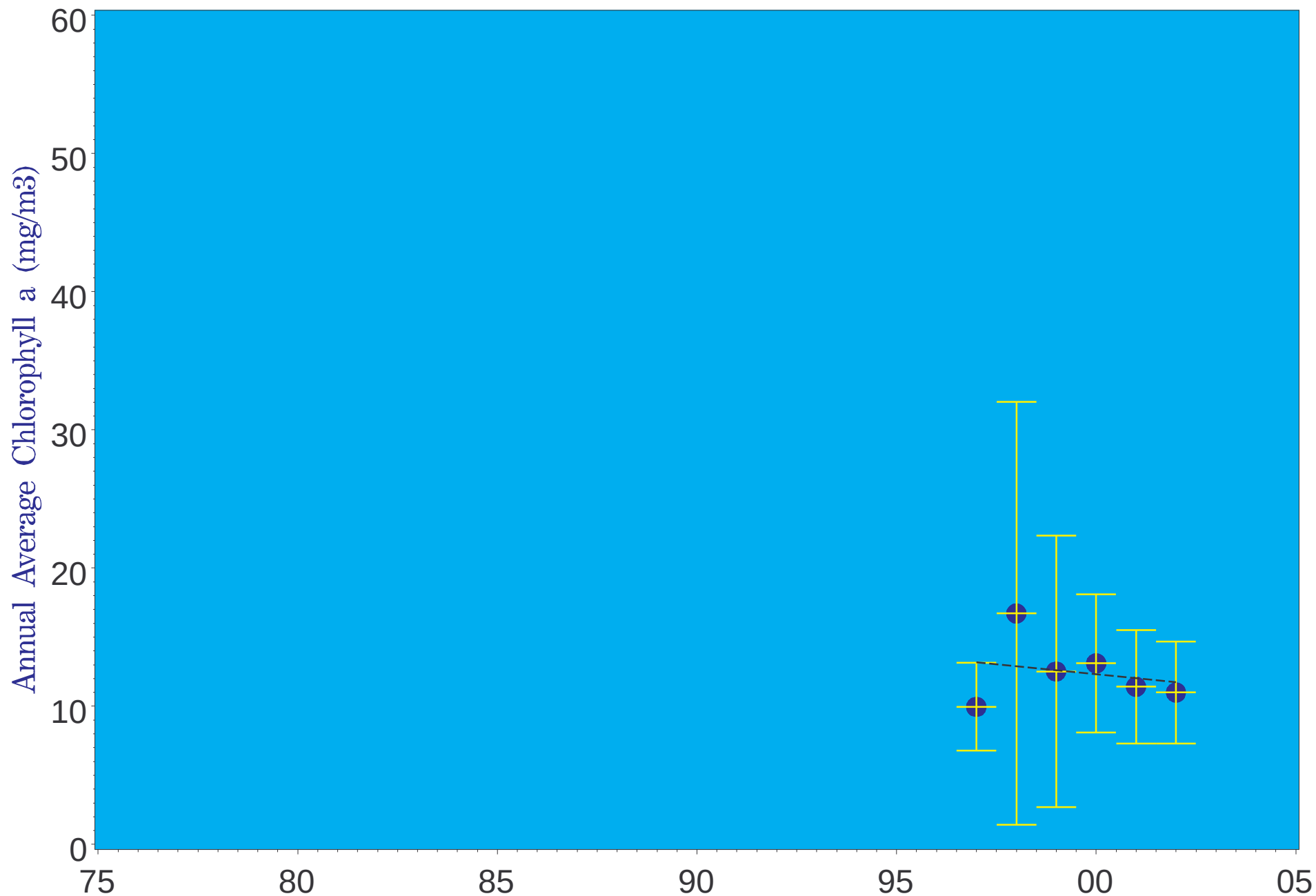


Figure 4.5.159 Long-term bottom chlorophyll a at river kilometer 15.5

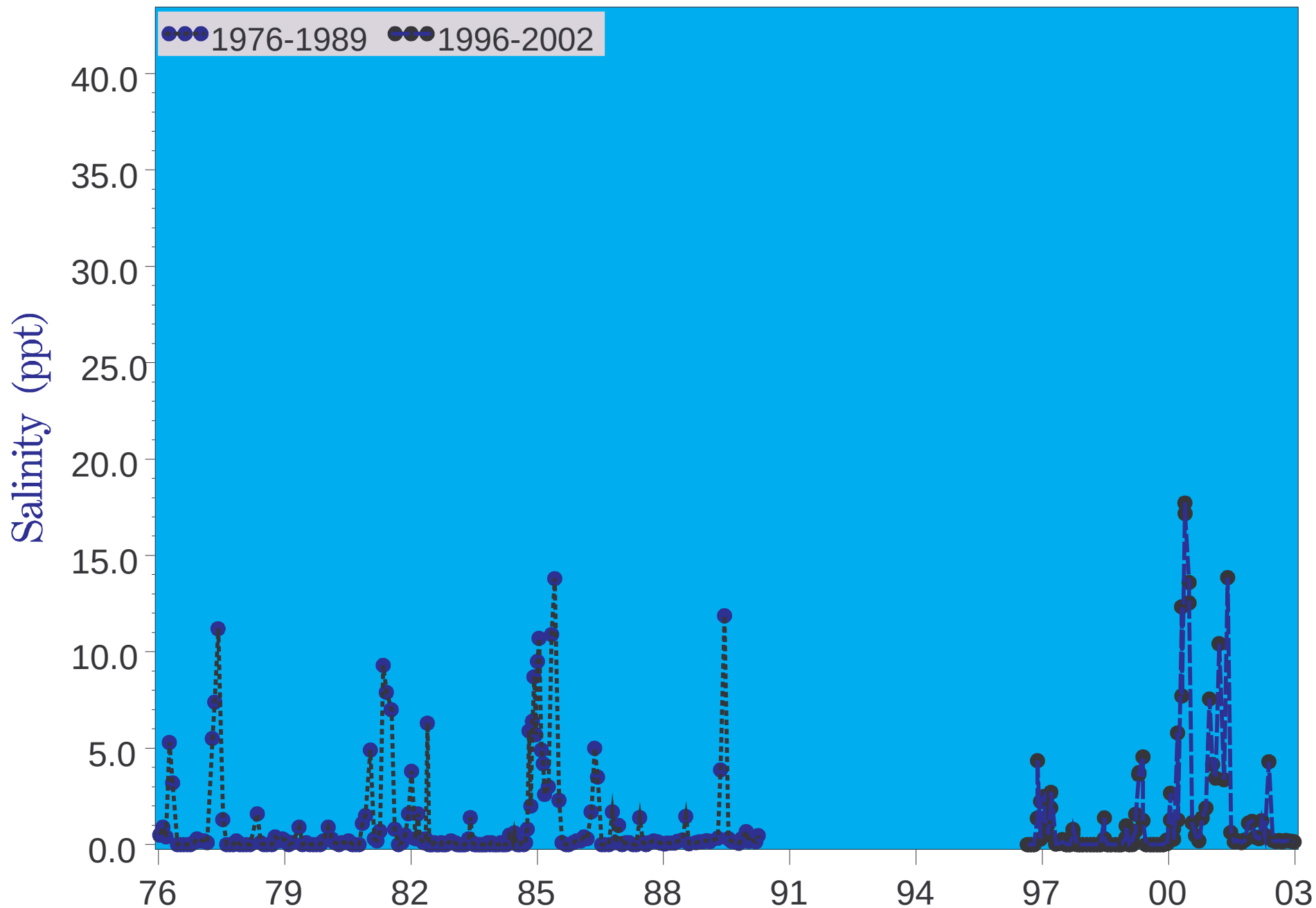


Figure 4.5.160 Long-term surface salinity at river kilometer 23.6



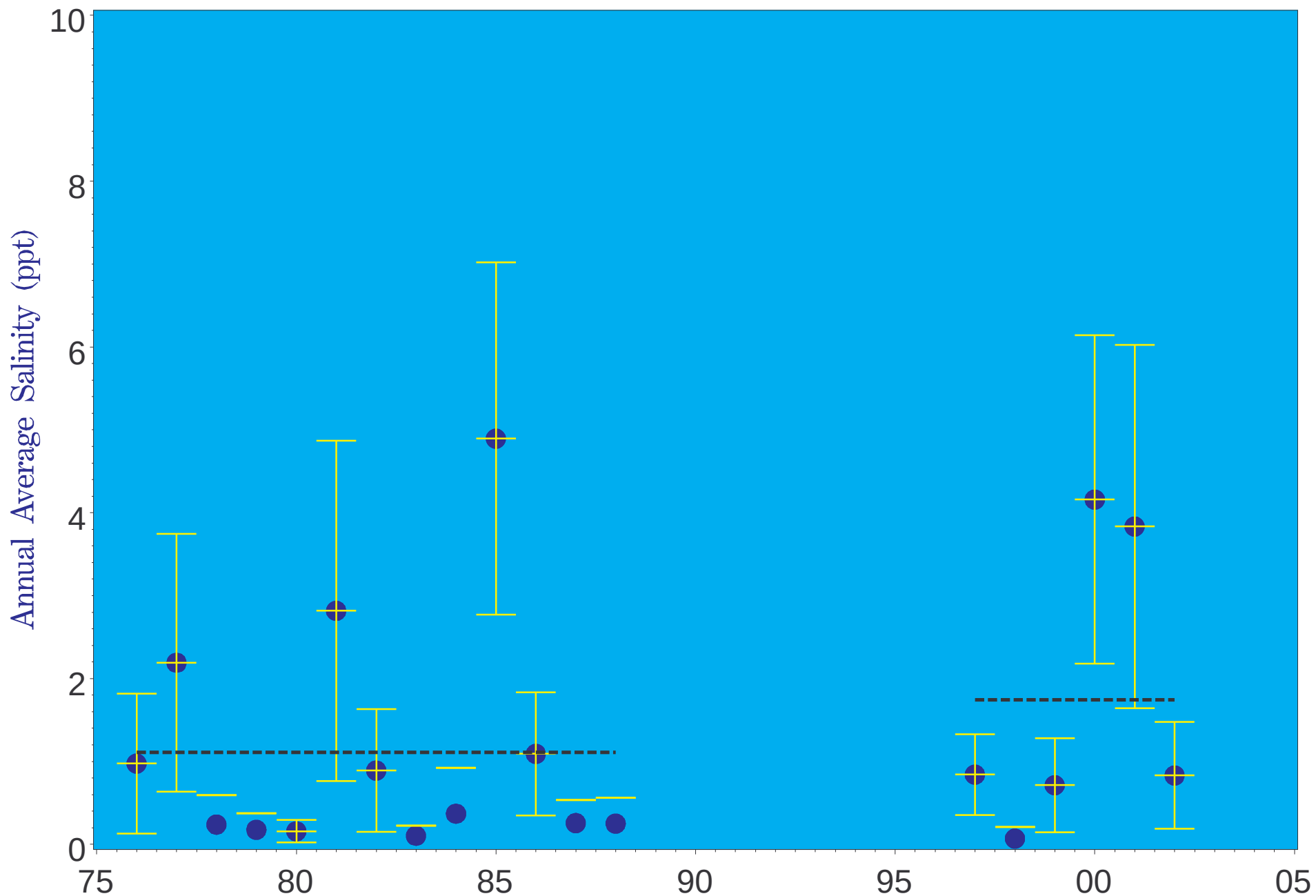


Figure 4.5.161 Long-term surface salinity at river kilometer 23.6

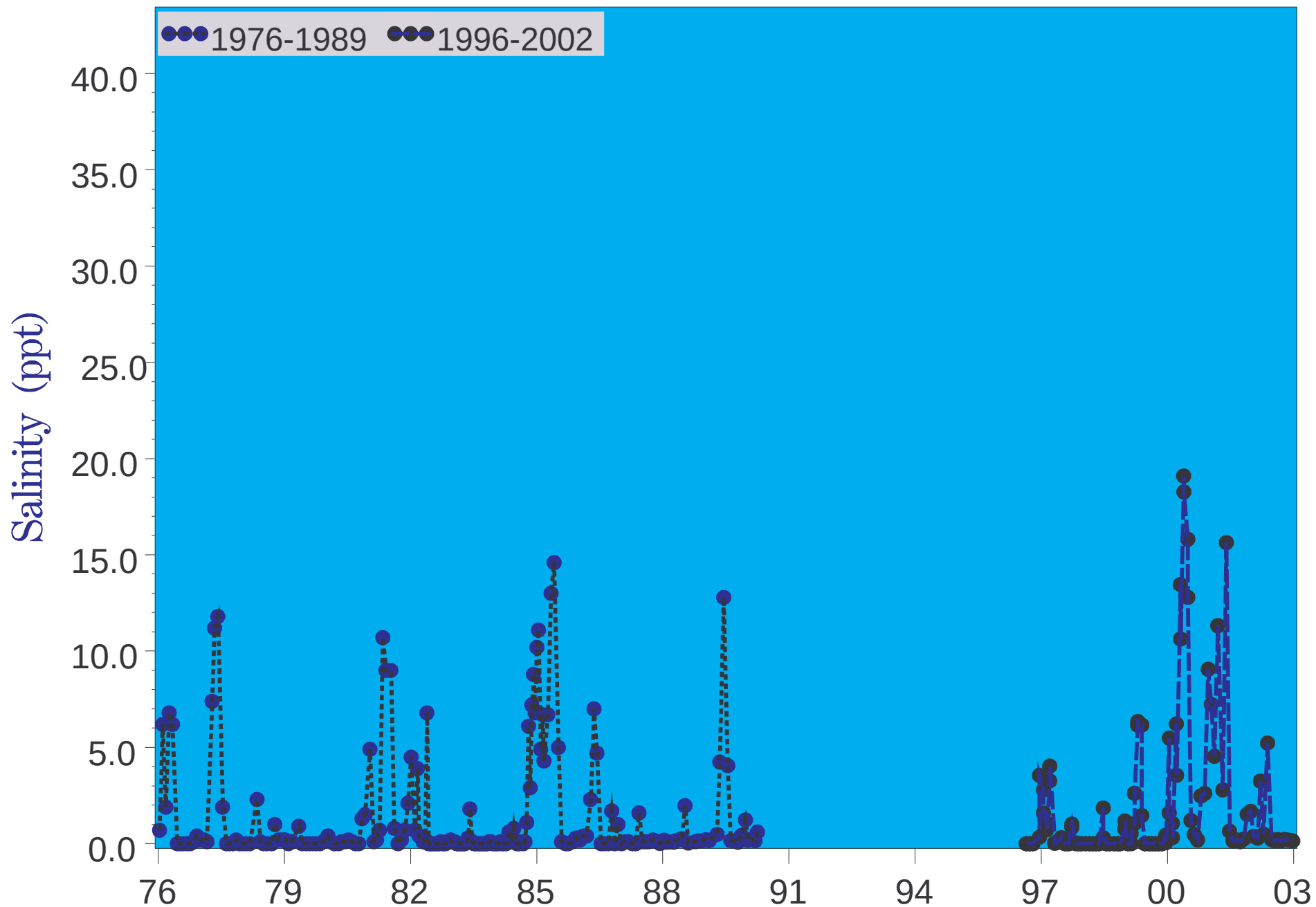


Figure 4.5.162 Long-term bottom salinity at river kilometer 23.6

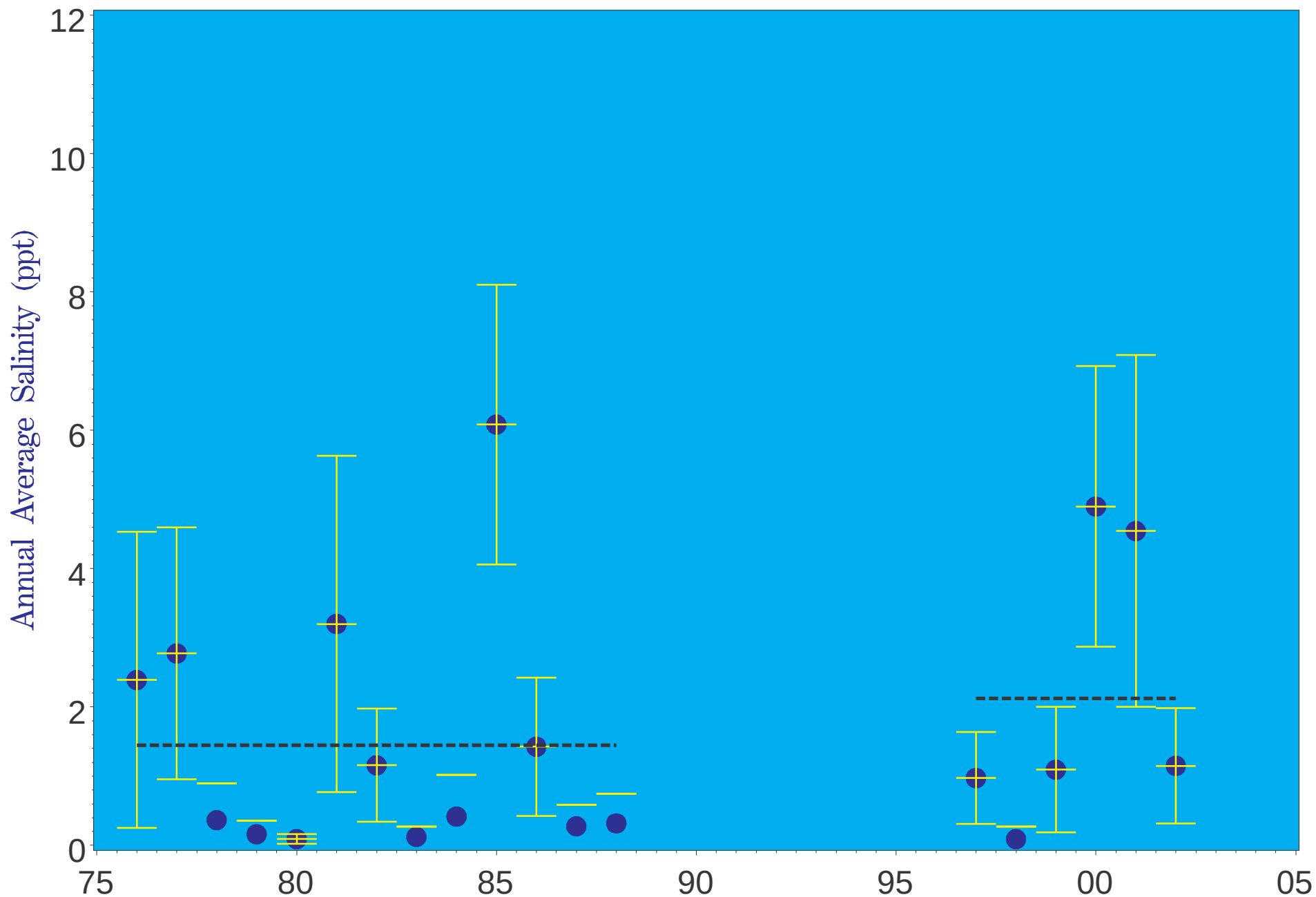


Figure 4.5.163 Long-term bottom salinity at river kilometer 23.6

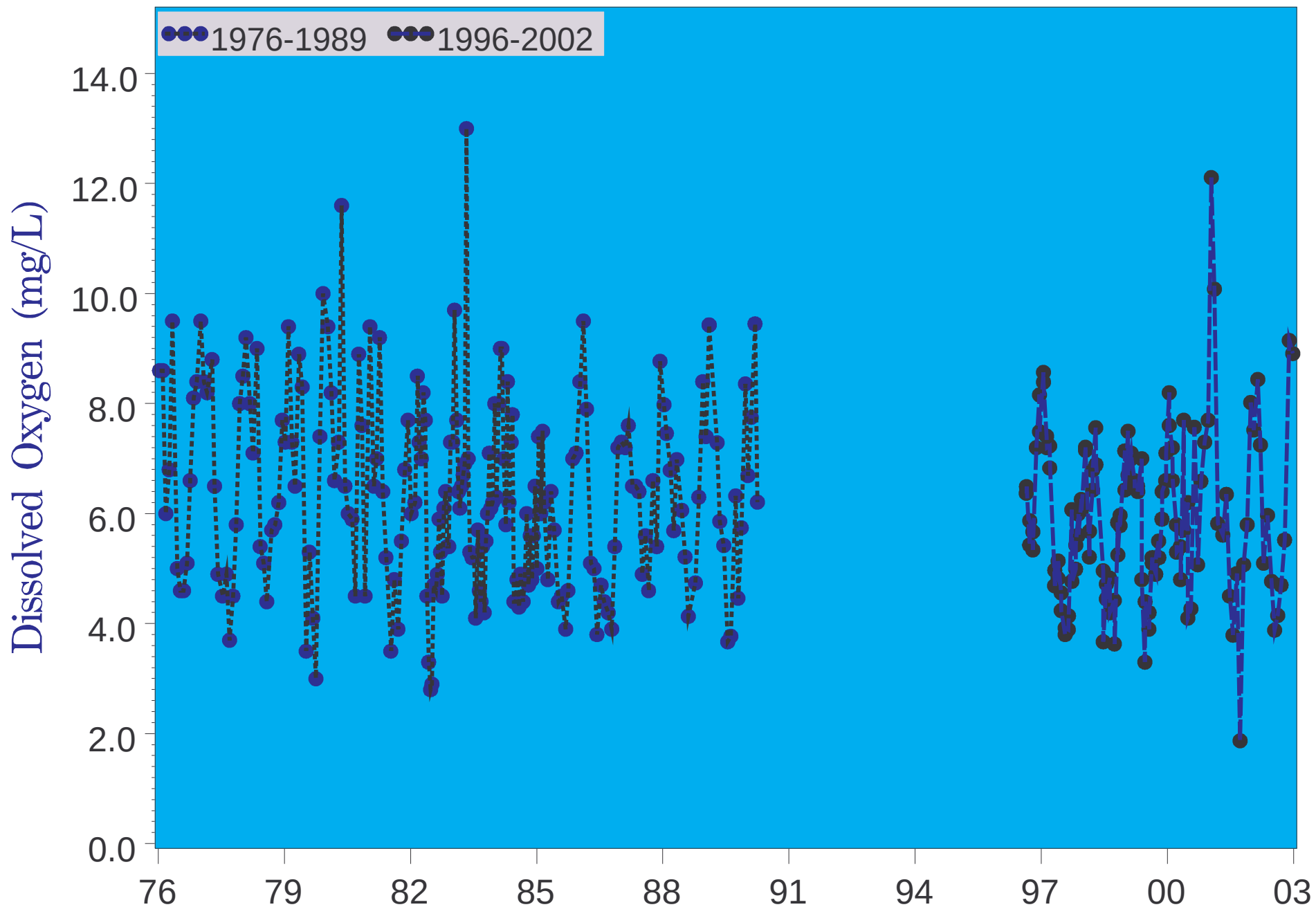


Figure 4.5.164 Long-term surface dissolved oxygen at river kilometer 23.6

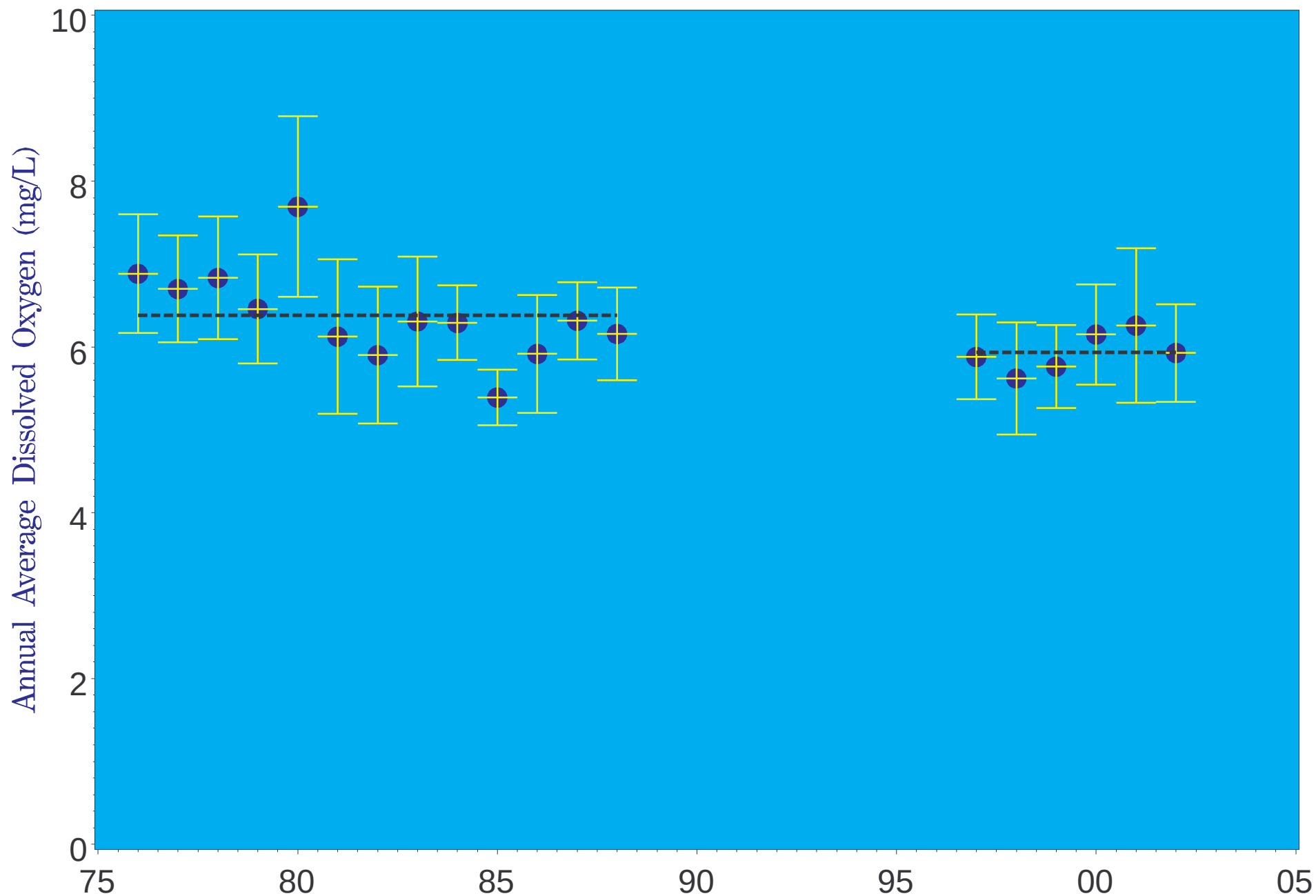


Figure 4.5.165 Long-term surface dissolved oxygen at river kilometer 23.6

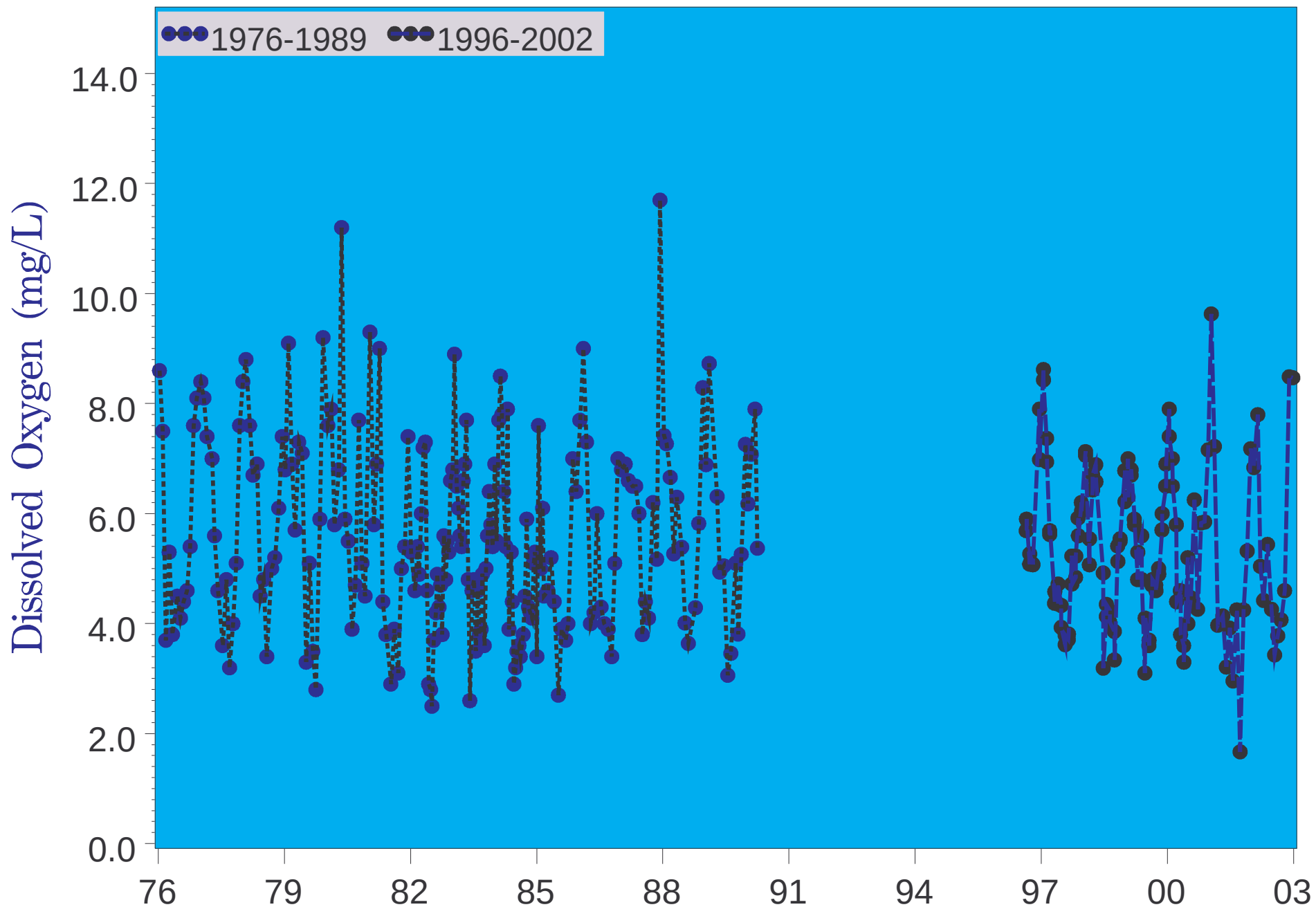


Figure 4.5.166 Long-term bottom dissolved oxygen at river kilometer 23.6

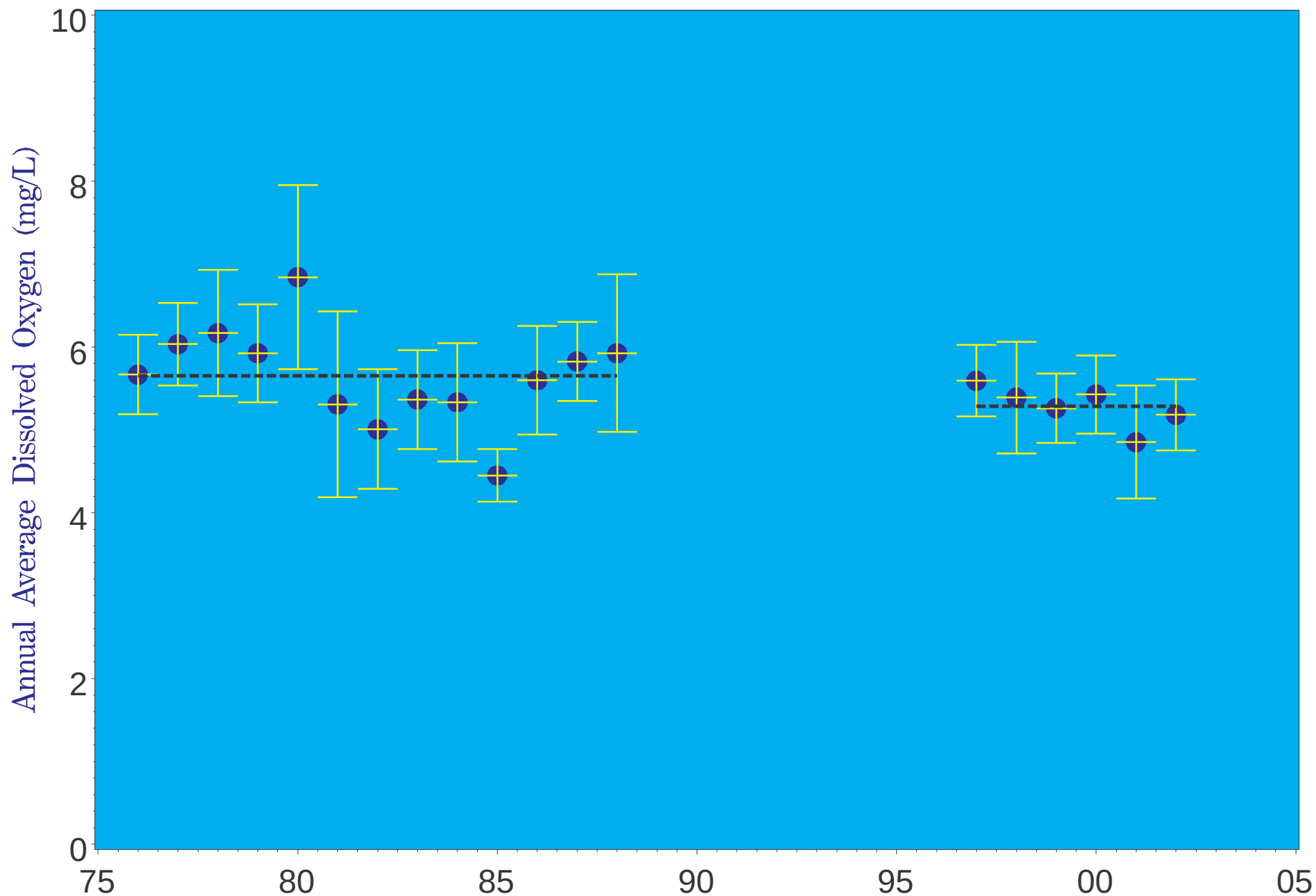


Figure 4.5.167 Long-term bottom dissolved oxygen at river kilometer 23.6

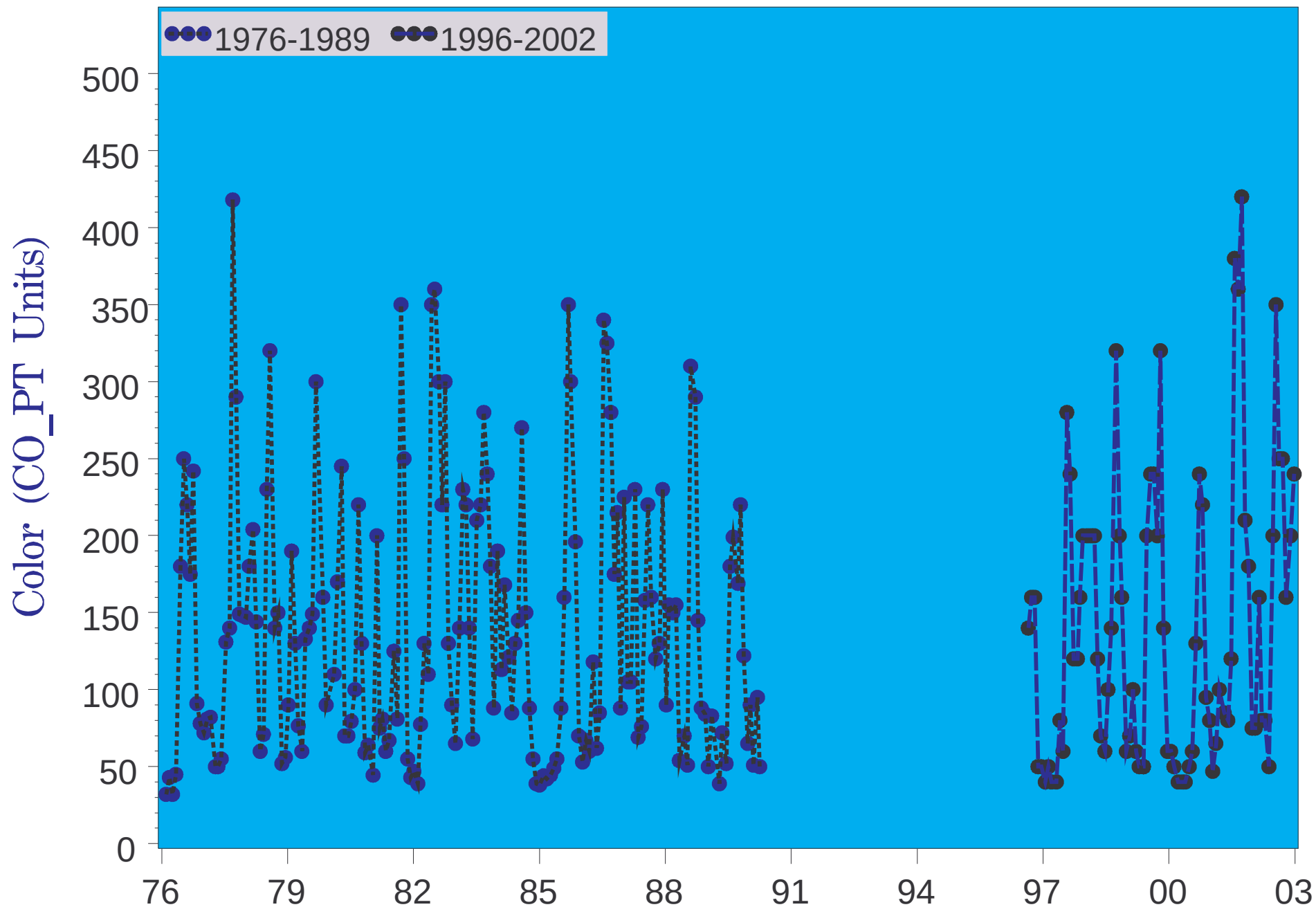


Figure 4.5.168 Long-term surface color at river kilometer 23.6



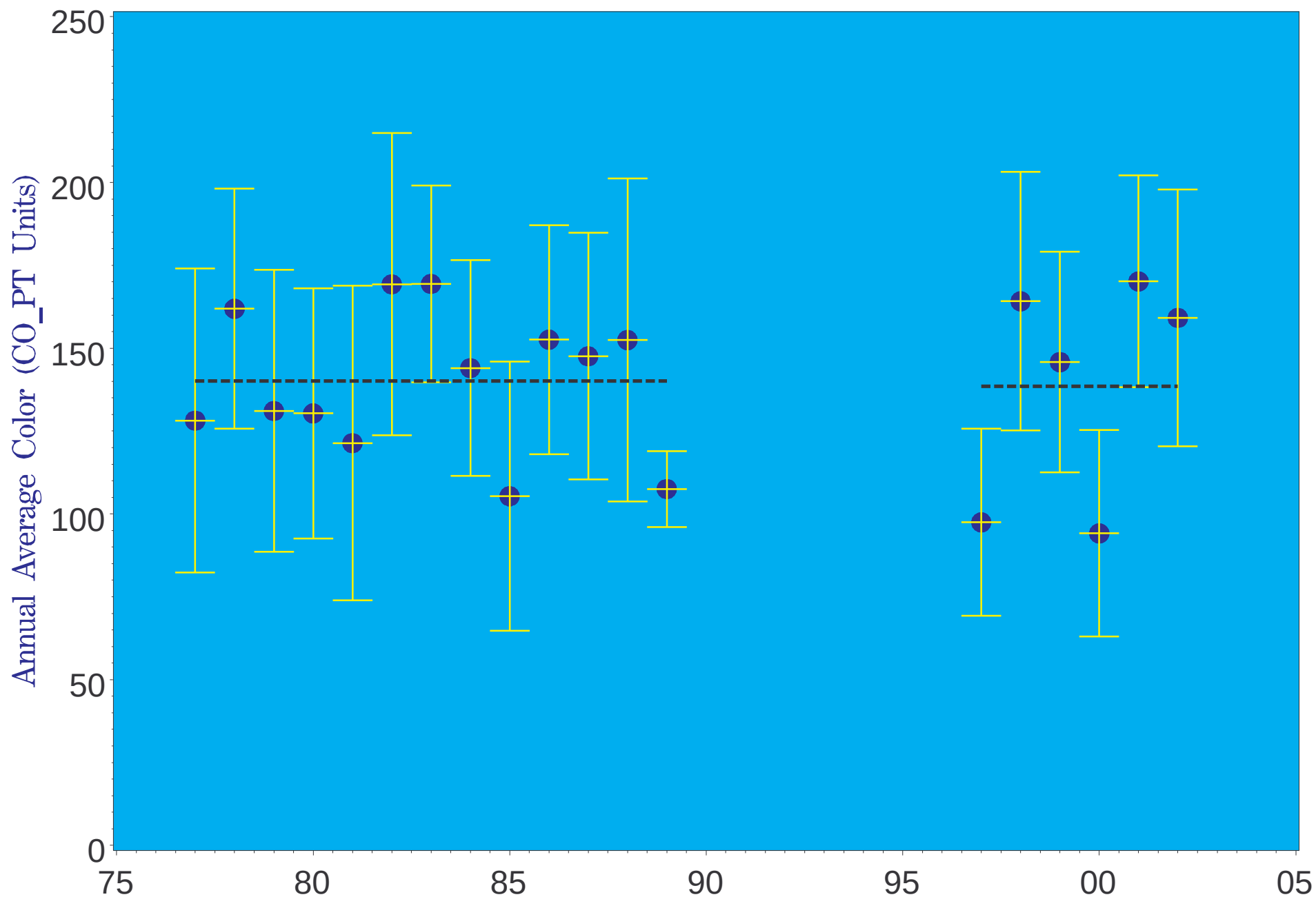


Figure 4.5.169 Long-term surface color at river kilometer 23.6

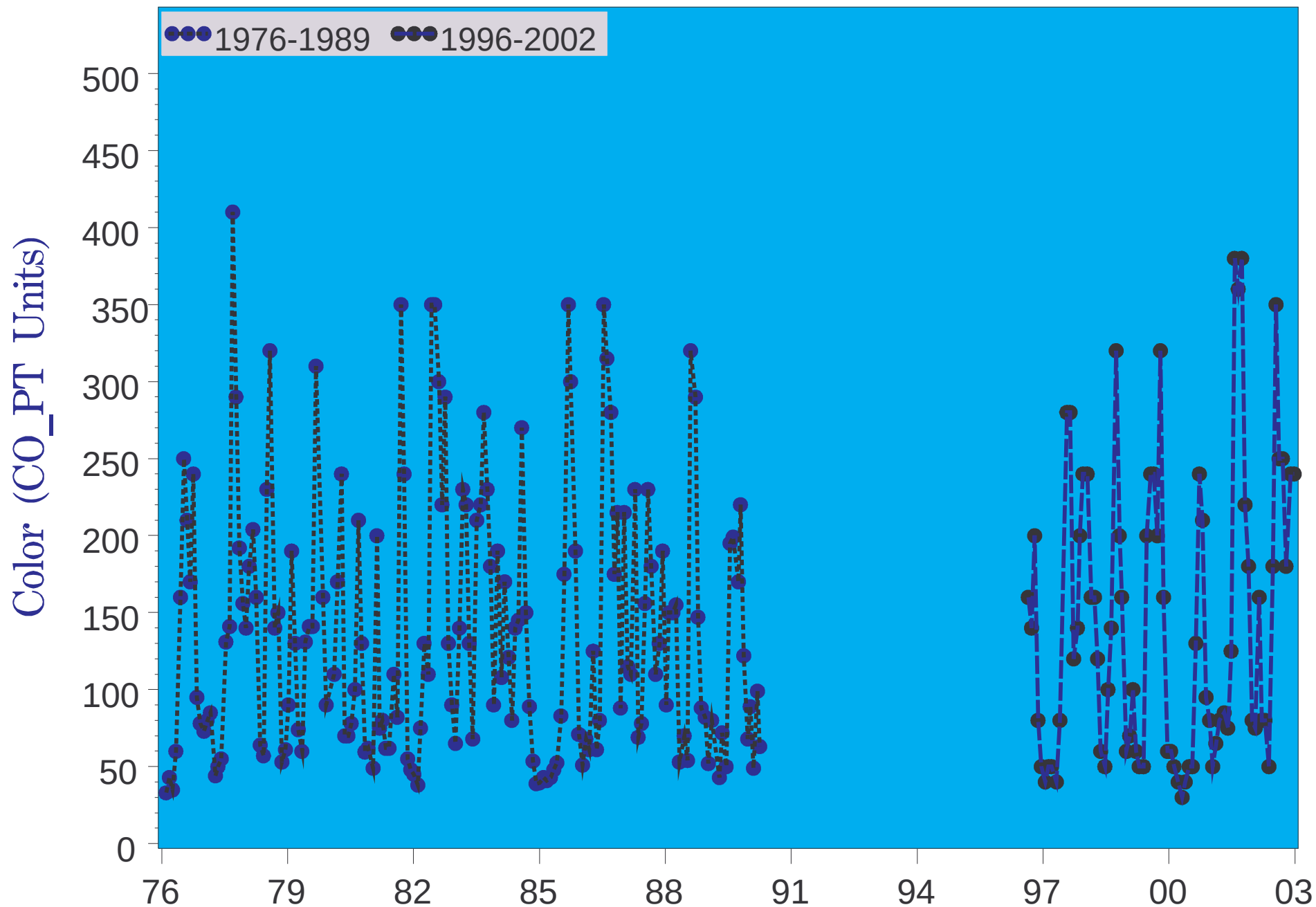


Figure 4.5.170 Long-term bottom color at river kilometer 23.6

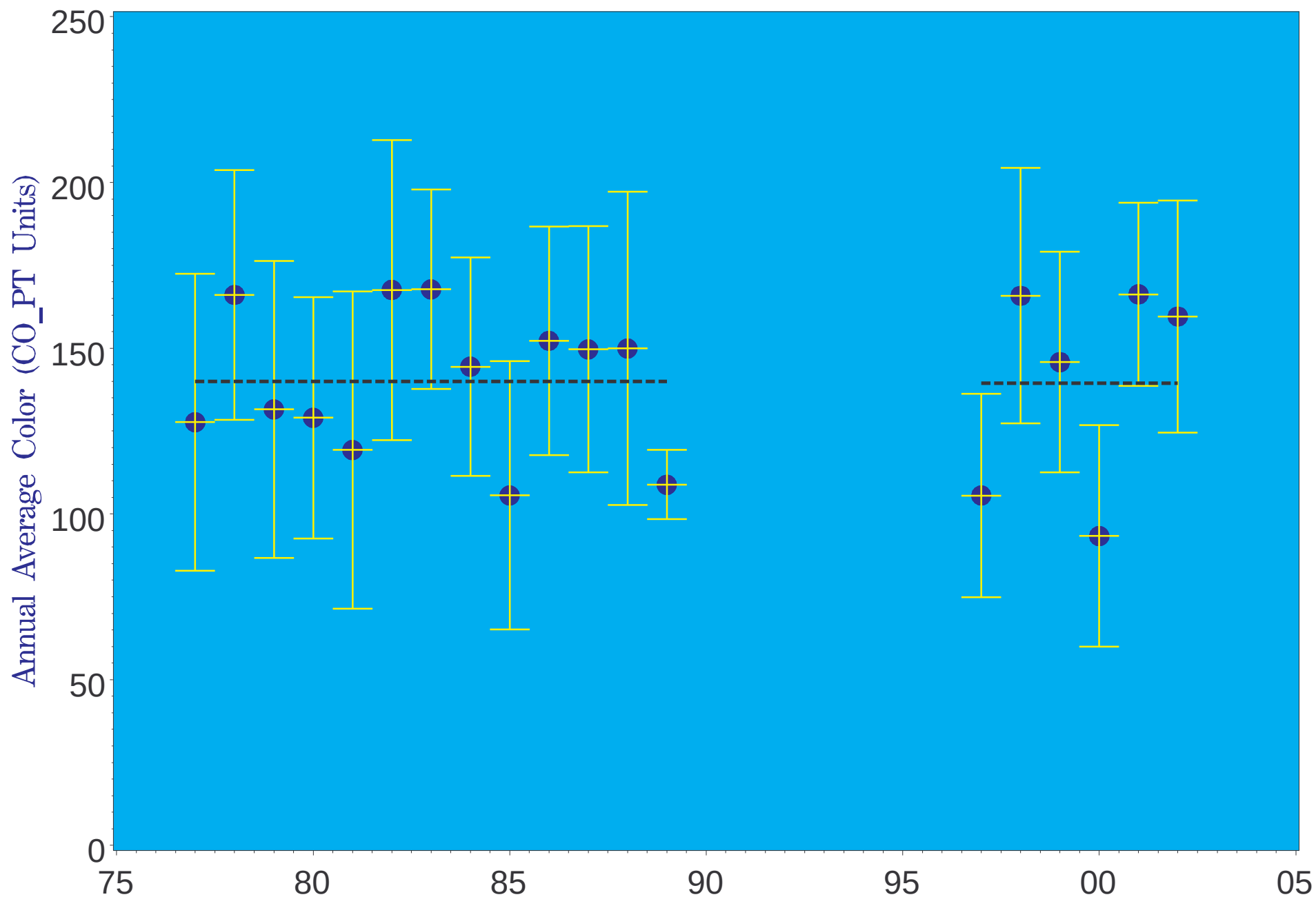


Figure 4.5.171 Long-term bottom color at river kilometer 23.6

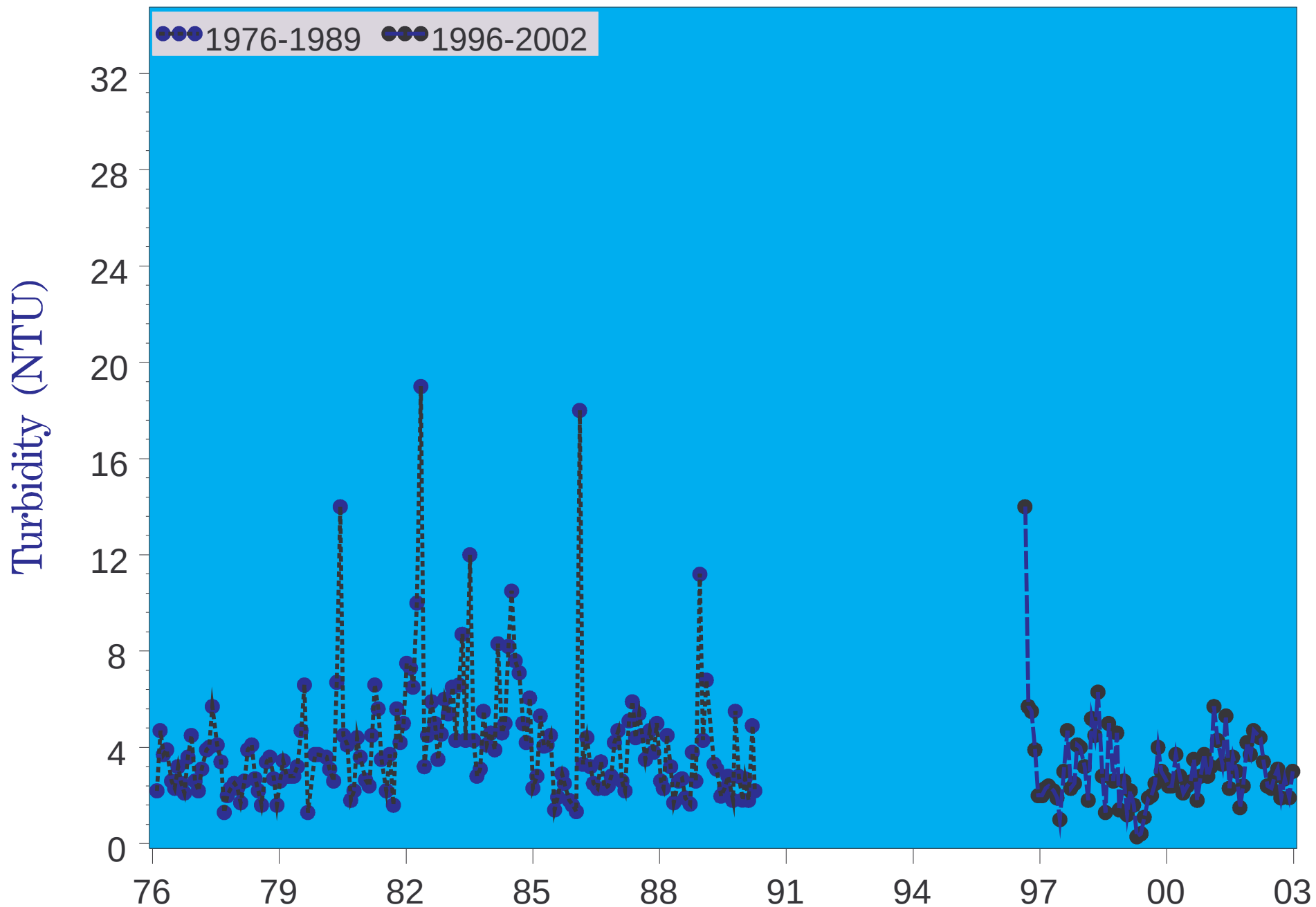


Figure 4.5.172 Long-term surface turbidity at river kilometer 23.6

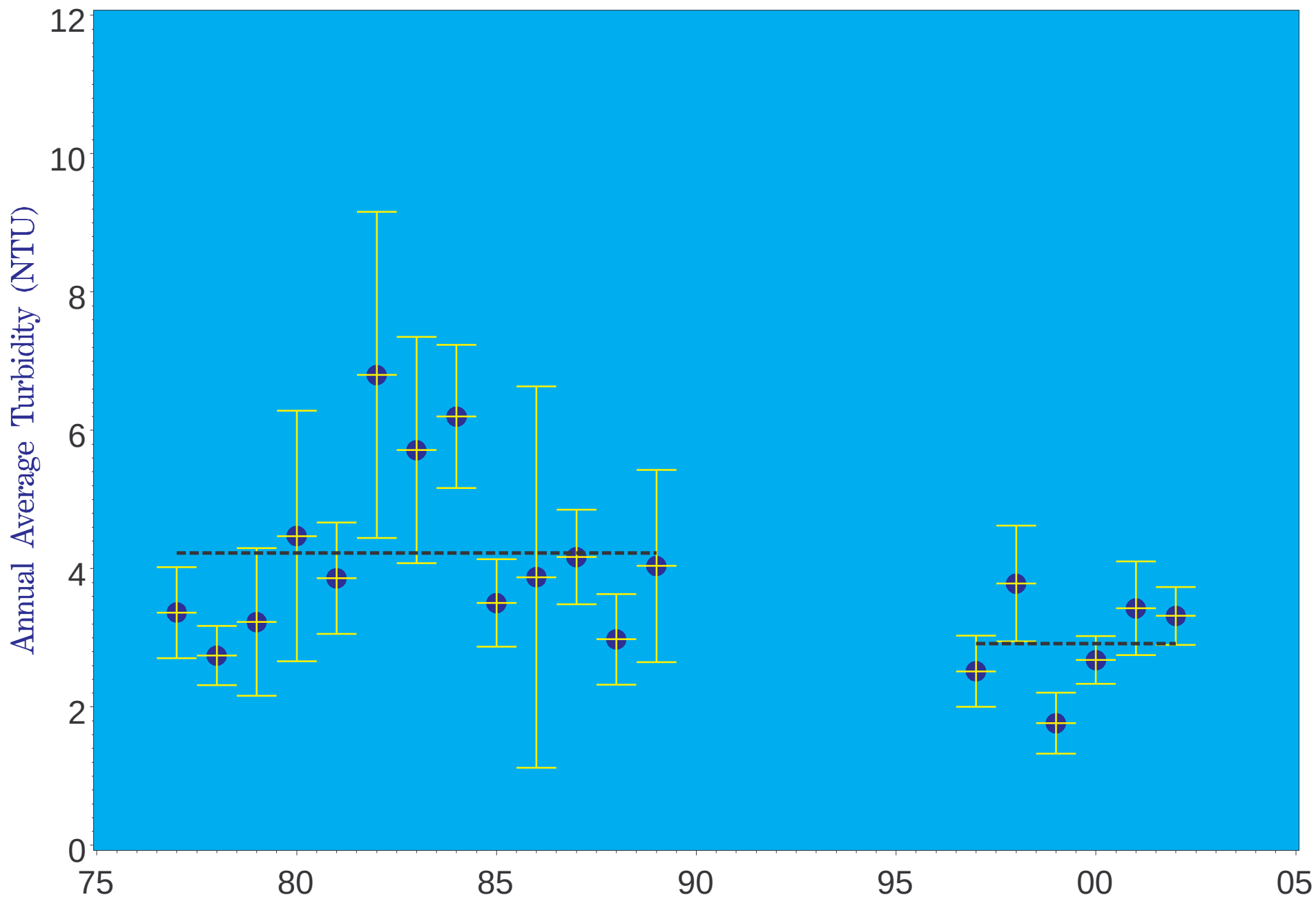


Figure 4.5.173 Long-term surface turbidity at river kilometer 23.6

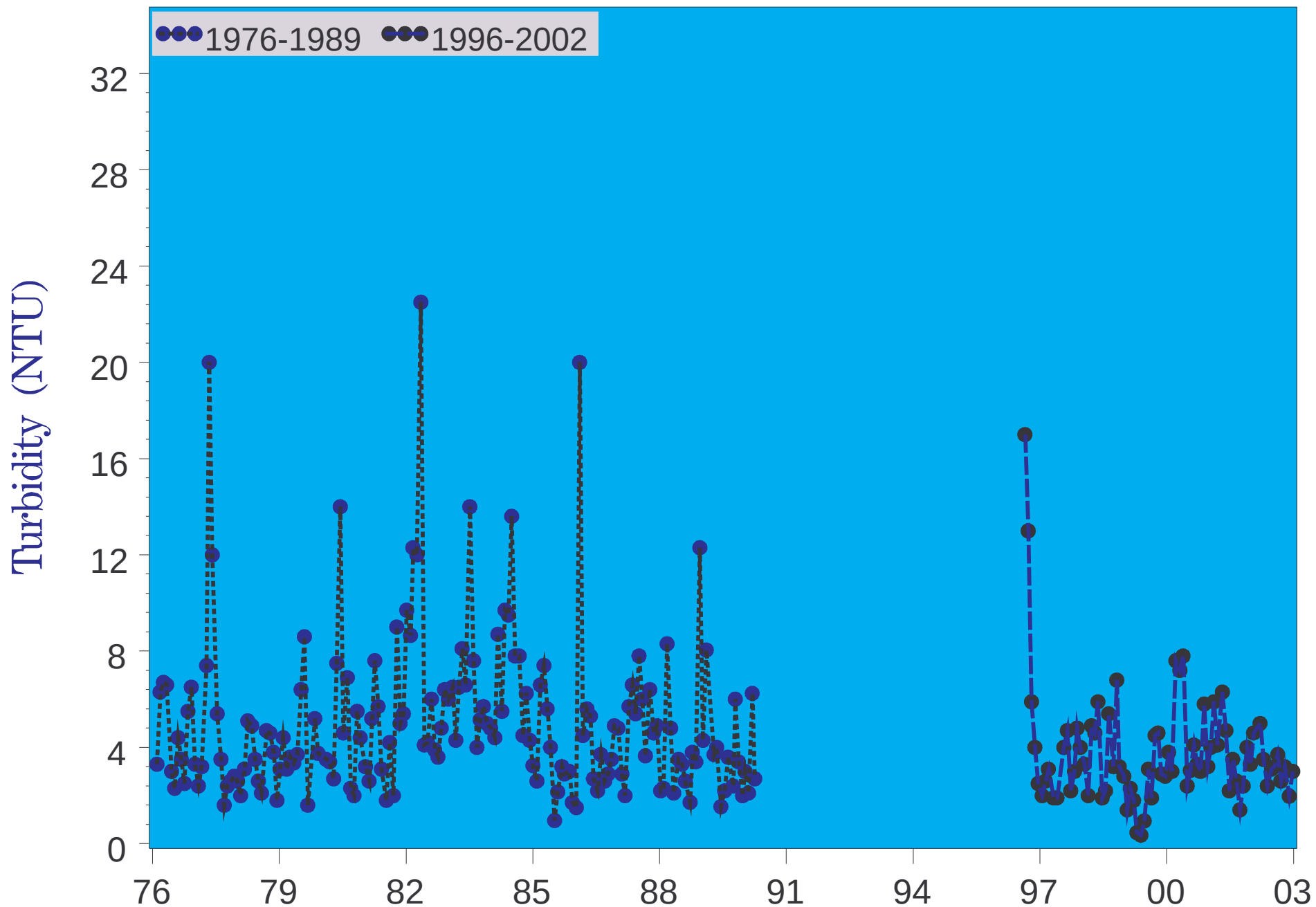


Figure 4.5.174 Long-term bottom turbidity at river kilometer 23.6

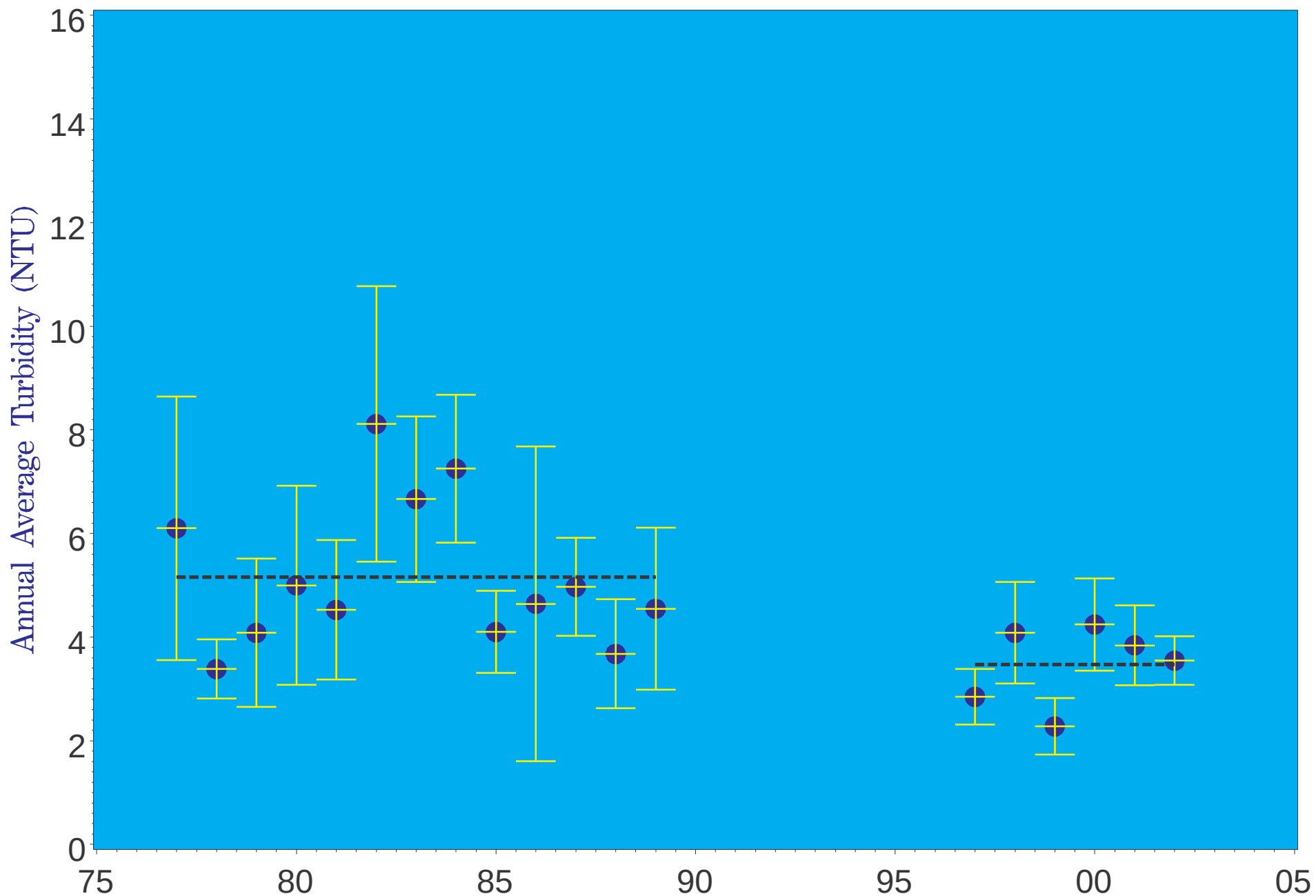


Figure 4.5.175 Long-term bottom turbidity at river kilometer 23.6

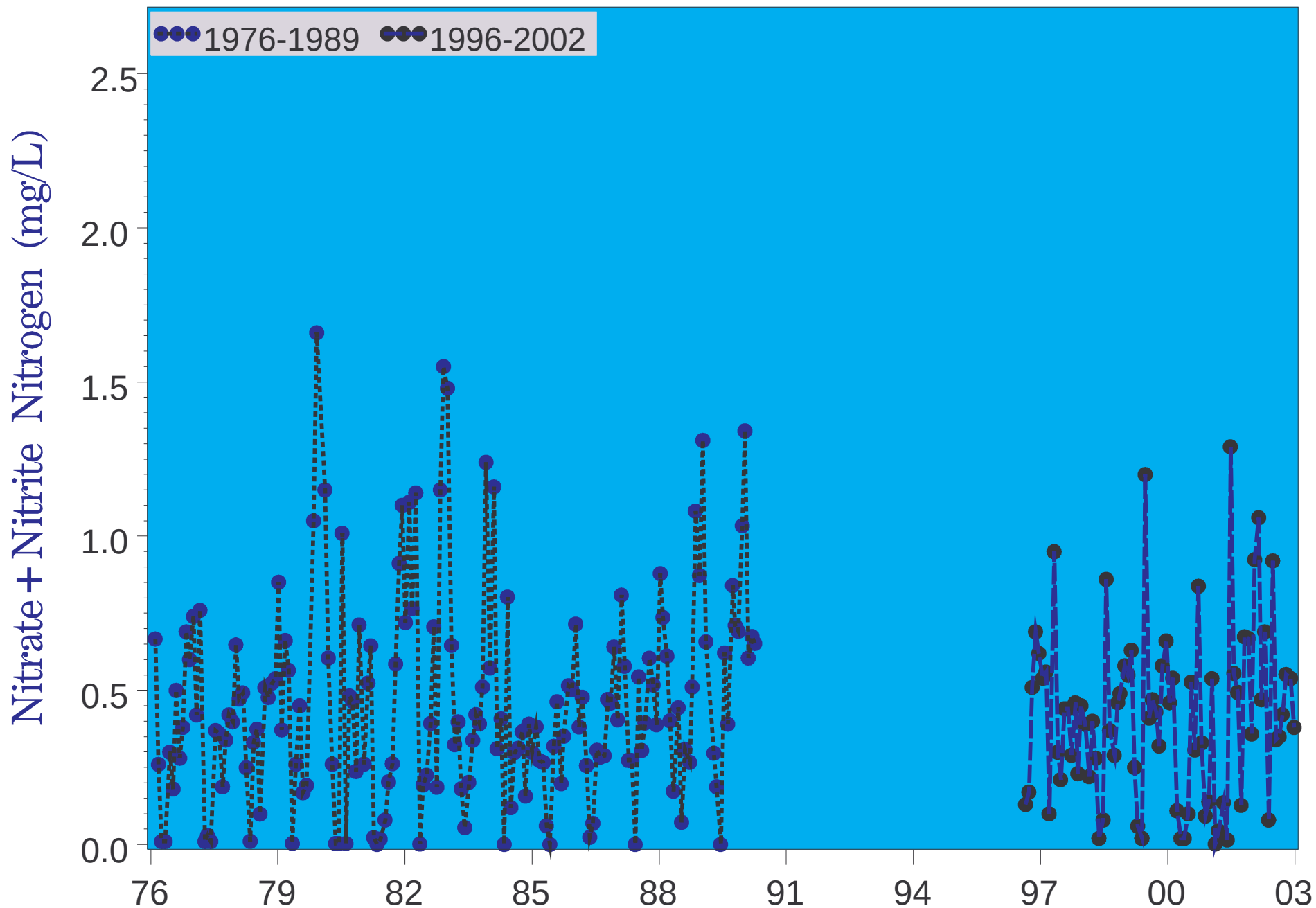


Figure 4.5.176 Long-term surface nitrate/nitrite nitrogen at river kilometer 23.6



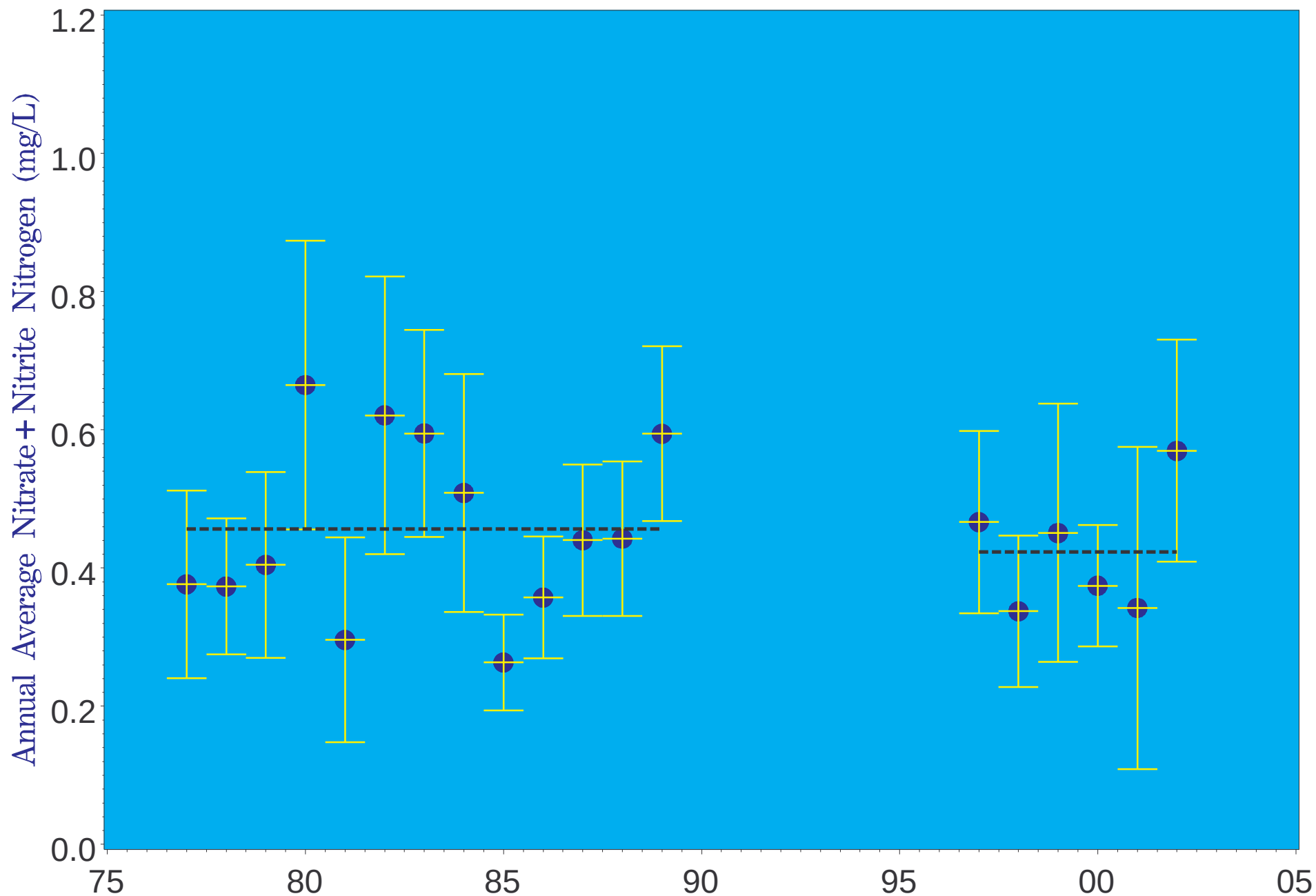


Figure 4.5.177 Long-term surface nitrate/nitrite nitrogen at river kilometer 23.6

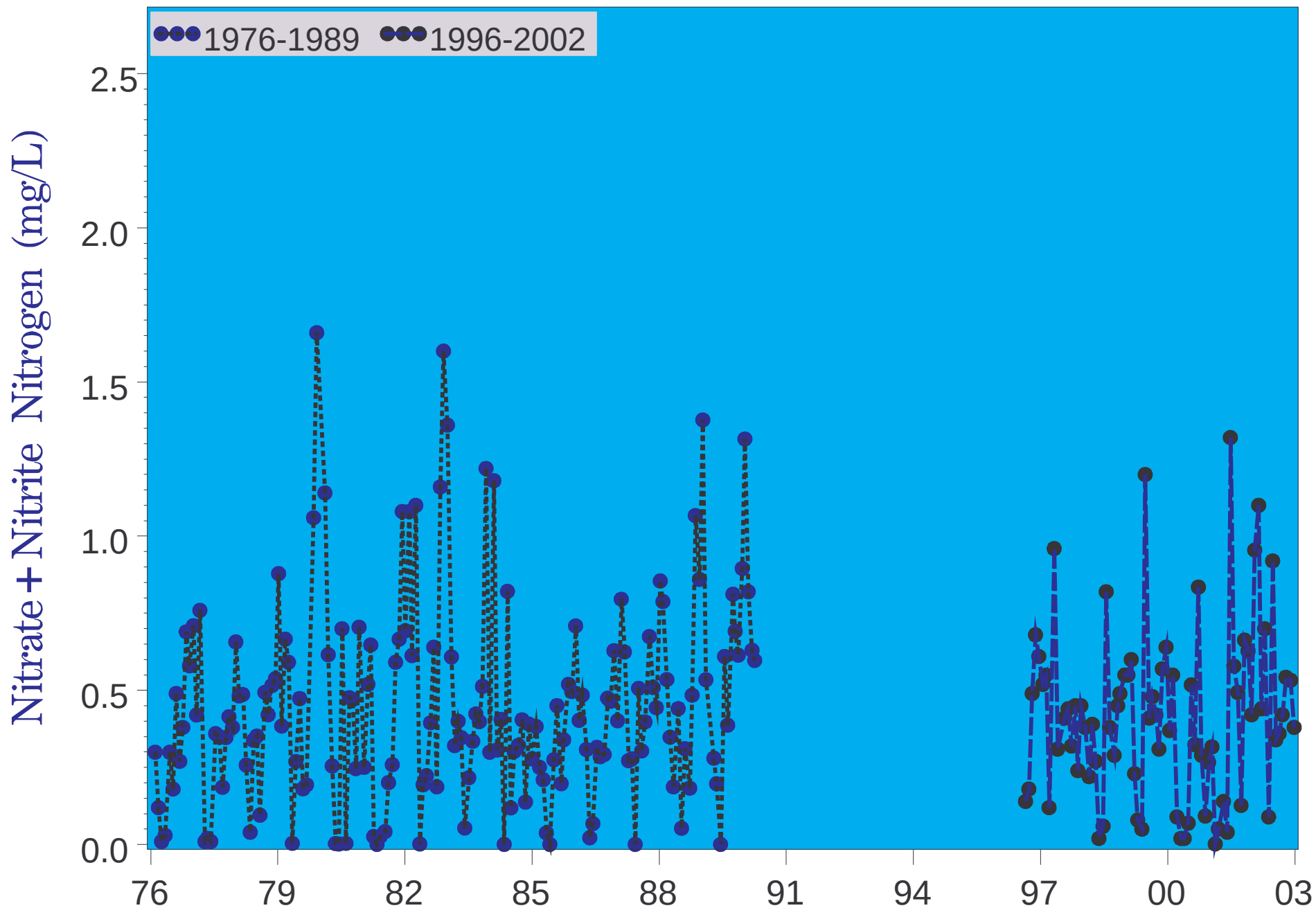


Figure 4.5.178 Long-term bottom nitrate/nitrite nitrogen at river kilometer 23.6

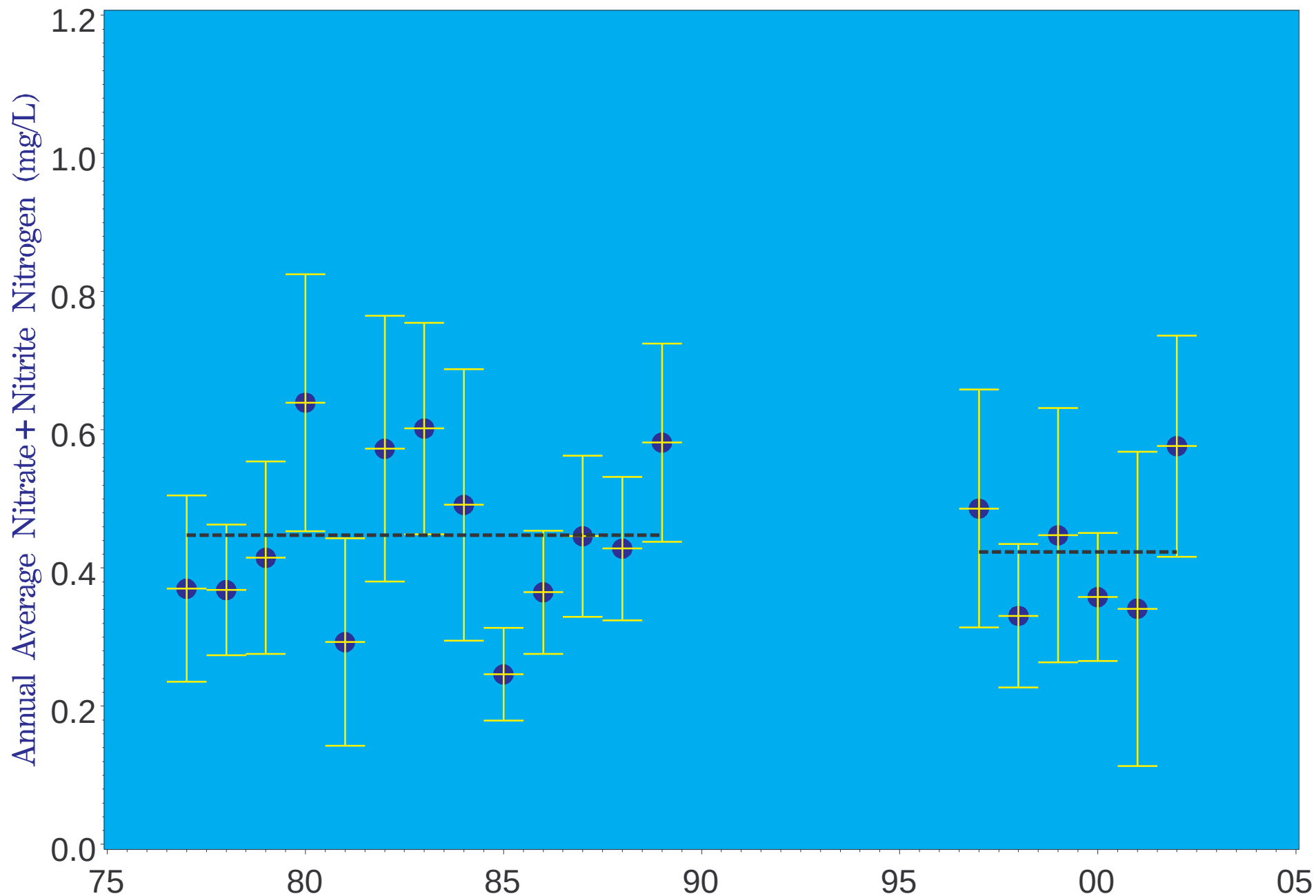


Figure 4.5.179 Long-term bottom nitrate/nitrite nitrogen at river kilometer 23.6

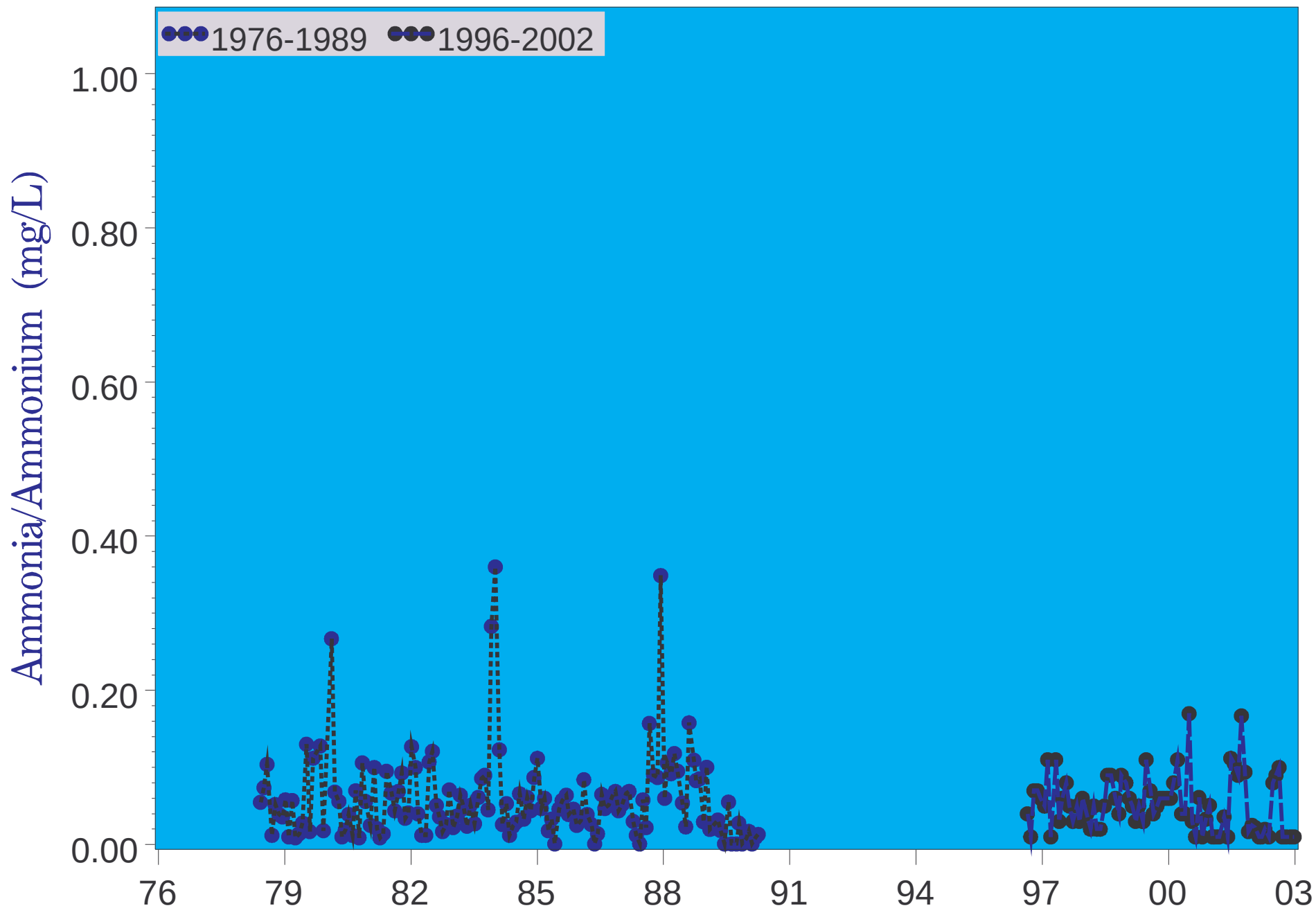


Figure 4.5.180 Long-term surface ammonia/ammonium at river kilometer 23.6

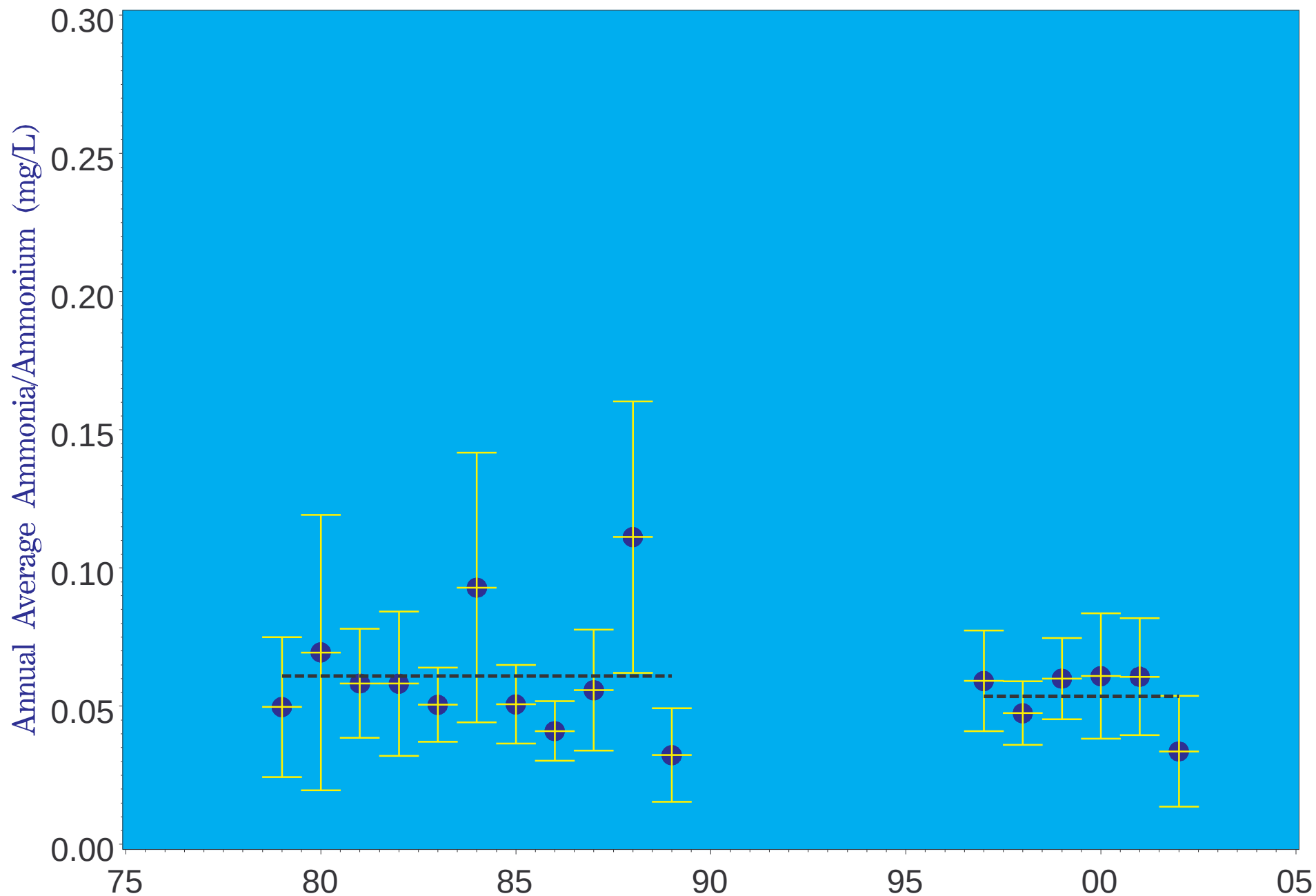


Figure 4.5.181 Long-term surface ammonia/ammonium at river kilometer 23.6

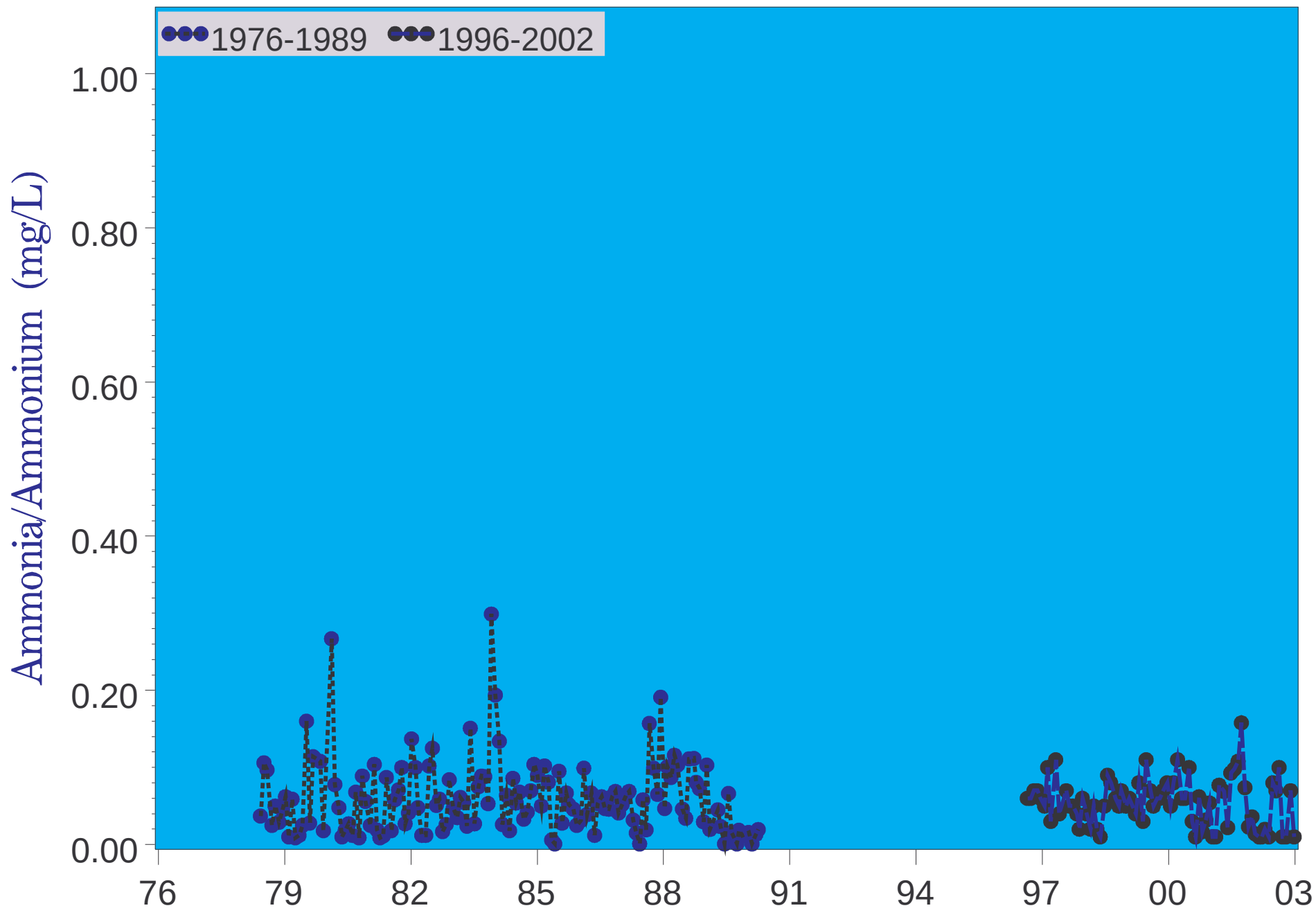


Figure 4.5.182 Long-term bottom ammonia/ammonium at river kilometer 23.6

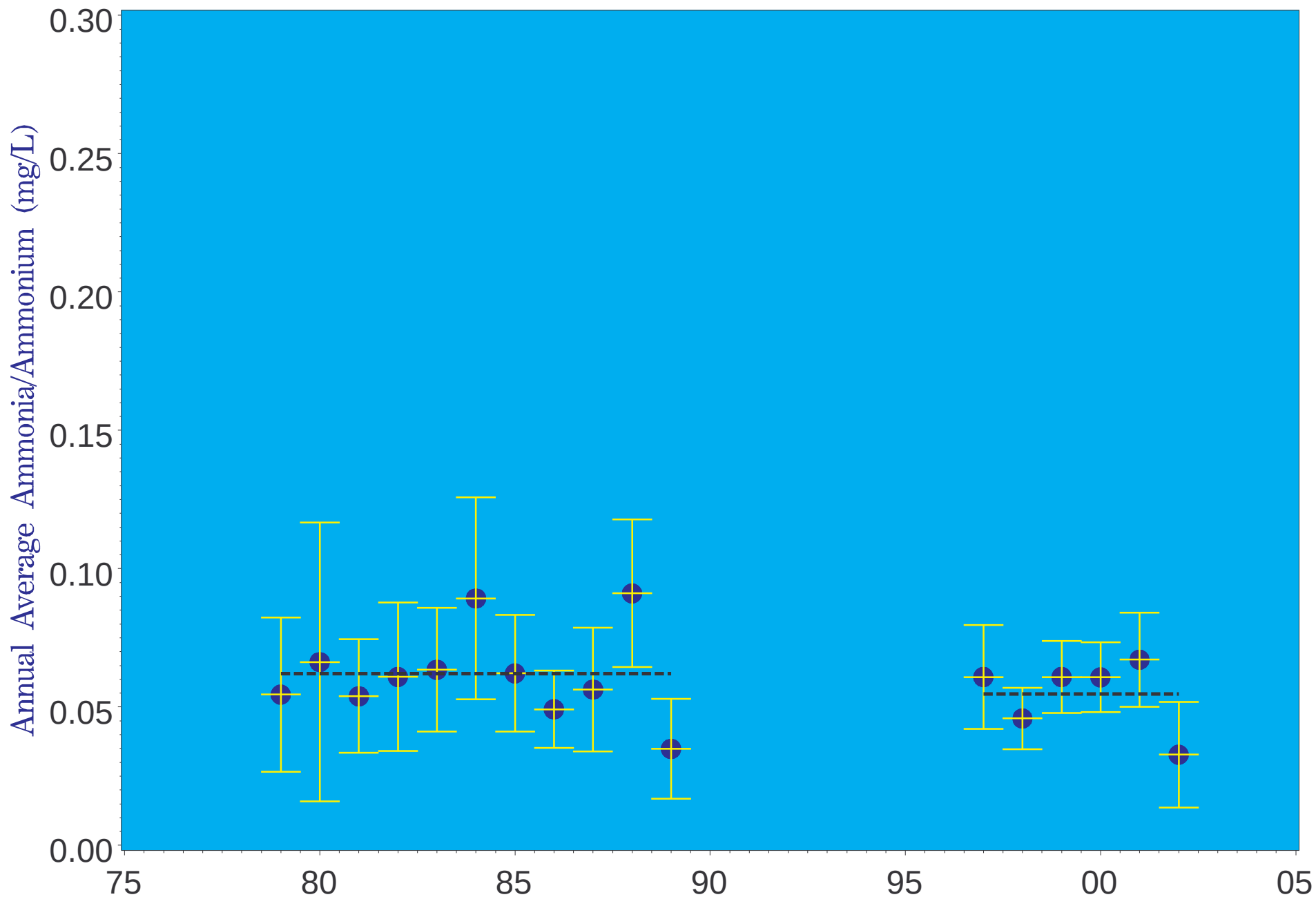


Figure 4.5.183 Long-term bottom ammonia/ammonium at river kilometer 23.6

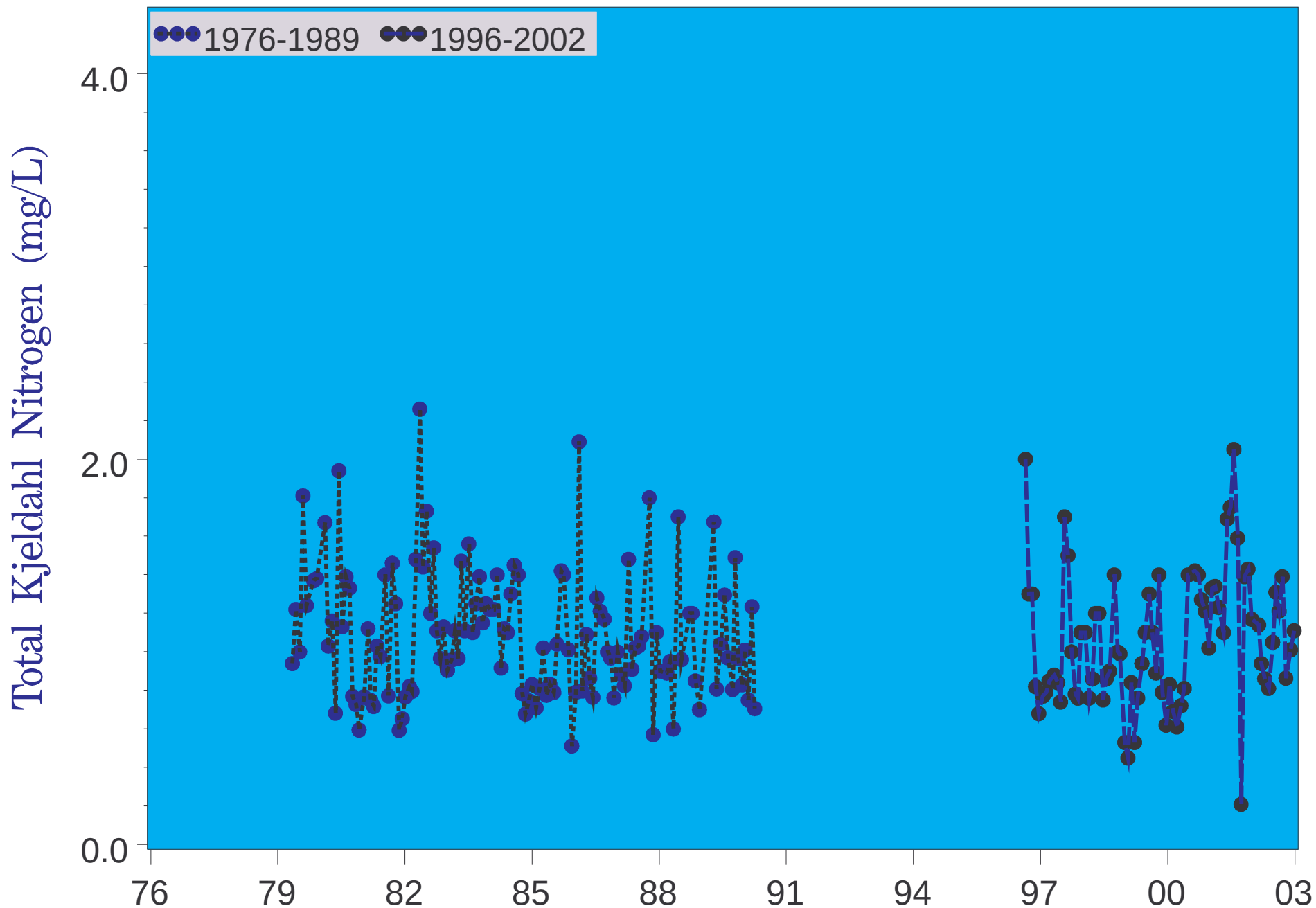


Figure 4.5.184 Long-term surface total Kjeldahl nitrogen at river kilometer 23.6



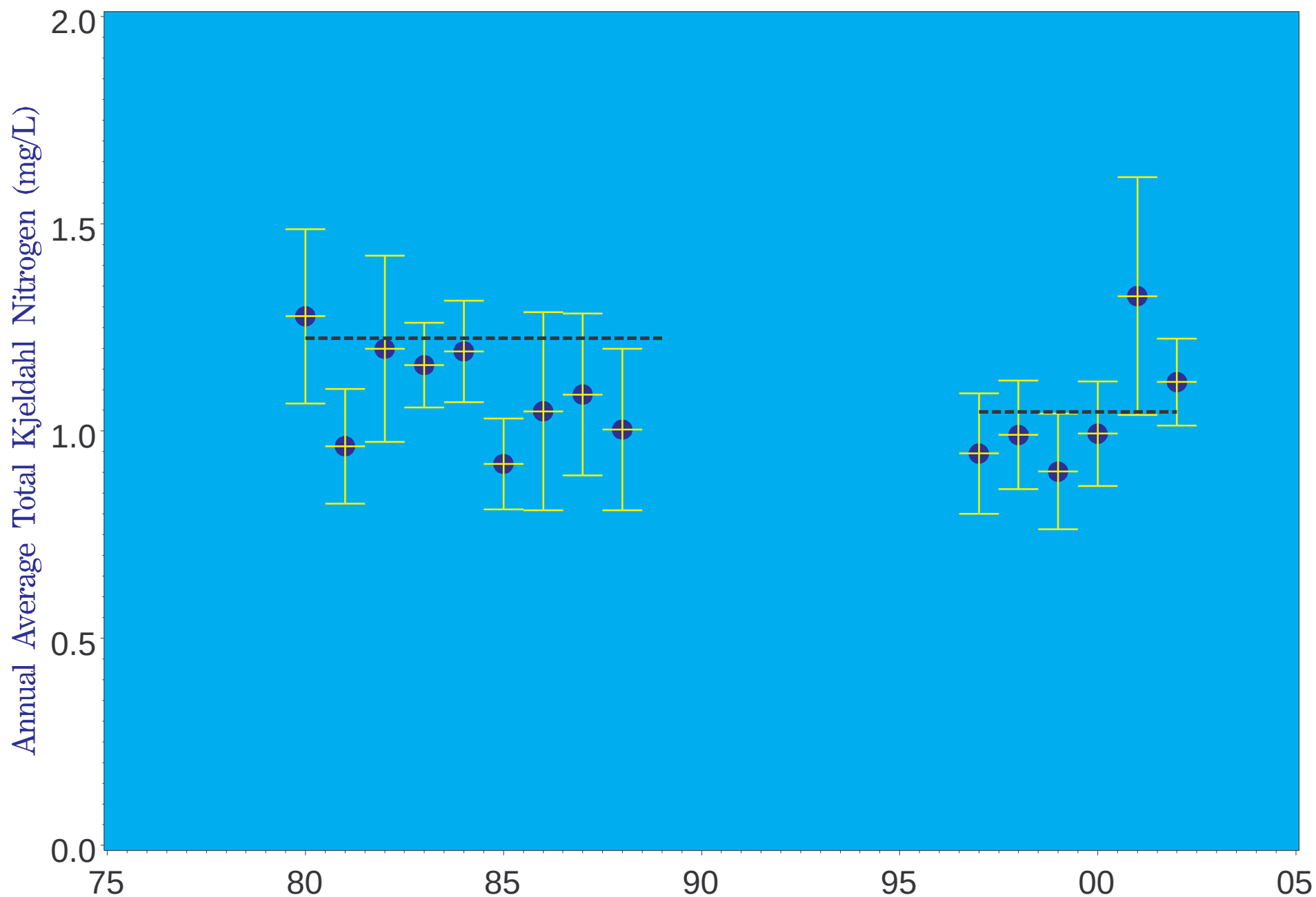


Figure 4.5.185 Long-term surface total Kjeldahl nitrogen at river kilometer 23.6

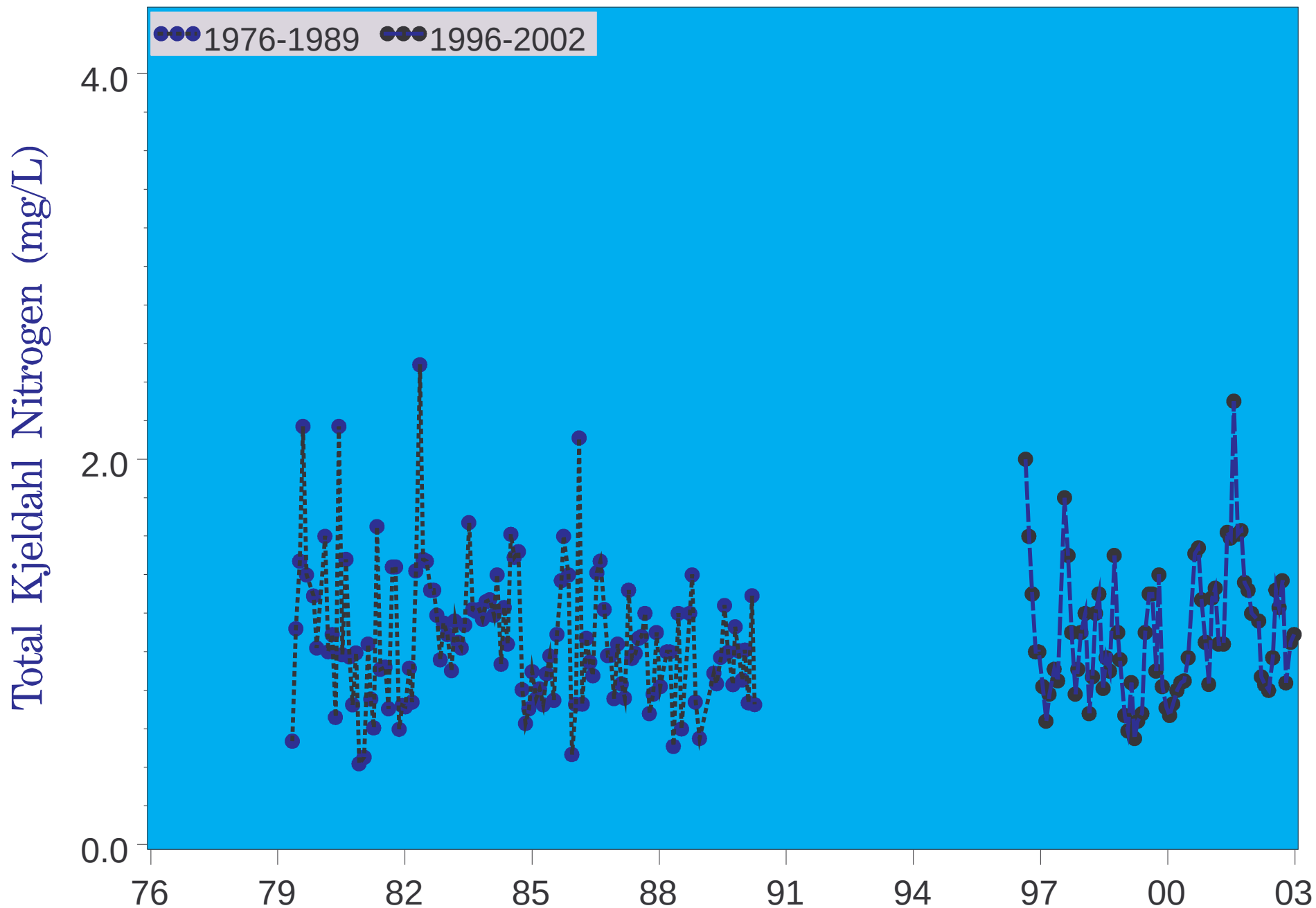


Figure 4.5.186 Long-term bottom total Kjeldhal nitrogen at river kilometer 23.6

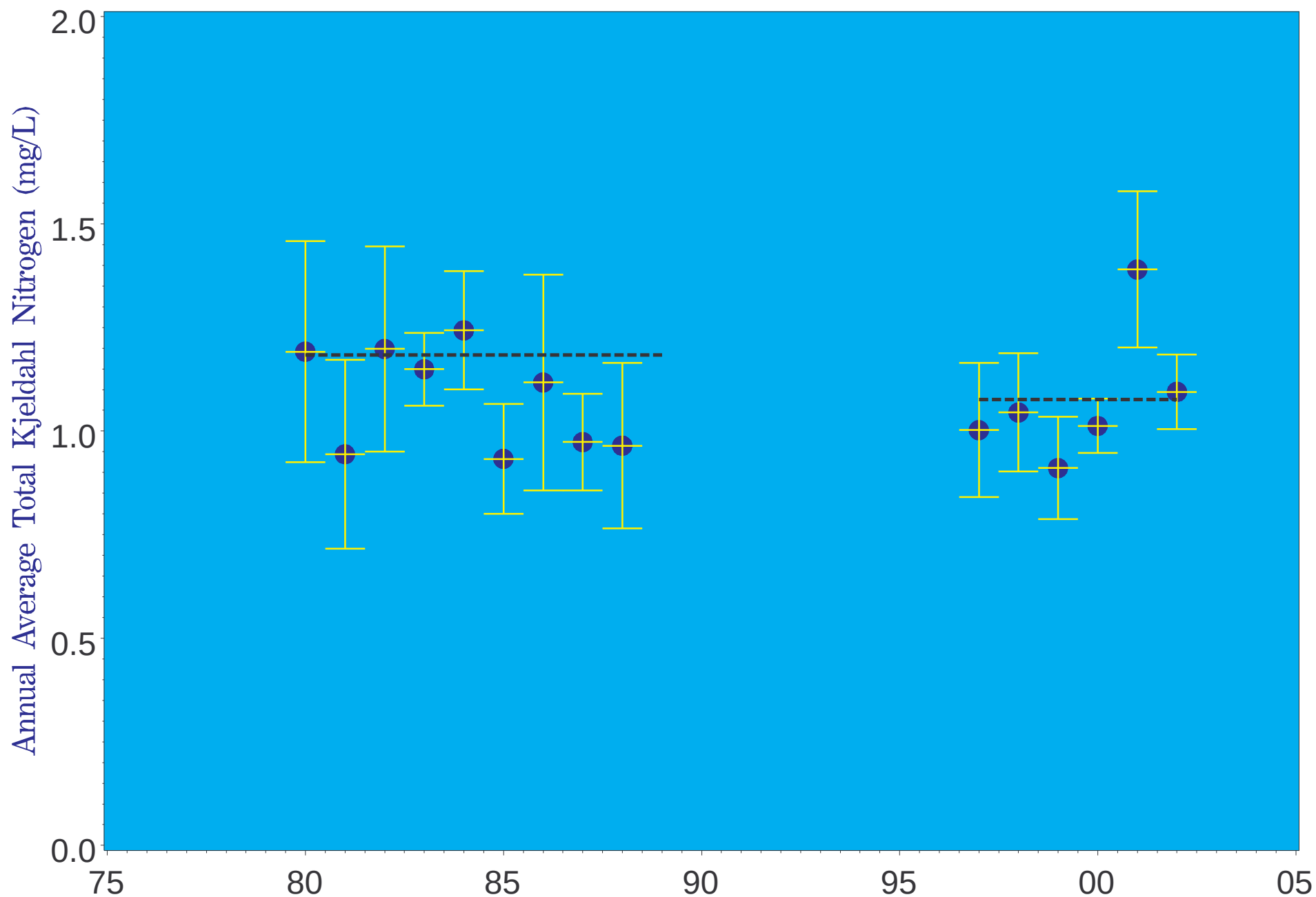


Figure 4.5.187 Long-term bottom total Kjeldhal nitrogen at river kilometer 23.6

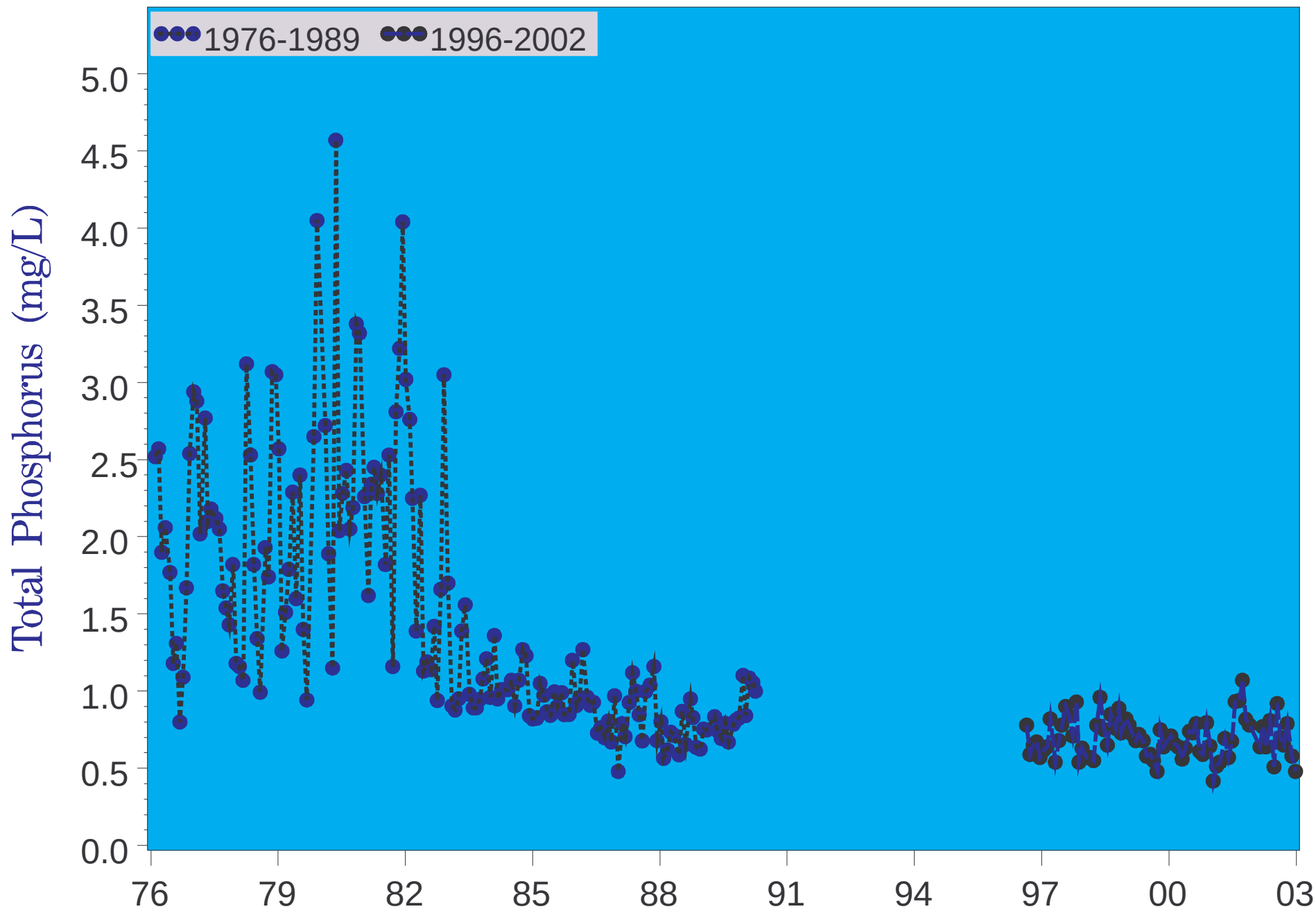


Figure 4.5.188 Long-term surface total phosphorus at river kilometer 23.6

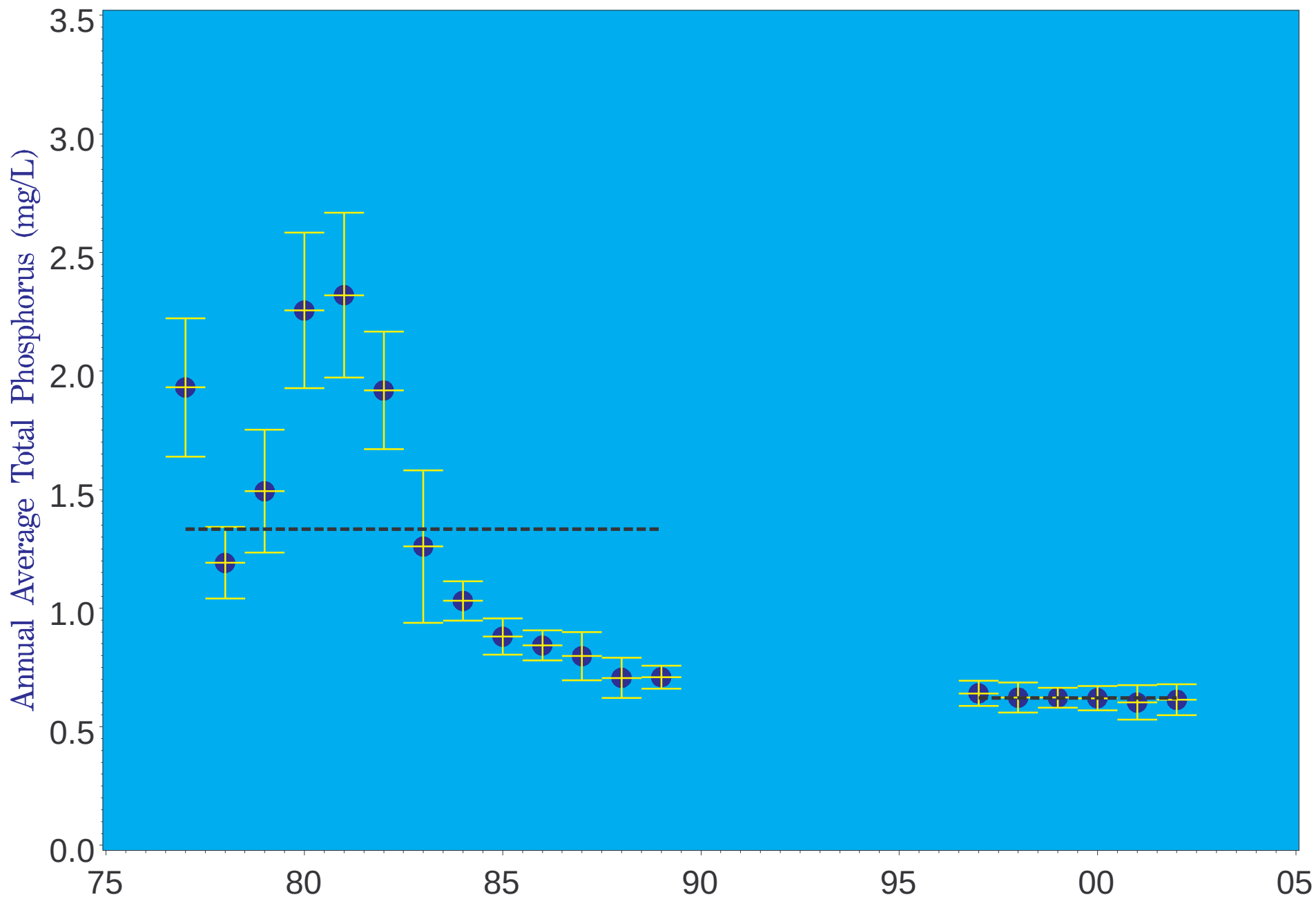


Figure 4.5.189 Long-term surface total phosphorus at river kilometer 23.6

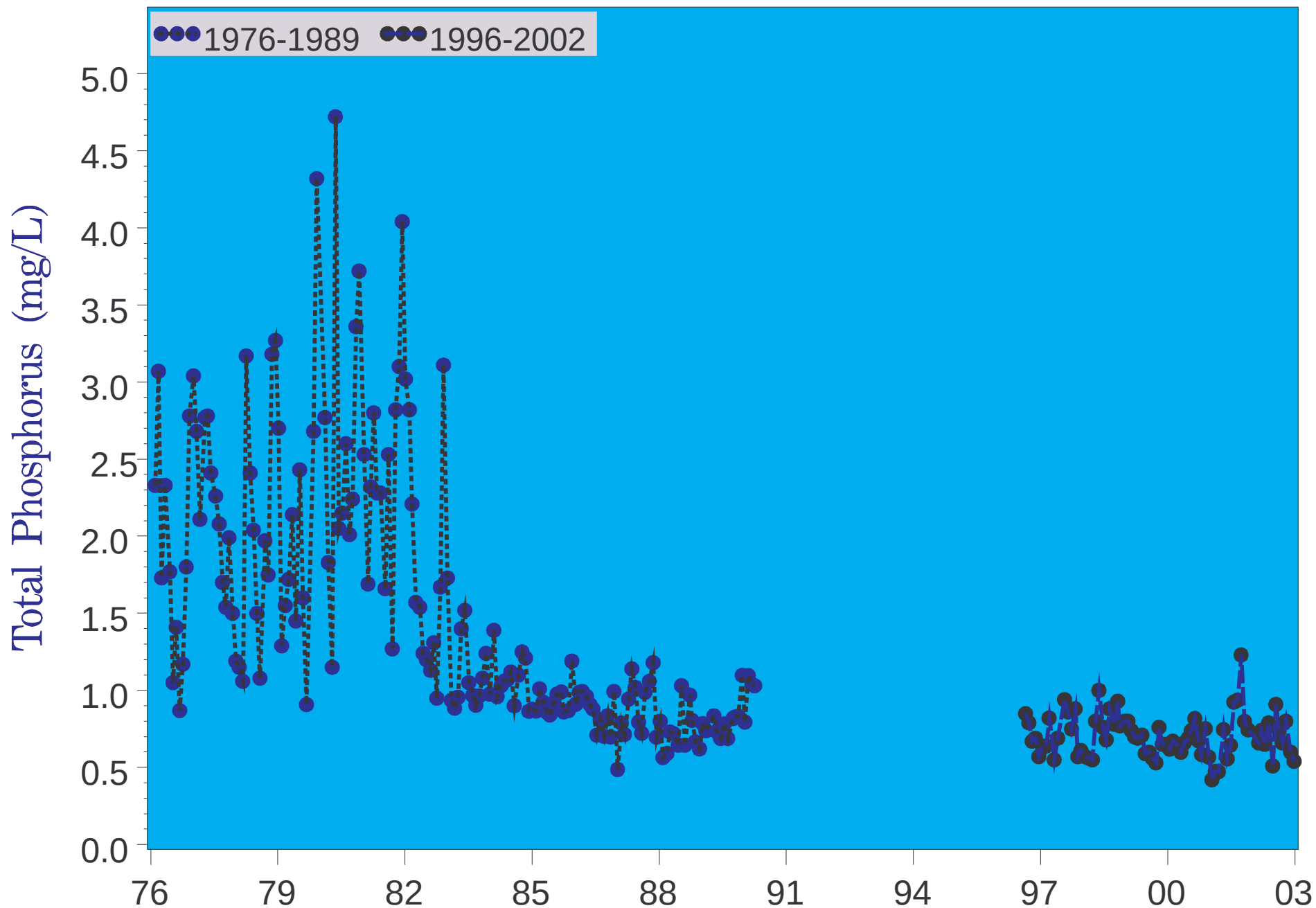


Figure 4.5.190 Long-term bottom total phosphorus at river kilometer 23.6

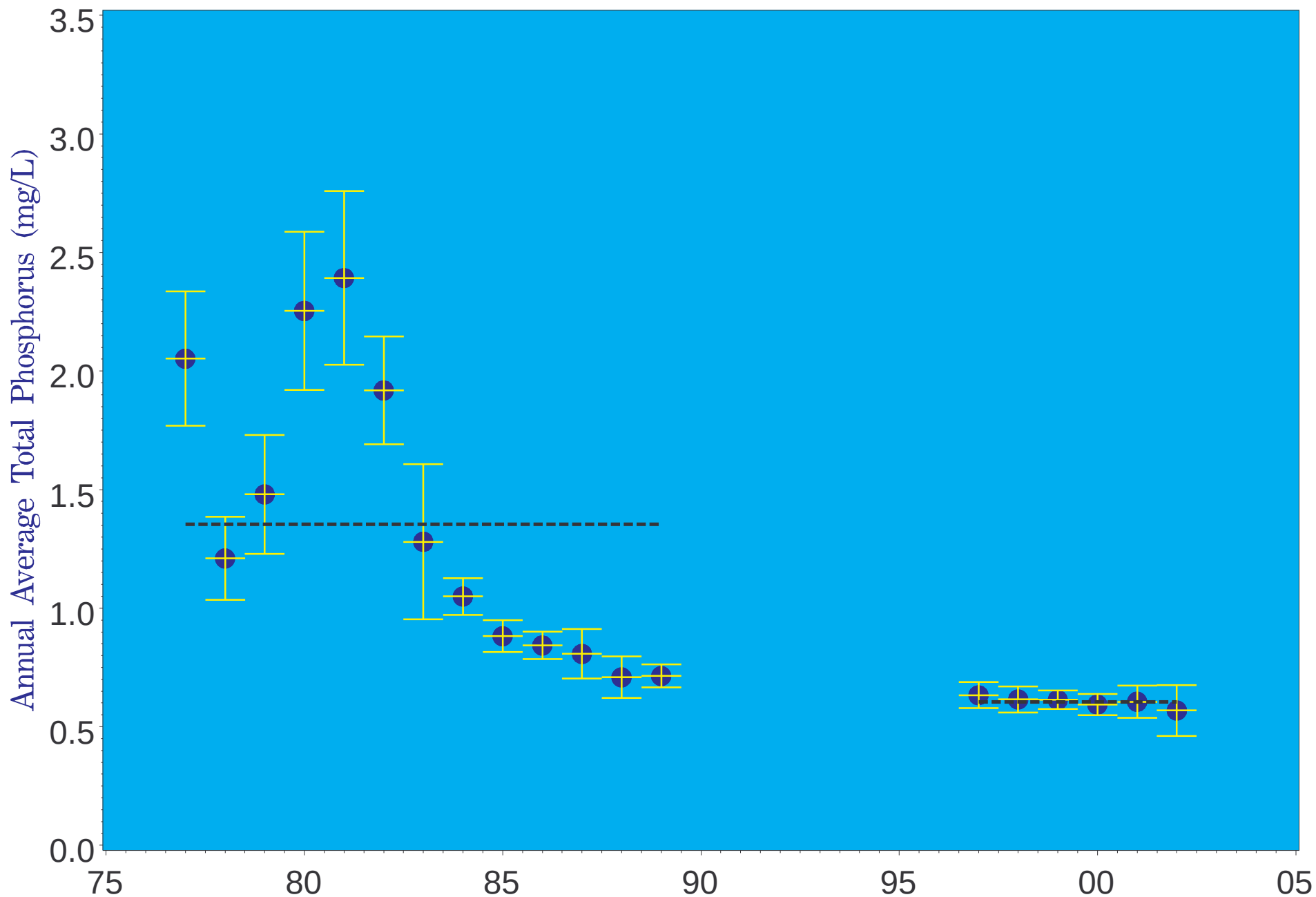


Figure 4.5.191 Long-term bottom total phosphorus at river kilometer 23.6

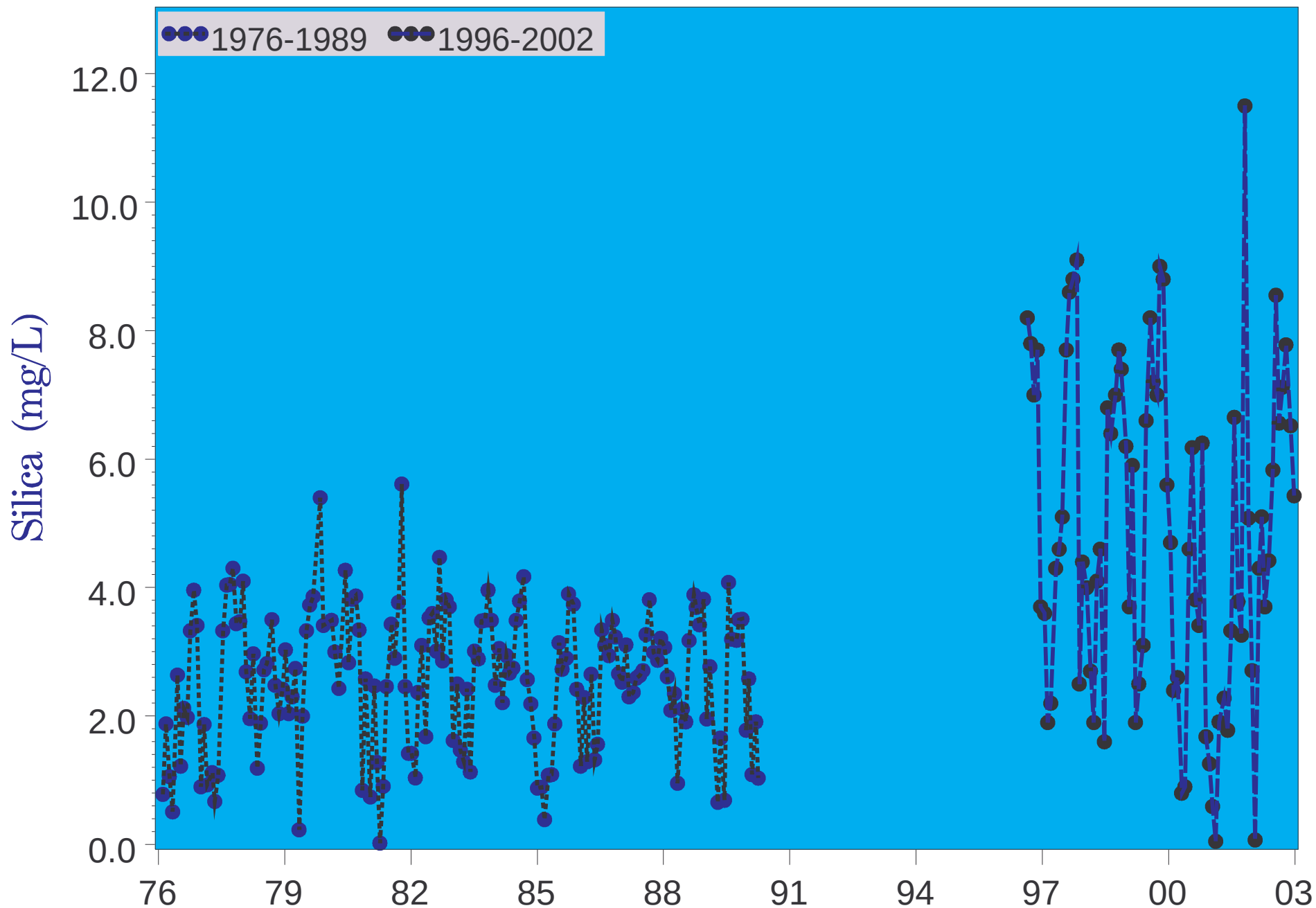


Figure 4.5.192 Long-term surface silica at river kilometer 23.6



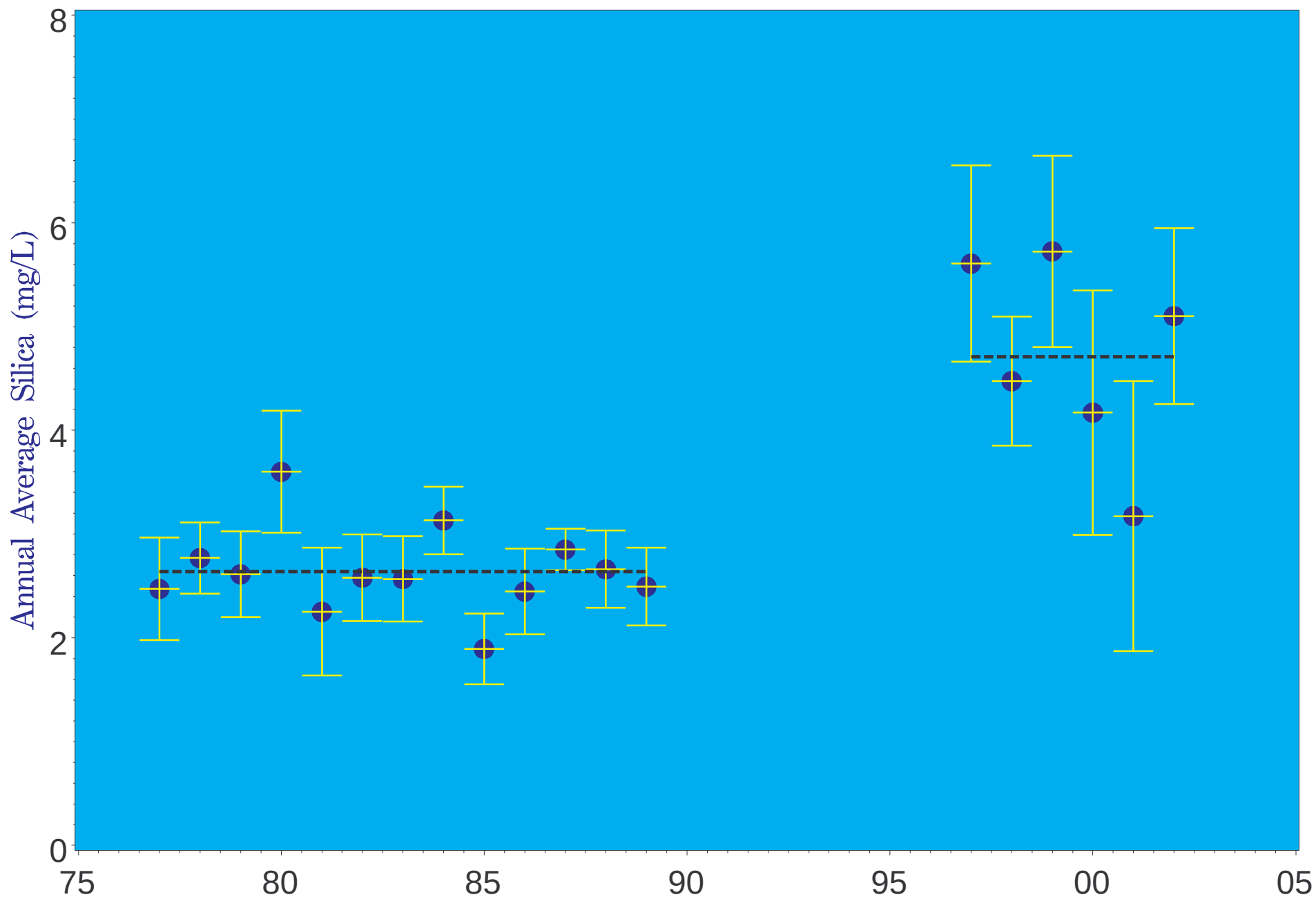


Figure 4.5.193 Long-term surface silica at river kilometer 23.6

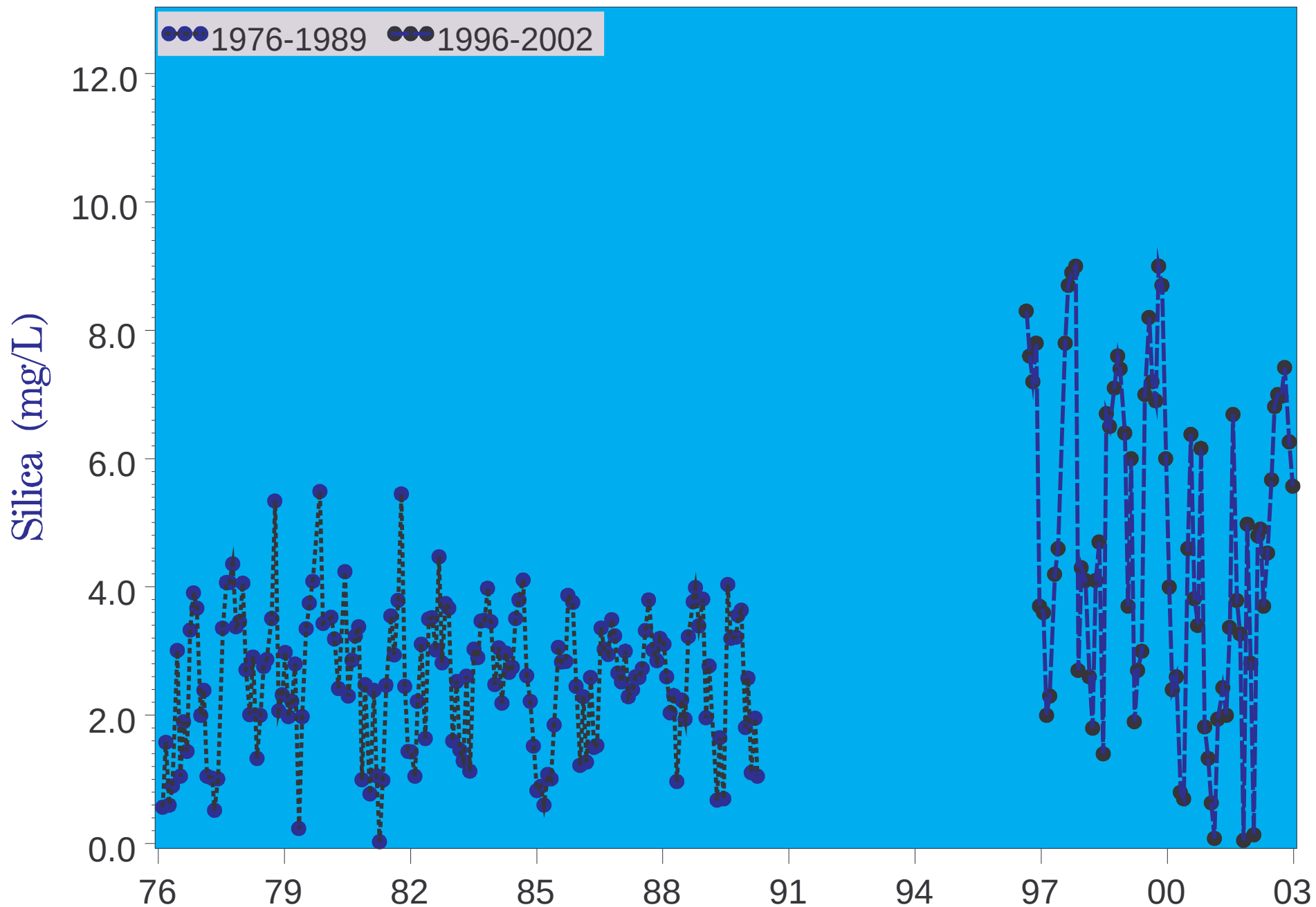


Figure 4.5.194 Long-term bottom silica at river kilometer 23.6

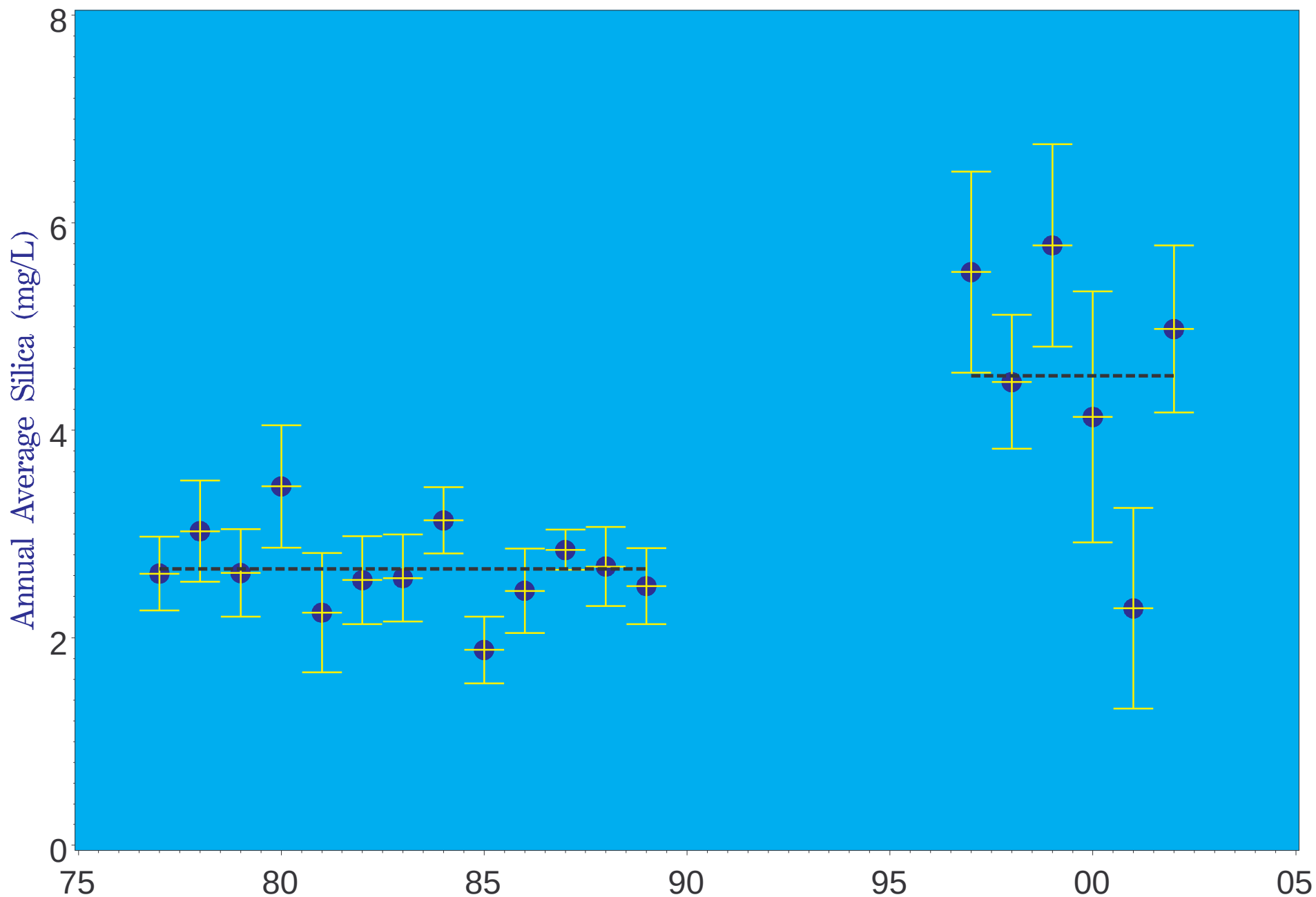


Figure 4.5.195 Long-term bottom silica at river kilometer 23.6

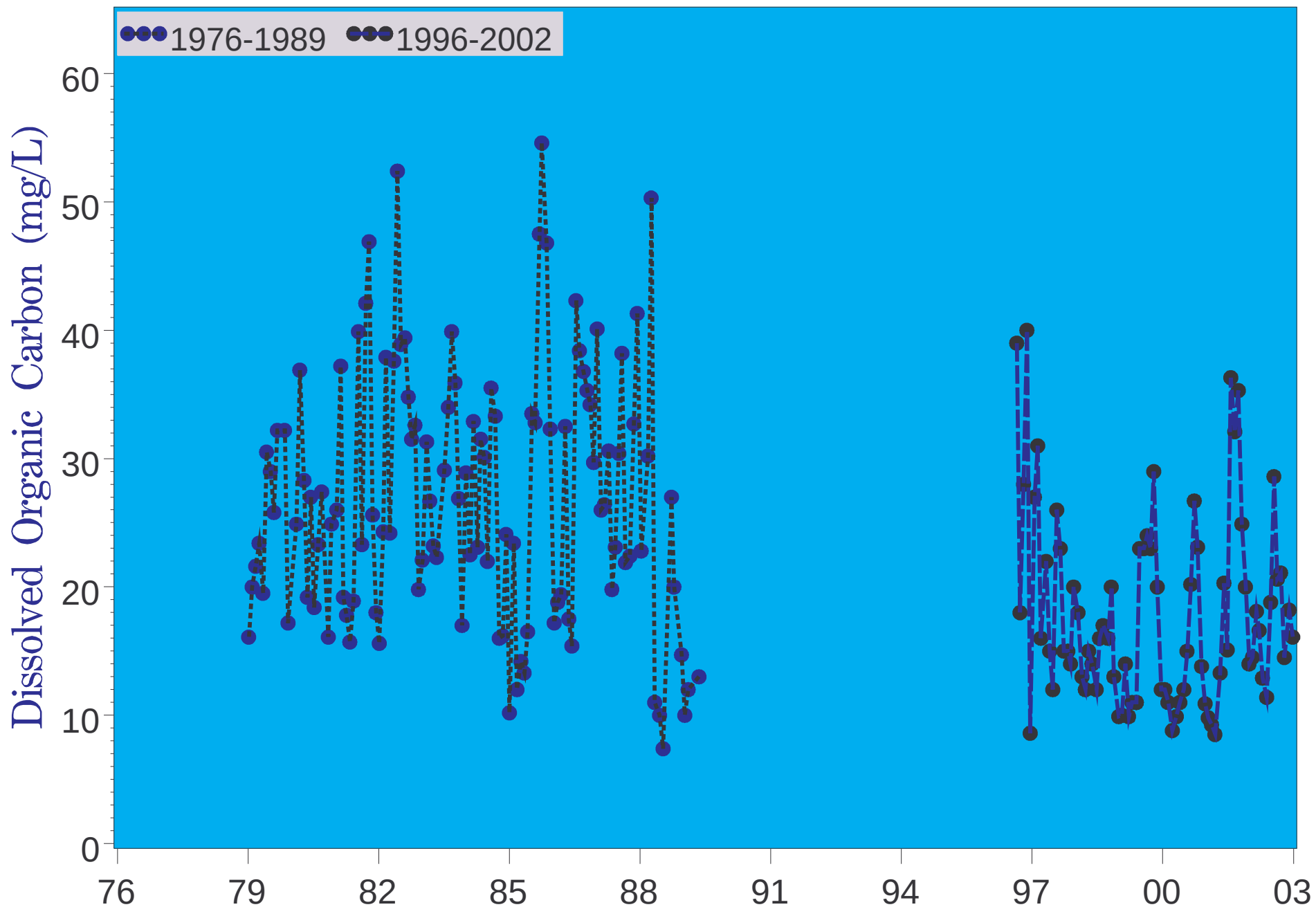


Figure 4.5.196 Long-term surface dissolved organic carbon at river kilometer 23.6

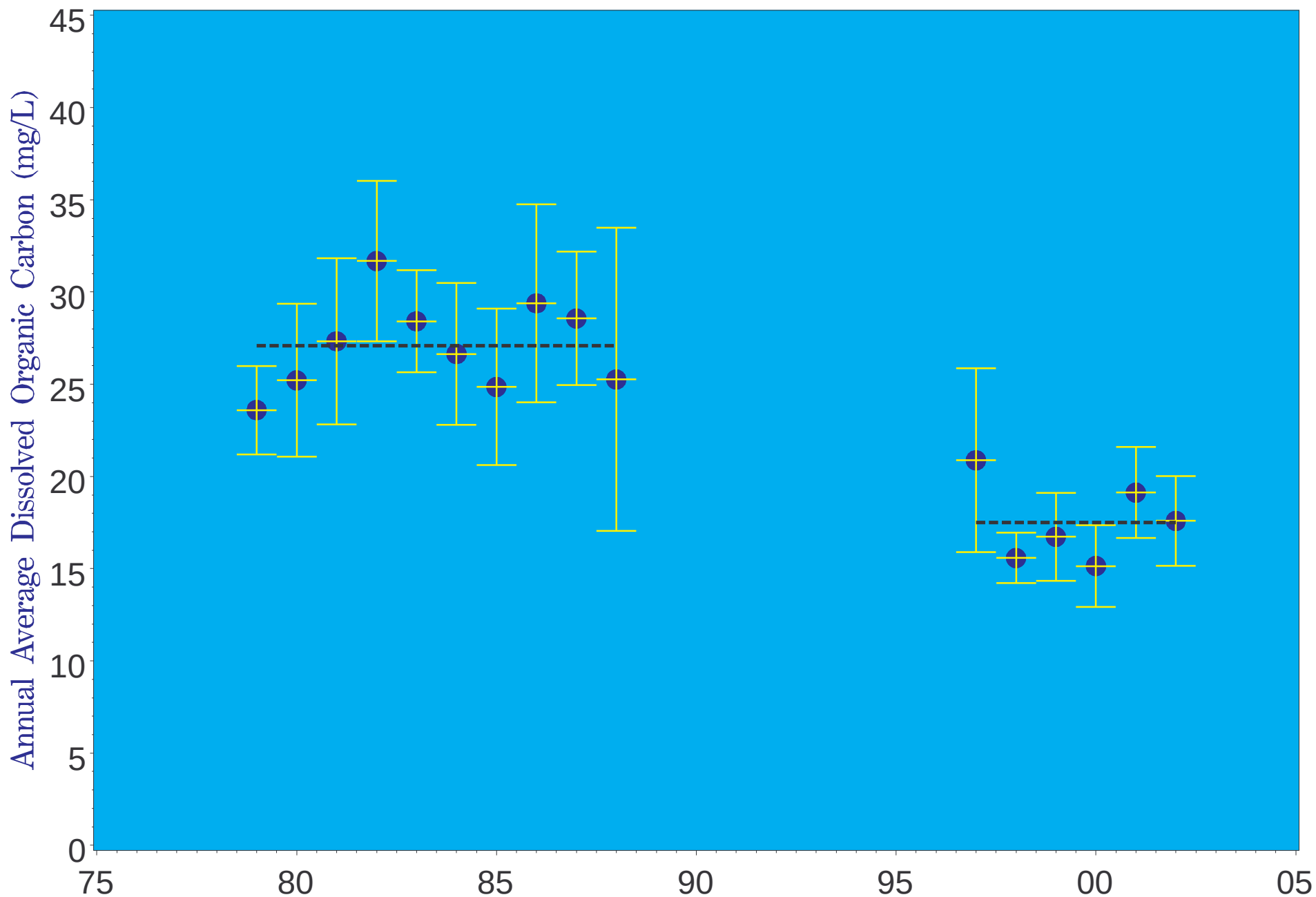


Figure 4.5.197 Long-term surface dissolved organic carbon at river kilometer 23.6

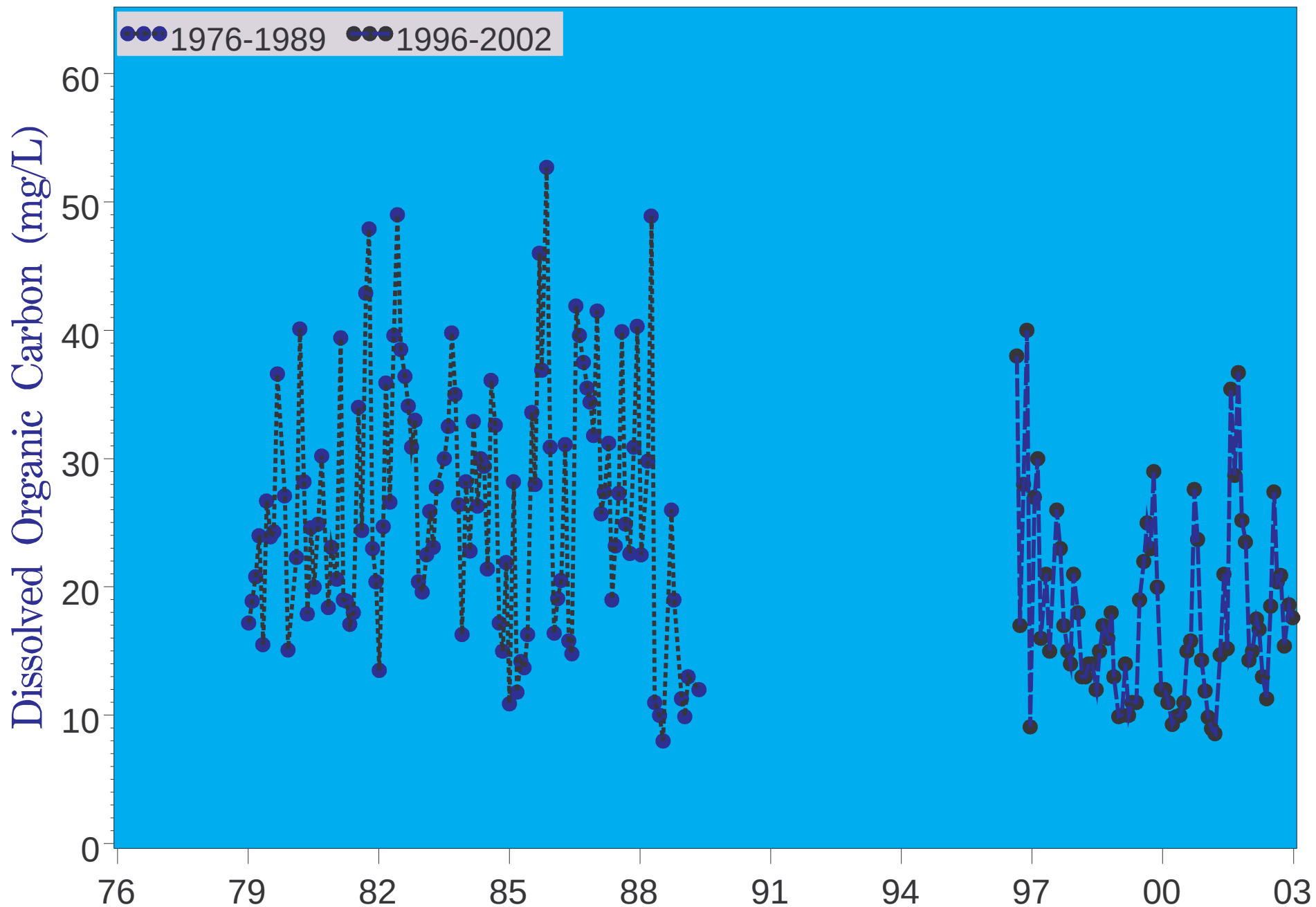


Figure 4.5.198 Long-term bottom dissolved organic carbon at river kilometer 23.6

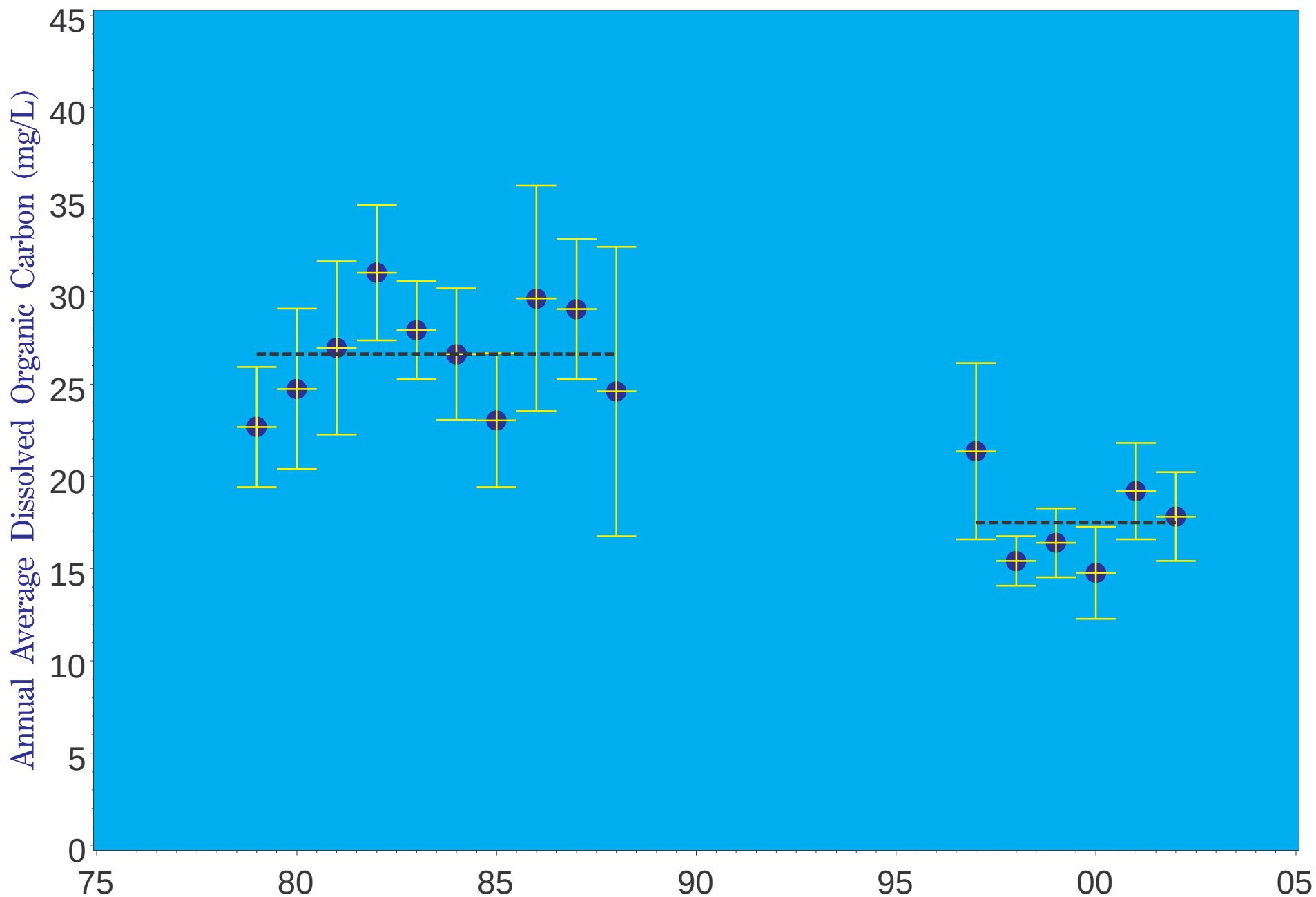


Figure 4.5.199 Long-term bottom dissolved organic carbon at river kilometer 23.6





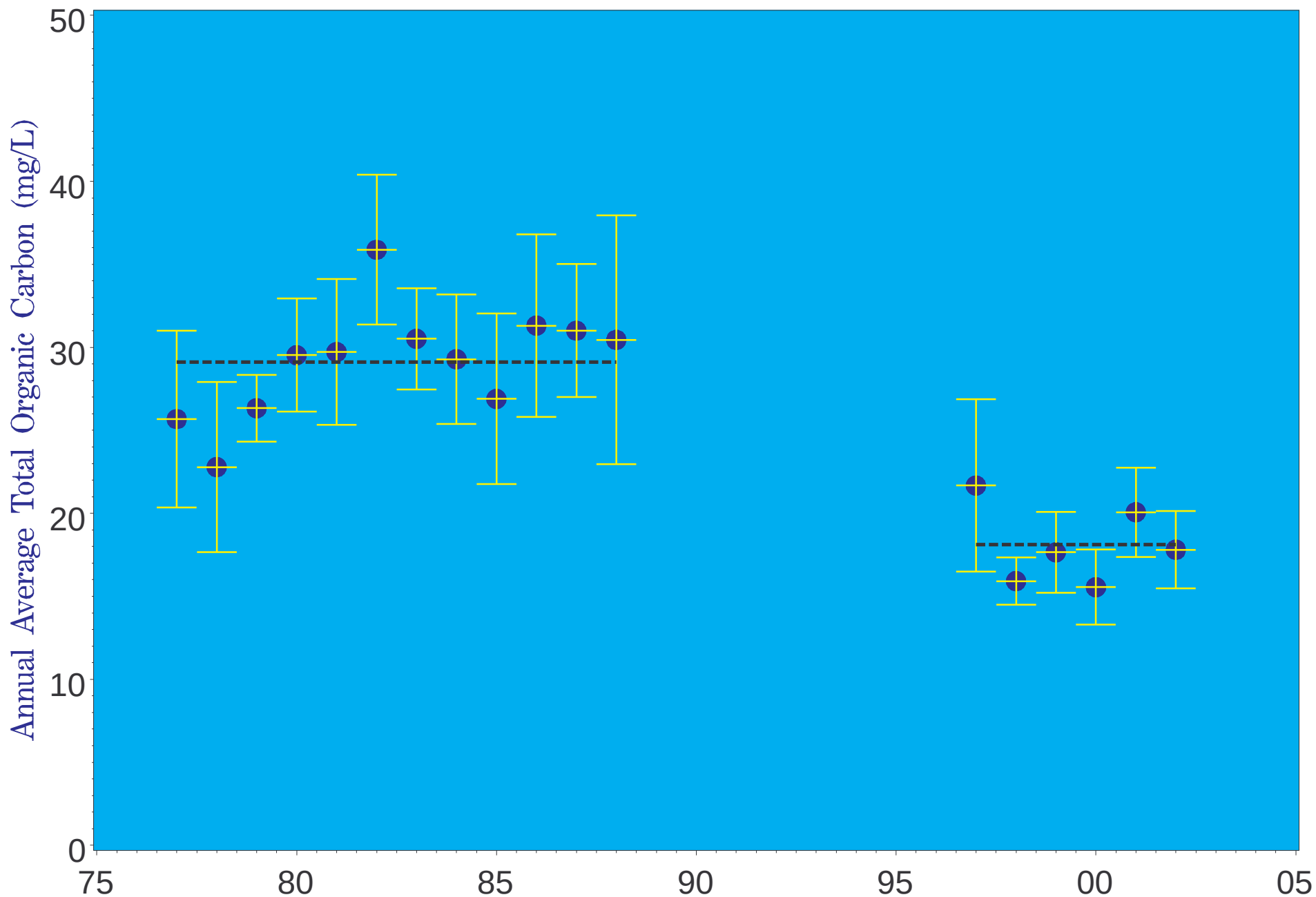


Figure 4.5.201 Long-term surface total organic carbon at river kilometer 23.6

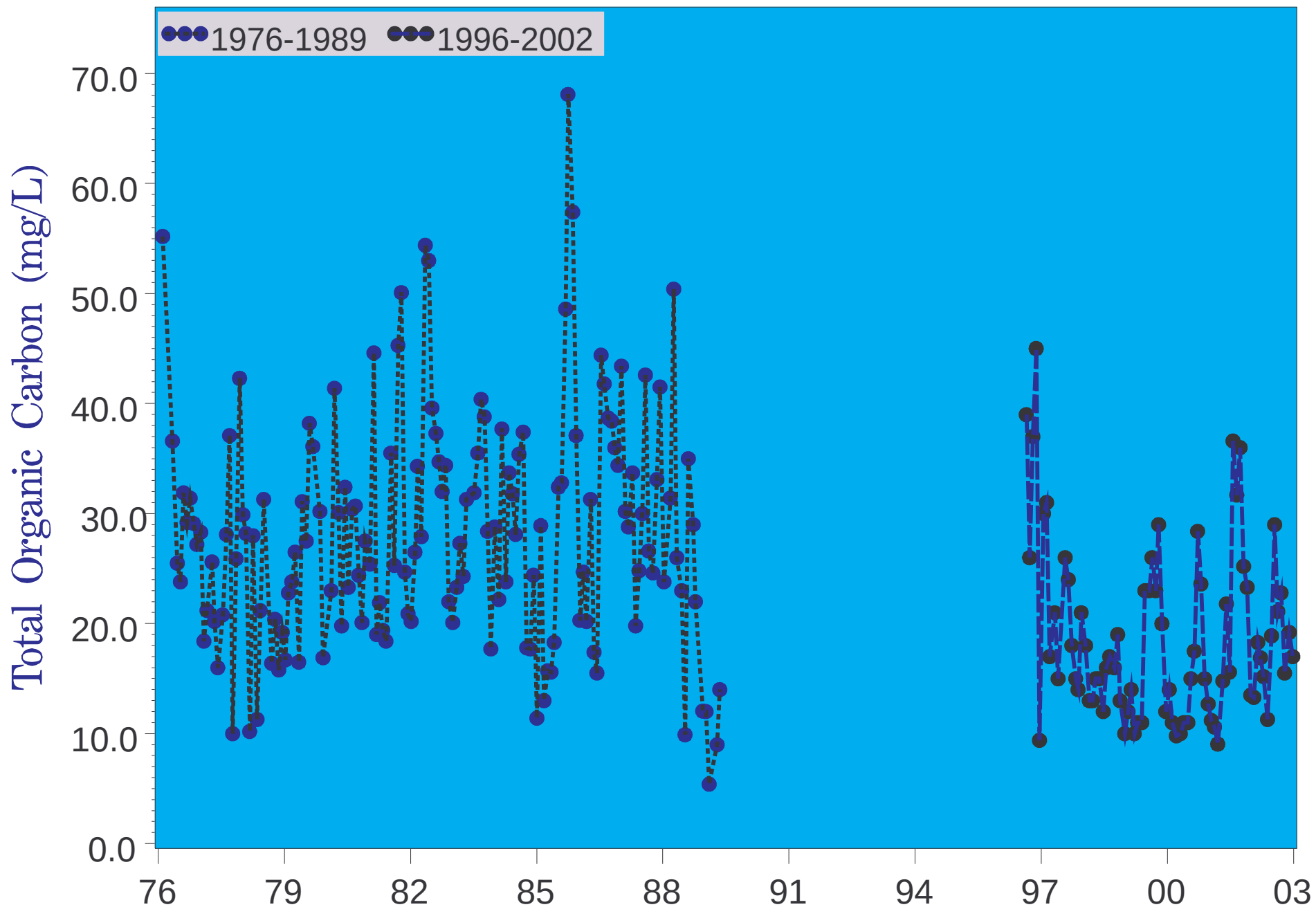


Figure 4.5.202 Long-term bottom total organic carbon at river kilometer 23.6

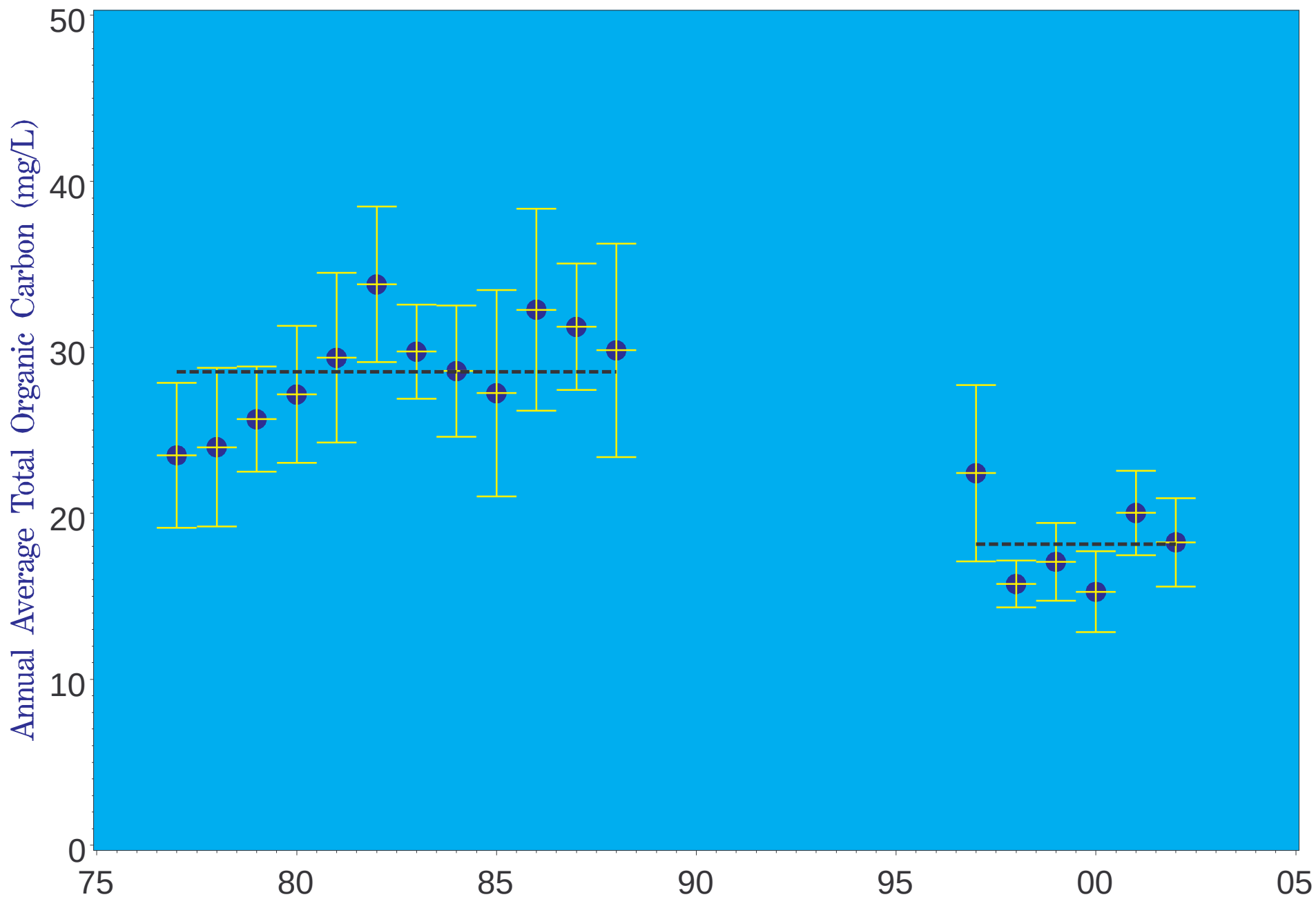


Figure 4.5.203 Long-term bottom total organic carbon at river kilometer 23.6

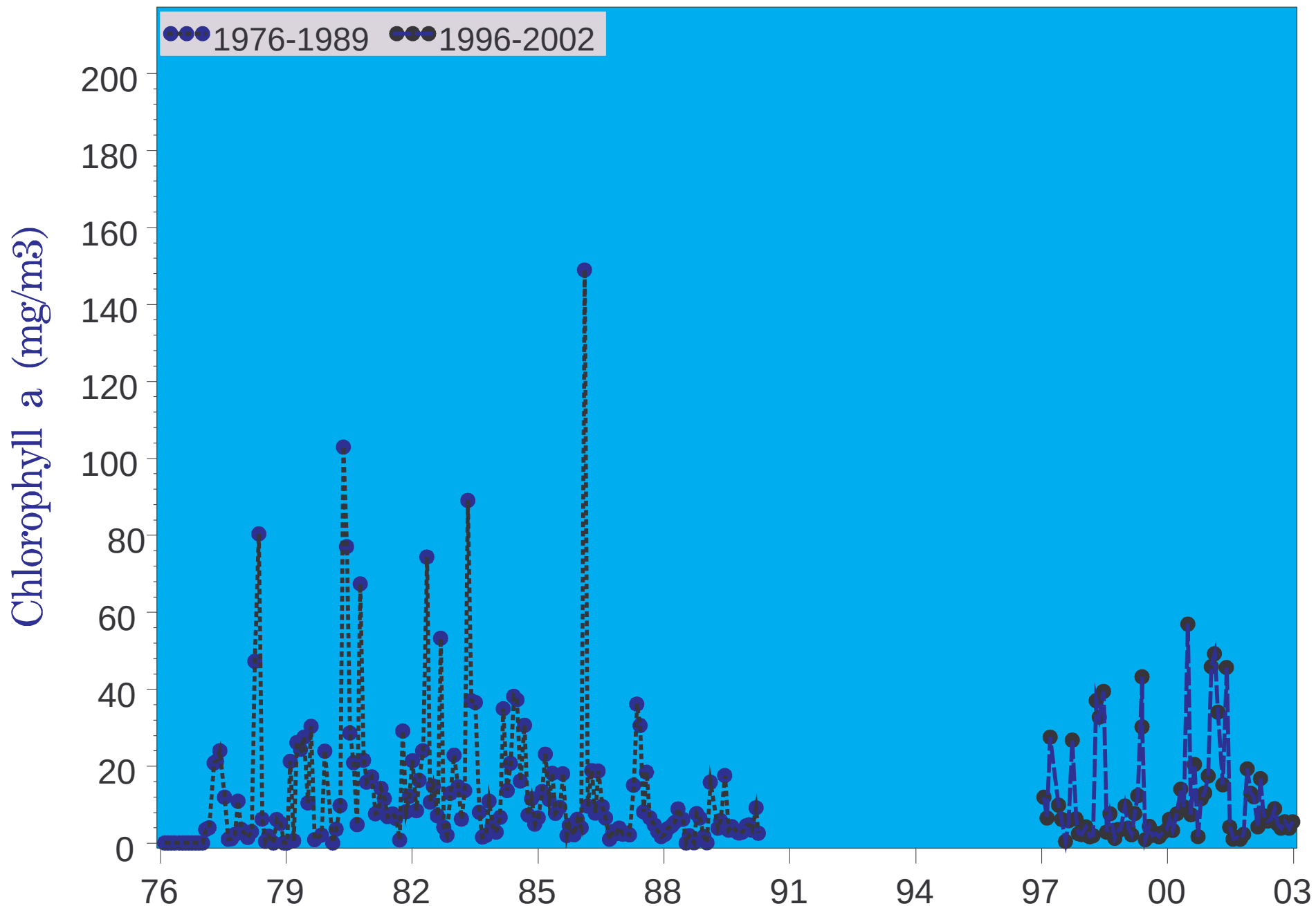


Figure 4.5.204 Long-term surface chlorophyll a at river kilometer 23.6

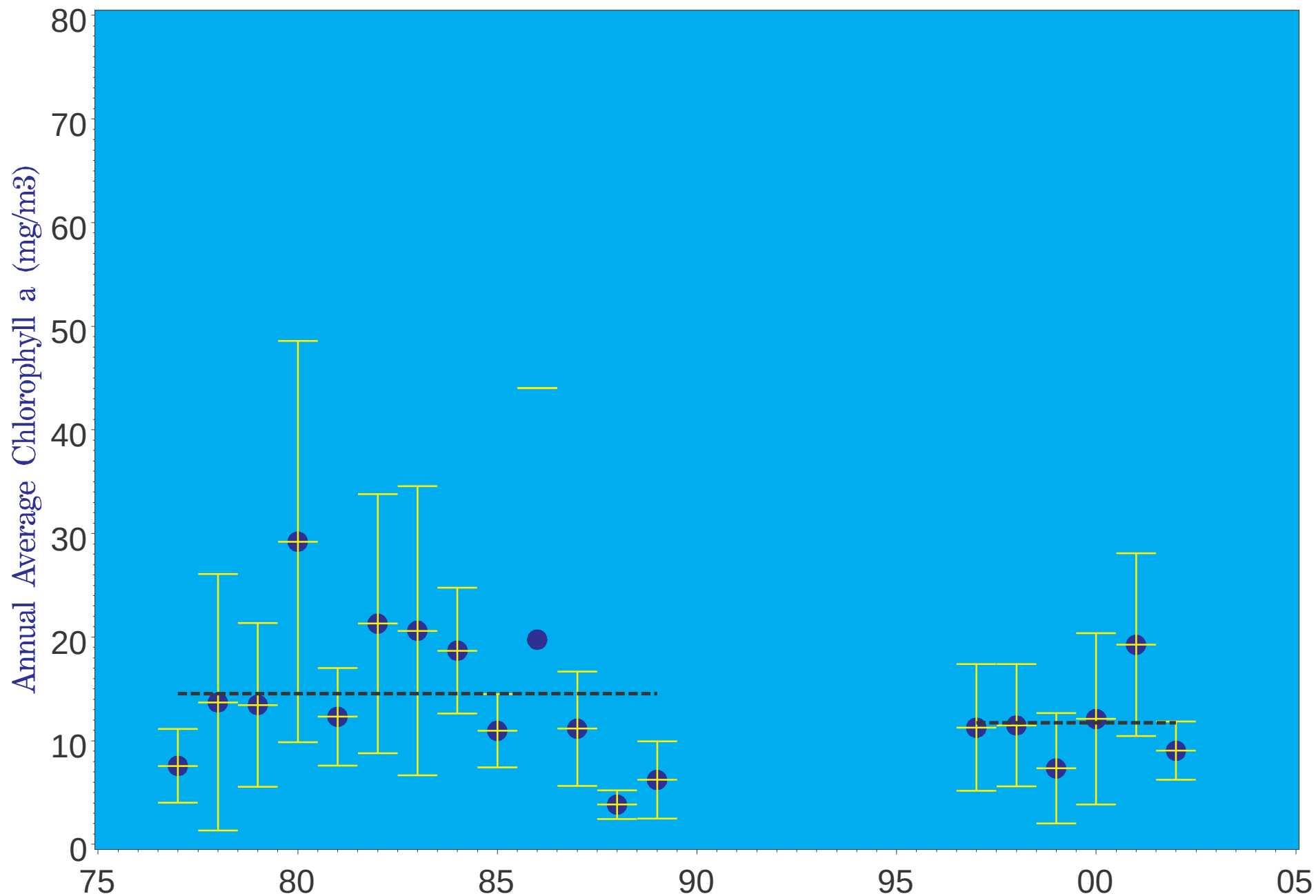


Figure 4.5.205 Long-term surface chlorophyll a at river kilometer 23.6

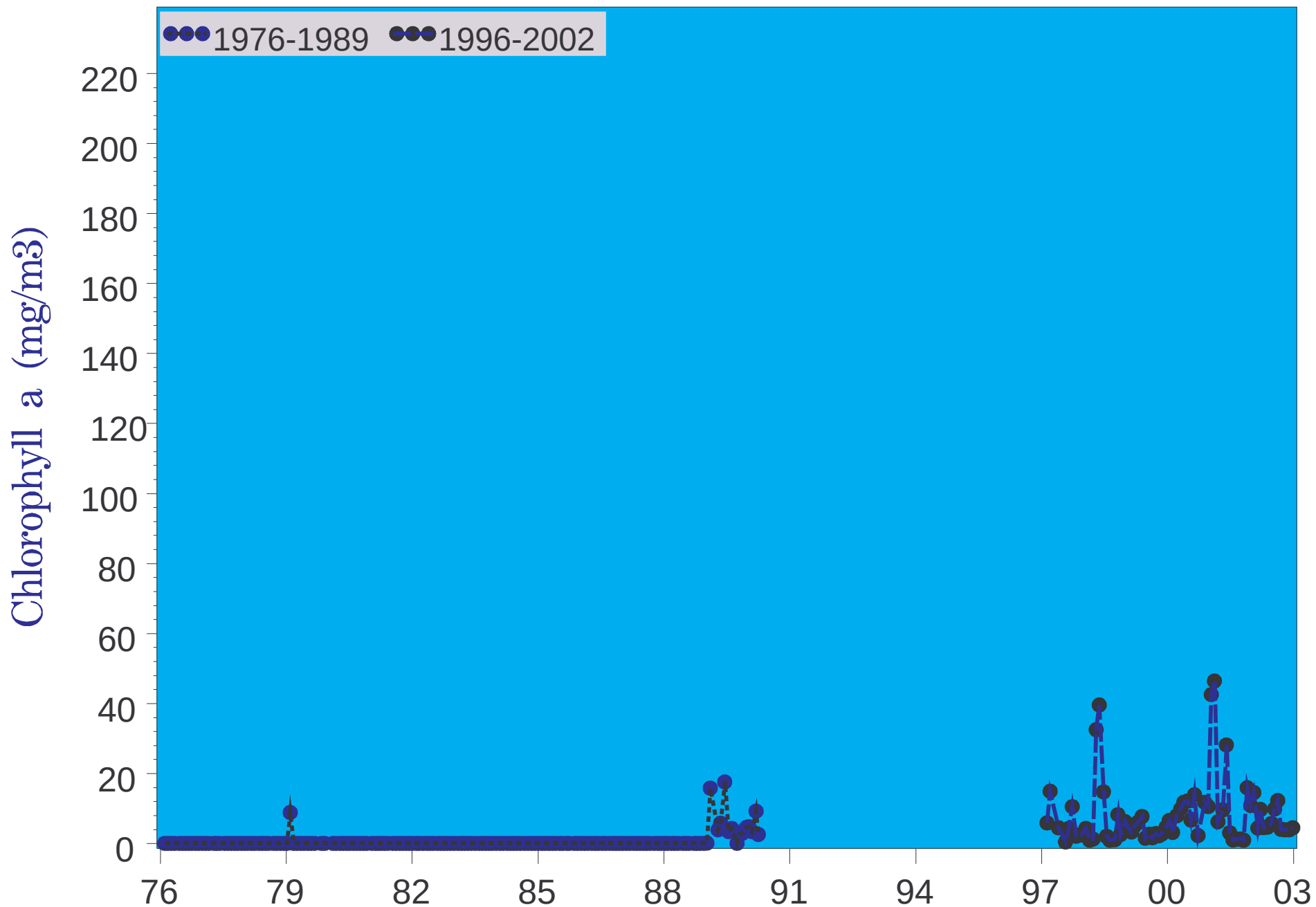


Figure 4.5.206 Long-term bottom chlorophyll a at river kilometer 23.6

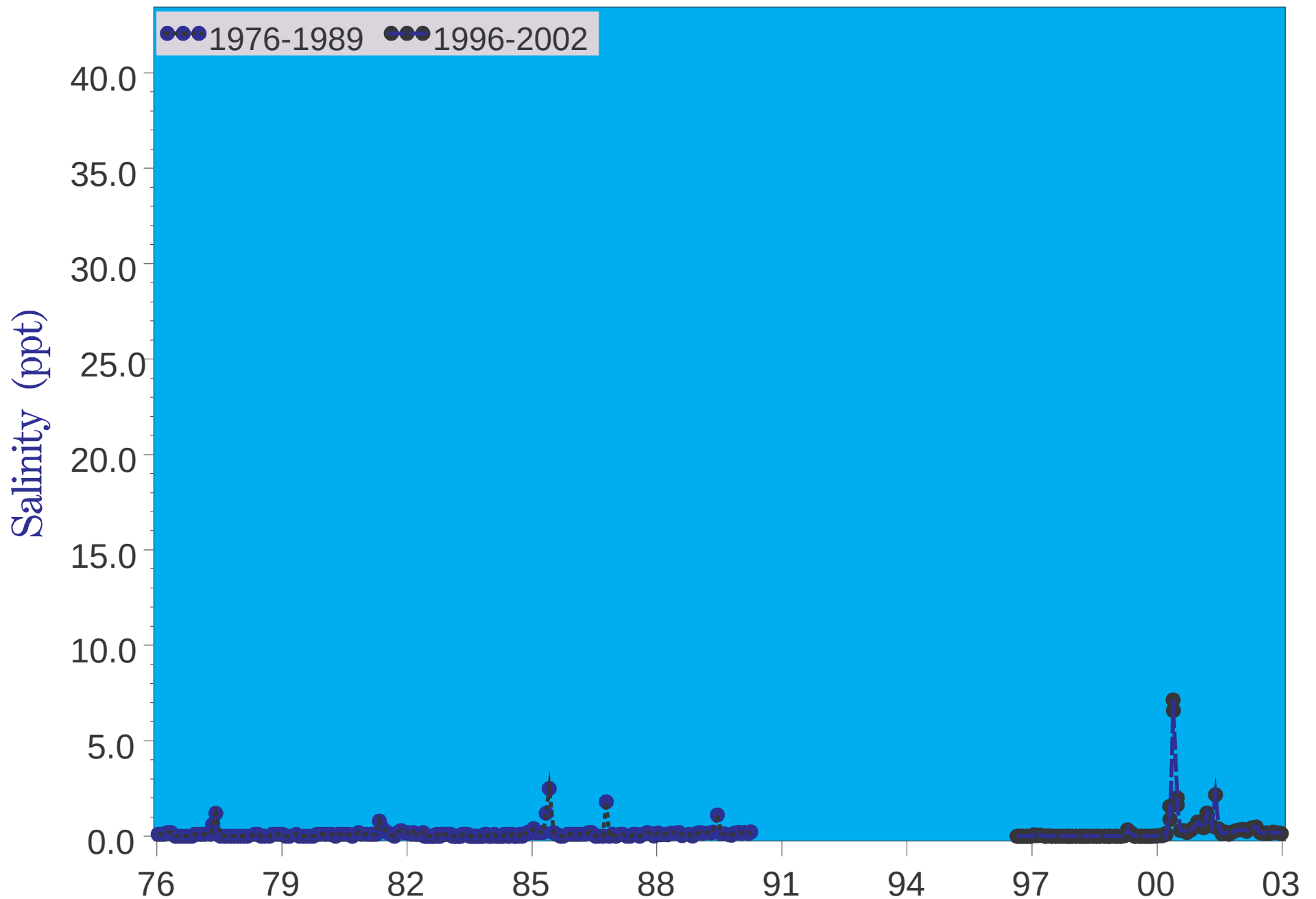


Figure 4.5.208 Long-term surface salinity at river kilometer 30.4

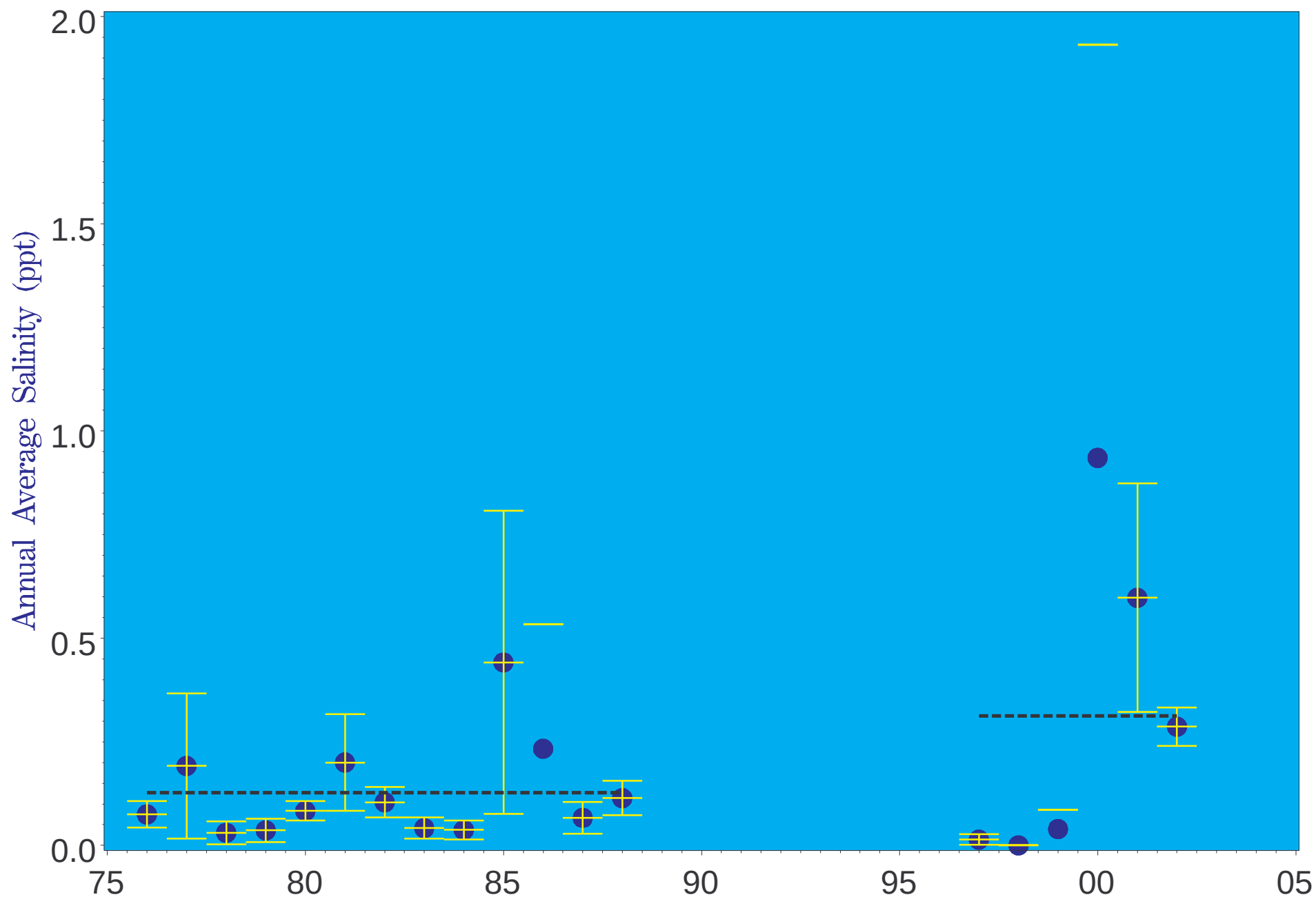


Figure 4.5.209 Long-term surface salinity at river kilometer 30.4



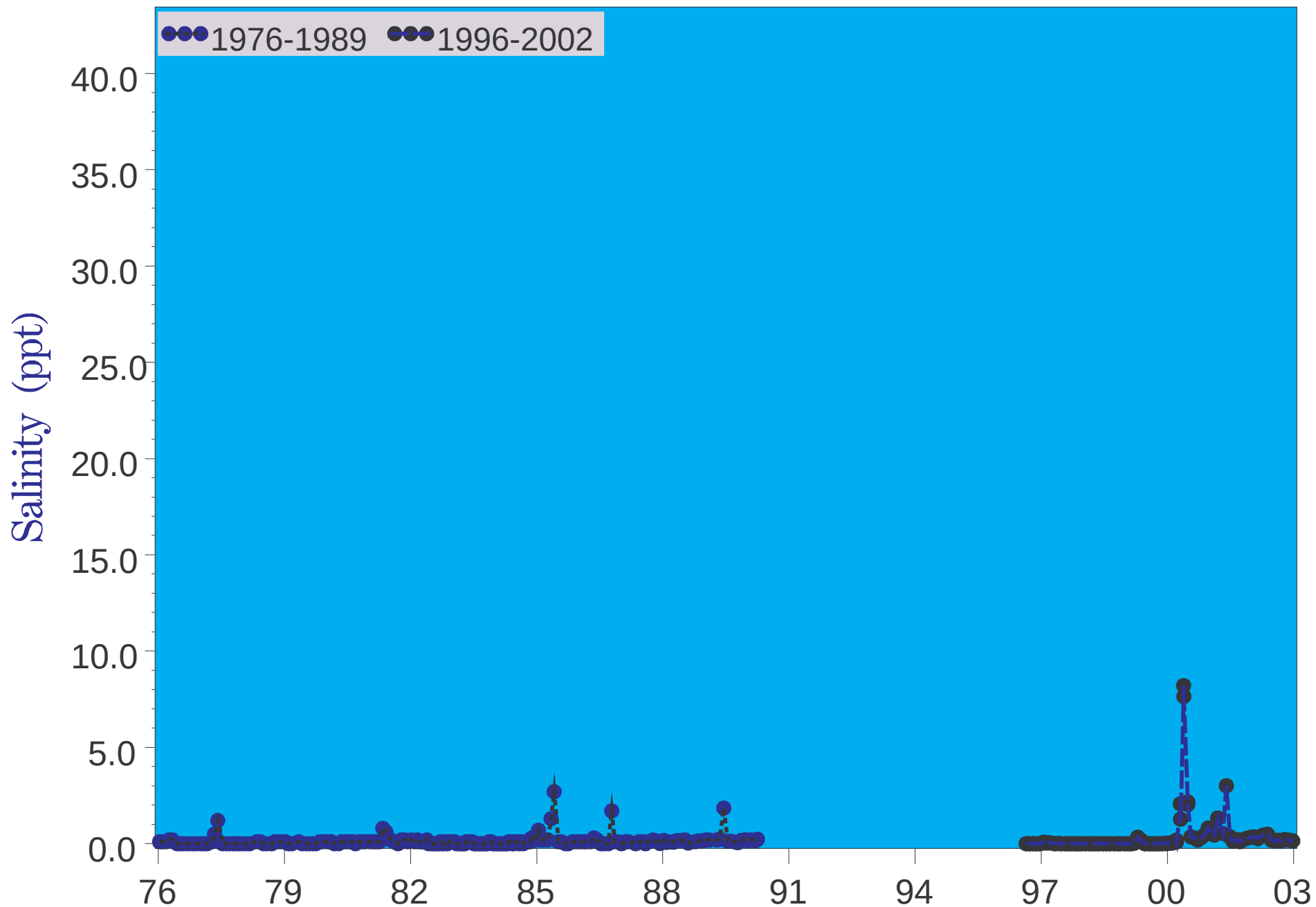


Figure 4.5.210 Long-term bottom salinity at river kilometer 30.4

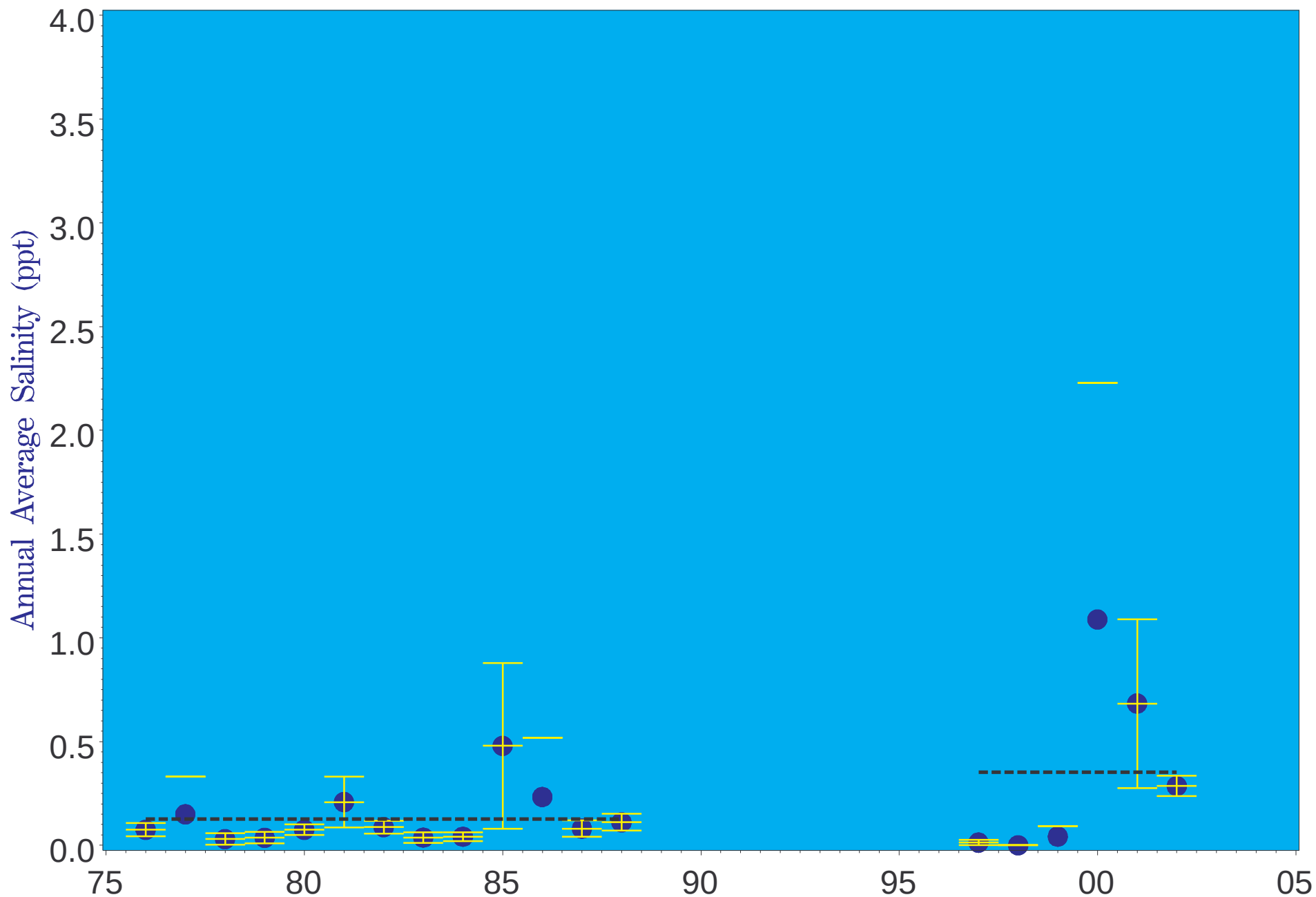


Figure 4.5.211 Long-term bottom salinity at river kilometer 30.4

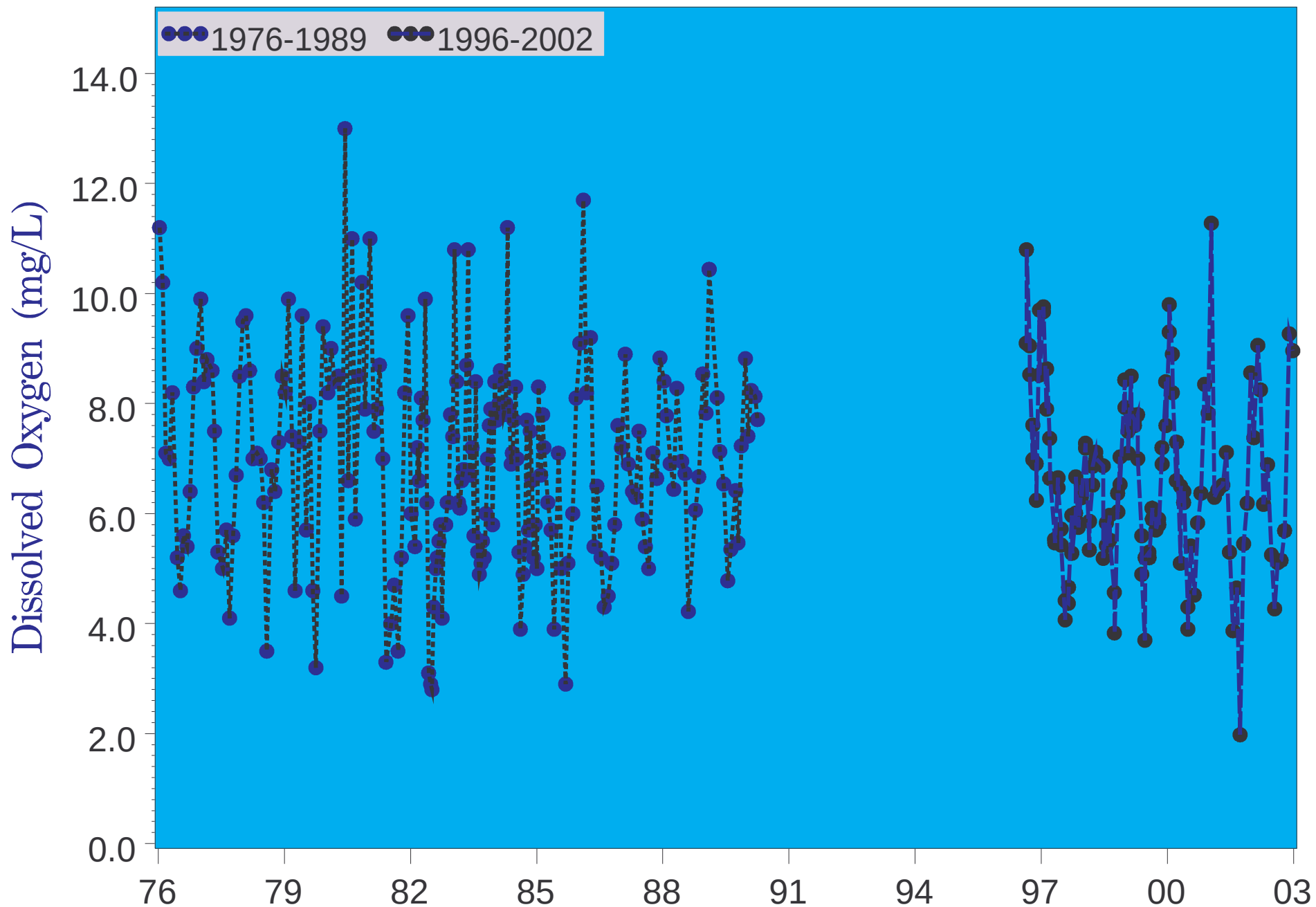


Figure 4.5.212 Long-term surface dissolved oxygen at river kilometer 30.4

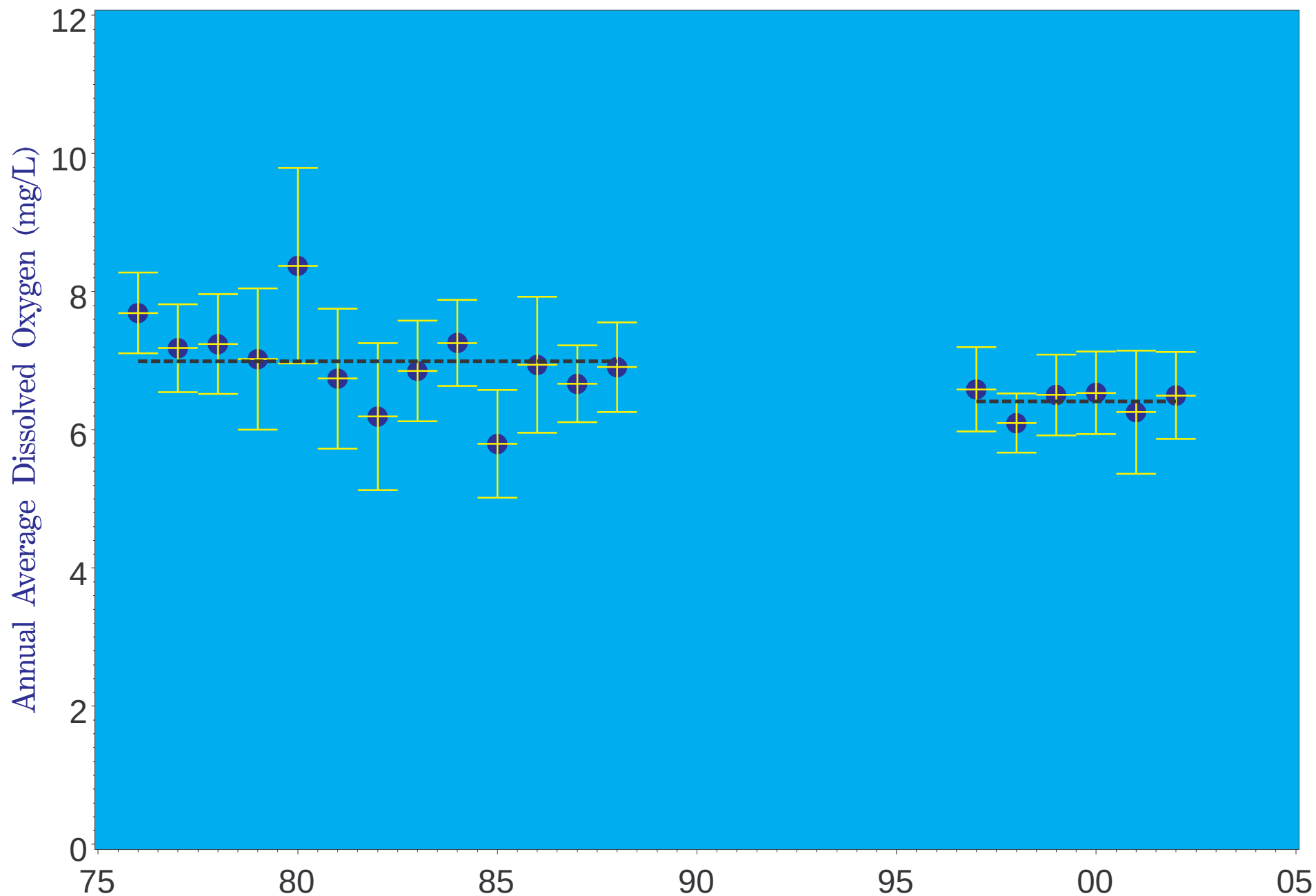


Figure 4.5.213 Long-term surface dissolved oxygen at river kilometer 30.4

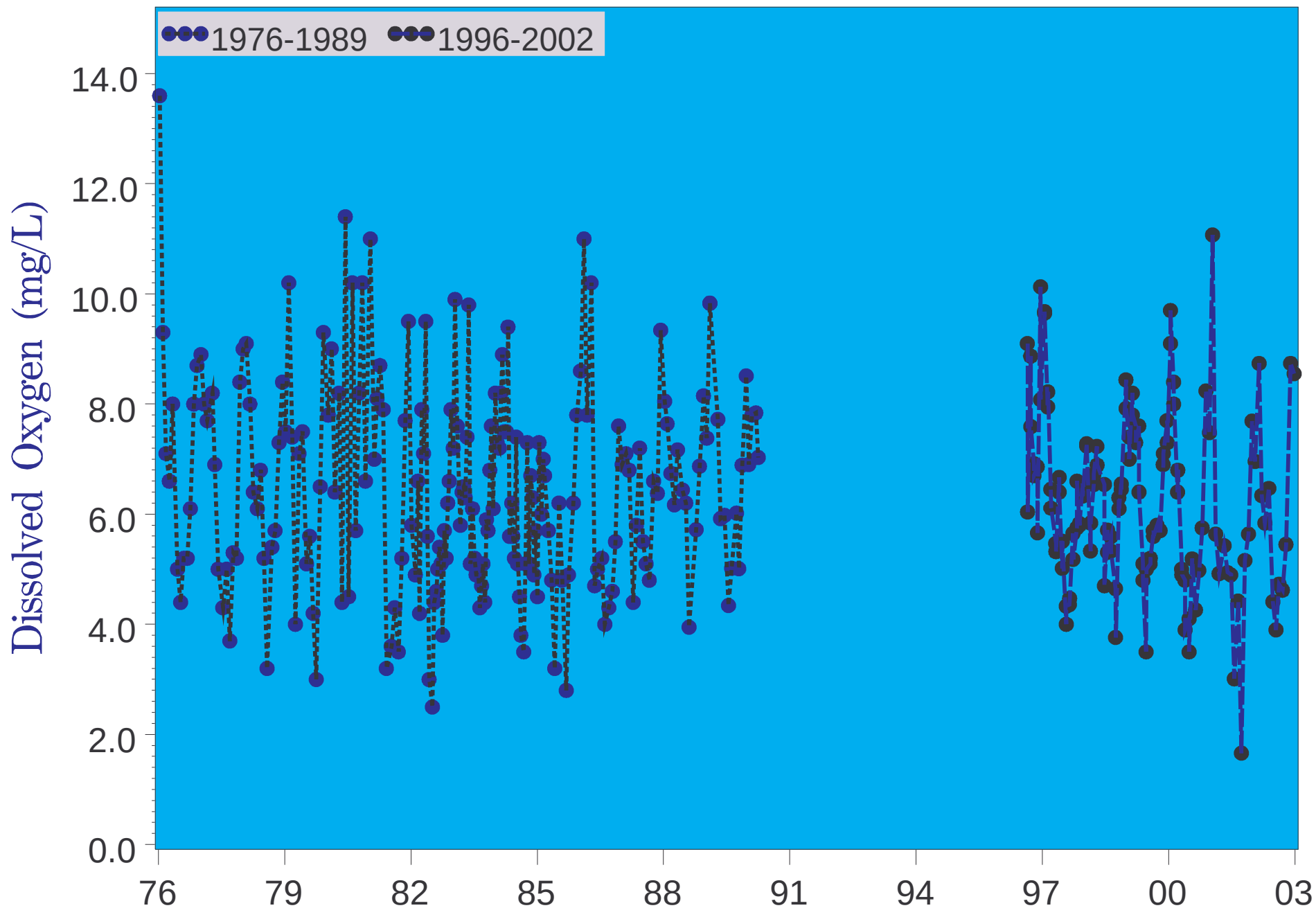


Figure 4.5.214 Long-term bottom dissolved oxygen at river kilometer 30.4

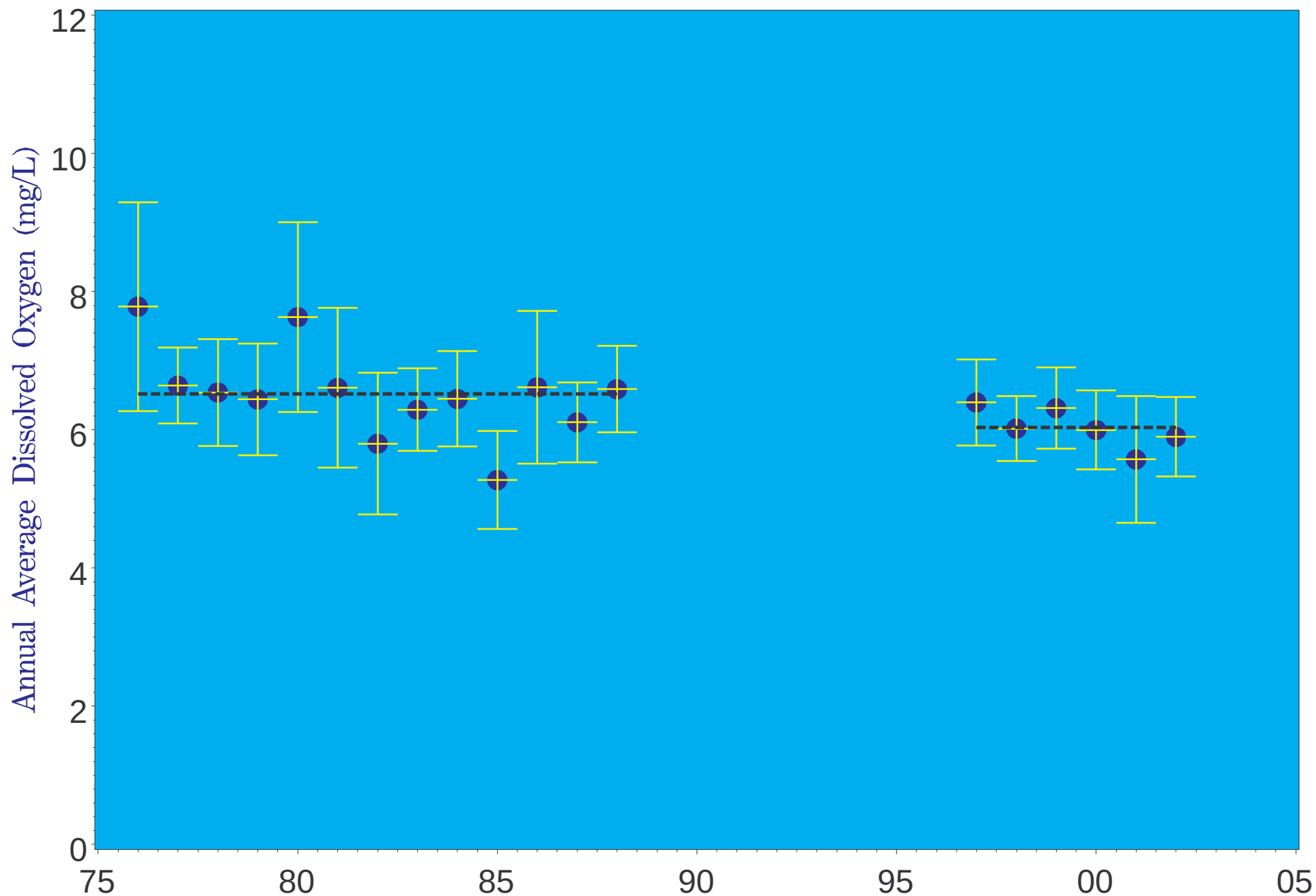


Figure 4.5.215 Long-term bottom dissolved oxygen at river kilometer 30.4

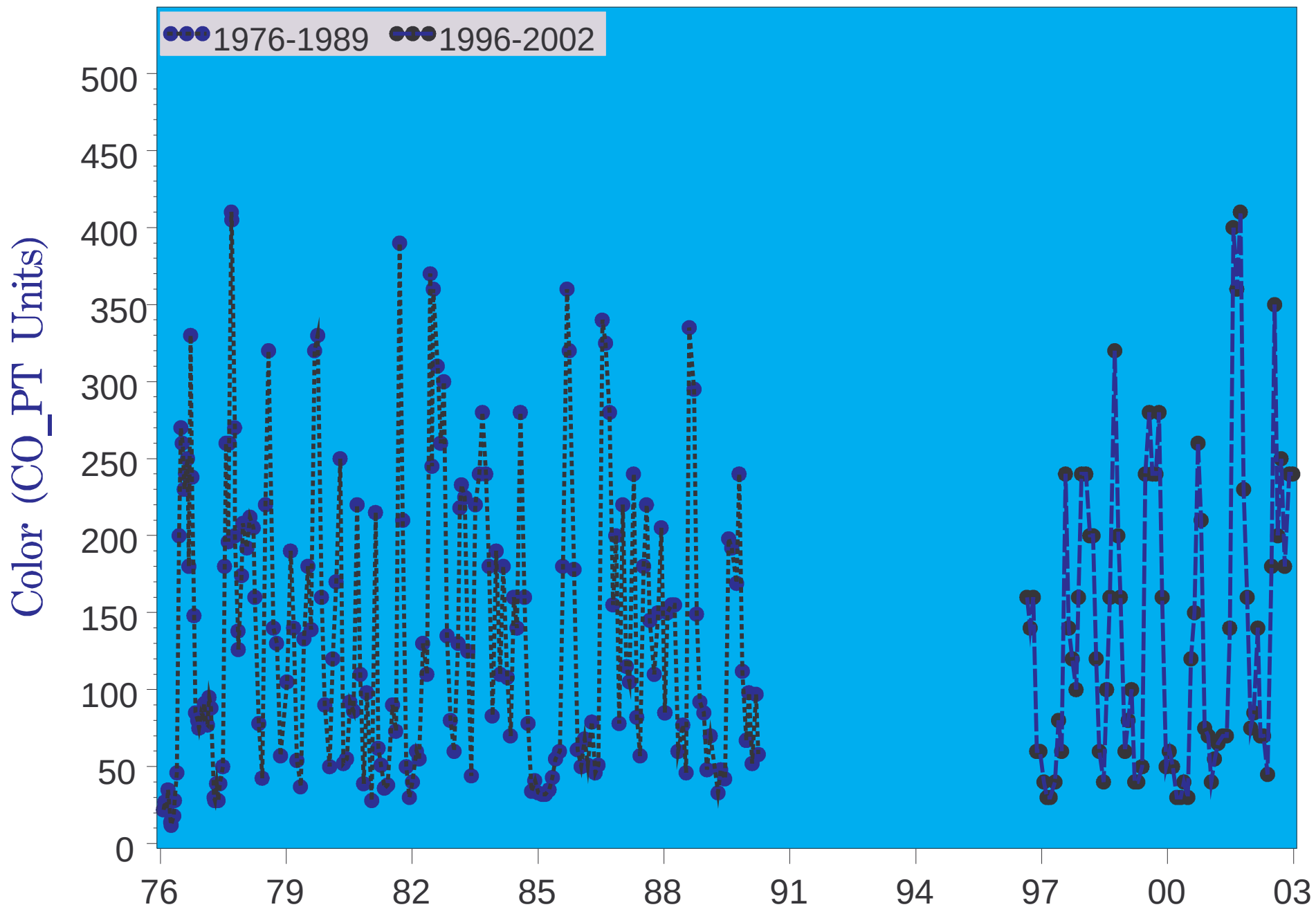


Figure 4.5.216 Long-term surface color at river kilometer 30.4

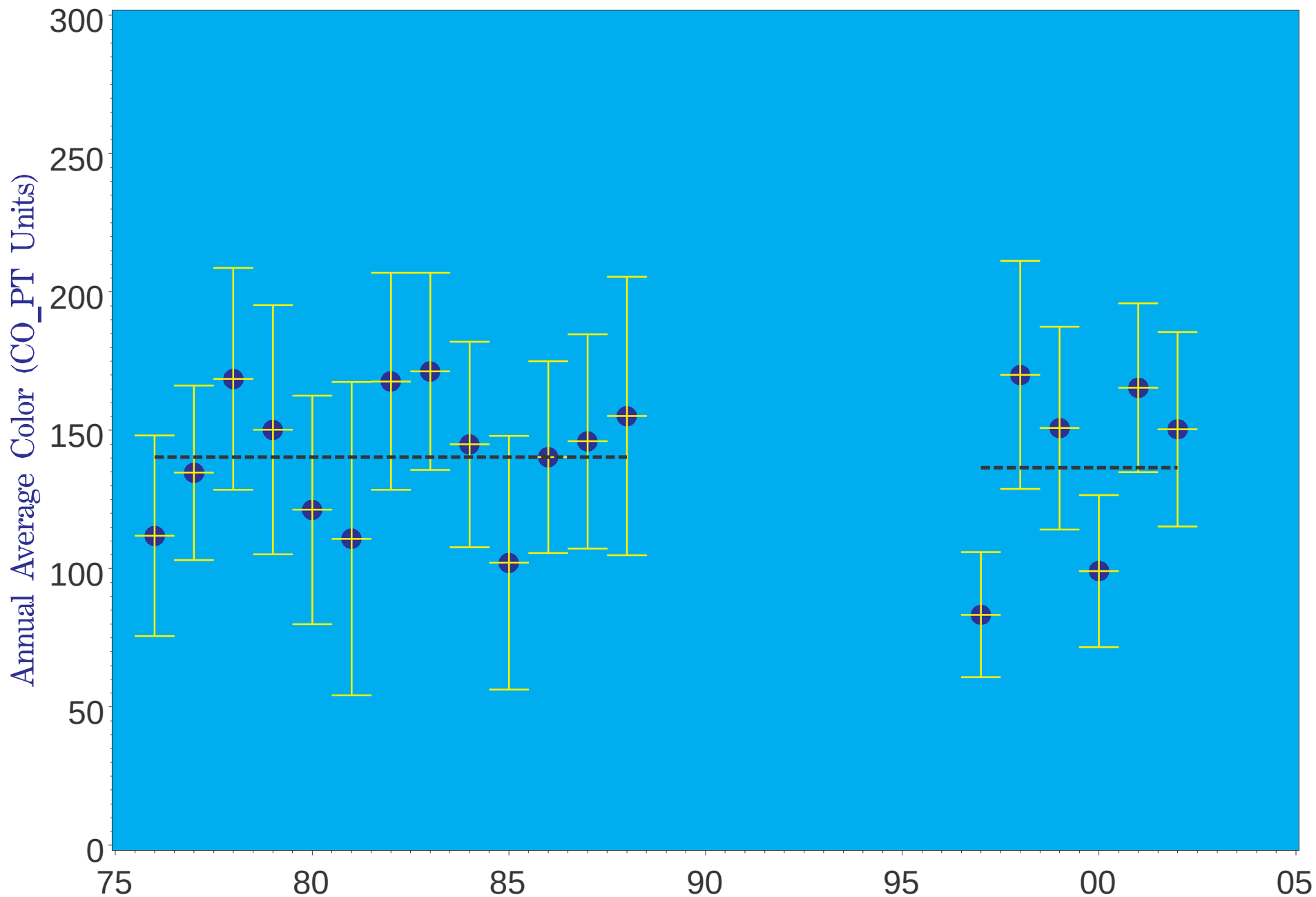


Figure 4.5.217 Long-term surface color at river kilometer 30.4



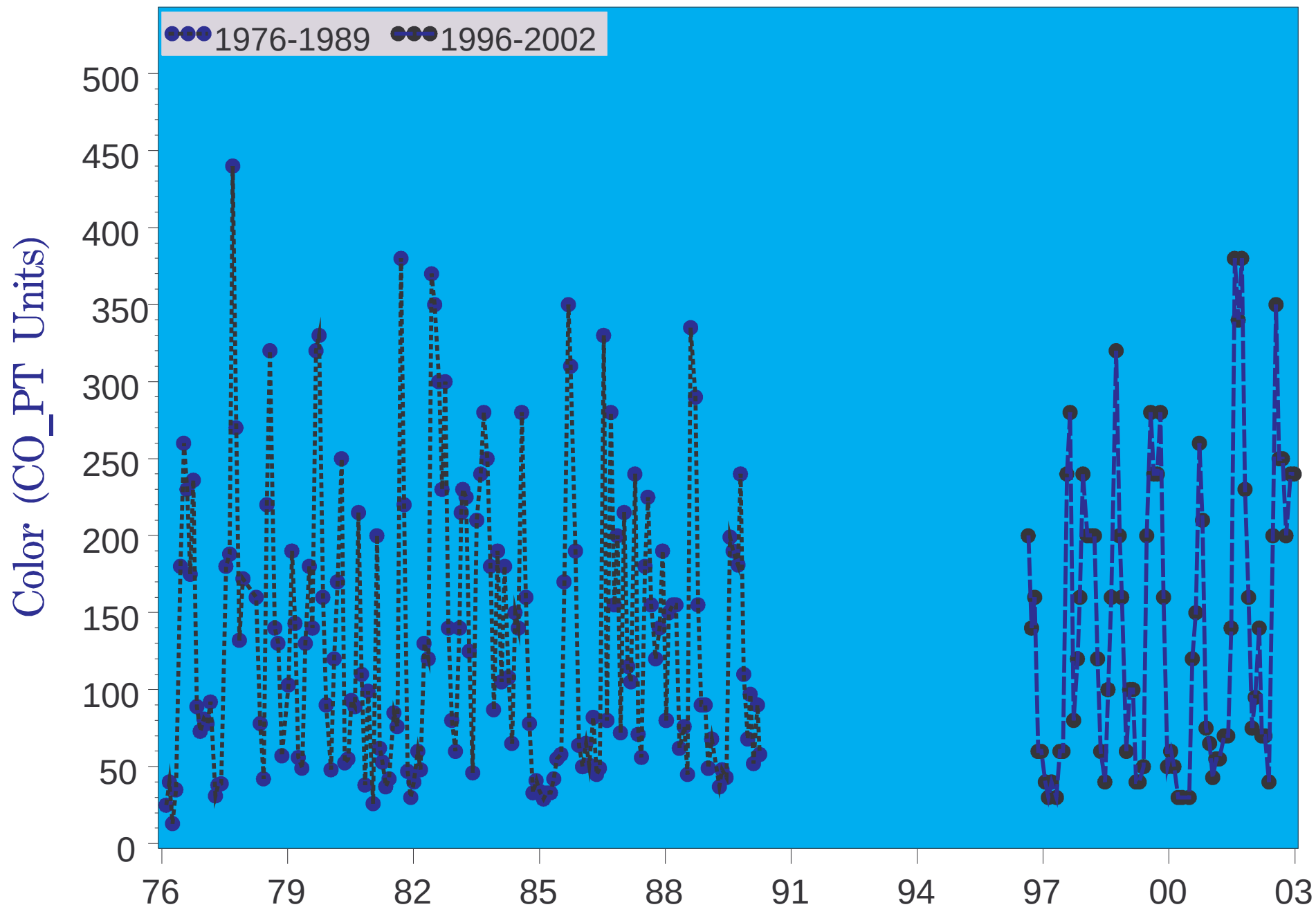


Figure 4.5.218 Long-term bottom color at river kilometer 30.4

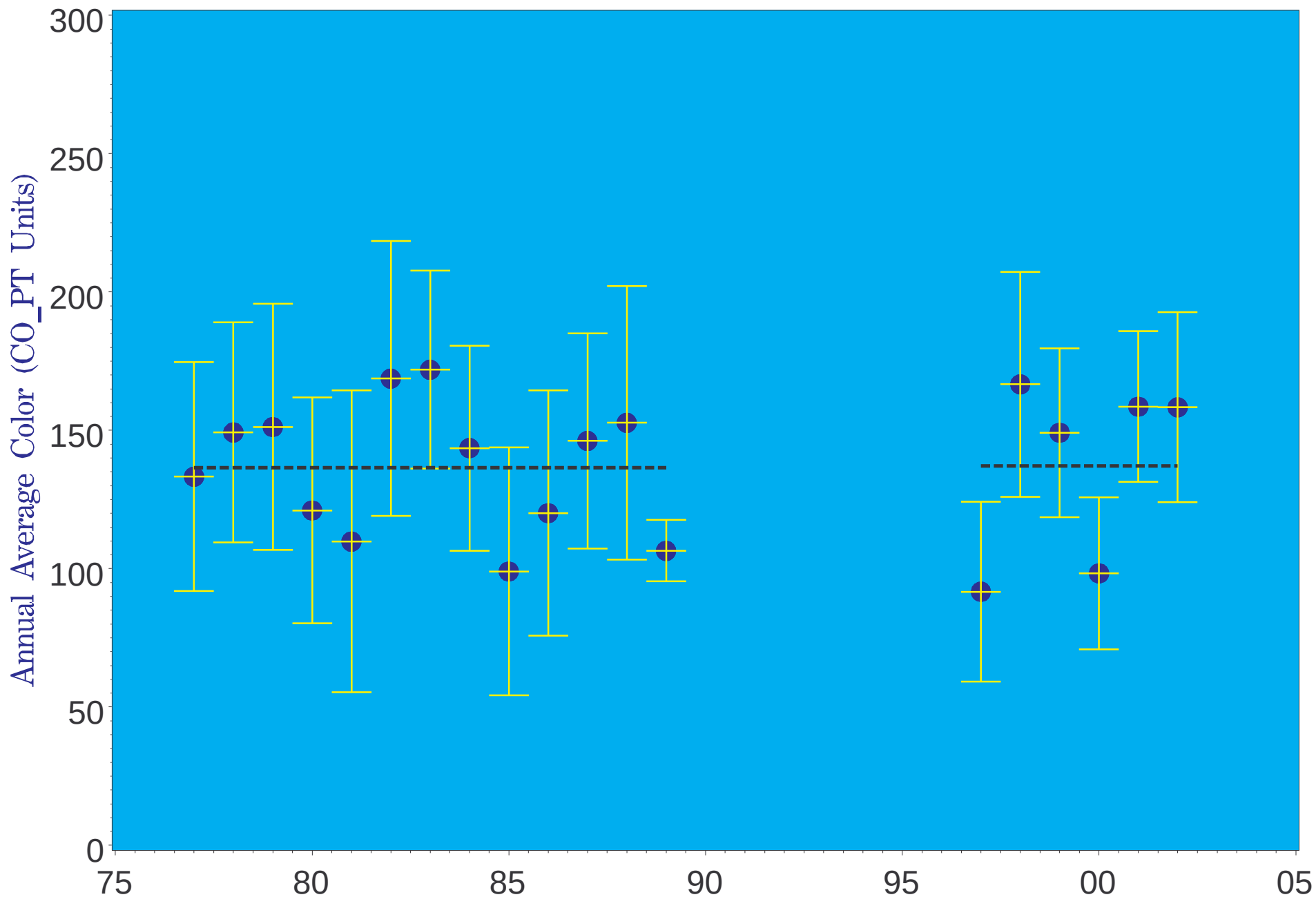


Figure 4.5.219 Long-term bottom color at river kilometer 30.4

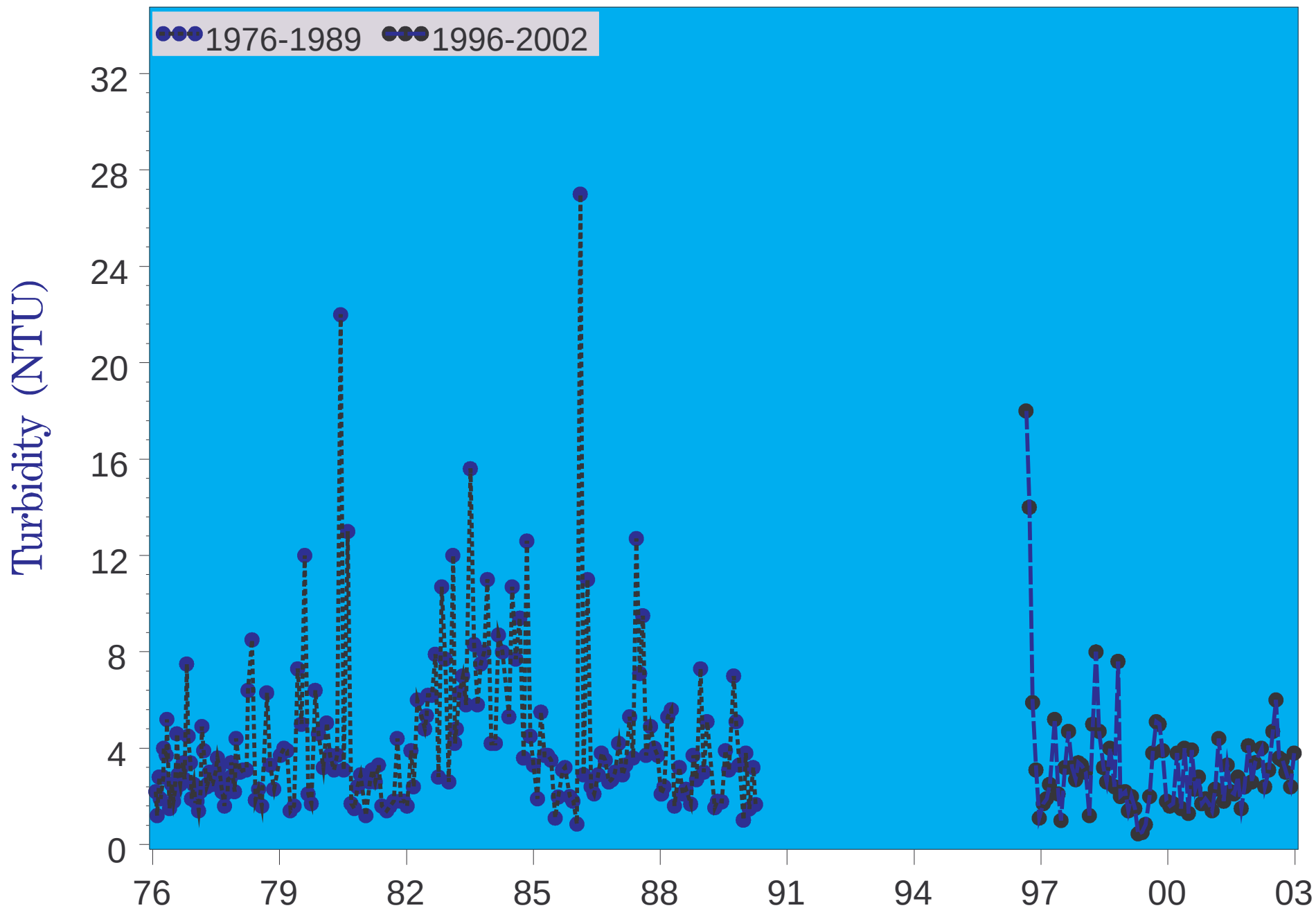


Figure 4.5.220 Long-term surface turbidity at river kilometer 30.4

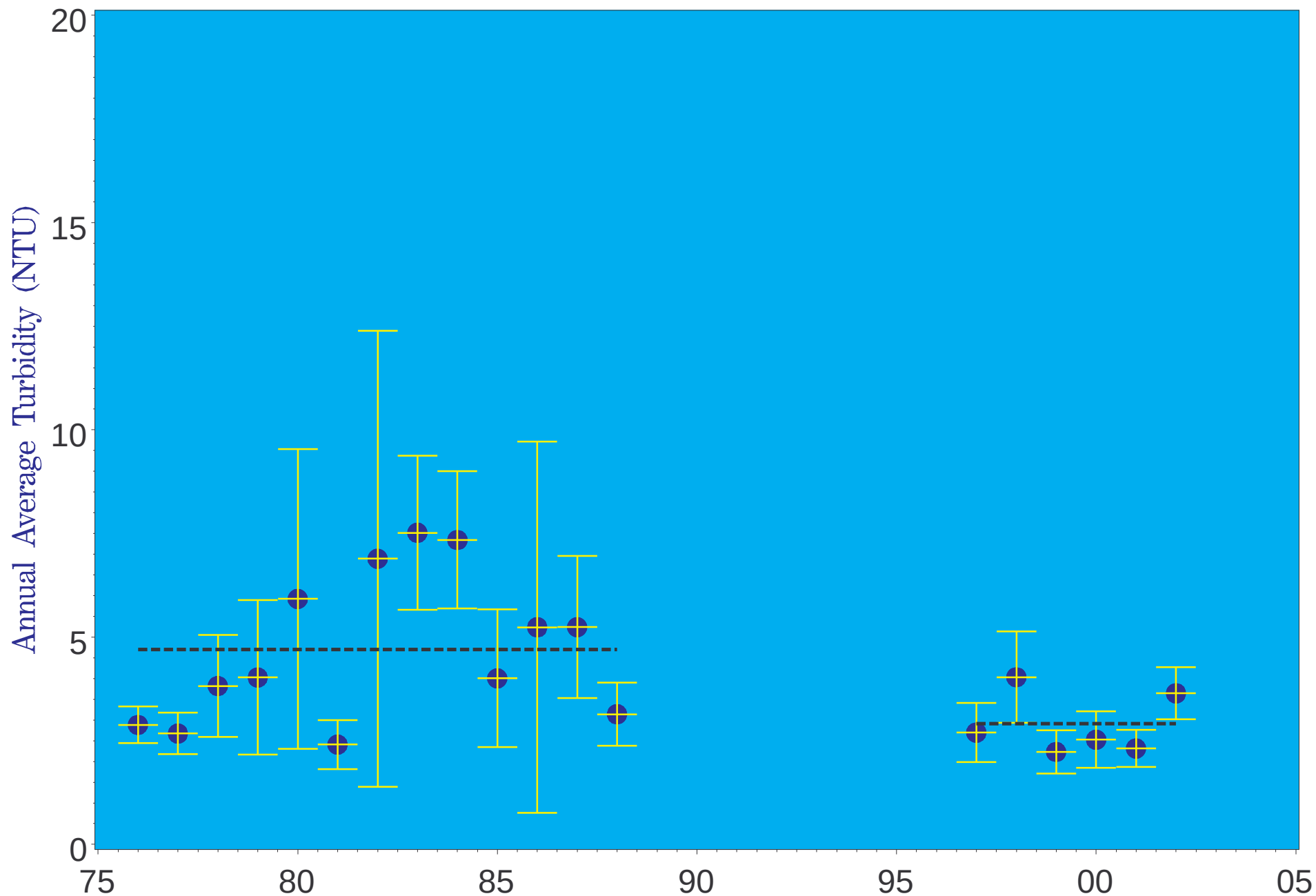


Figure 4.5.221 Long-term surface turbidity at river kilometer 30.4

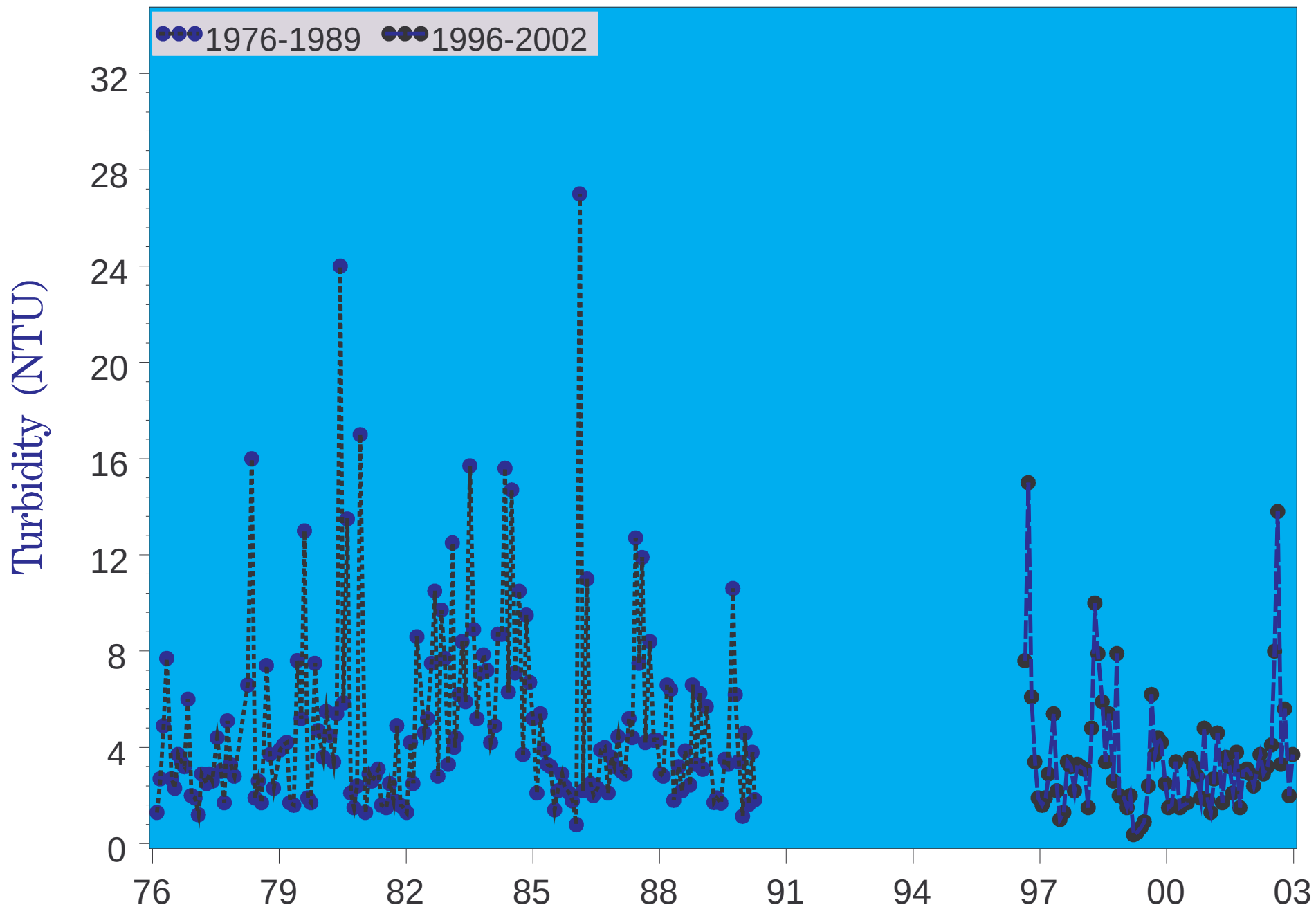


Figure 4.5.222 Long-term bottom turbidity at river kilometer 30.4

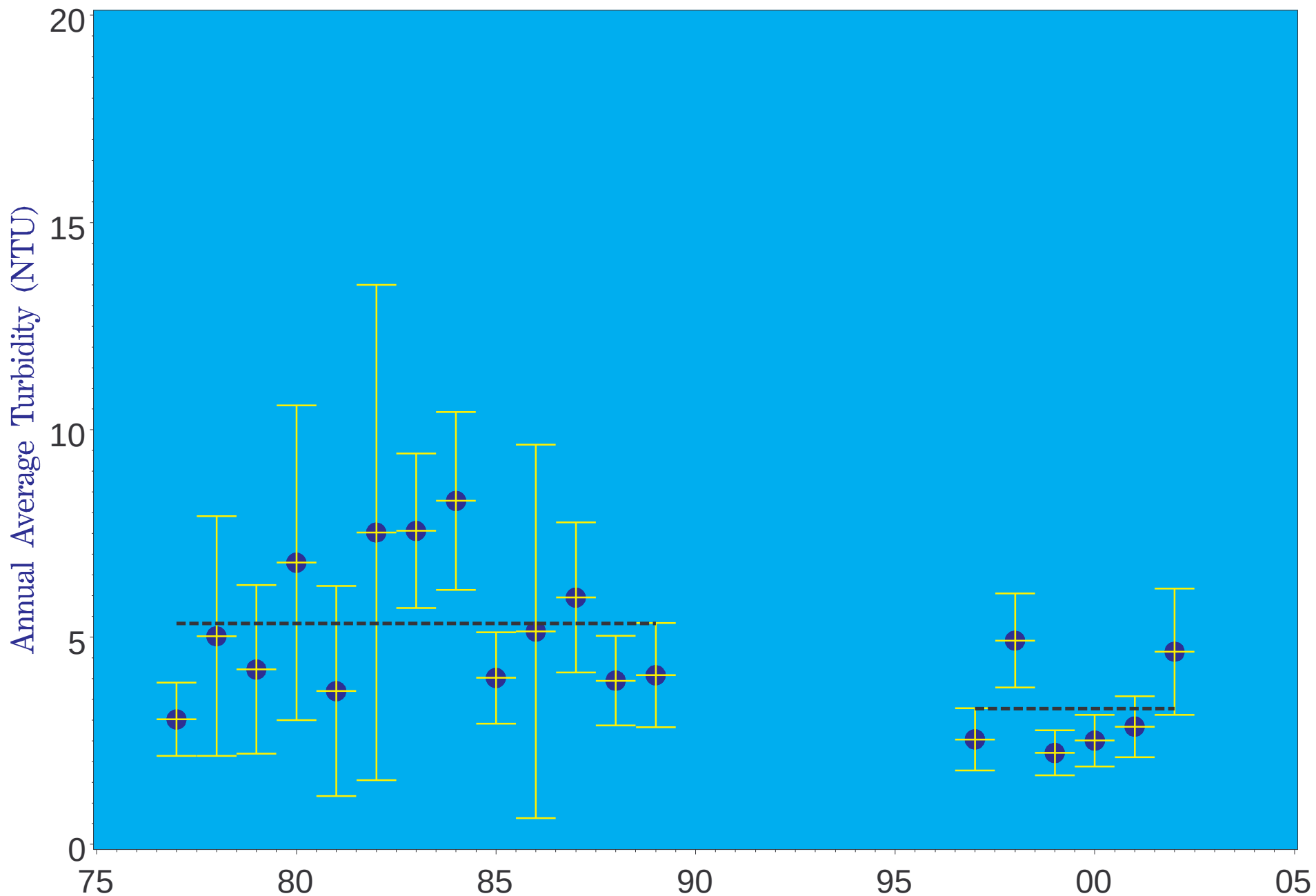


Figure 4.5.223 Long-term bottom turbidity at river kilometer 30.4

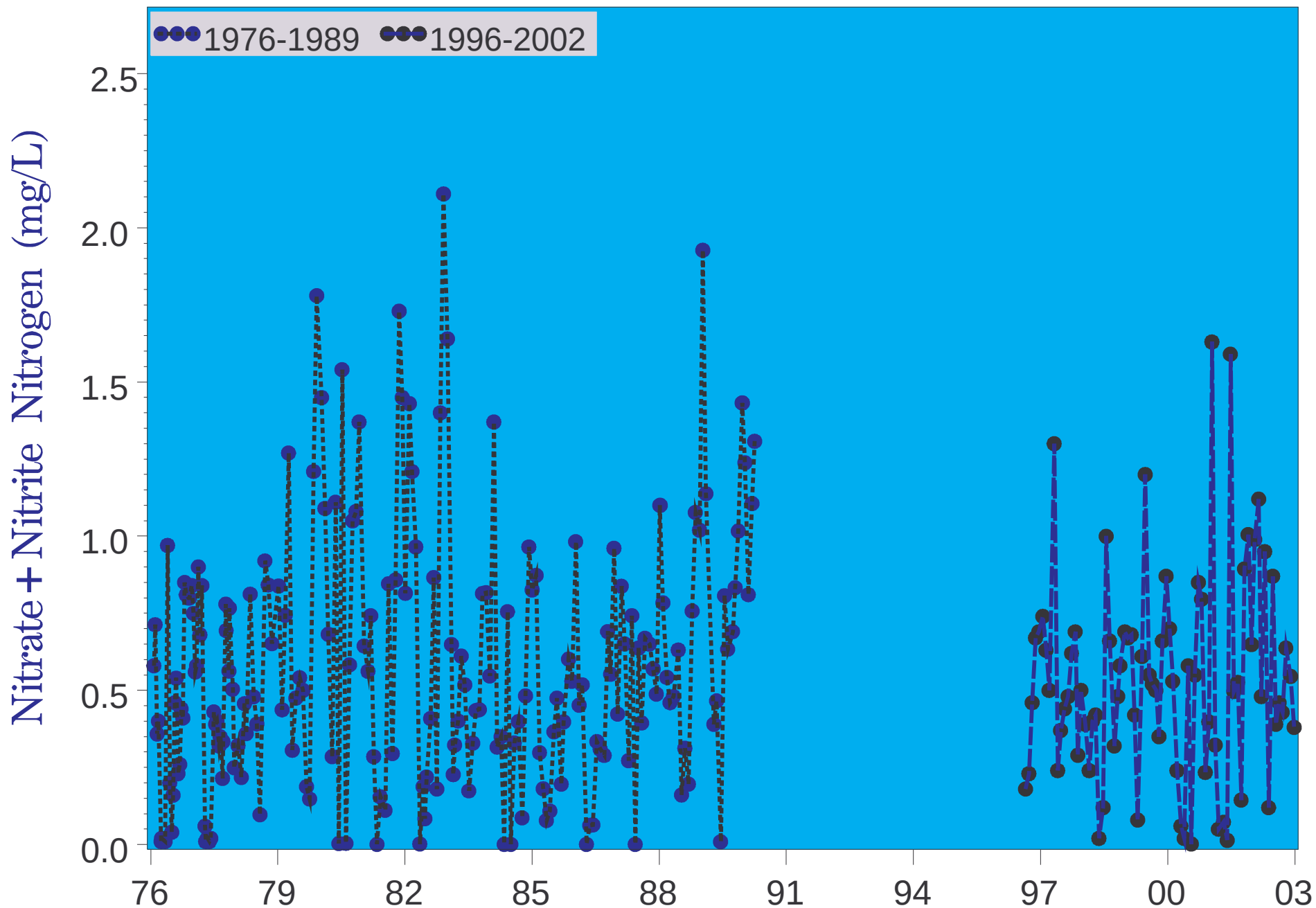


Figure 4.5.224 Long-term surface nitrate/nitrite nitrogen at river kilometer 30.4

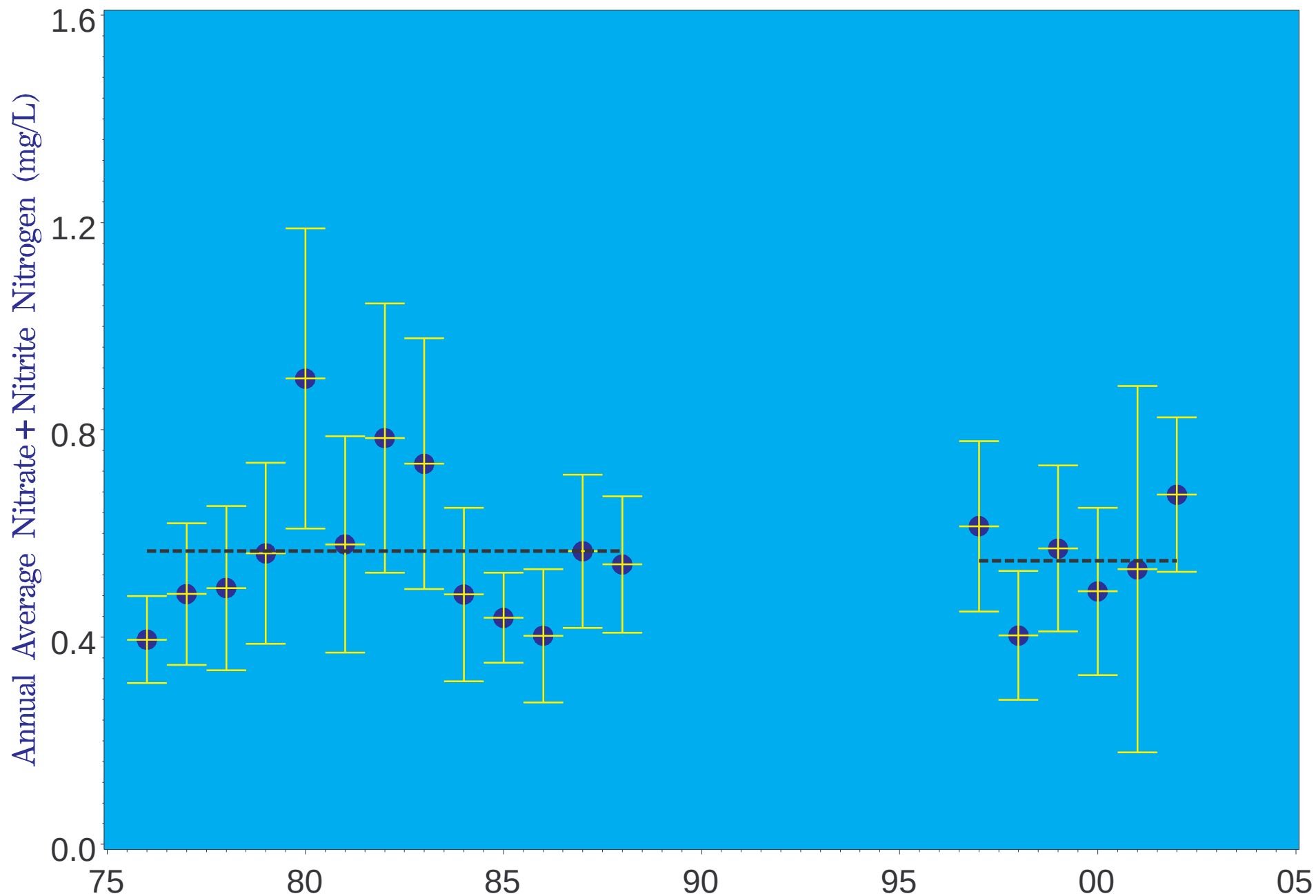


Figure 4.5.225 Long-term surface nitrate/nitrite nitrogen at river kilometer 30.4



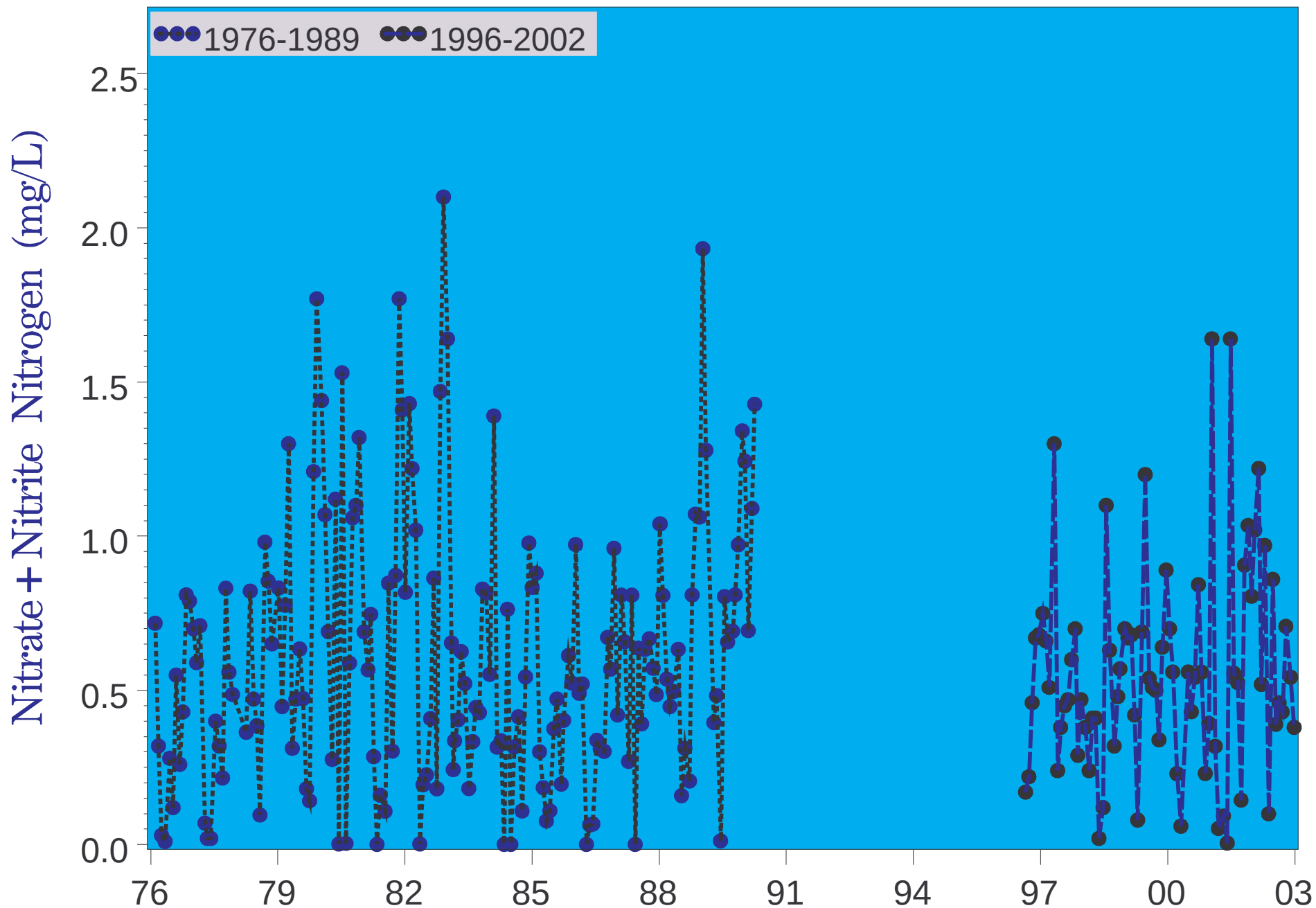


Figure 4.5.226 Long-term bottom nitrate/nitrite nitrogen at river kilometer 30.4

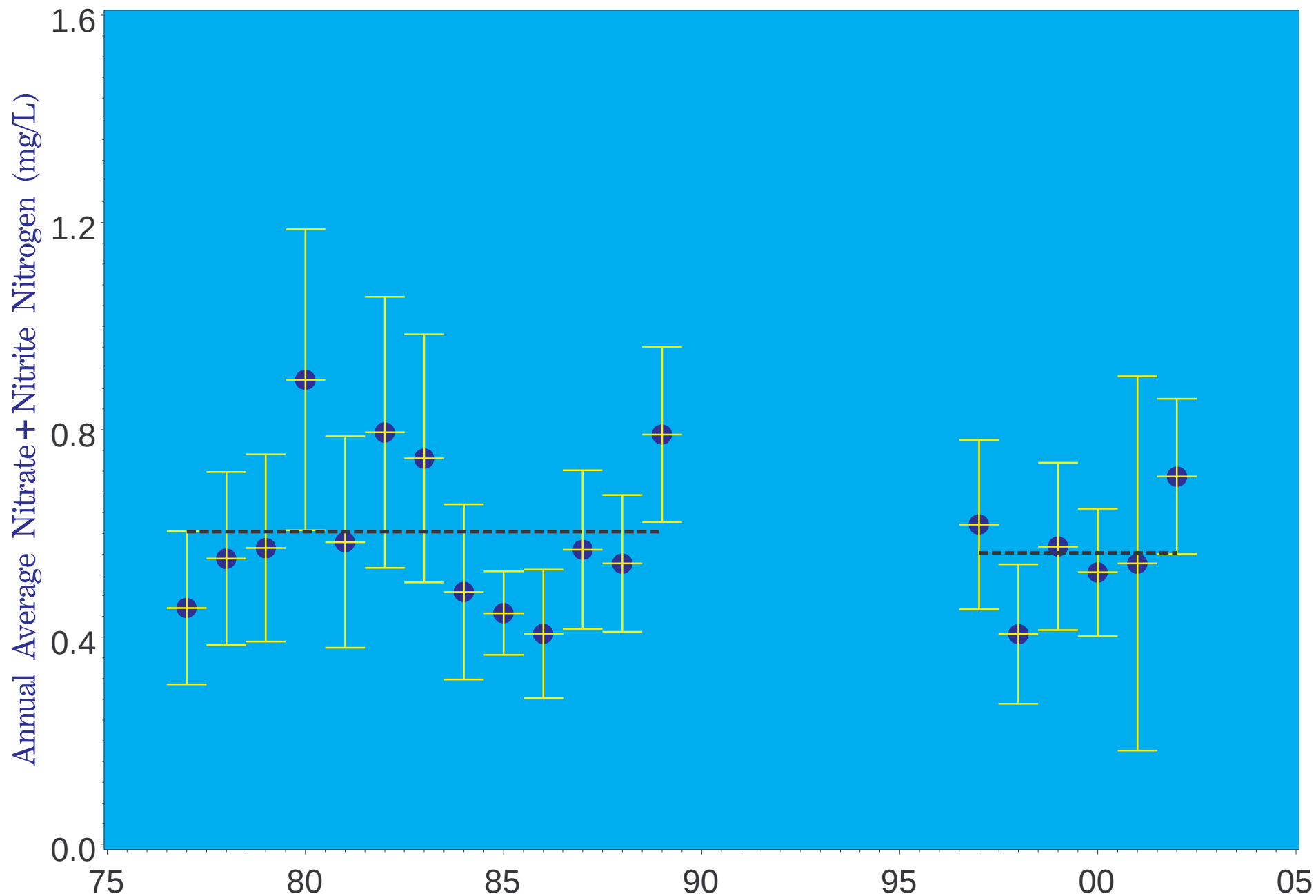


Figure 4.5.227 Long-term bottom nitrate/nitrite nitrogen at river kilometer 30.4

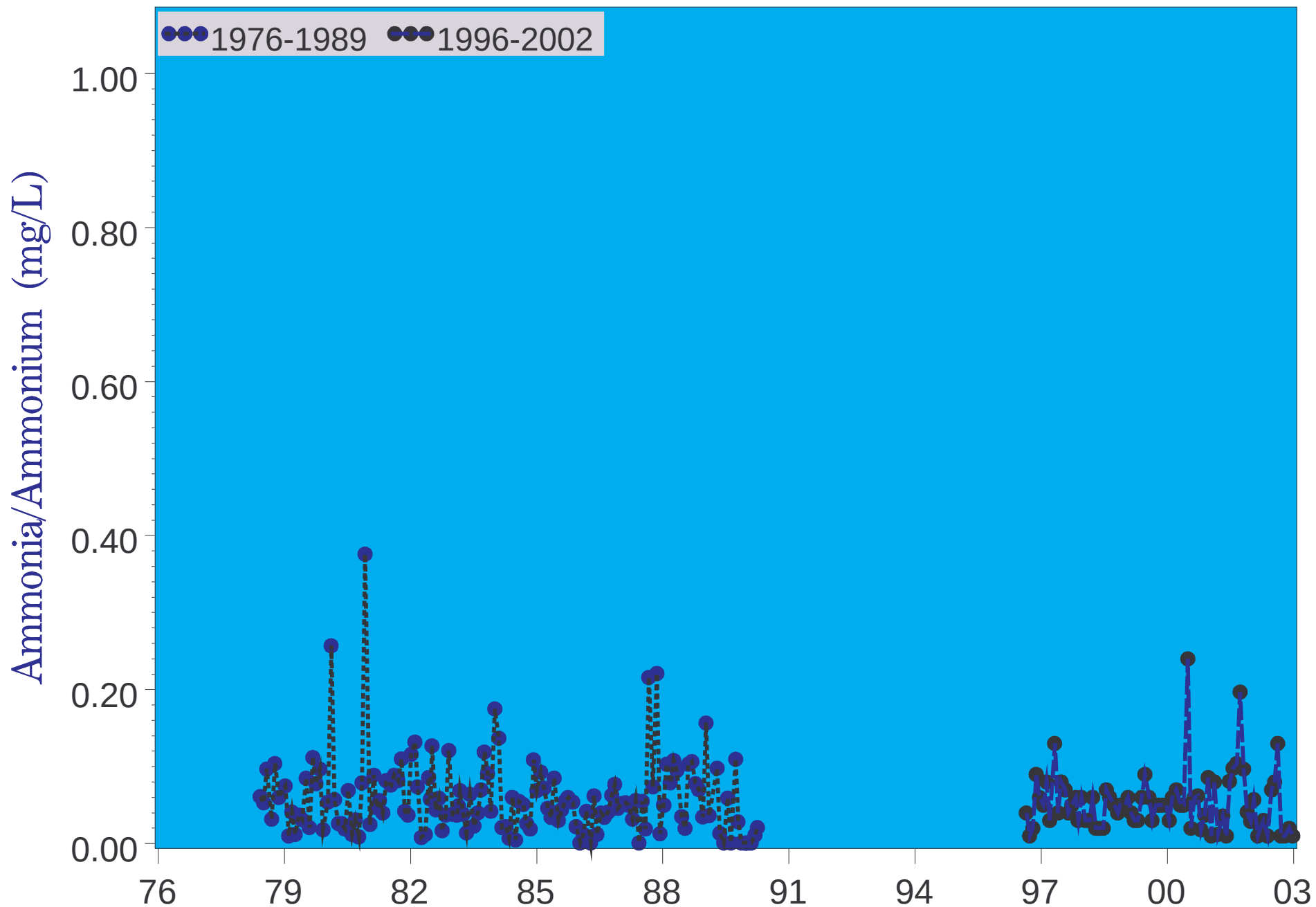


Figure 4.5.228 Long-term surface ammonia/ammonium at river kilometer 30.4

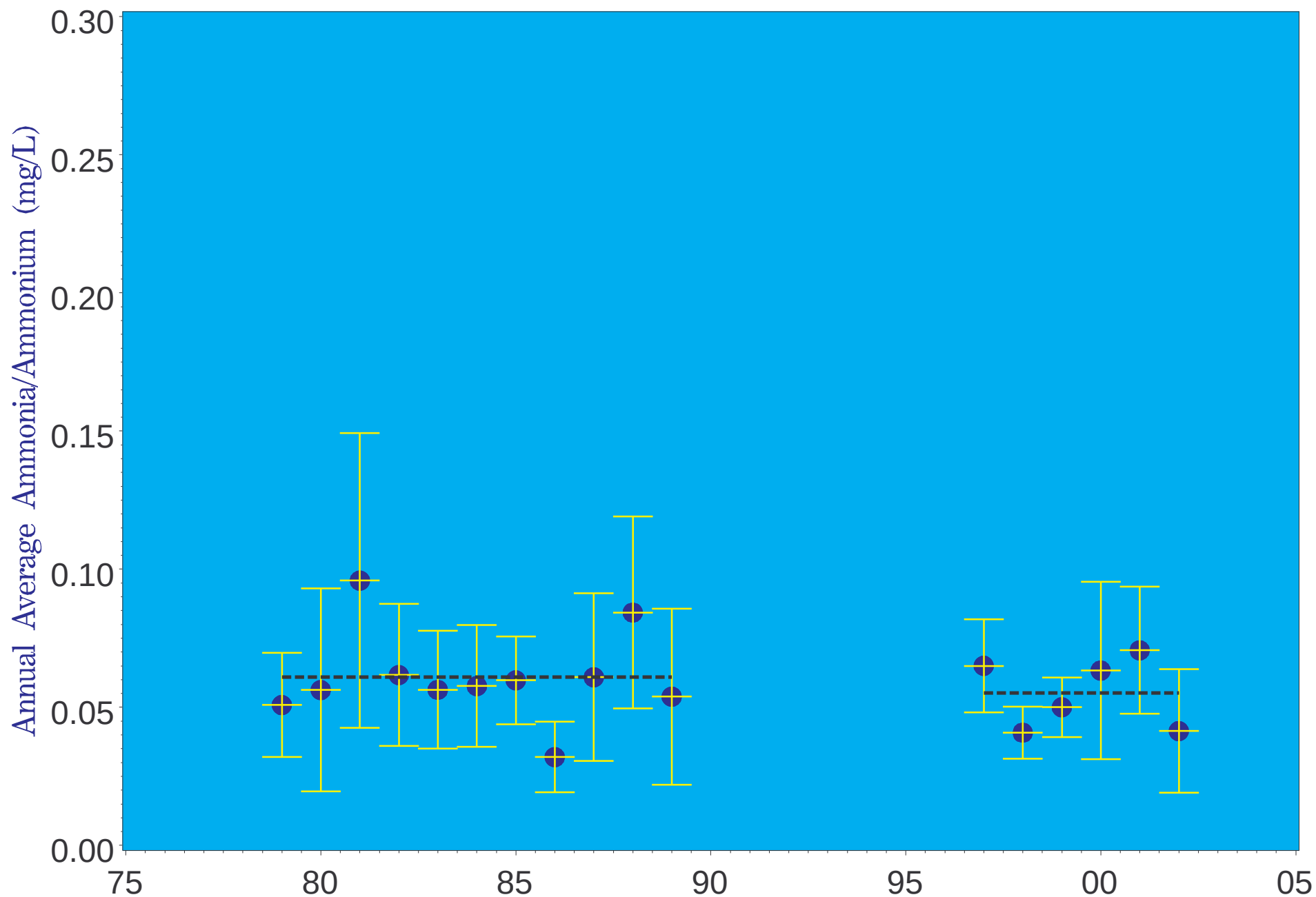


Figure 4.5.229 Long-term surface ammonia/ammonium at river kilometer 30.4

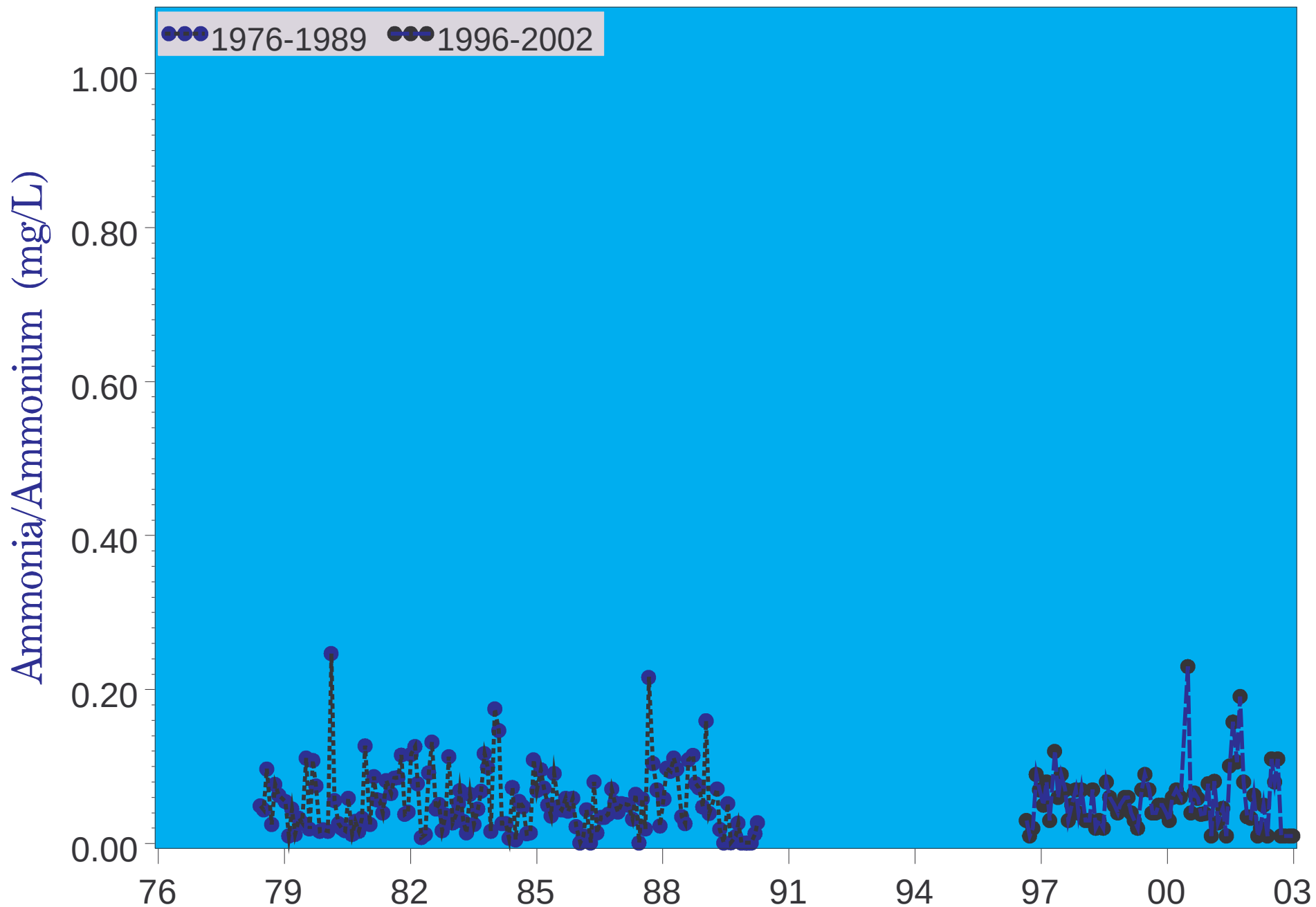


Figure 4.5.230 Long-term bottom ammonia/ammonium at river kilometer 30.4

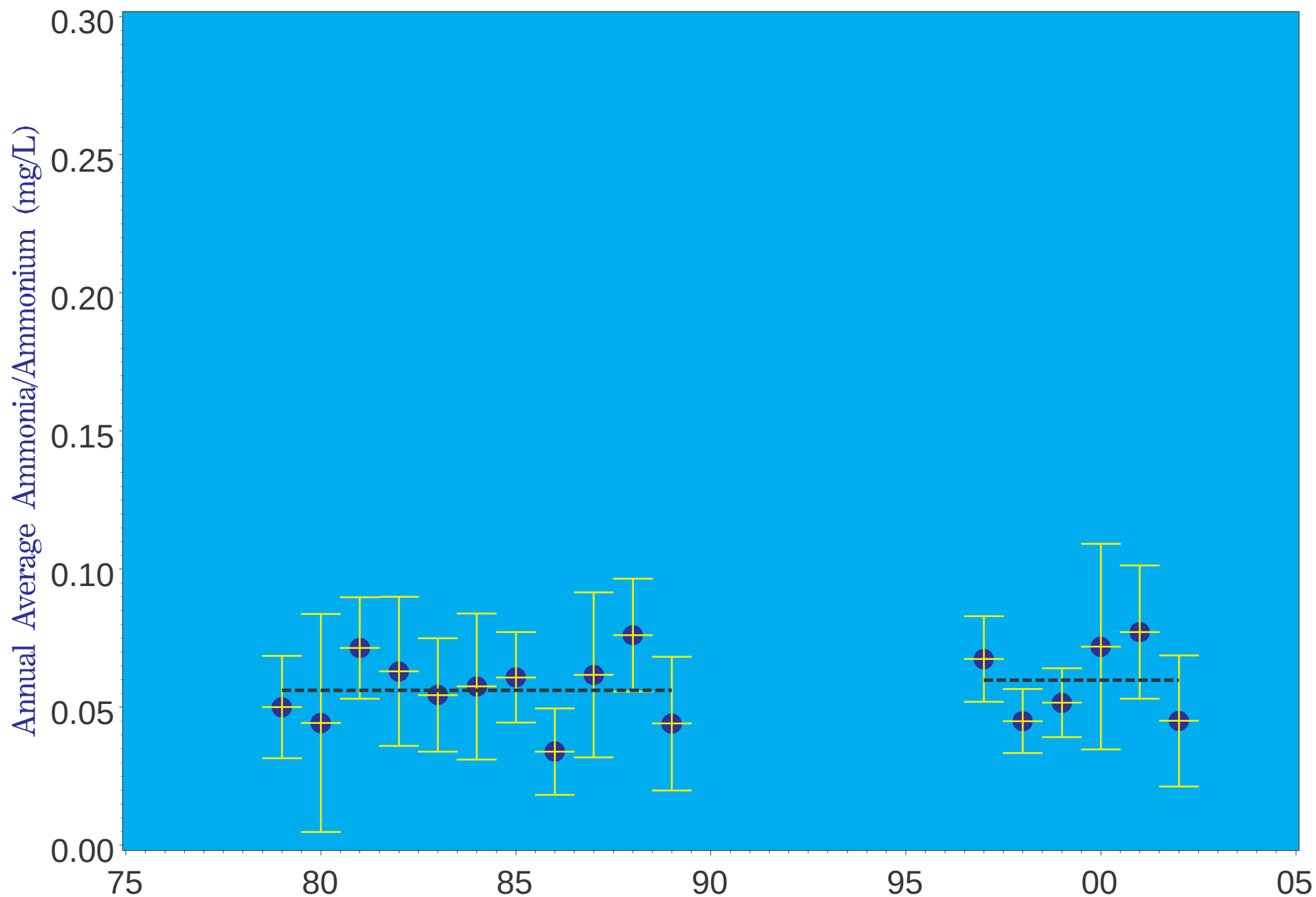


Figure 4.5.231 Long-term bottom ammonia/ammonium at river kilometer 30.4

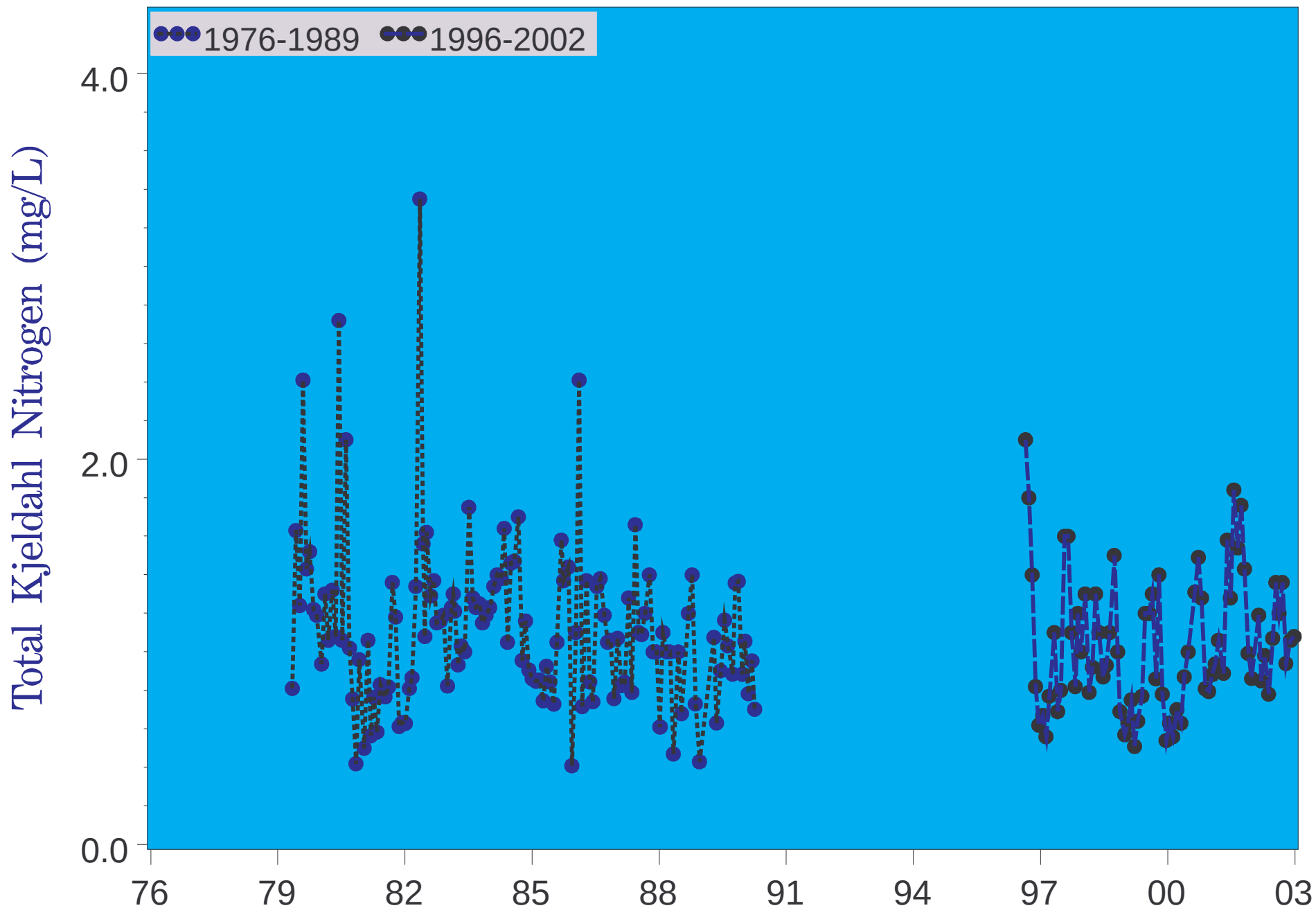


Figure 4.5.232 Long-term surface total Kjeldahl nitrogen at river kilometer 30.4

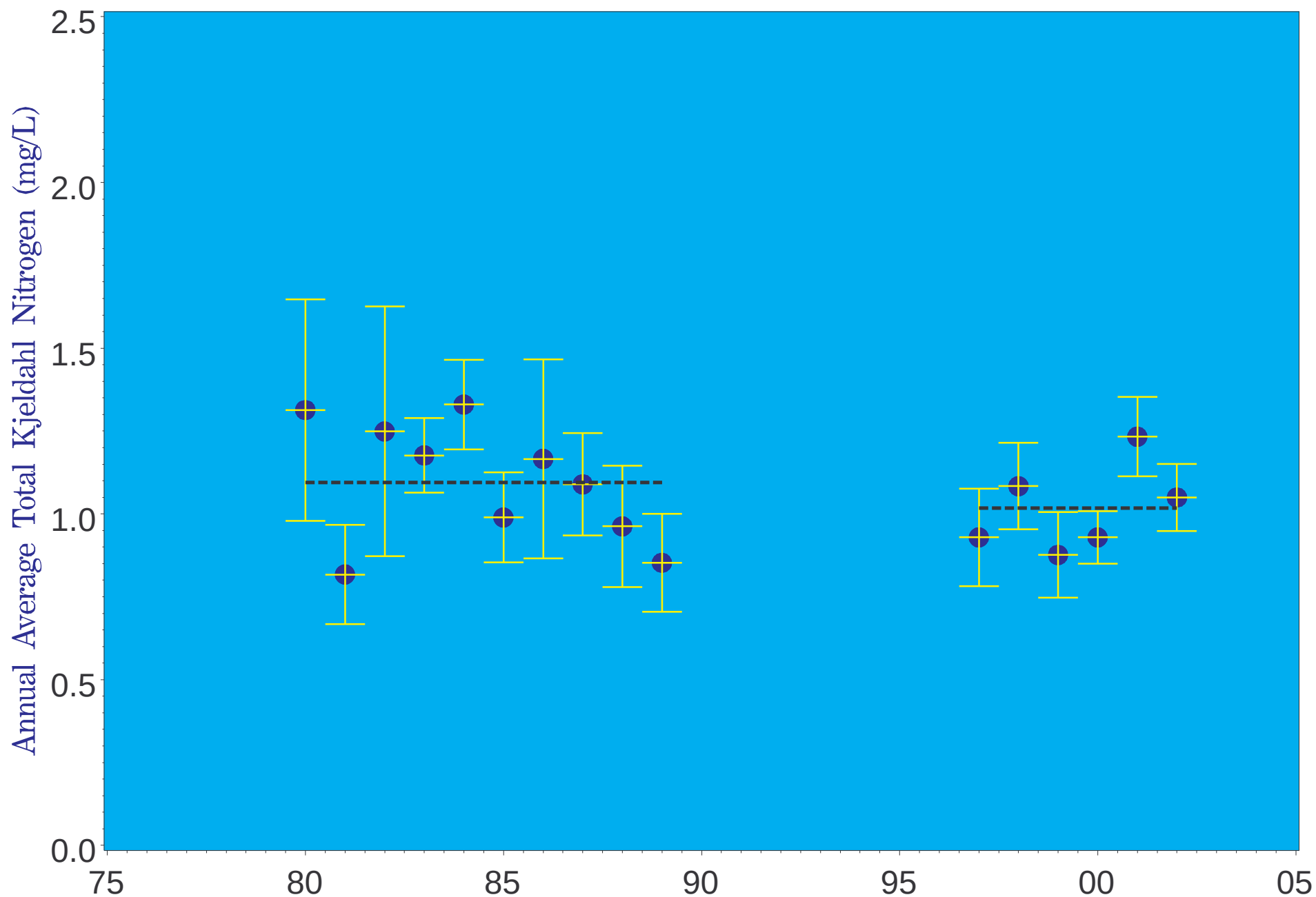


Figure 4.5.233 Long-term surface total Kjeldahl nitrogen at river kilometer 30.4



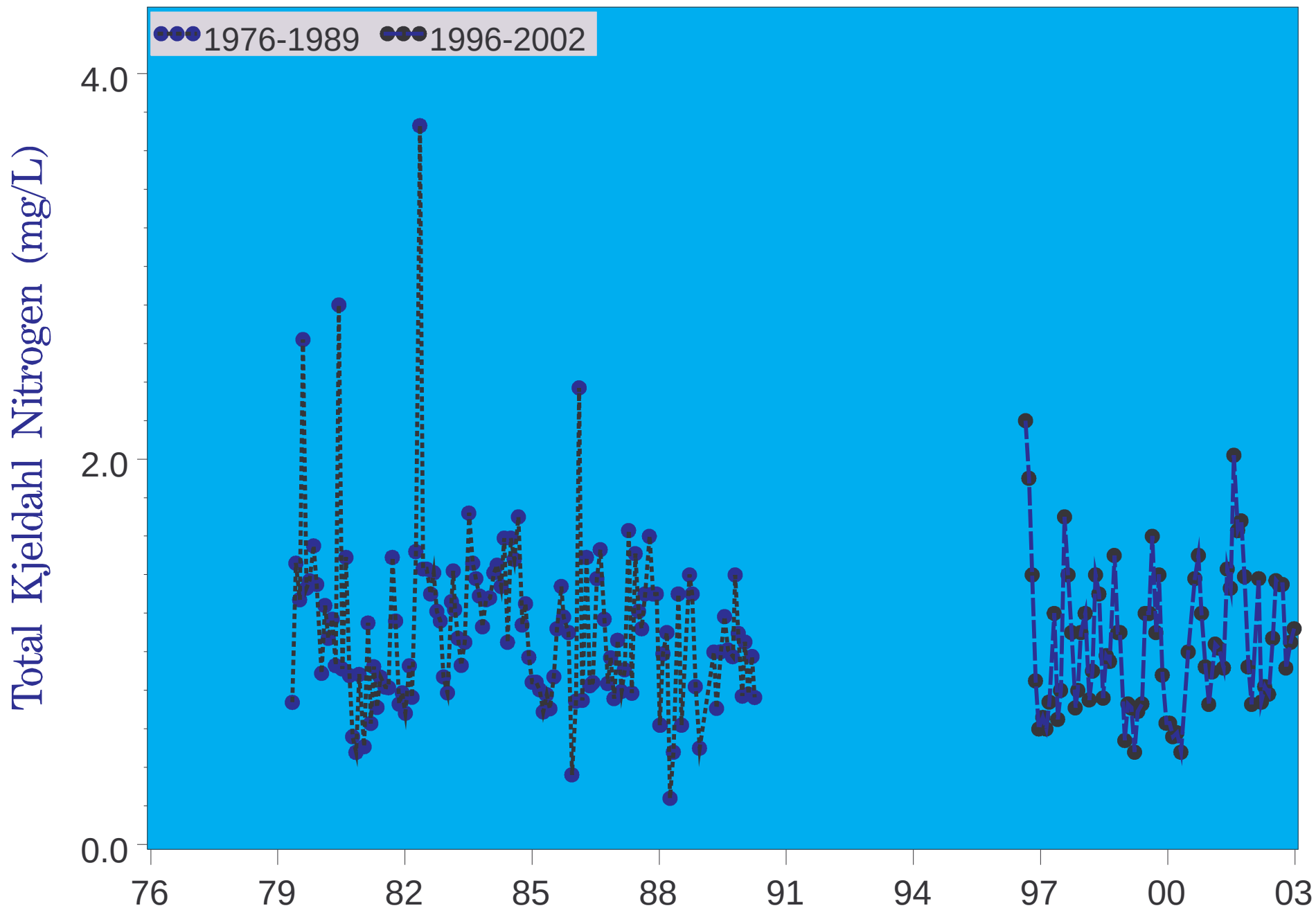


Figure 4.5.234 Long-term bottom total Kjeldhal nitrogen at river kilometer 30.4

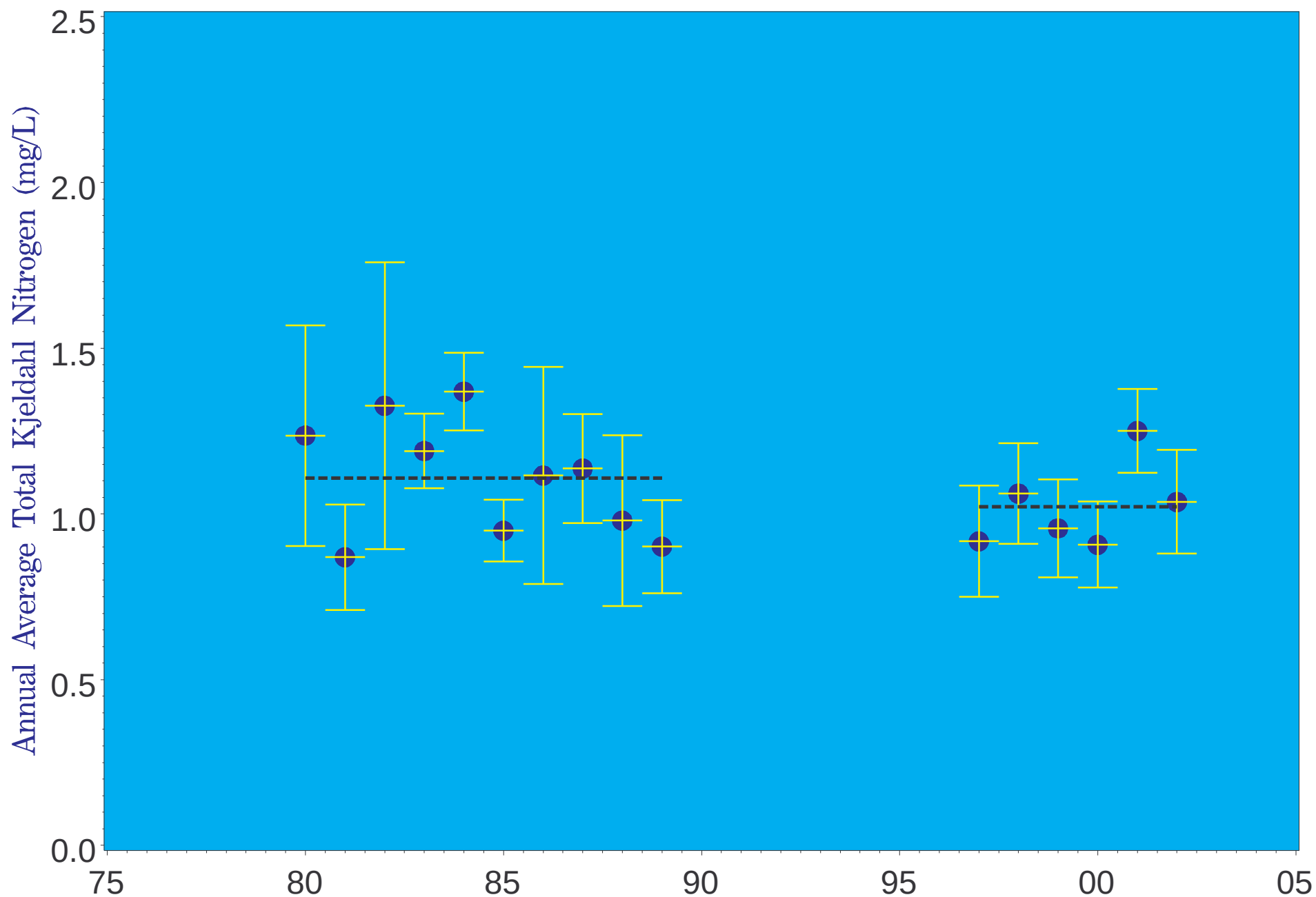


Figure 4.5.235 Long-term bottom total Kjeldhal nitrogen at river kilometer 30.4

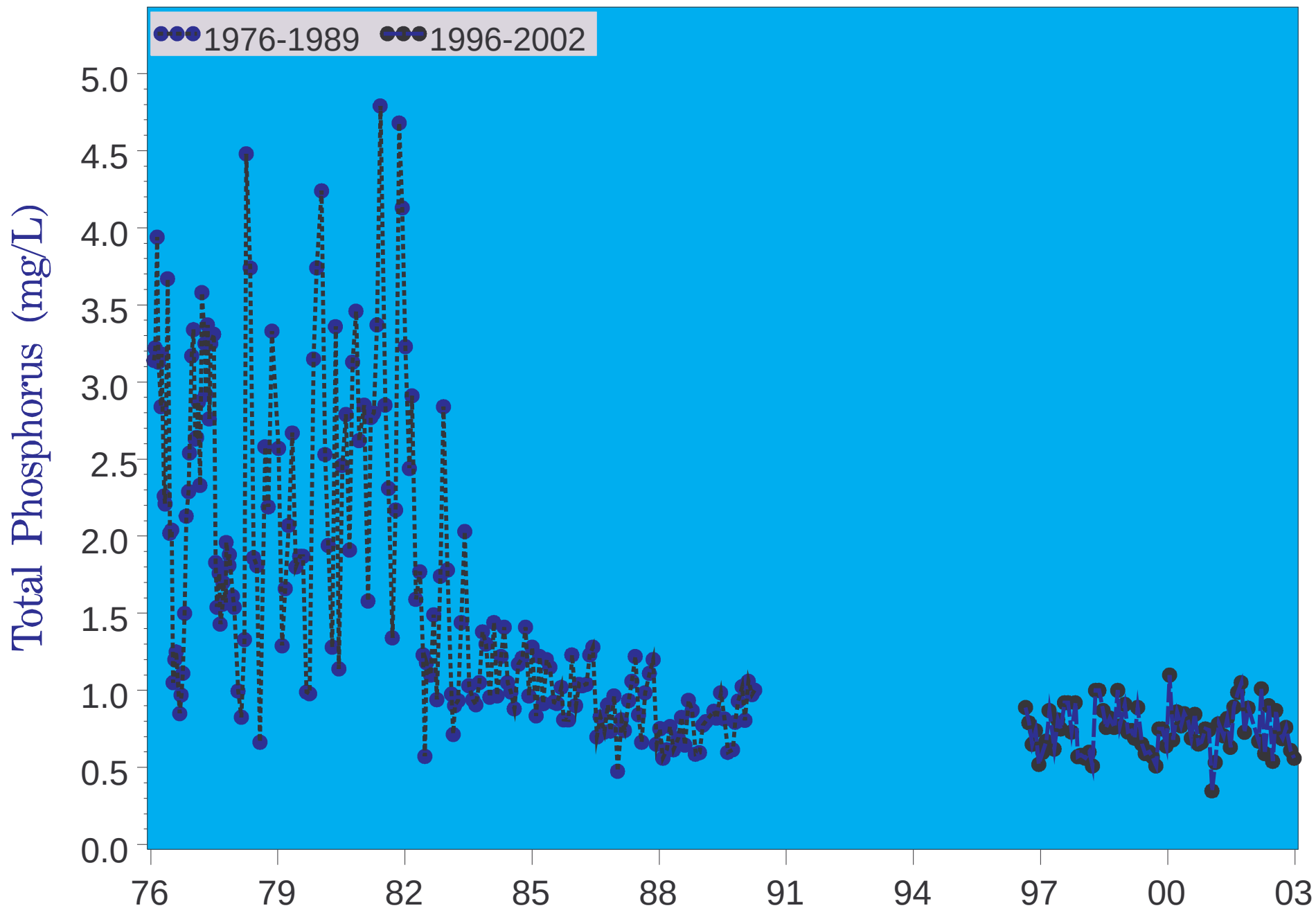


Figure 4.5.236 Long-term surface total phosphorus at river kilometer 30.4

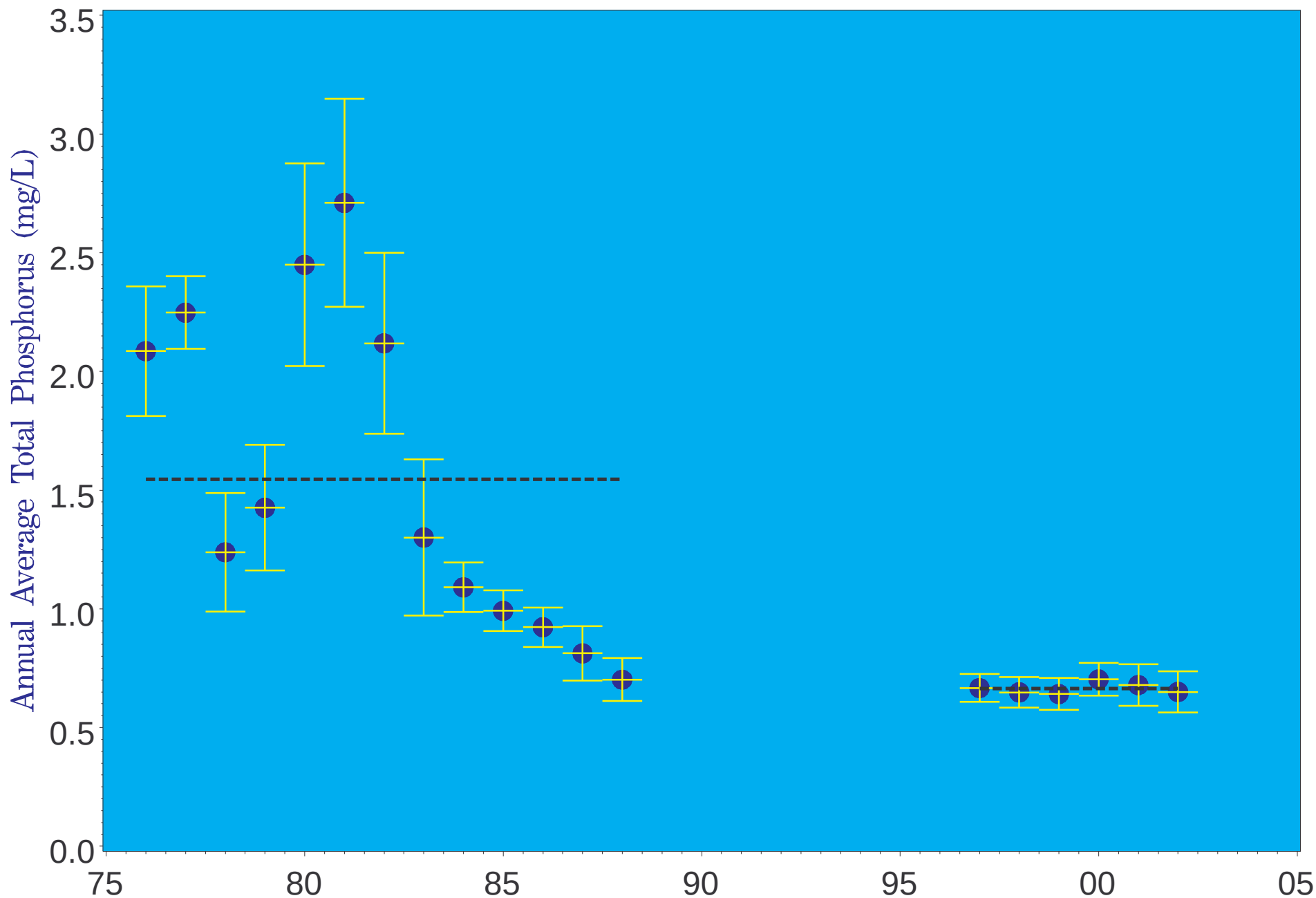


Figure 4.5.237 Long-term surface total phosphorus at river kilometer 30.4

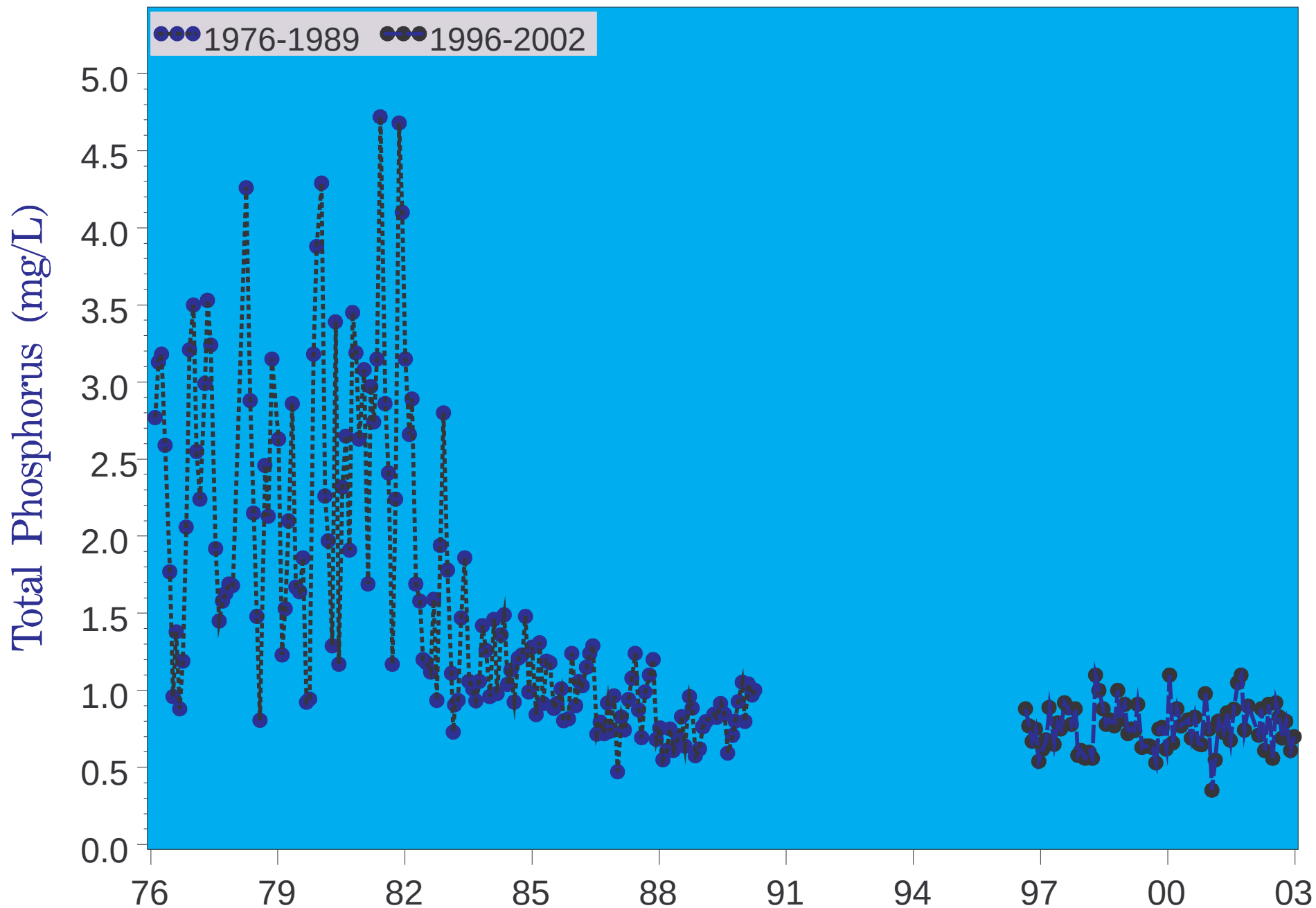


Figure 4.5.238 Long-term bottom total phosphorus at river kilometer 30.4

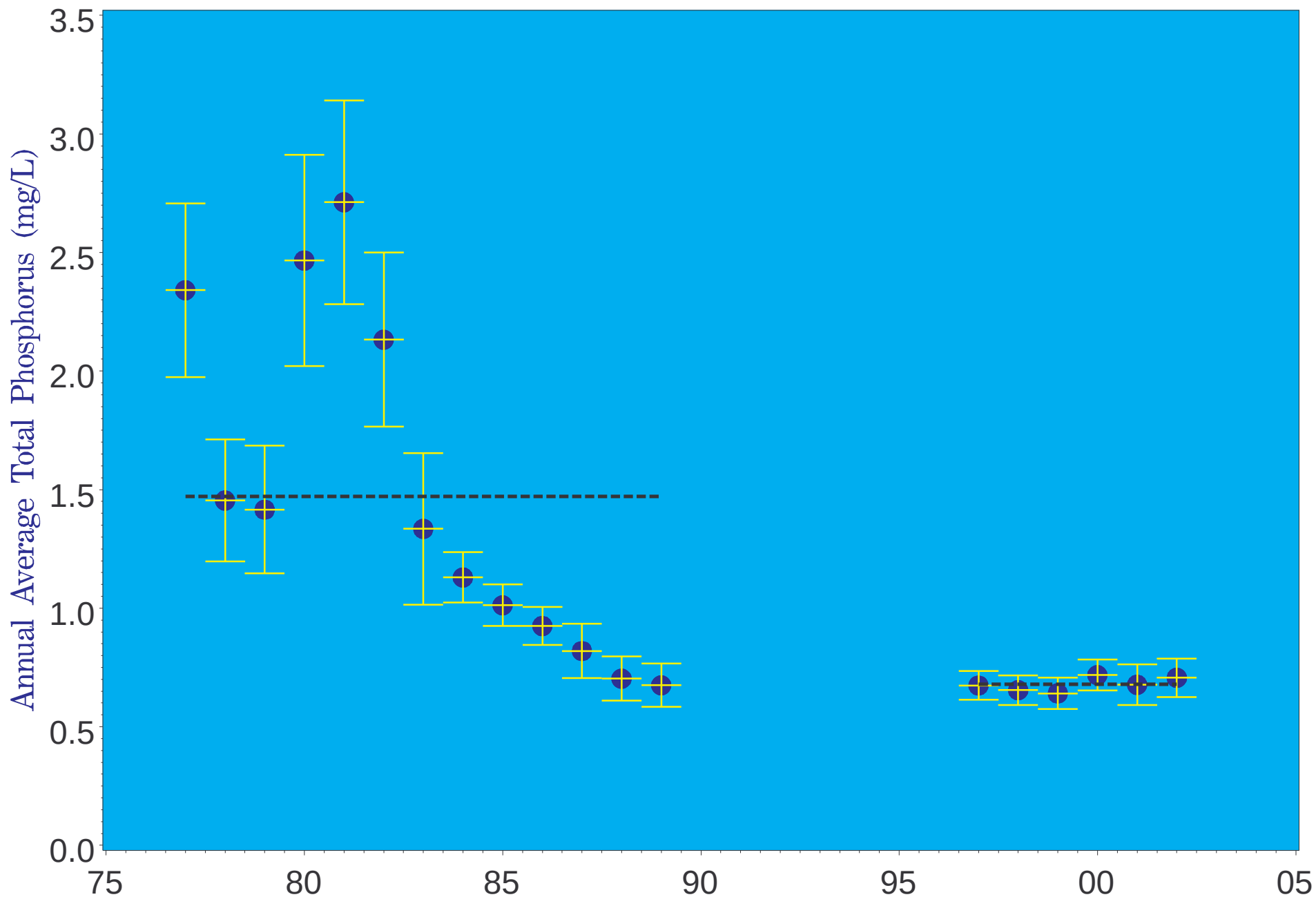


Figure 4.5.239 Long-term bottom total phosphorus at river kilometer 30.4

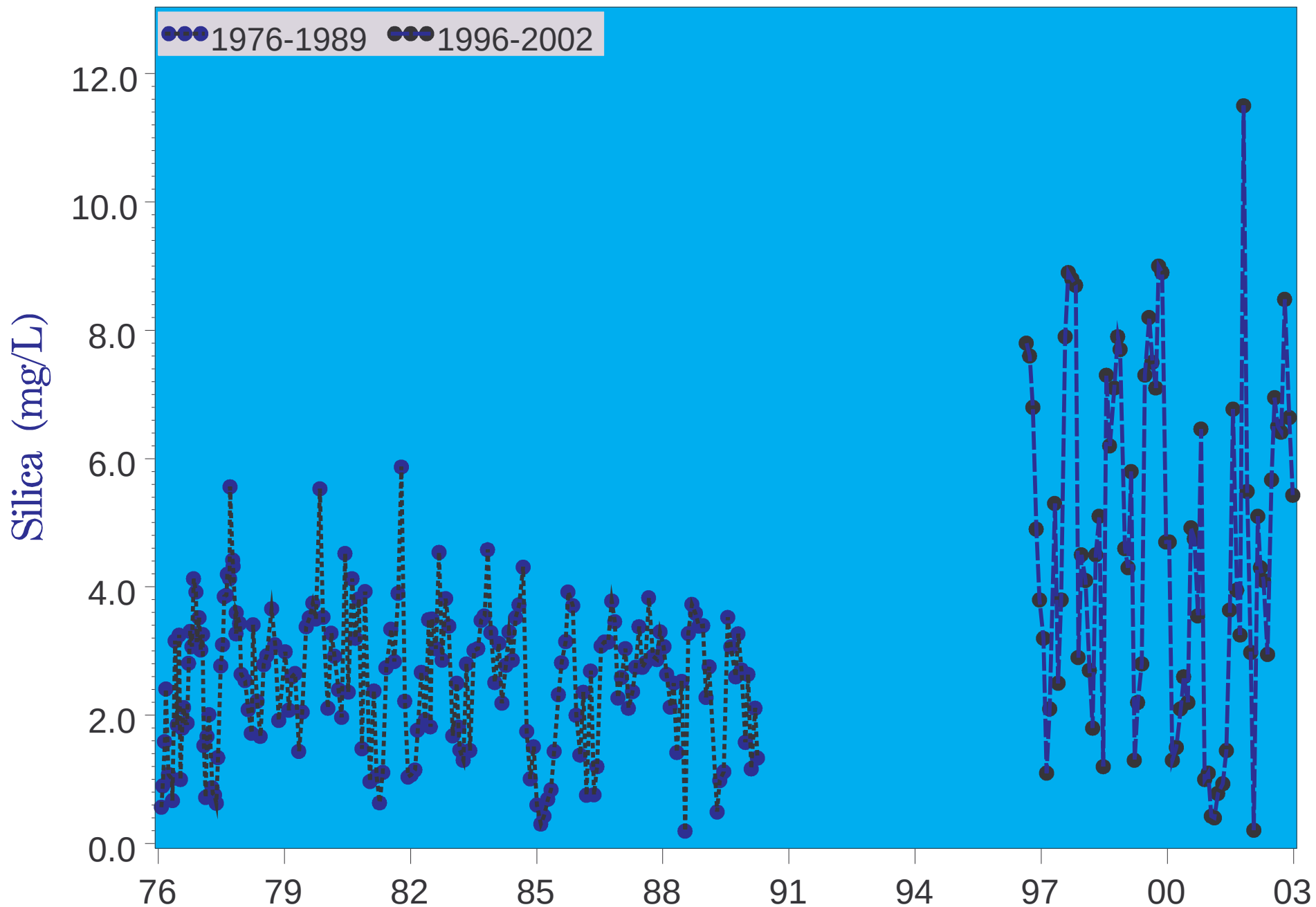


Figure 4.5.240 Long-term surface silica at river kilometer 30.4

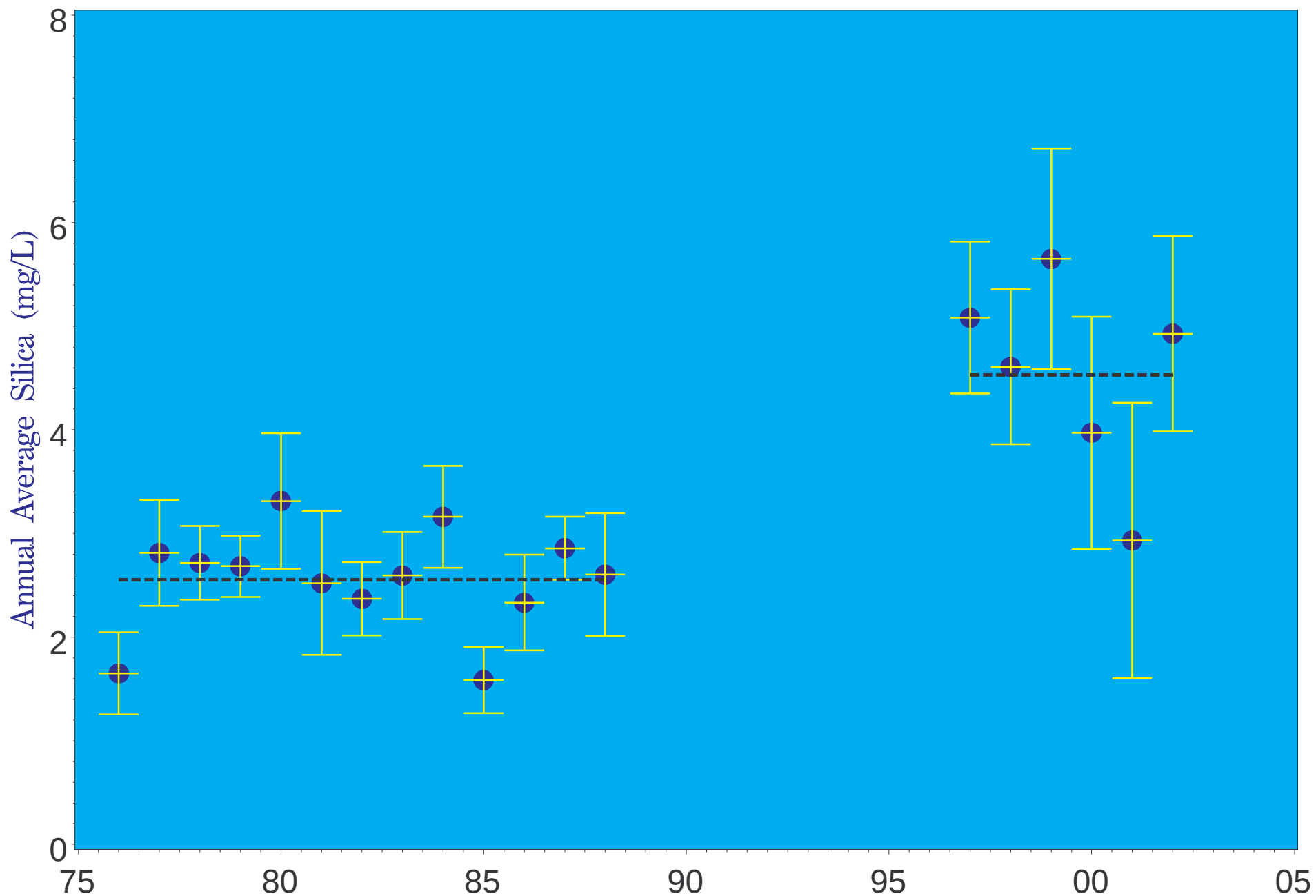


Figure 4.5.241 Long-term surface silica at river kilometer 30.4



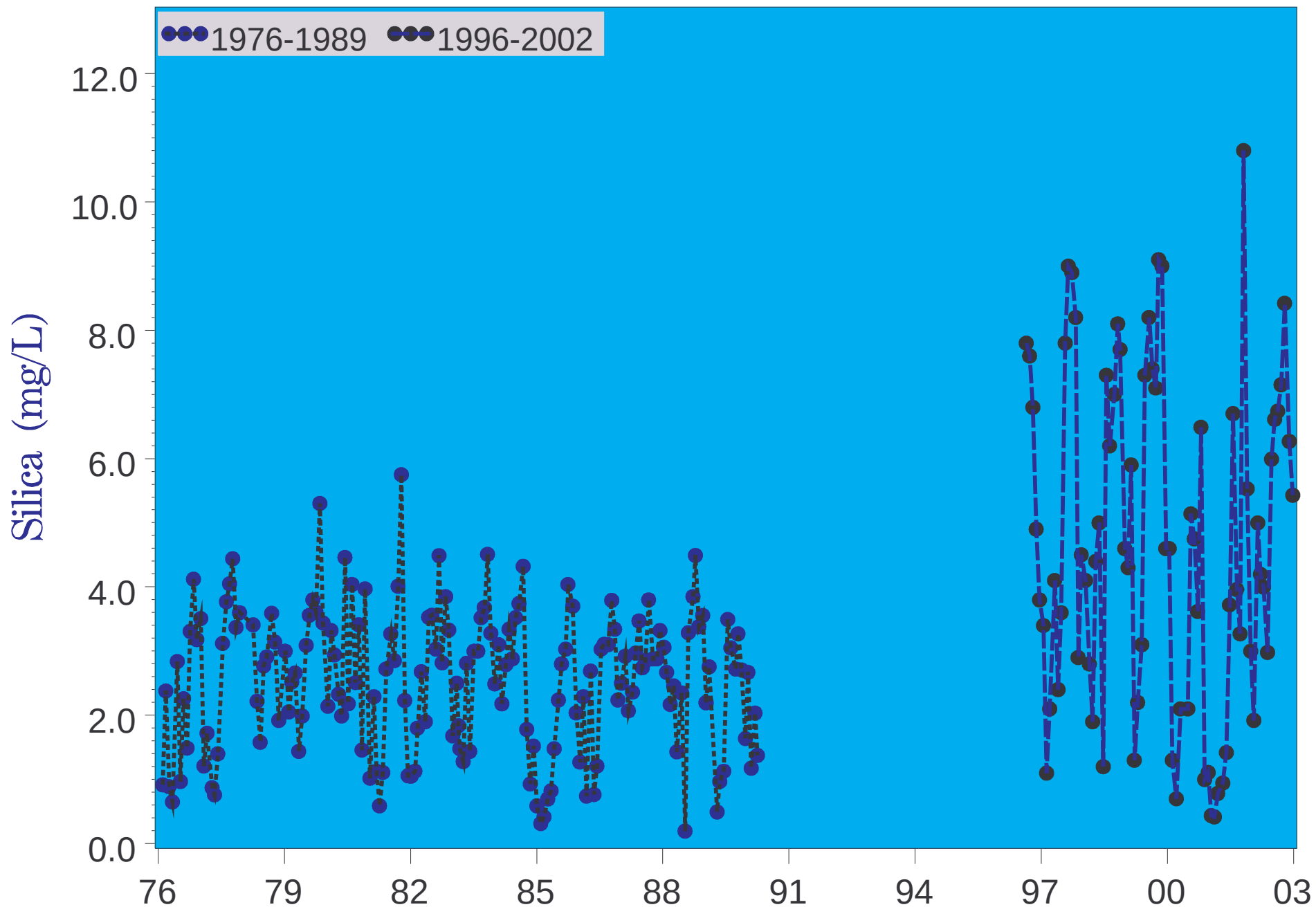


Figure 4.5.242 Long-term bottom silica at river kilometer 30.4

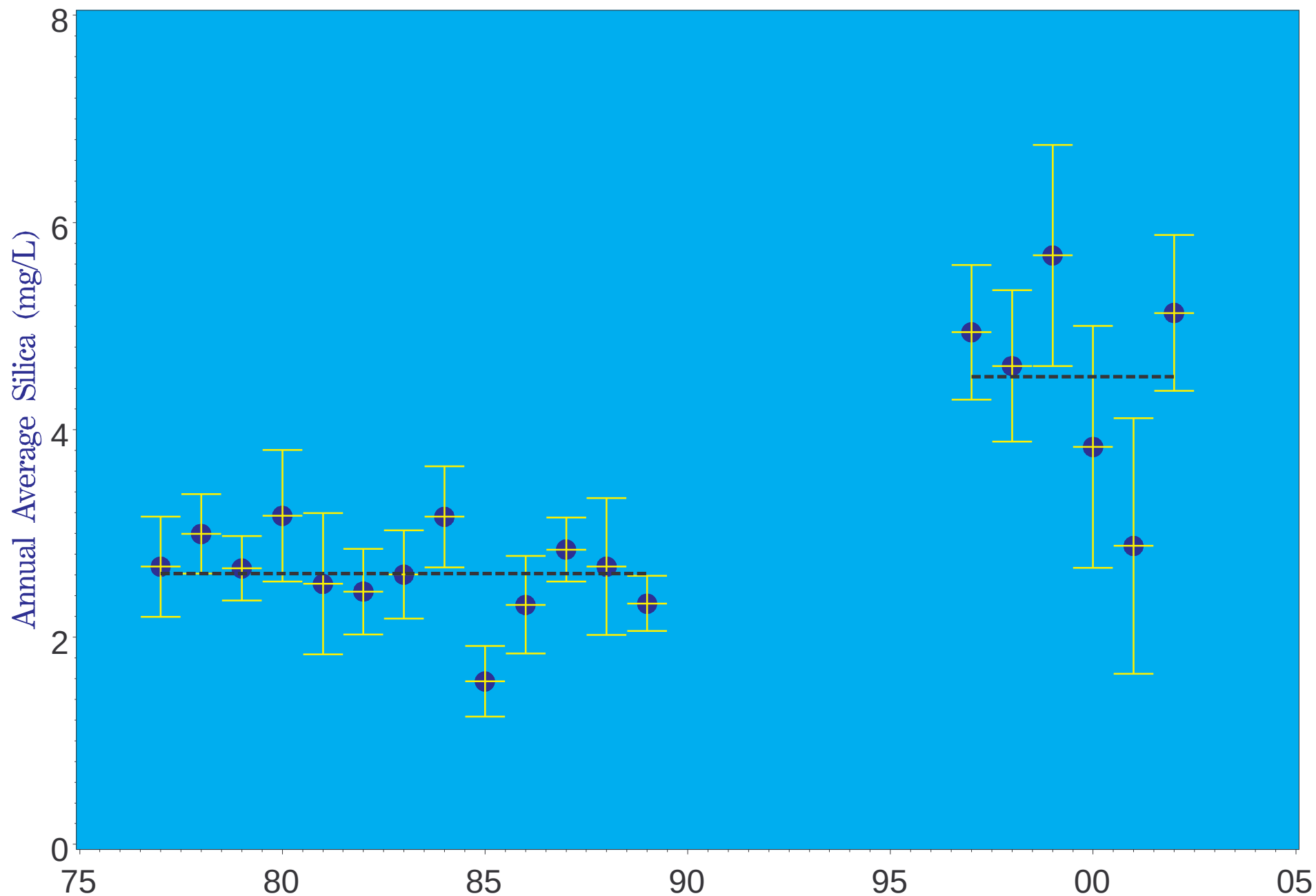


Figure 4.5.243 Long-term bottom silica at river kilometer 30.4



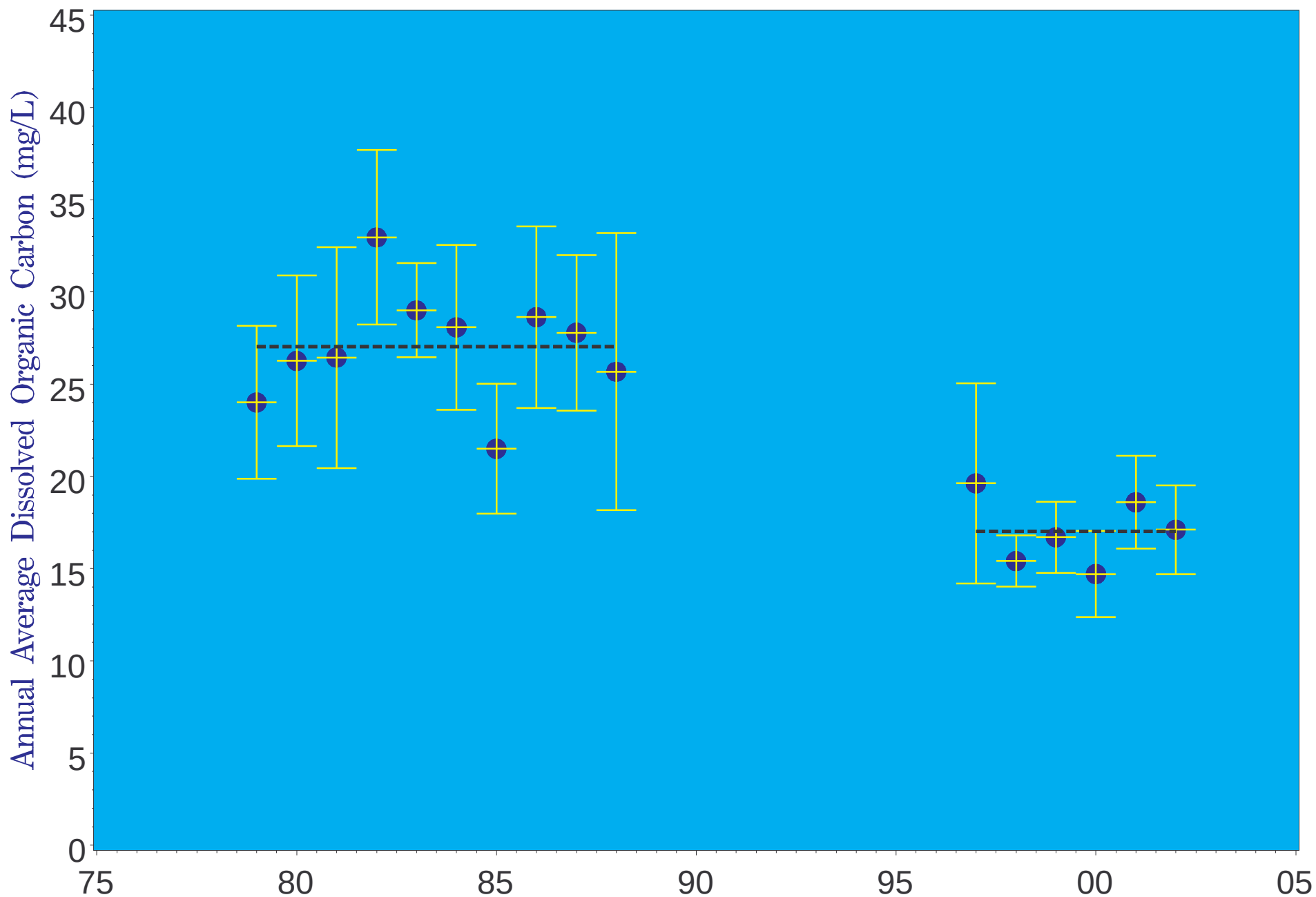


Figure 4.5.245 Long-term surface dissolved organic carbon at river kilometer 30.4

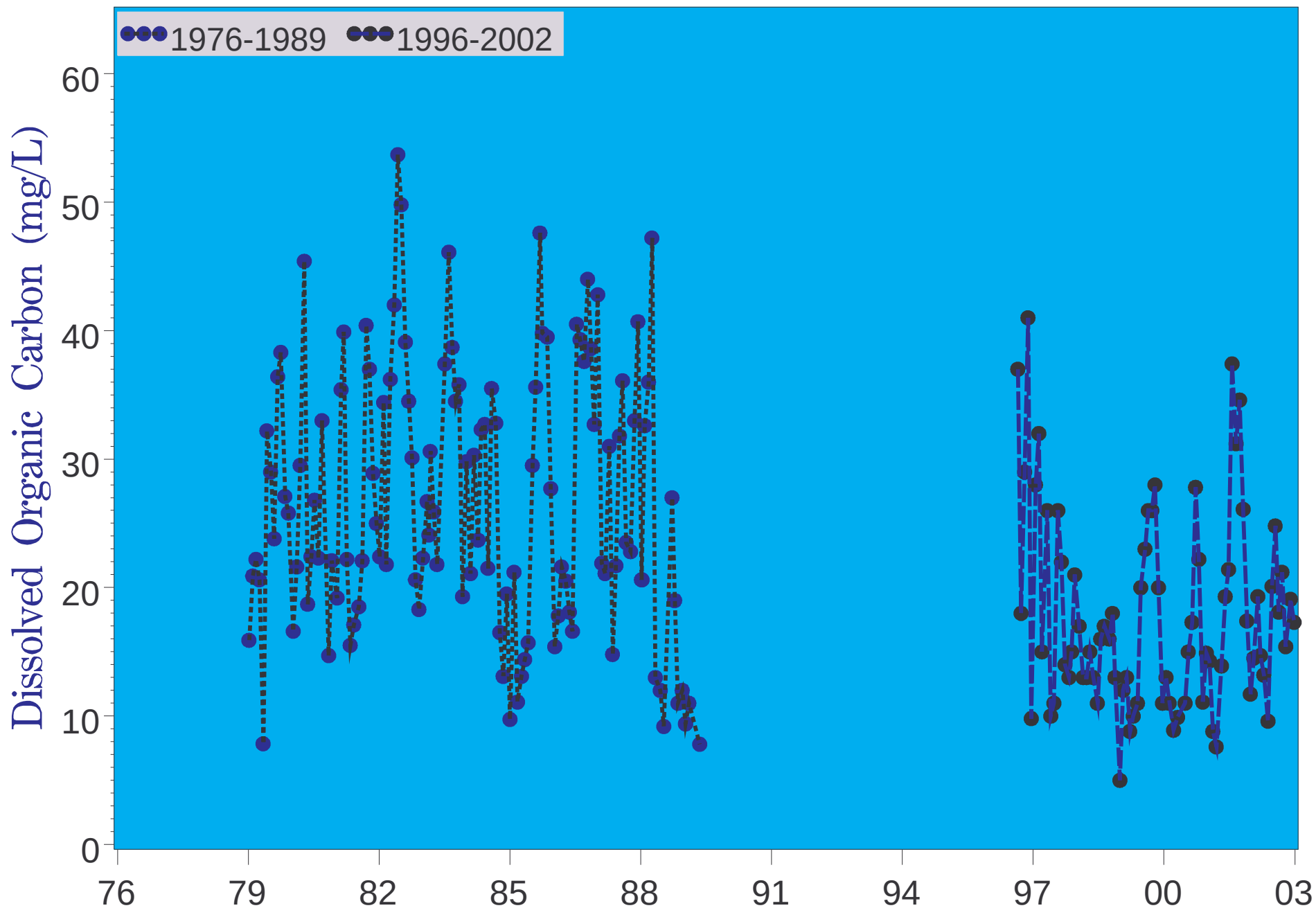


Figure 4.5.246 Long-term bottom dissolved organic carbon at river kilometer 30.4

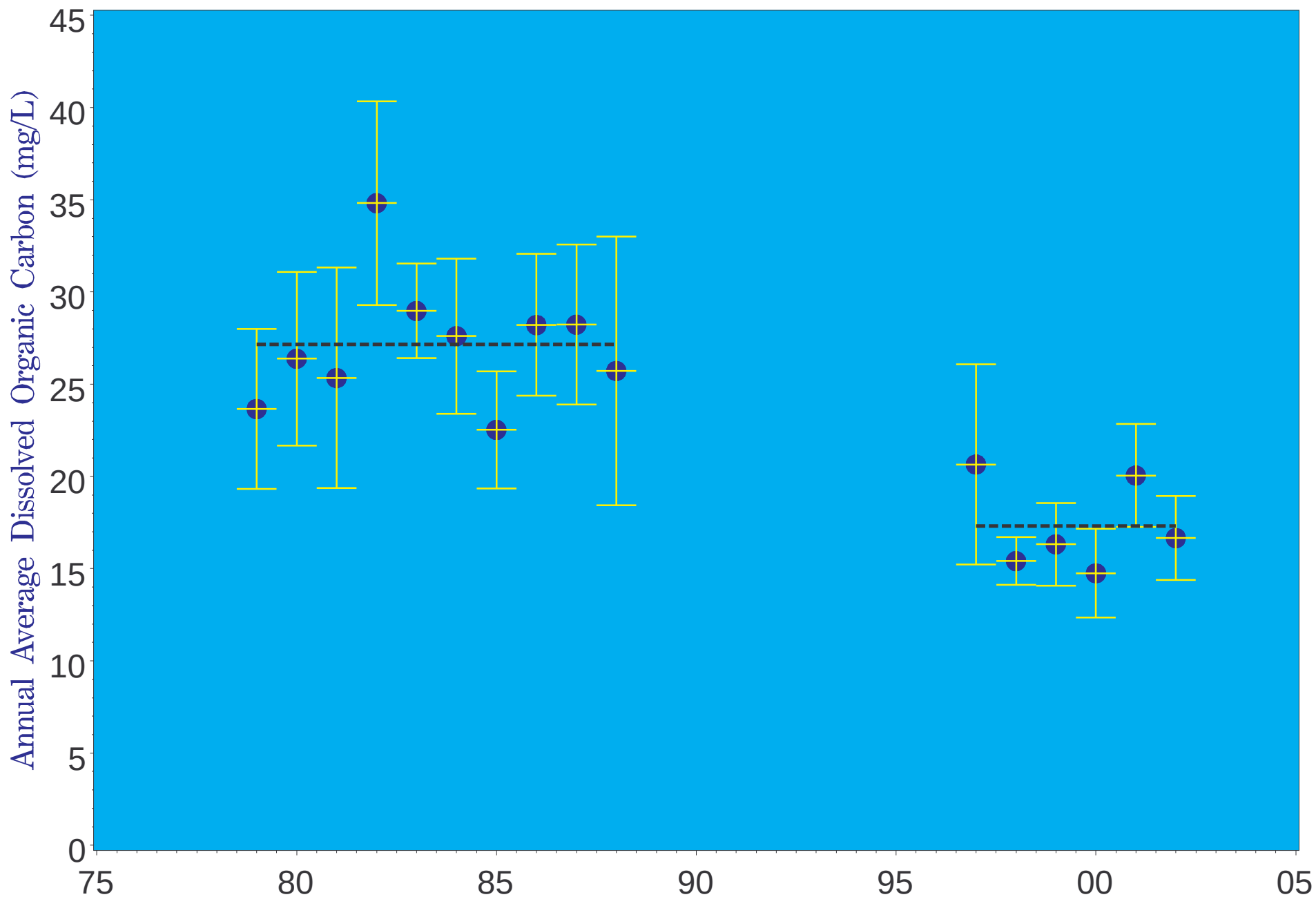


Figure 4.5.247 Long-term bottom dissolved organic carbon at river kilometer 30.4

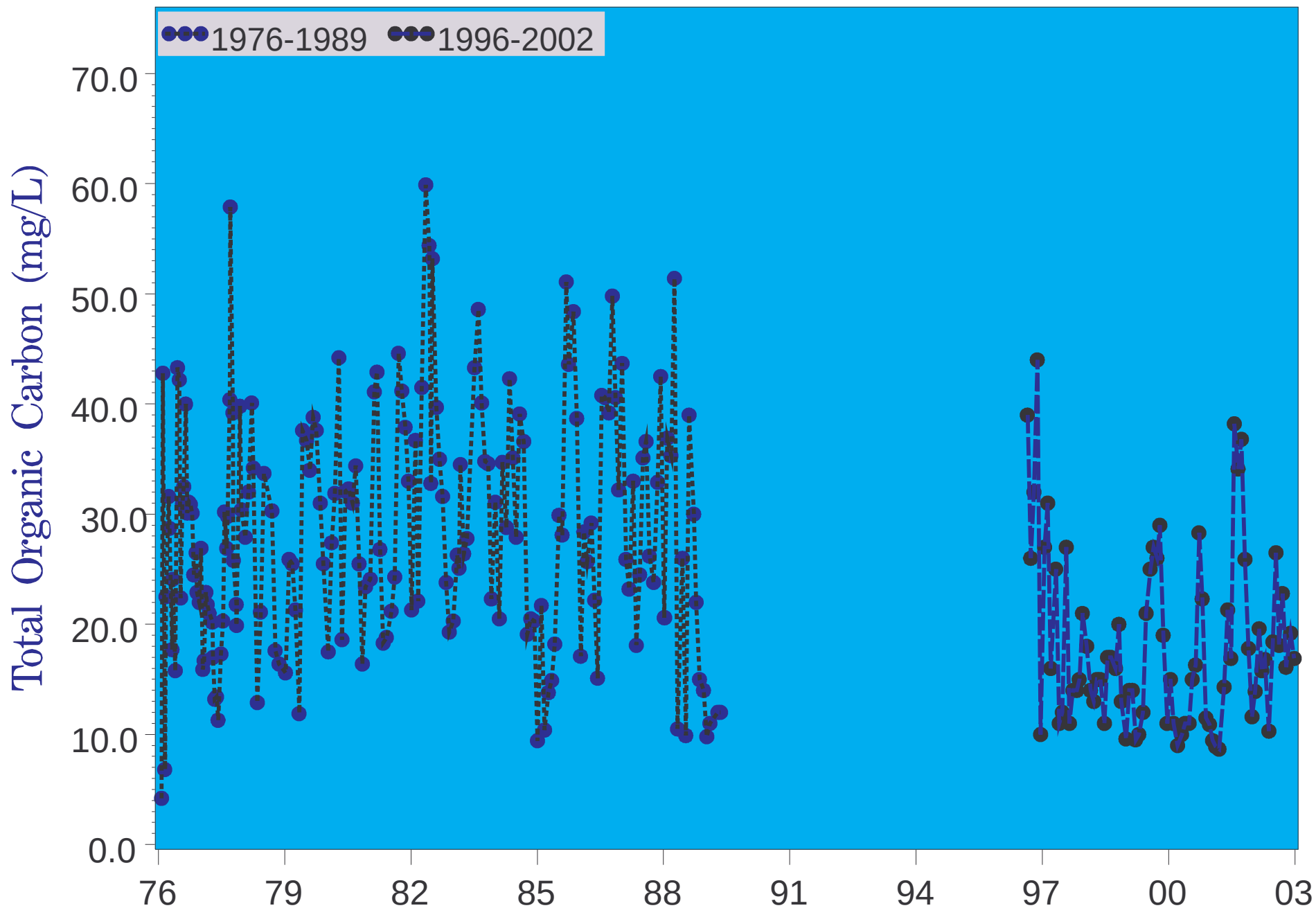


Figure 4.5.248 Long-term surface total organic carbon at river kilometer 30.4

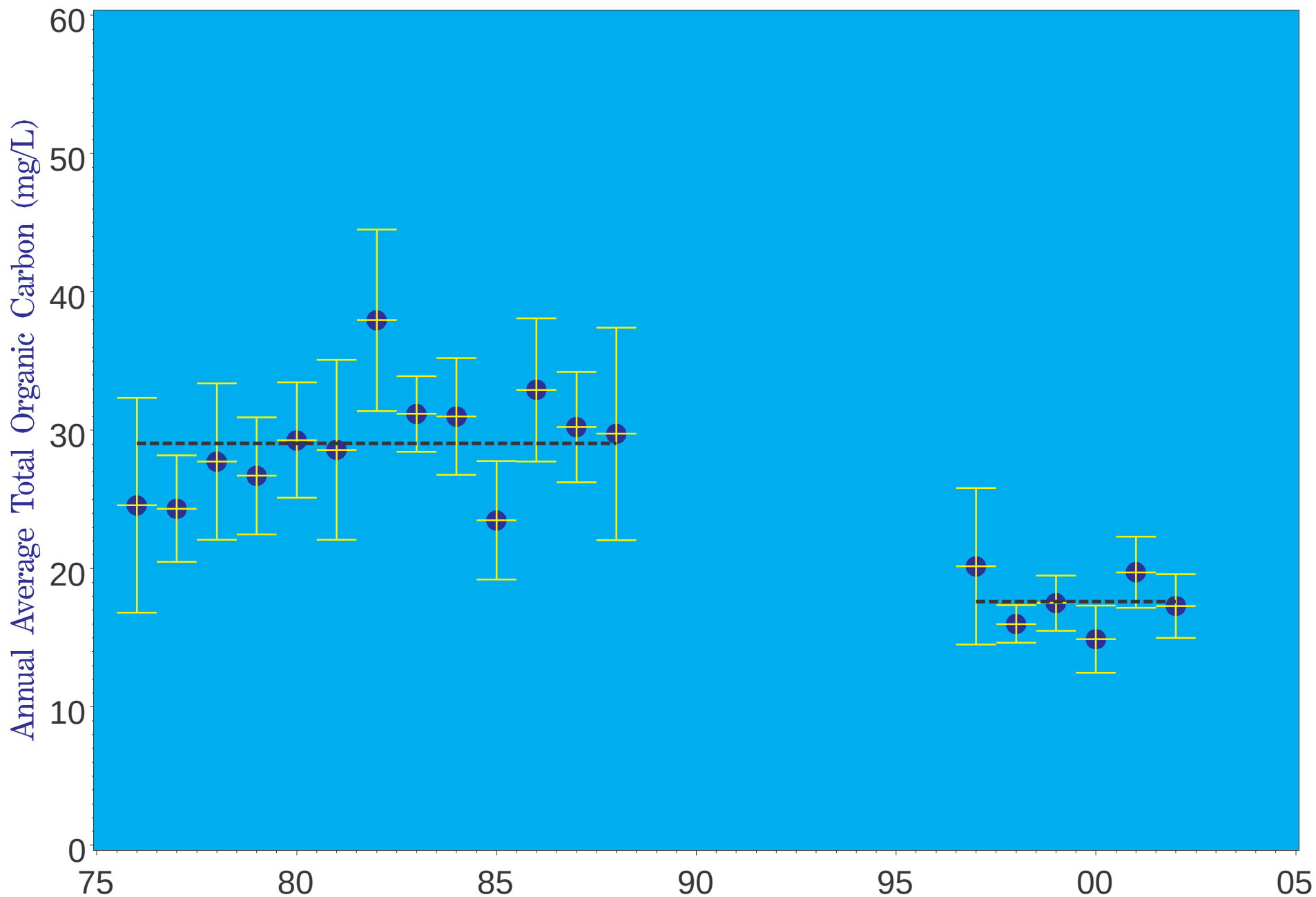


Figure 4.5.249 Long-term surface total organic carbon at river kilometer 30.4



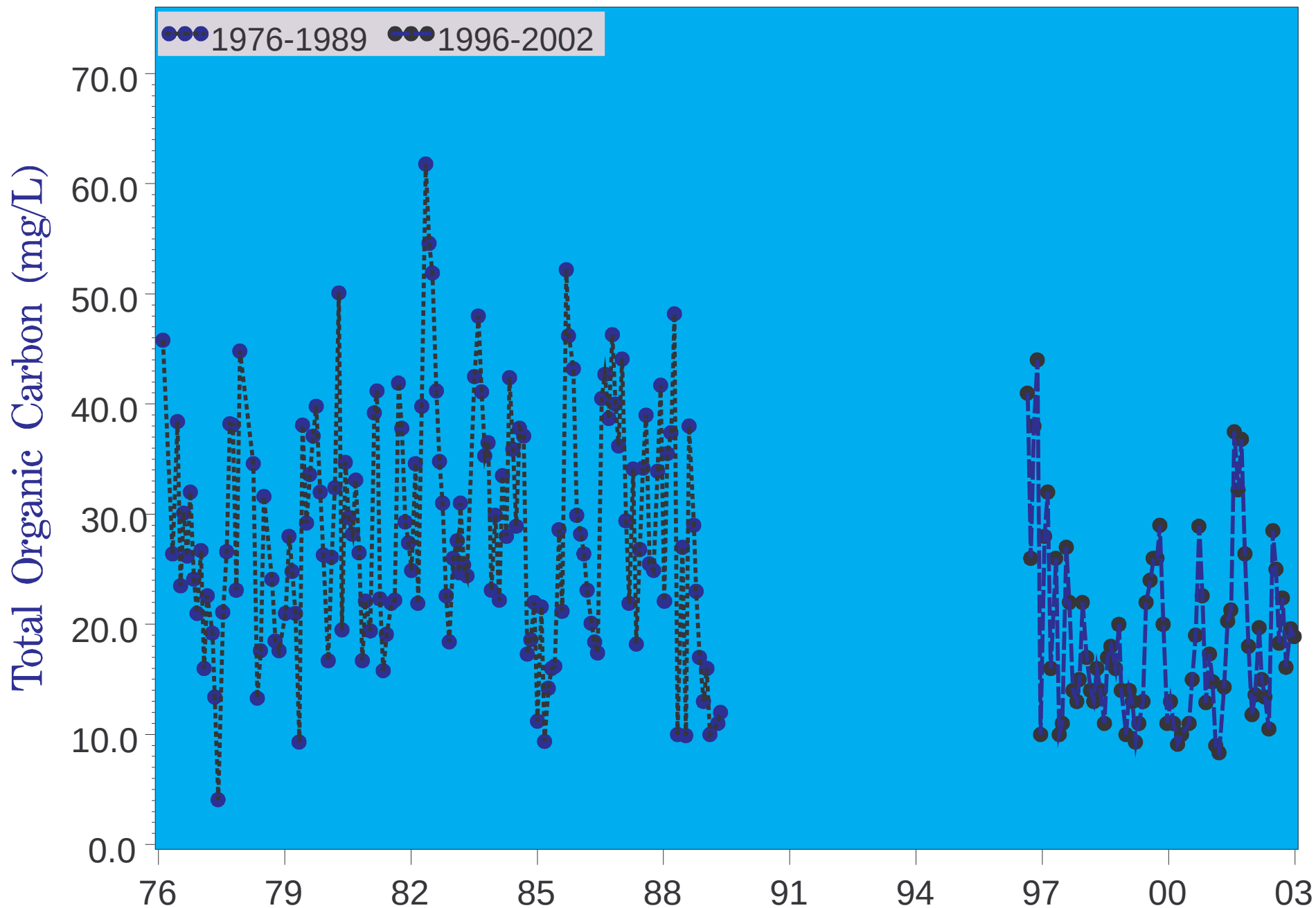


Figure 4.5.250 Long-term bottom total organic carbon at river kilometer 30.4

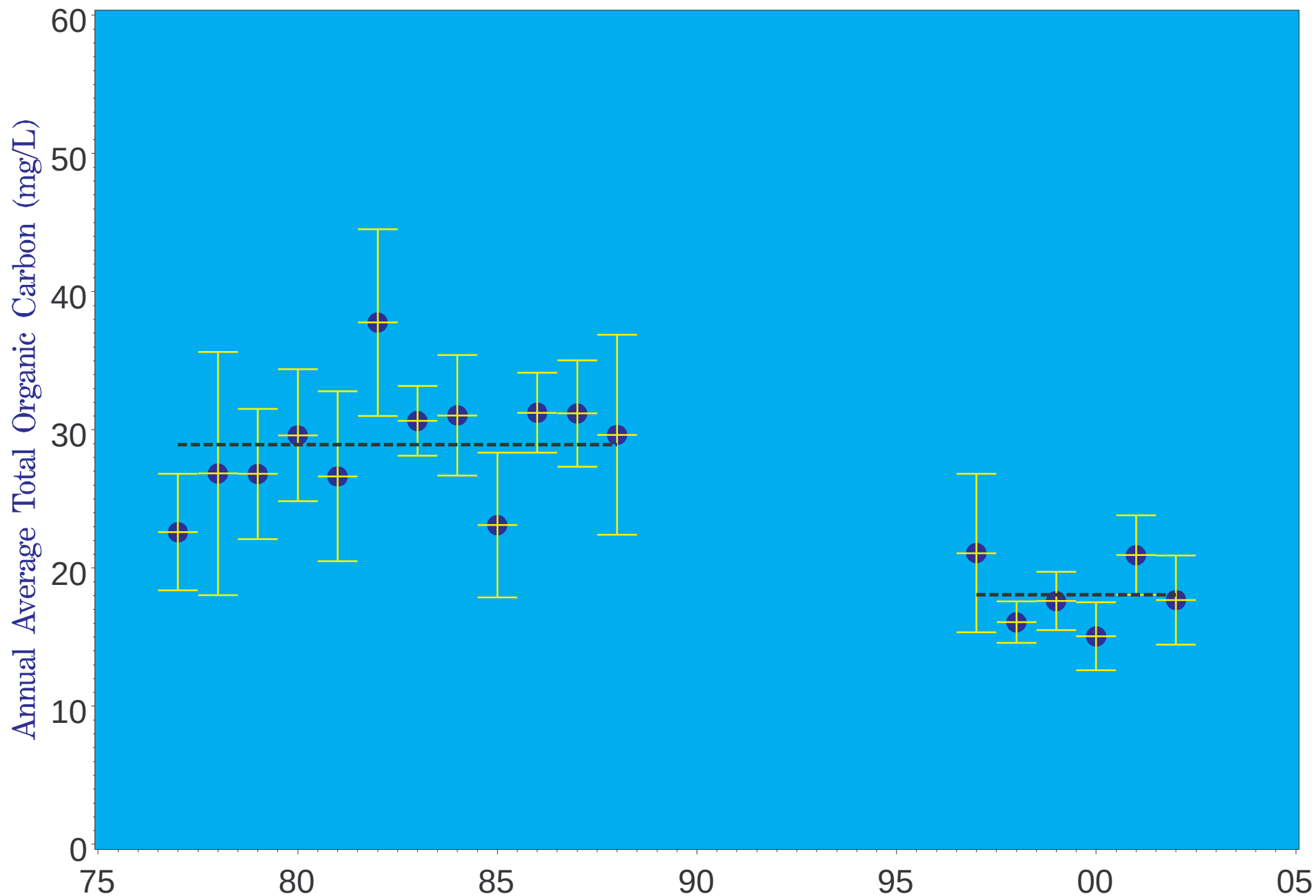


Figure 4.5.251 Long-term bottom total organic carbon at river kilometer 30.4

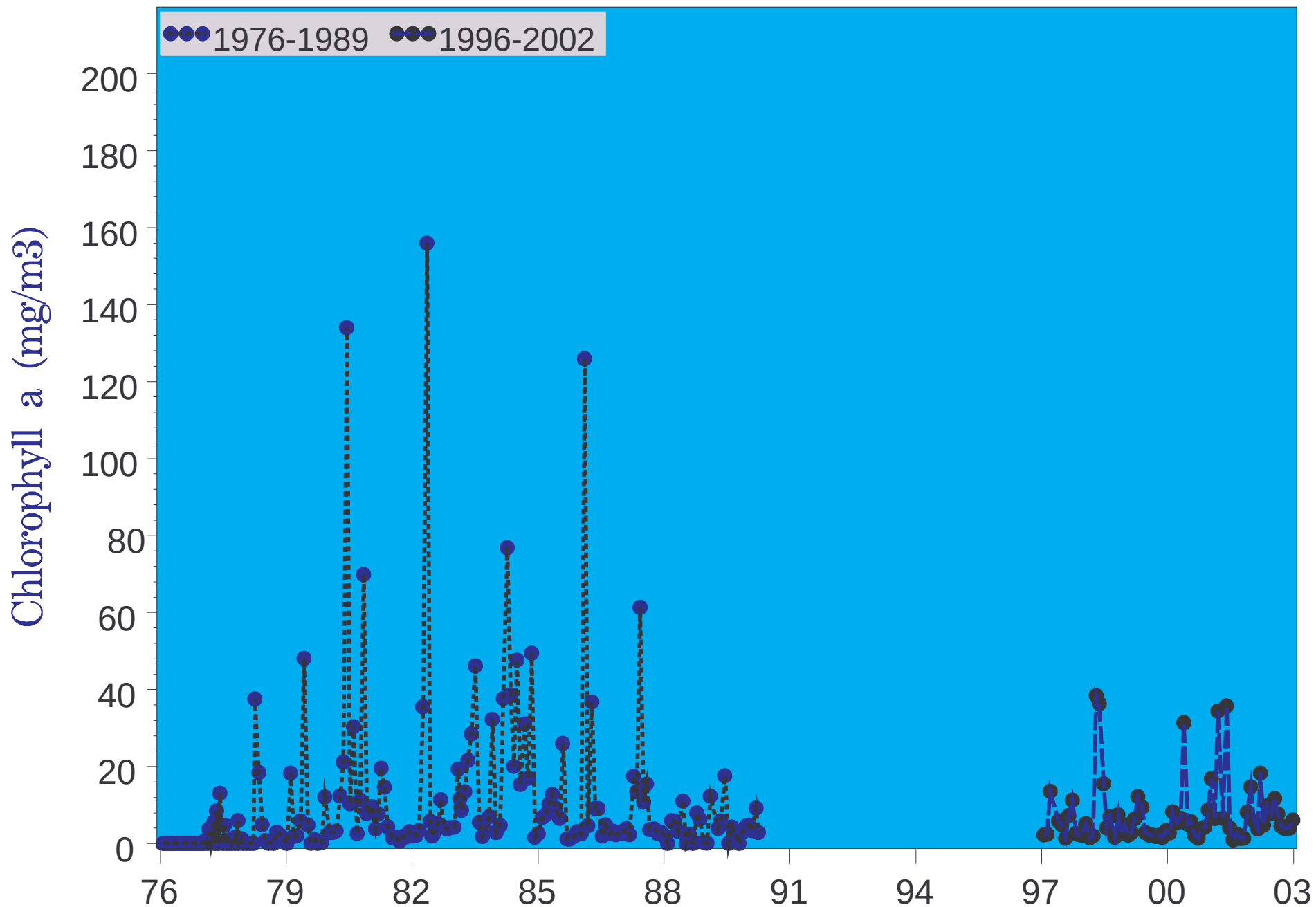


Figure 4.5.252 Long-term surface chlorophyll a at river kilometer 30.4

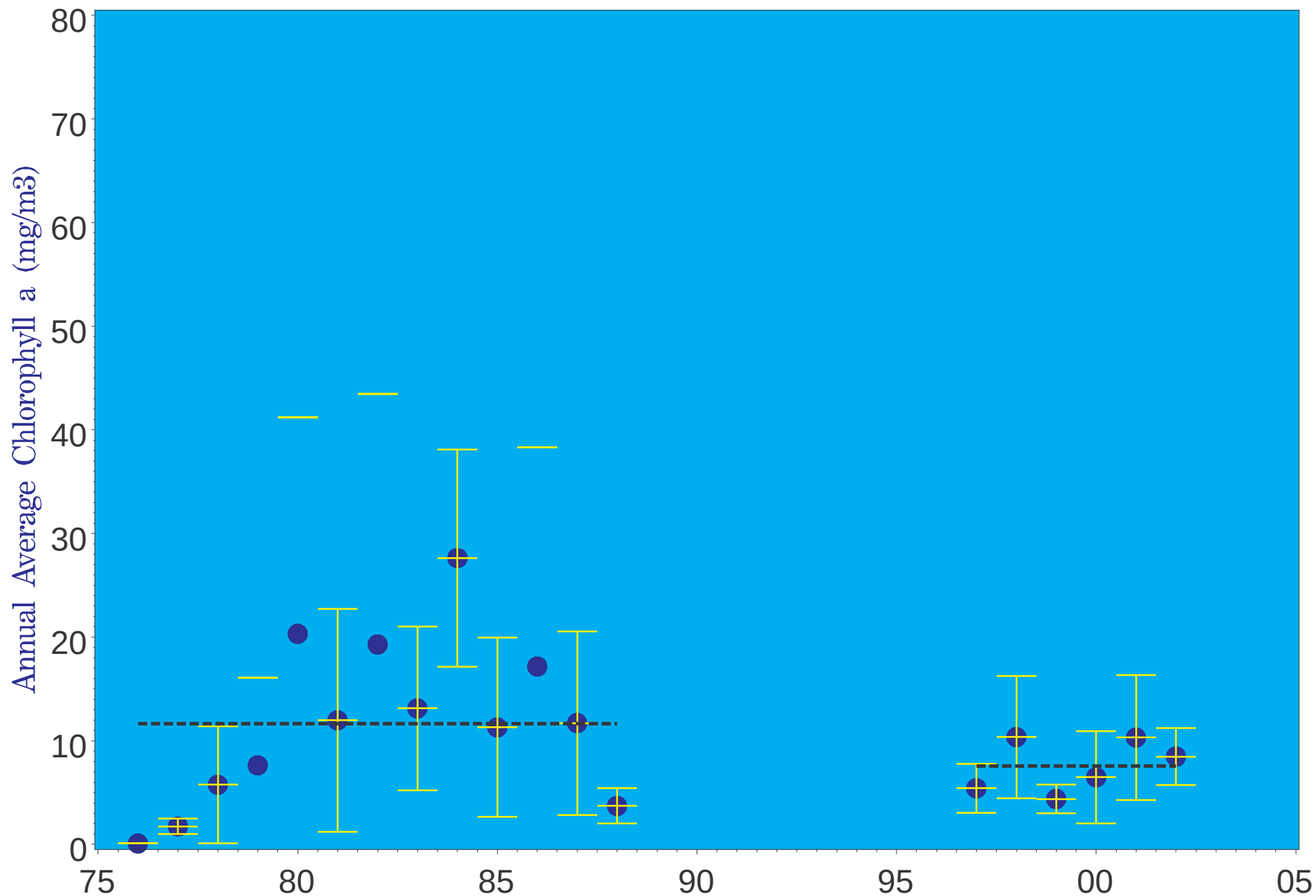


Figure 4.5.253 Long-term surface chlorophyll a at river kilometer 30.4

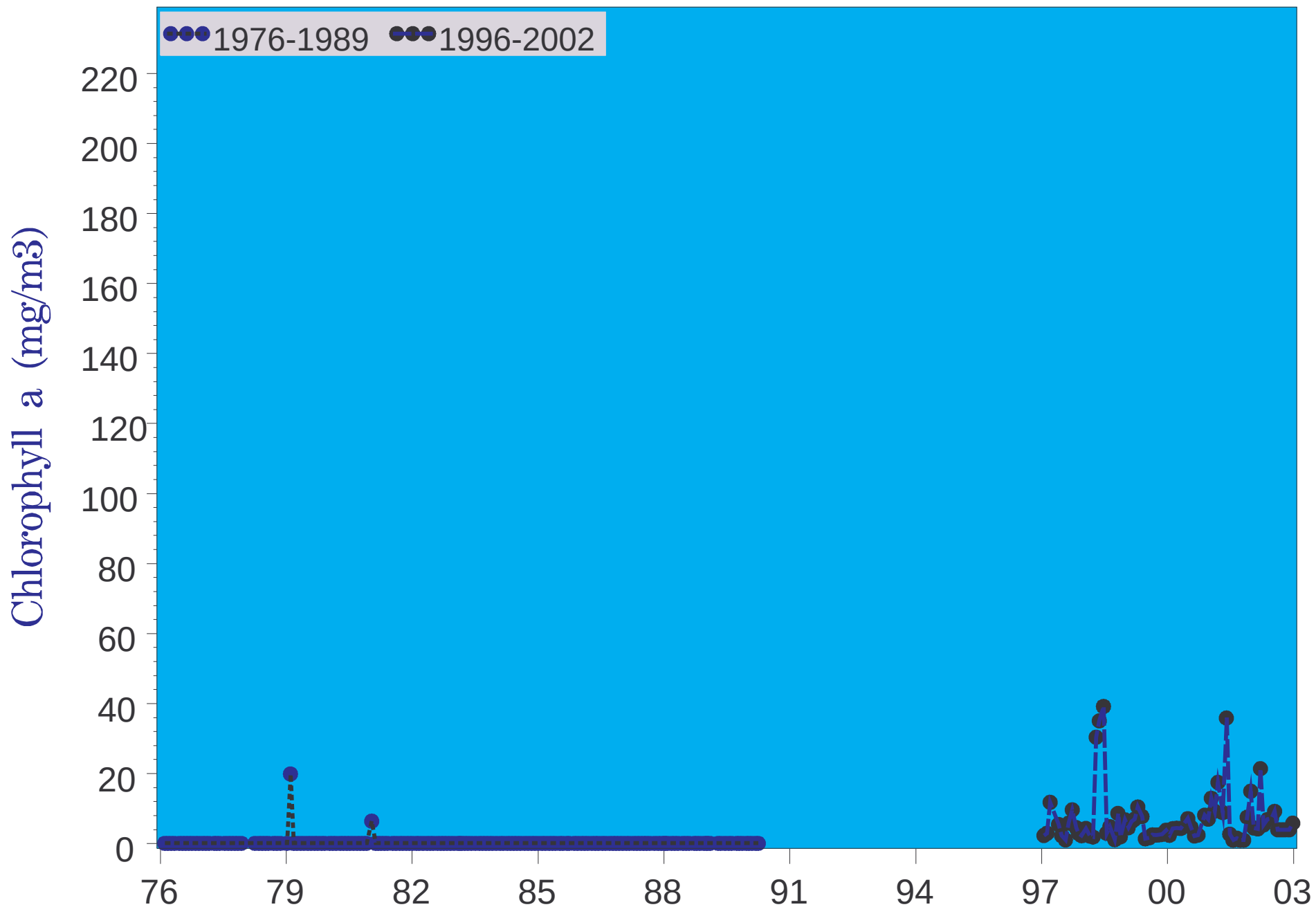


Figure 4.5.254 Long-term bottom chlorophyll a at river kilometer 30.4

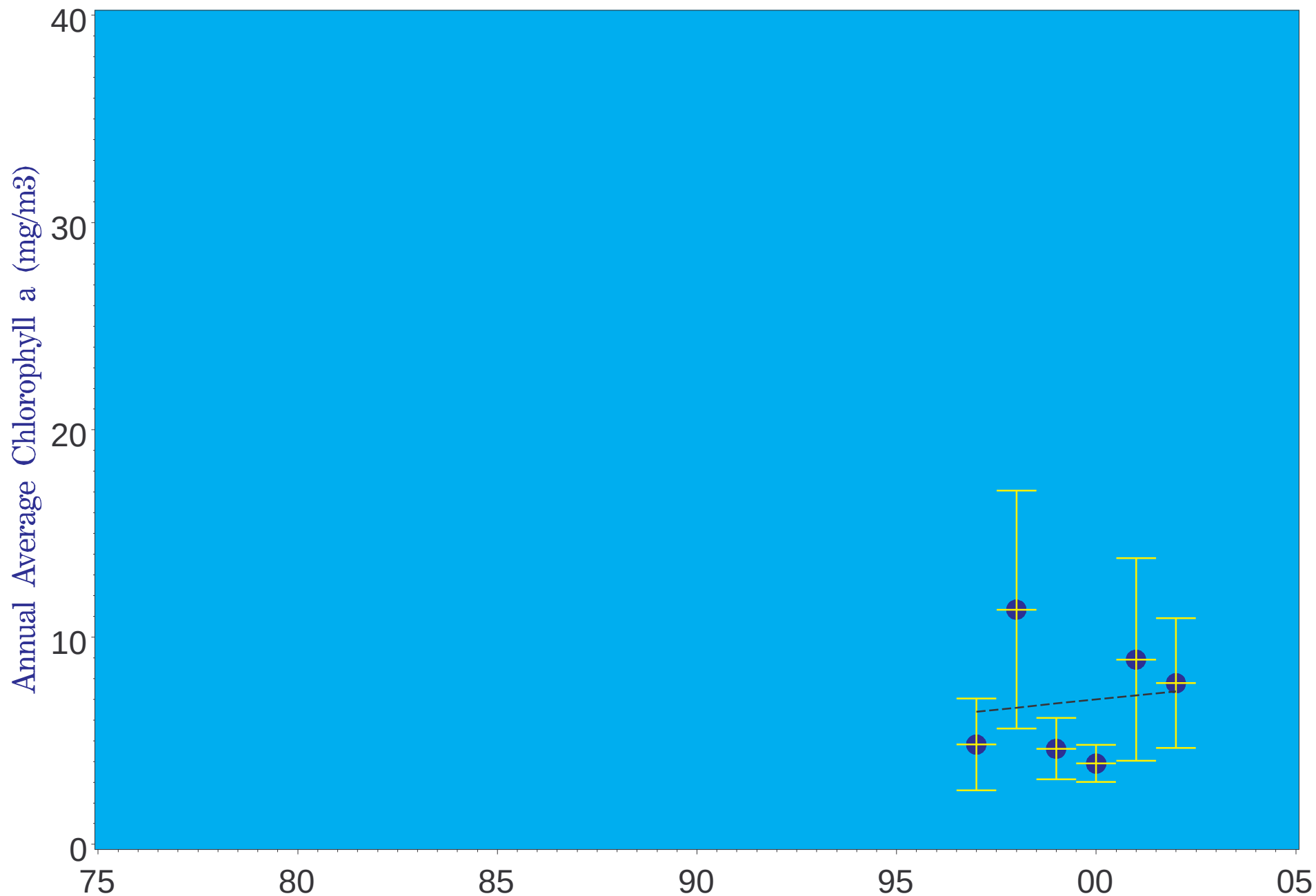


Figure 4.5.255 Long-term bottom chlorophyll a at river kilometer 30.4

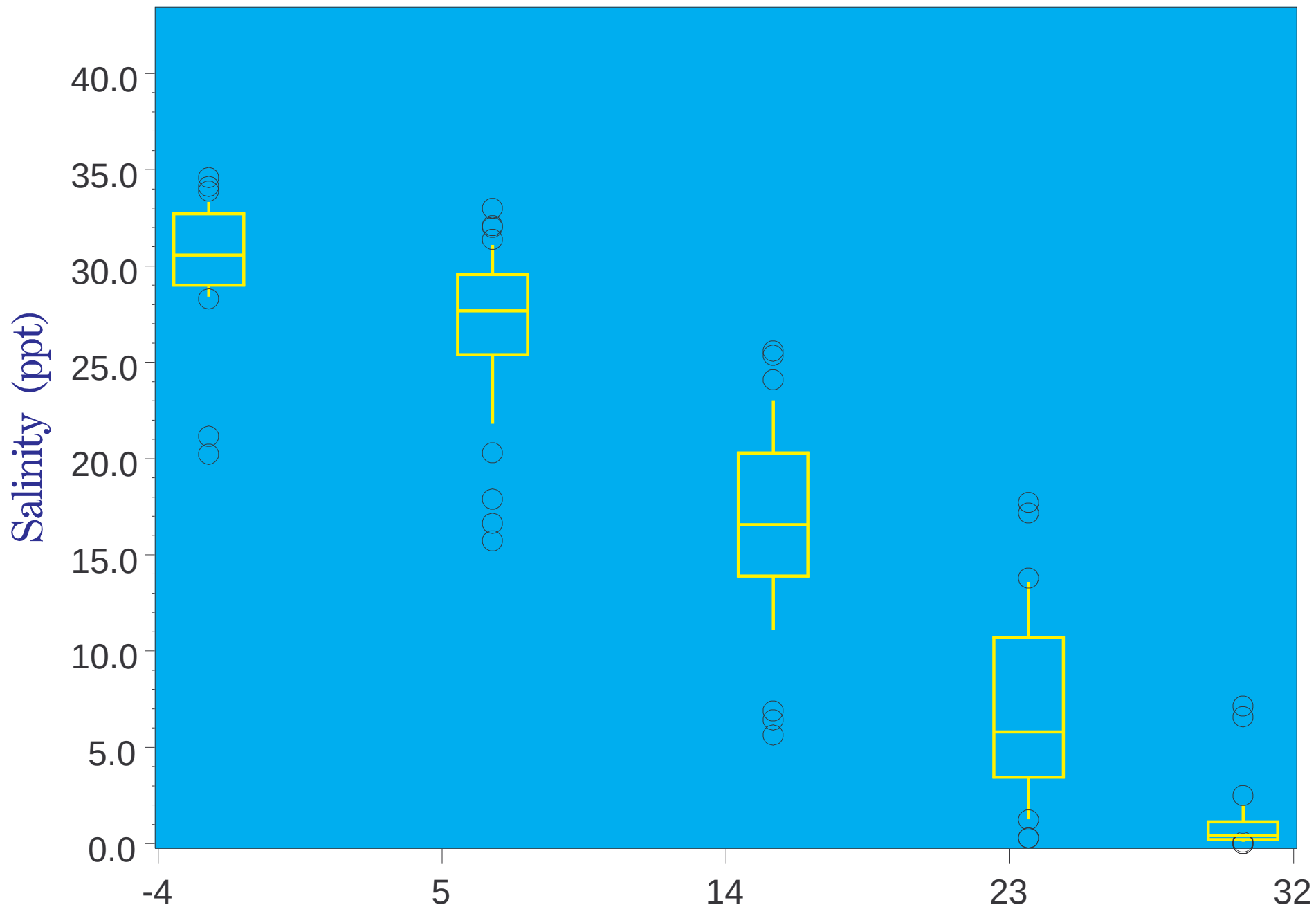


Figure 4.5.256 Box & whiskers of surface salinity by river kilometer (0 to 90 cfs)

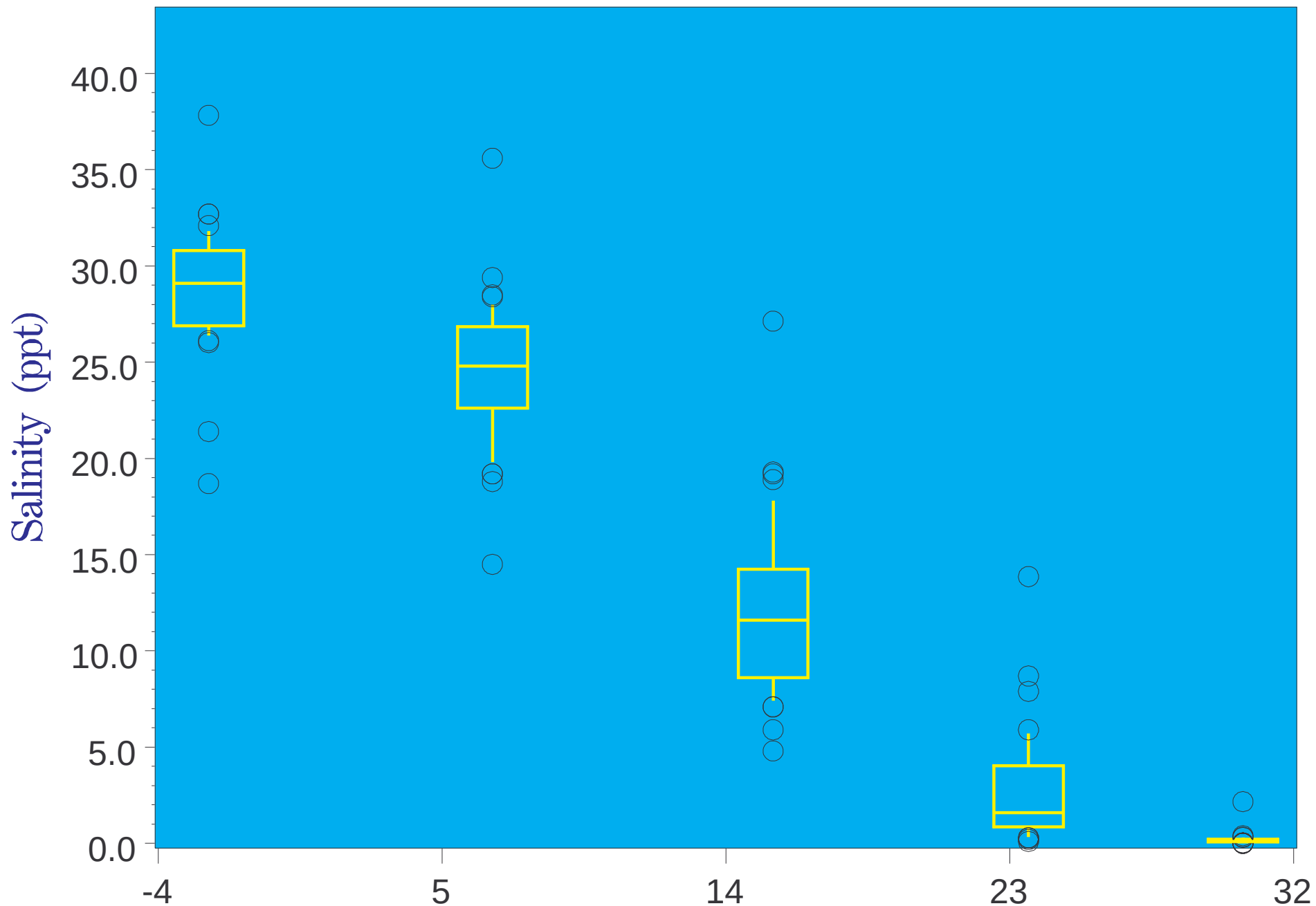


Figure 4.5.257 Box & whiskers of surface salinity by river kilometer (90 to 160 cfs)



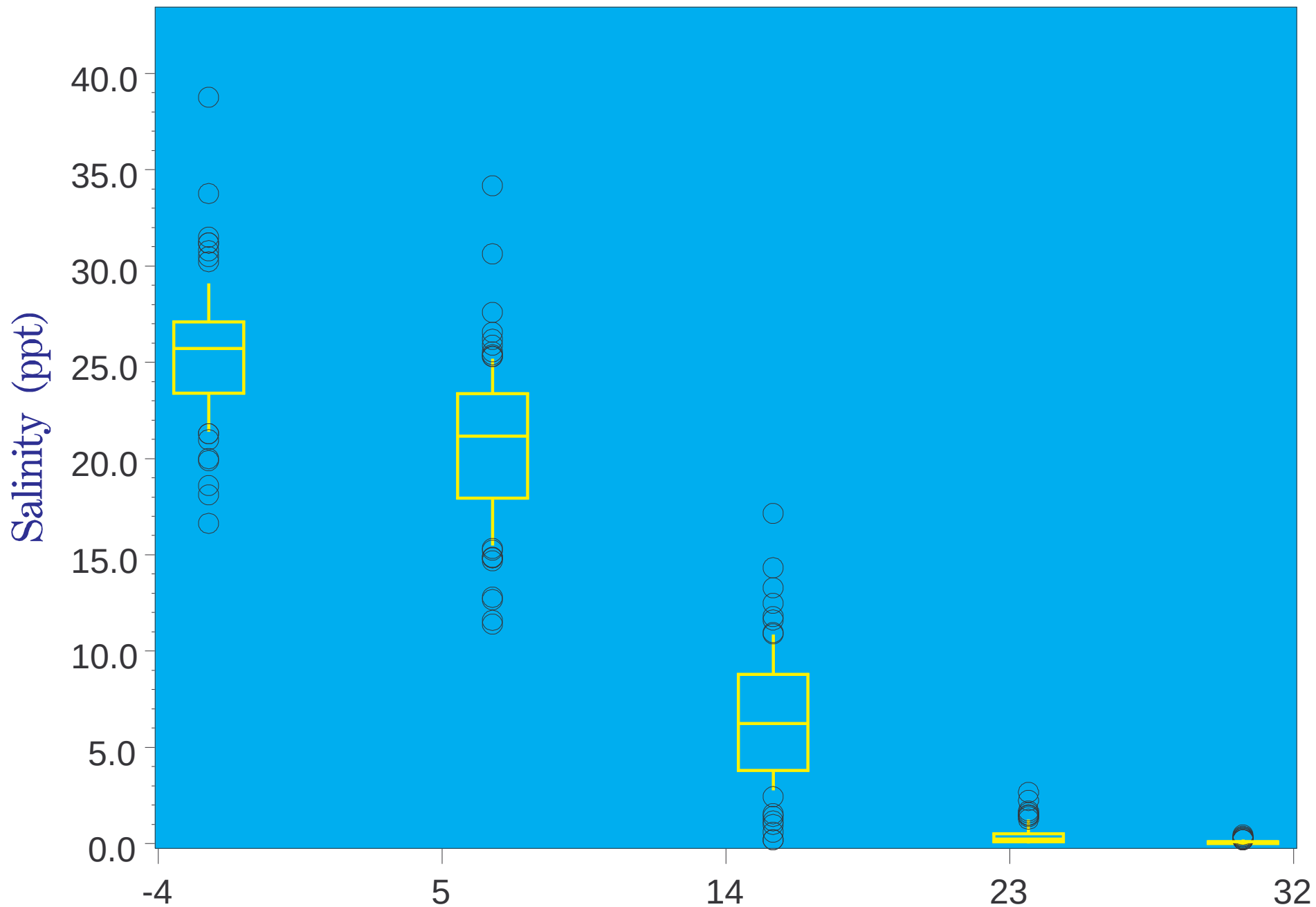


Figure 4.5.258 Box & whiskers of surface salinity by river kilometer (160 to 360 cfs)

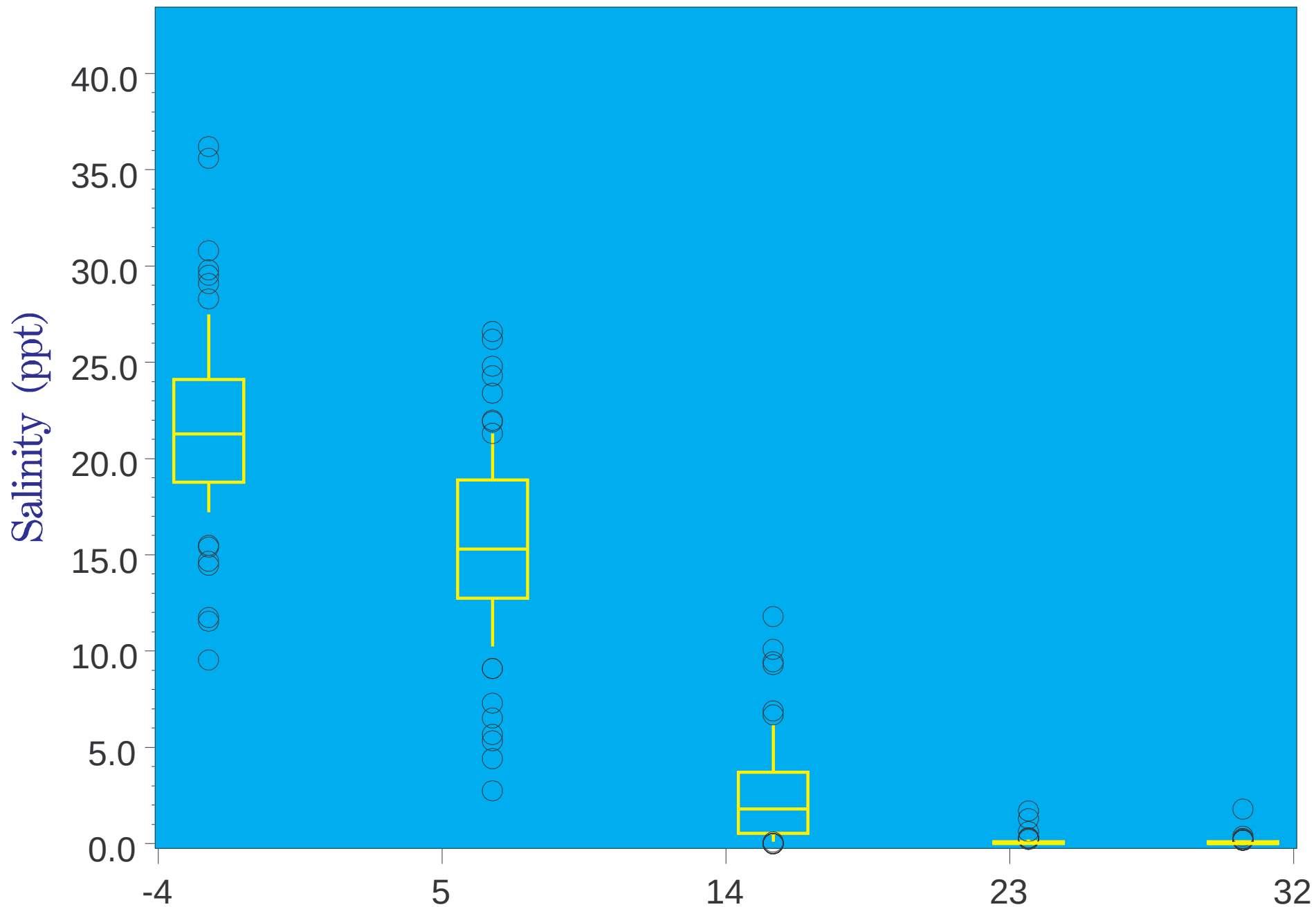


Figure 4.5.259 Box & whiskers of surface salinity by river kilometer (360 to 920 cfs)

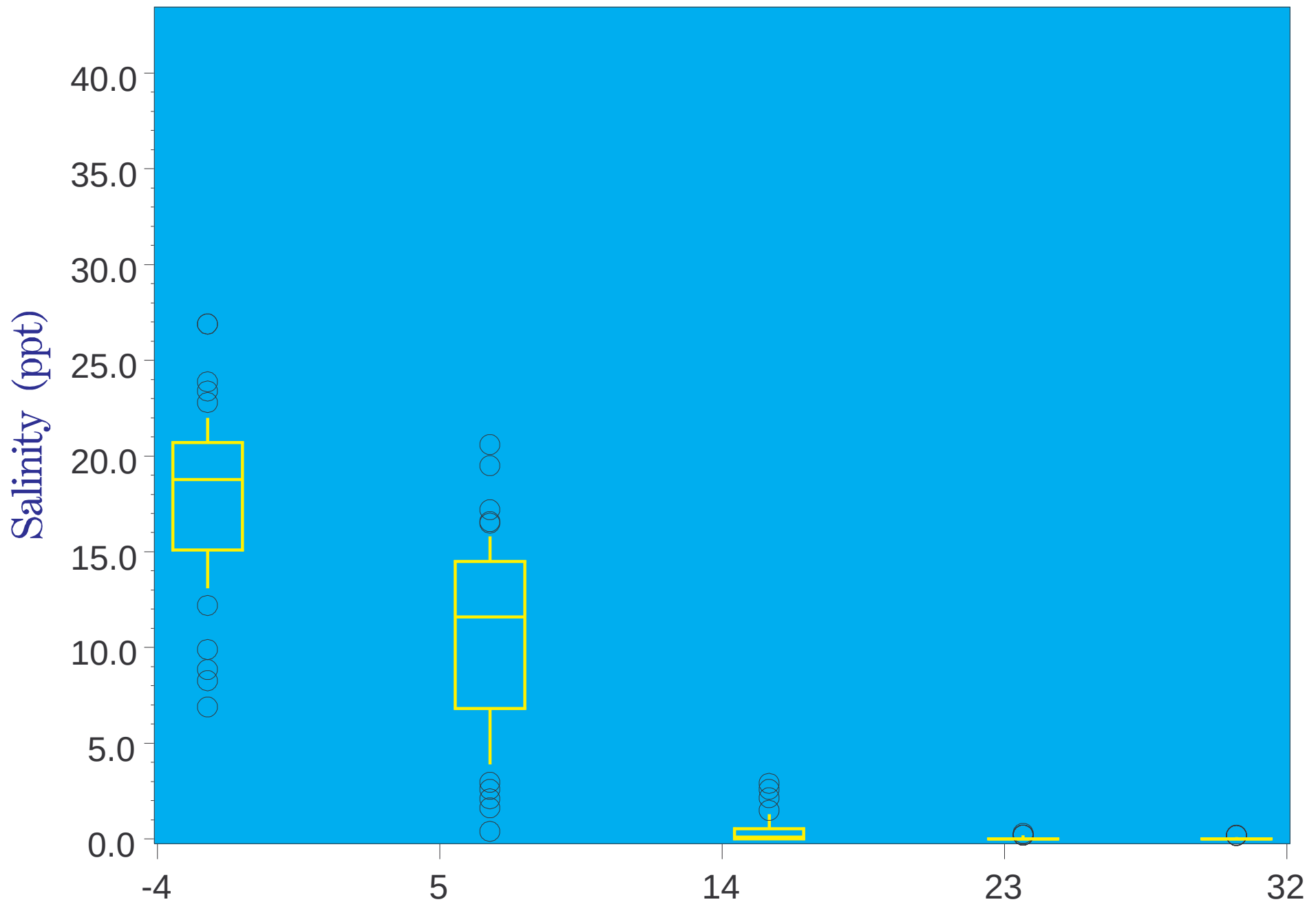


Figure 4.5.260 Box & whiskers of surface salinity by river kilometer (920 to 2100 cfs)

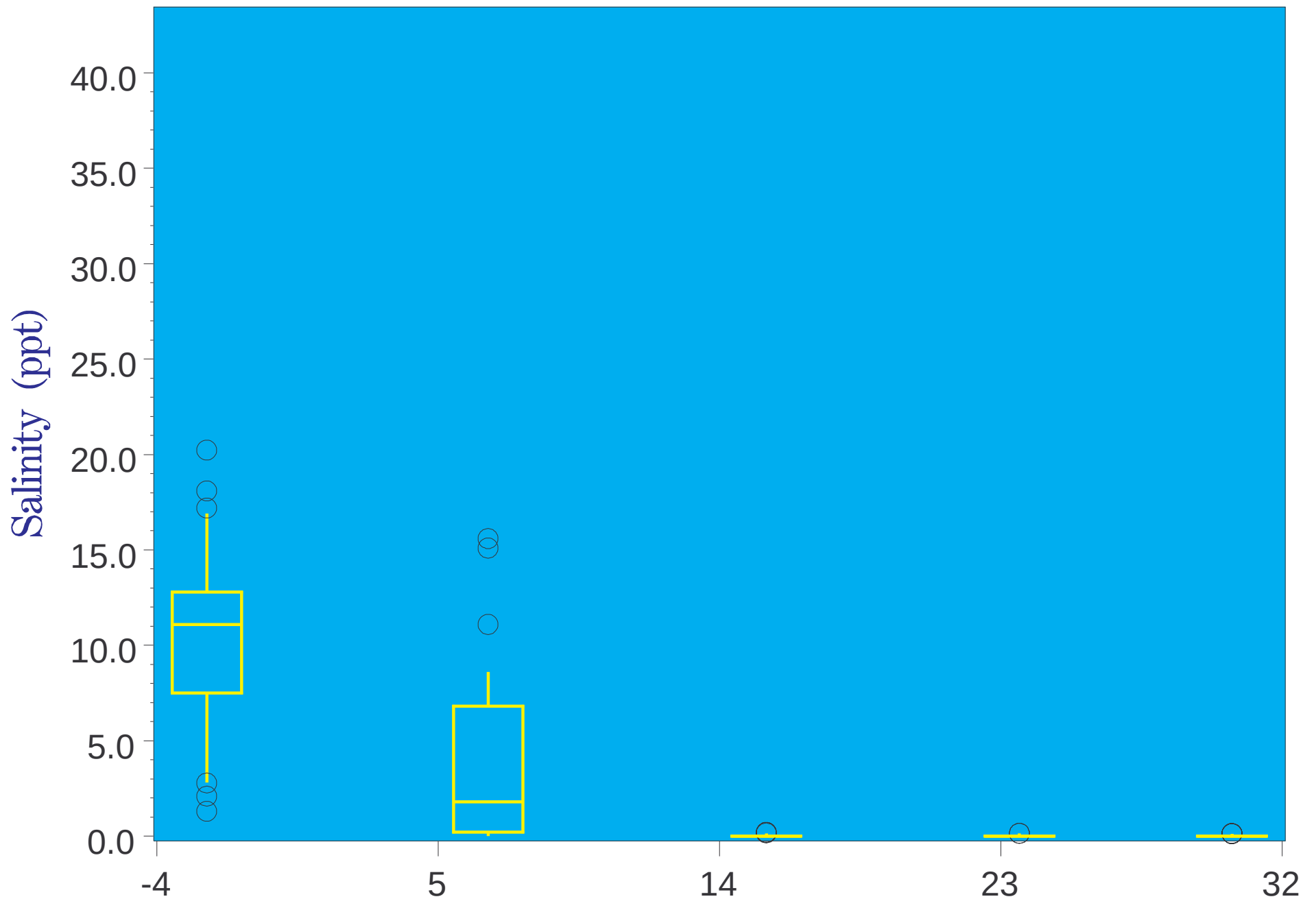


Figure 4.5.261 Box & whiskers of surface salinity by river kilometer (> 2100 cfs)

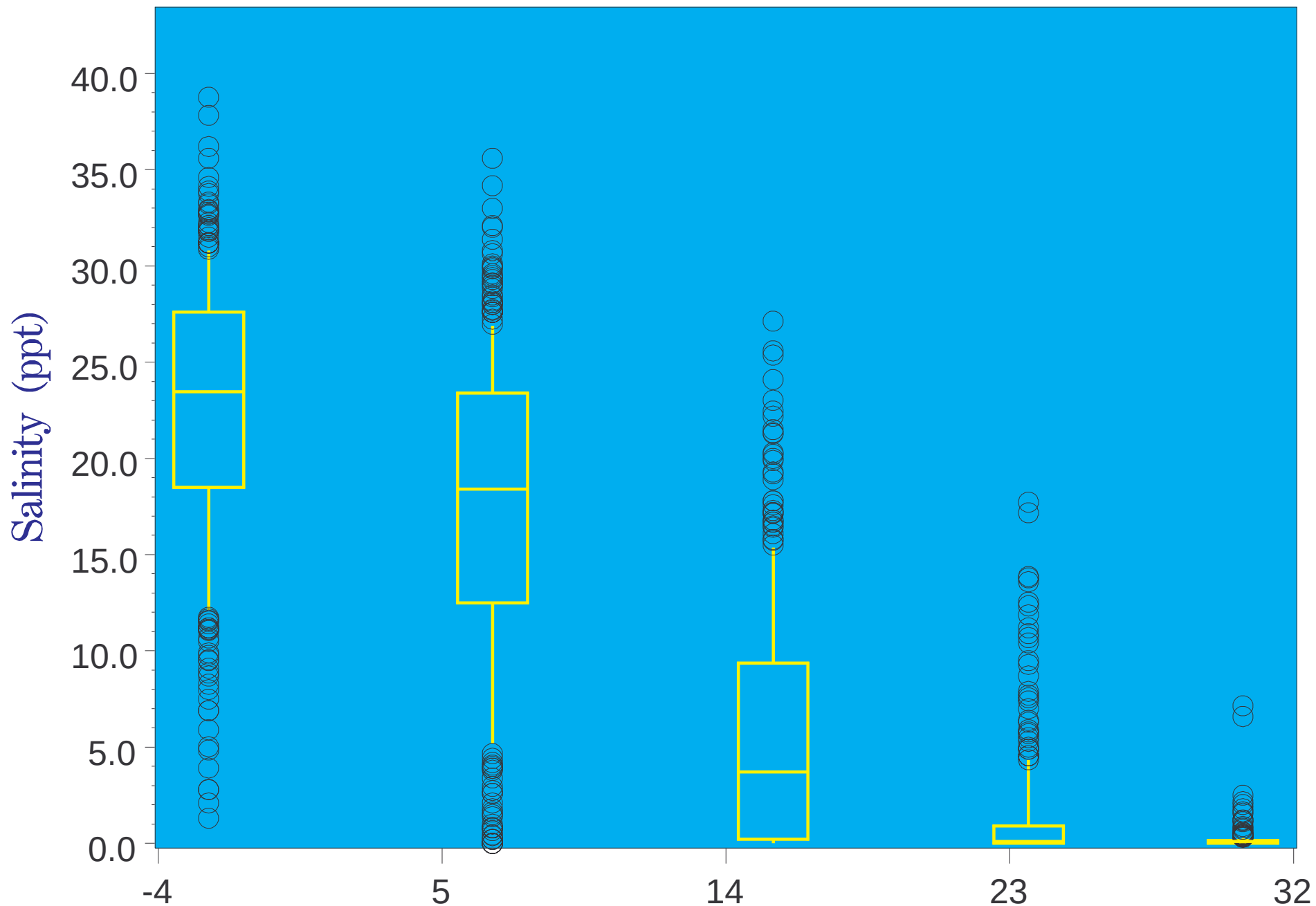


Figure 4.5.262 Box & whiskers of surface salinity by river kilometer (all flows)

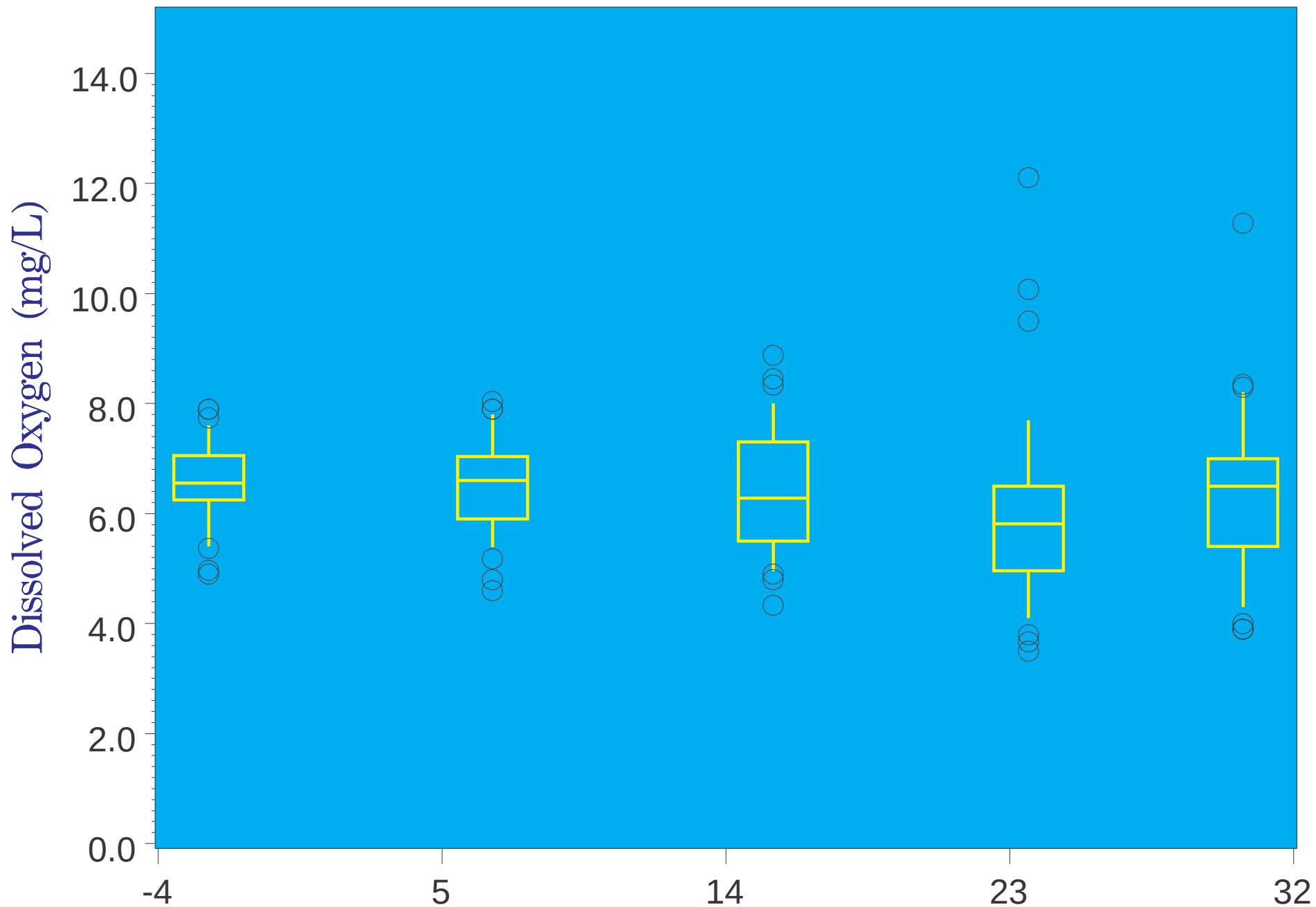


Figure 4.5.263 Box & whiskers of surface dissolved oxygen by river kilometer (0 to 90 cfs)

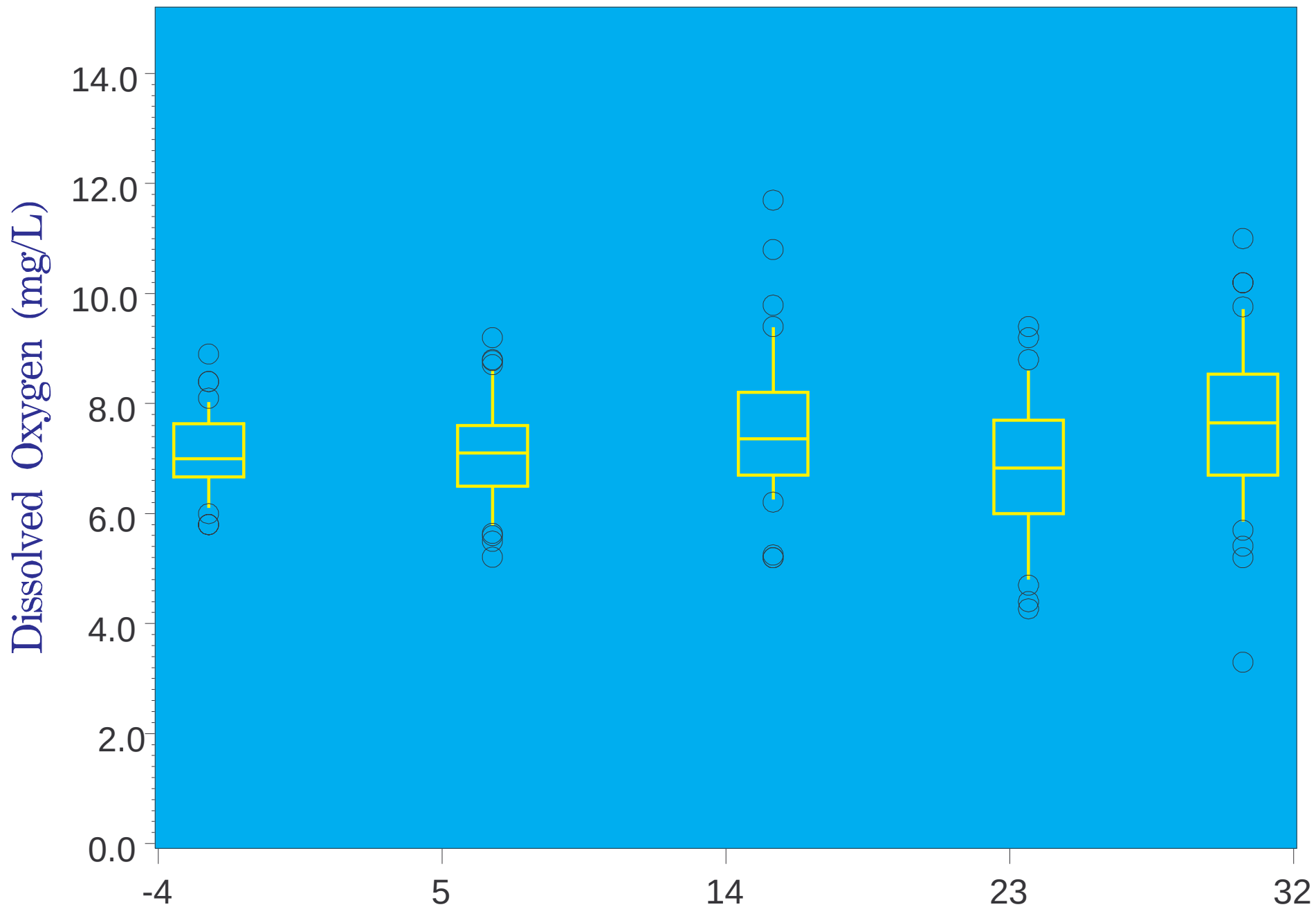


Figure 4.5.264 Box & whiskers of surface dissolved oxygen by river kilometer (90 to 160 cfs)

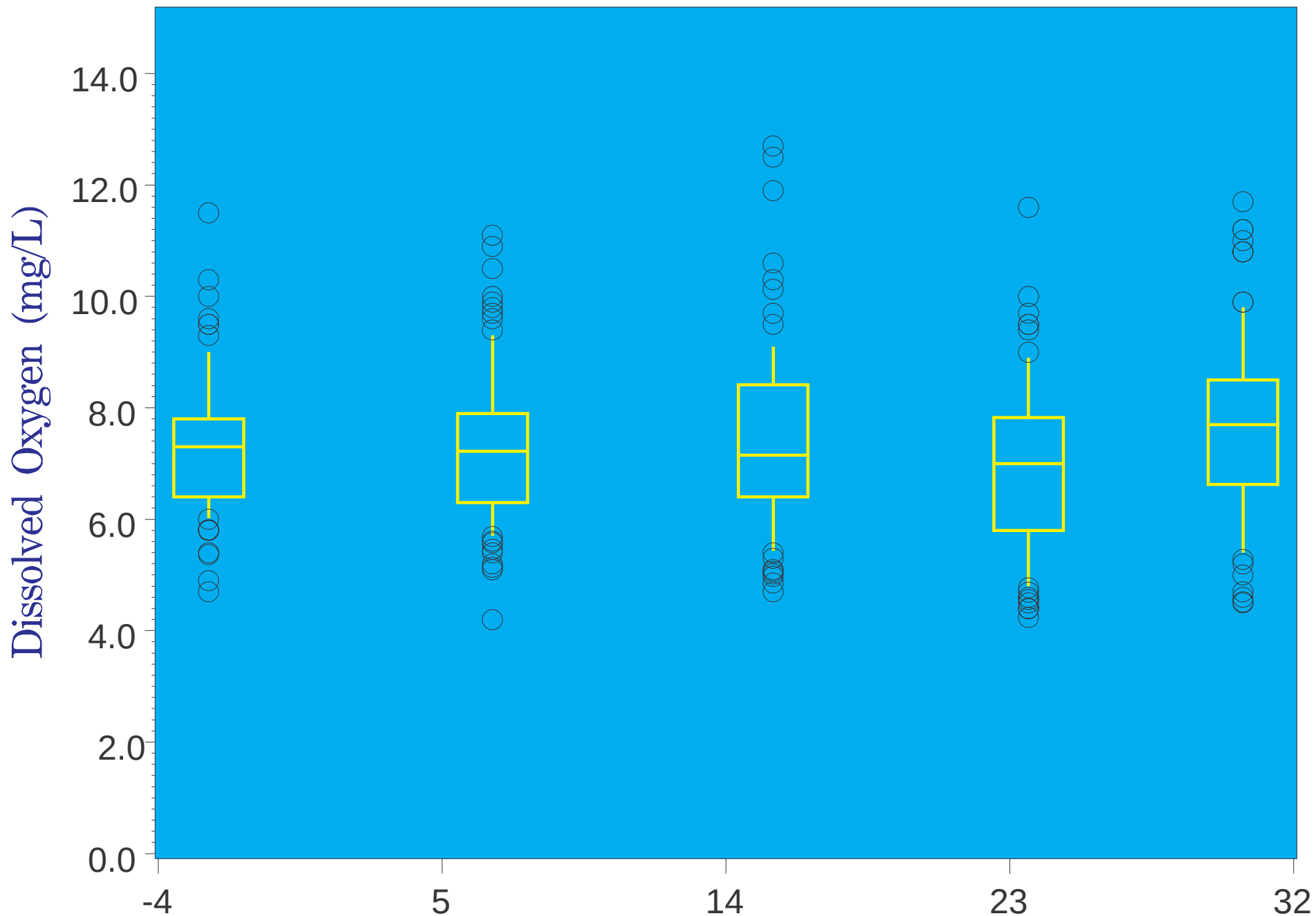


Figure 4.5.265 Box & whiskers of surface dissolved oxygen by river kilometer (160 to 360 cfs)



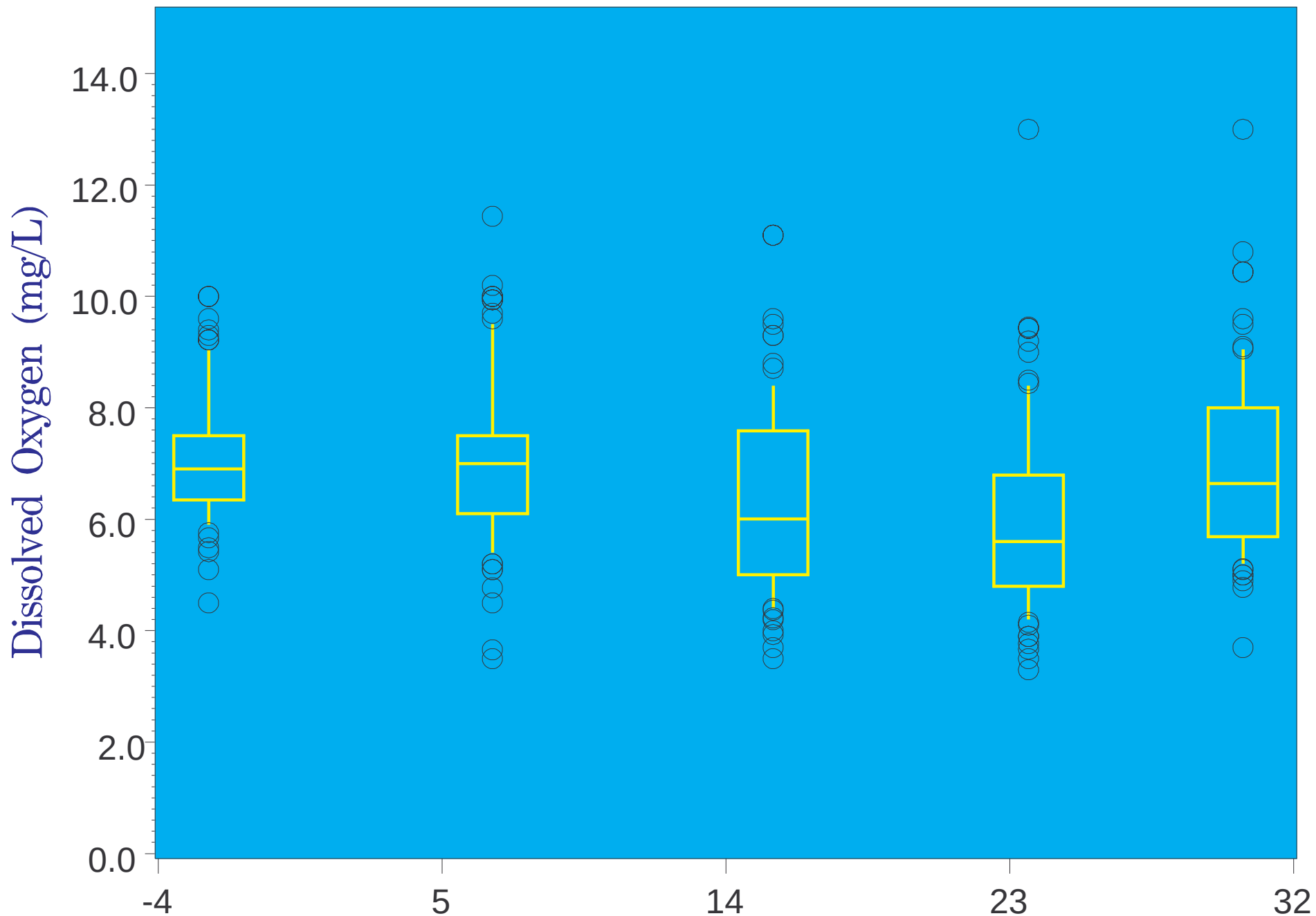


Figure 4.5.266 Box & whiskers of surface dissolved oxygen by river kilometer (360 to 920 cfs)

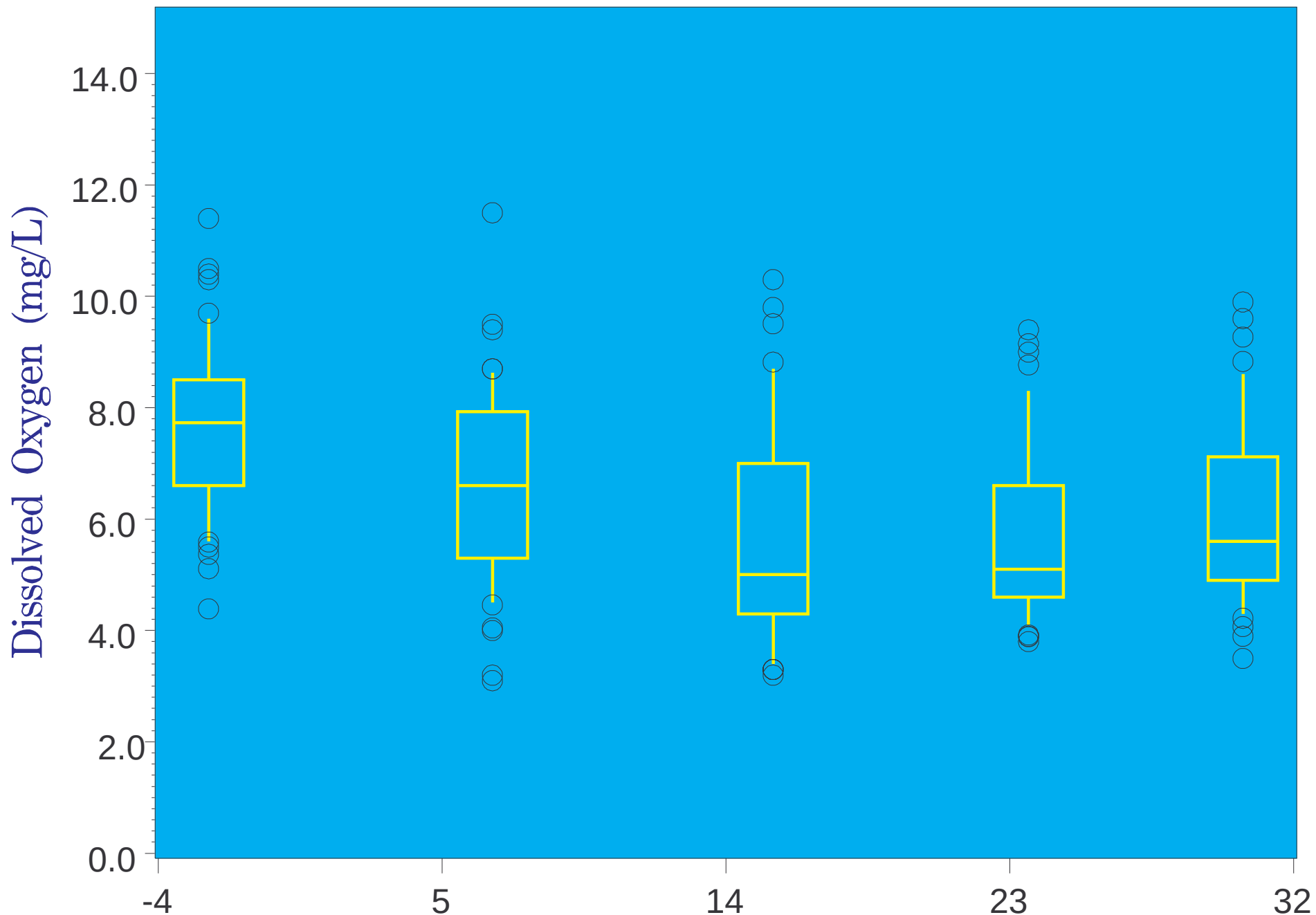


Figure 4.5.267 Box & whiskers of surface dissolved oxygen by river kilometer (920 to 2100 cfs)

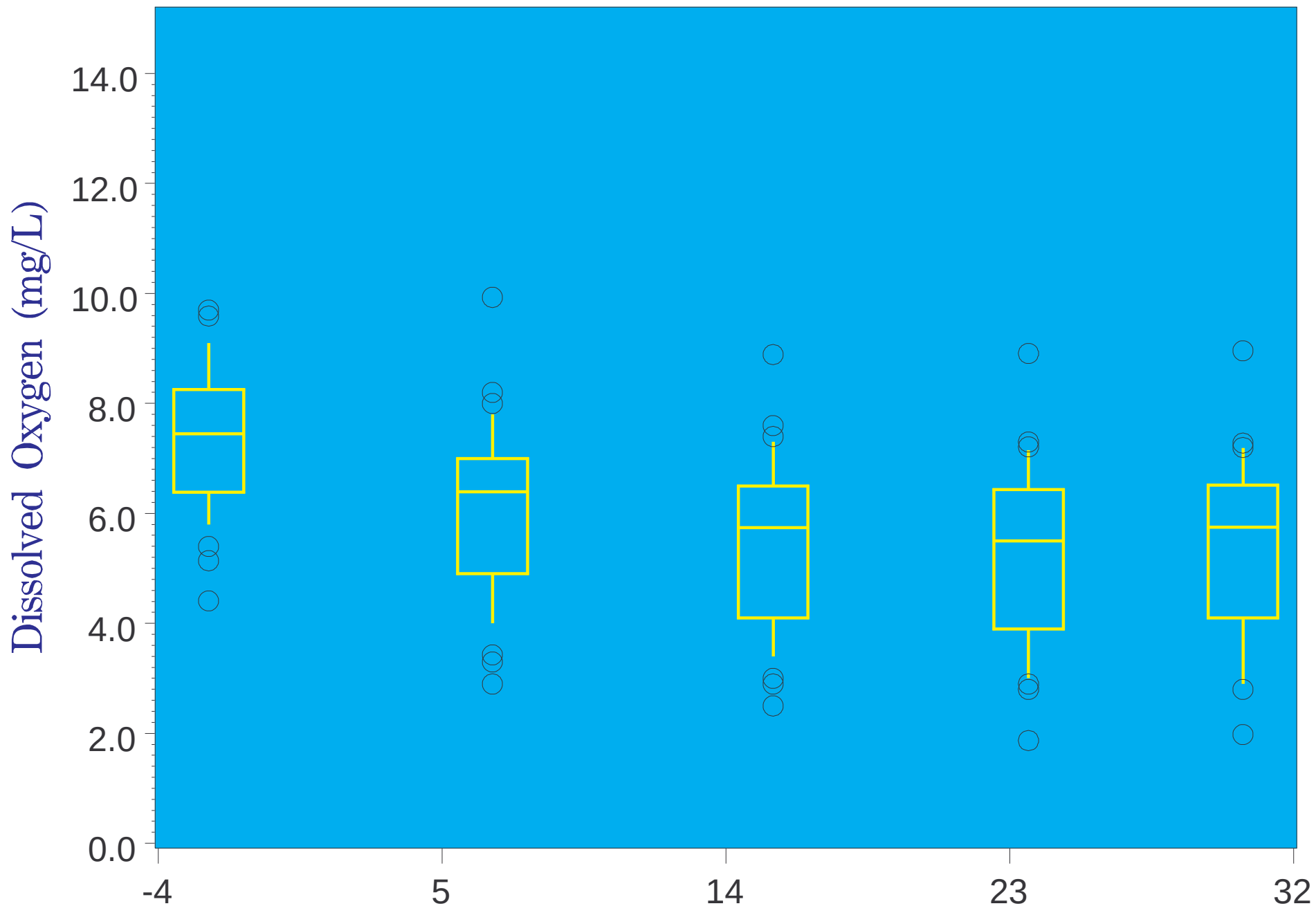


Figure 4.5.268 Box & whiskers of surface dissolved oxygen by river kilometer (> 2100 cfs)

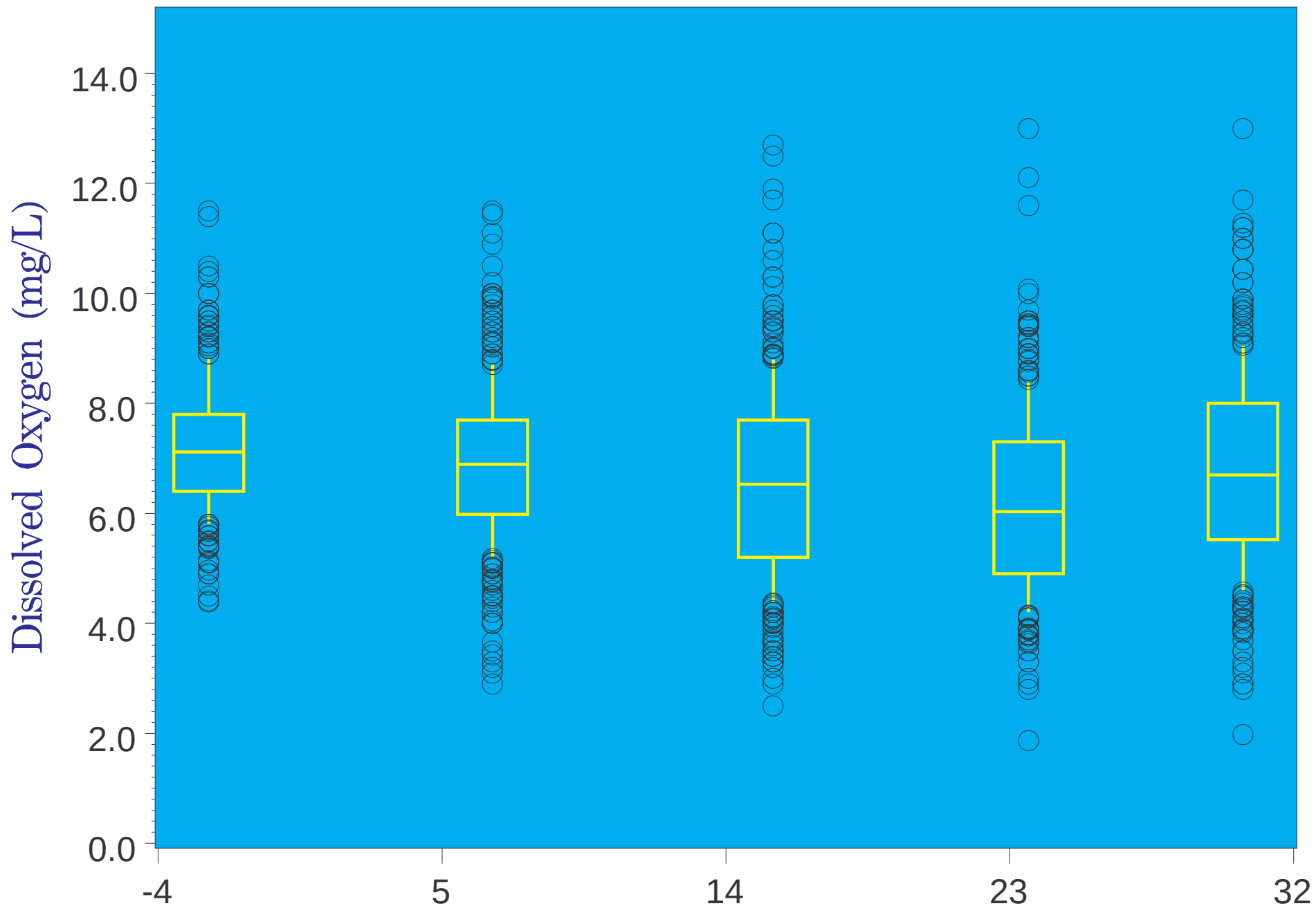


Figure 4.5.269 Box & whiskers of surface dissolved oxygen by river kilometer (all flows)

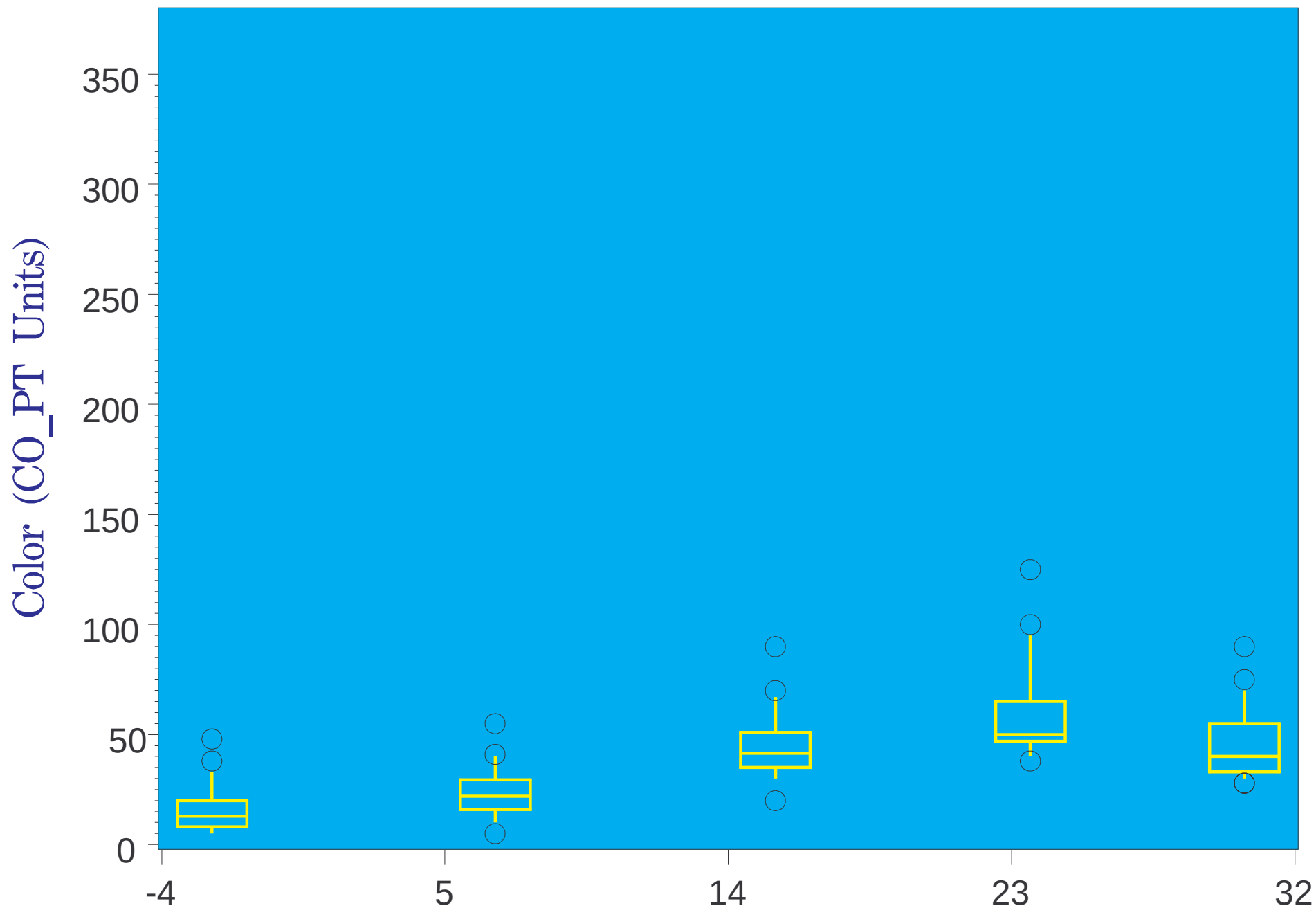


Figure 4.5.270 Box & whiskers of surface color by river kilometer (0 to 90 cfs)

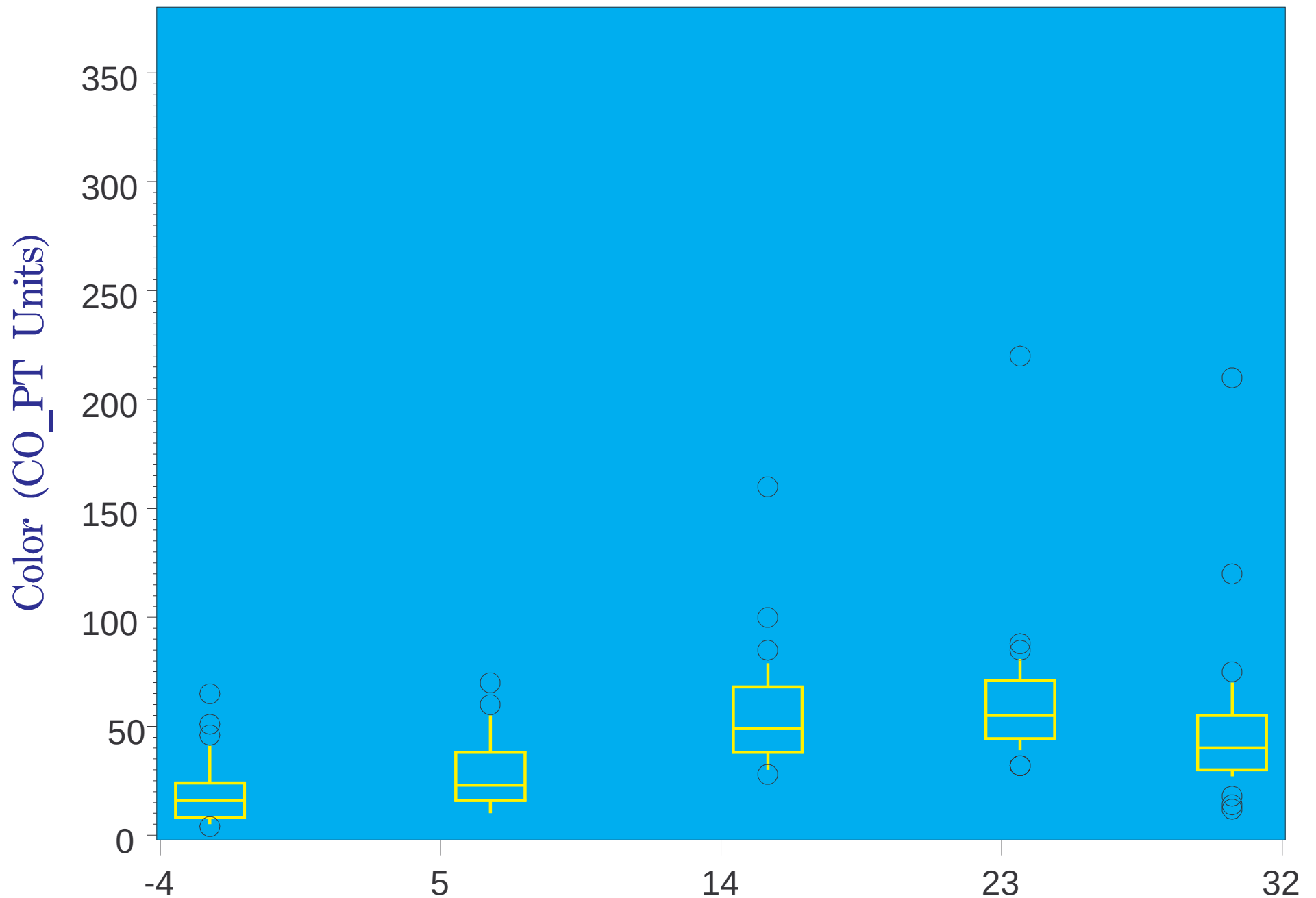


Figure 4.5.271 Box & whiskers of surface color by river kilometer (90 to 160 cfs)

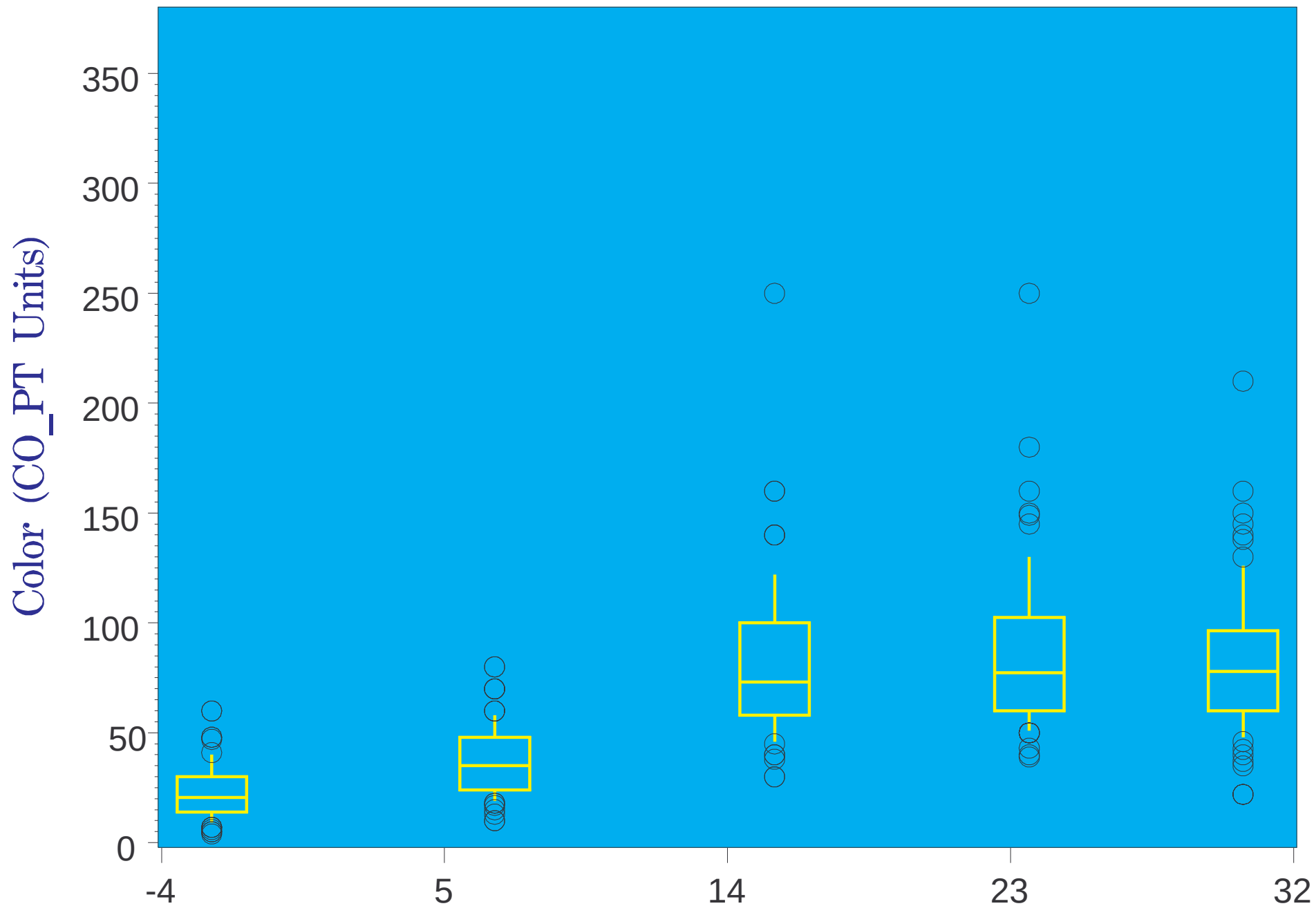


Figure 4.5.272 Box & whiskers of surface color by river kilometer (160 to 360 cfs)

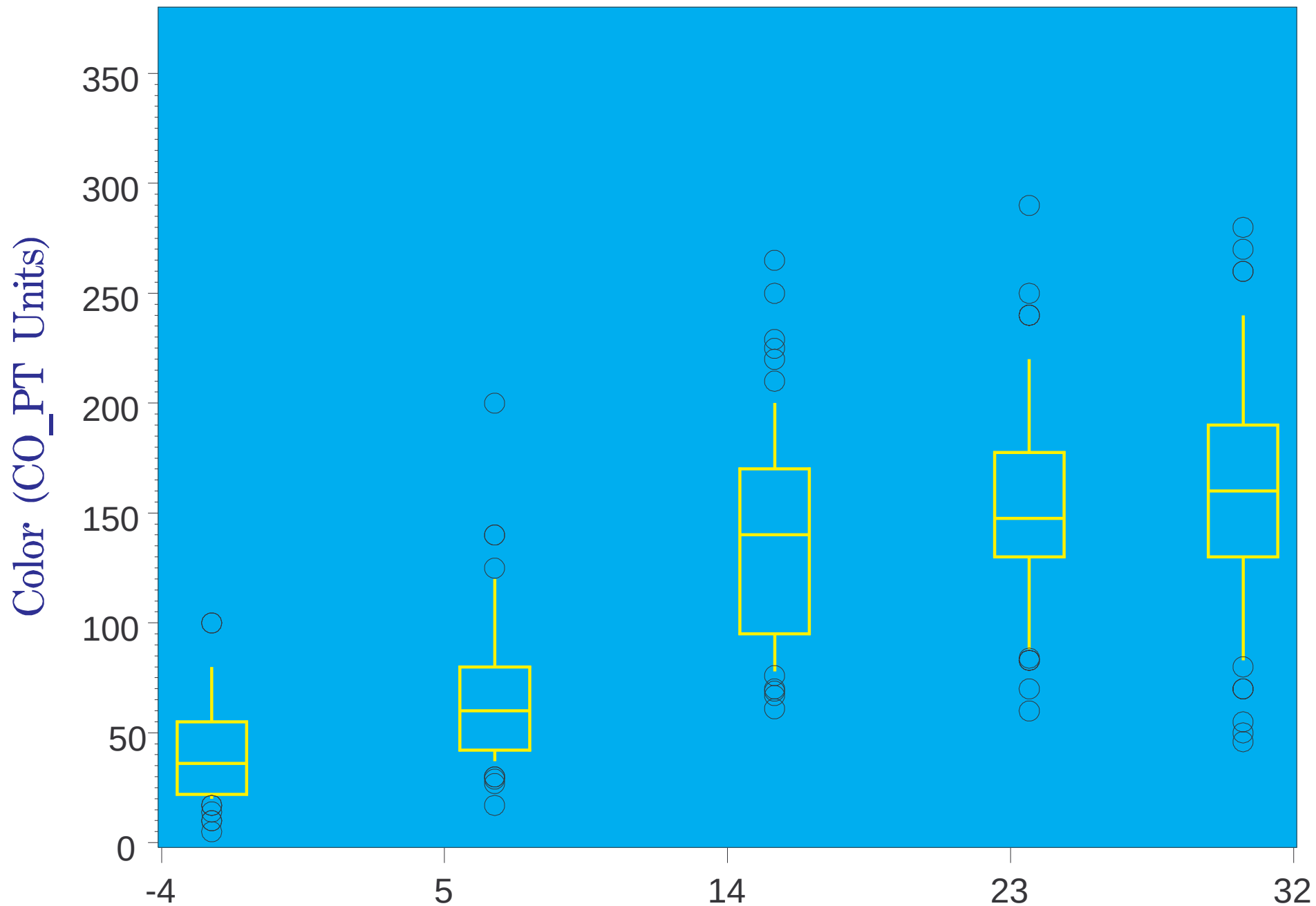


Figure 4.5.273 Box & whiskers of surface color by river kilometer (360 to 920 cfs)



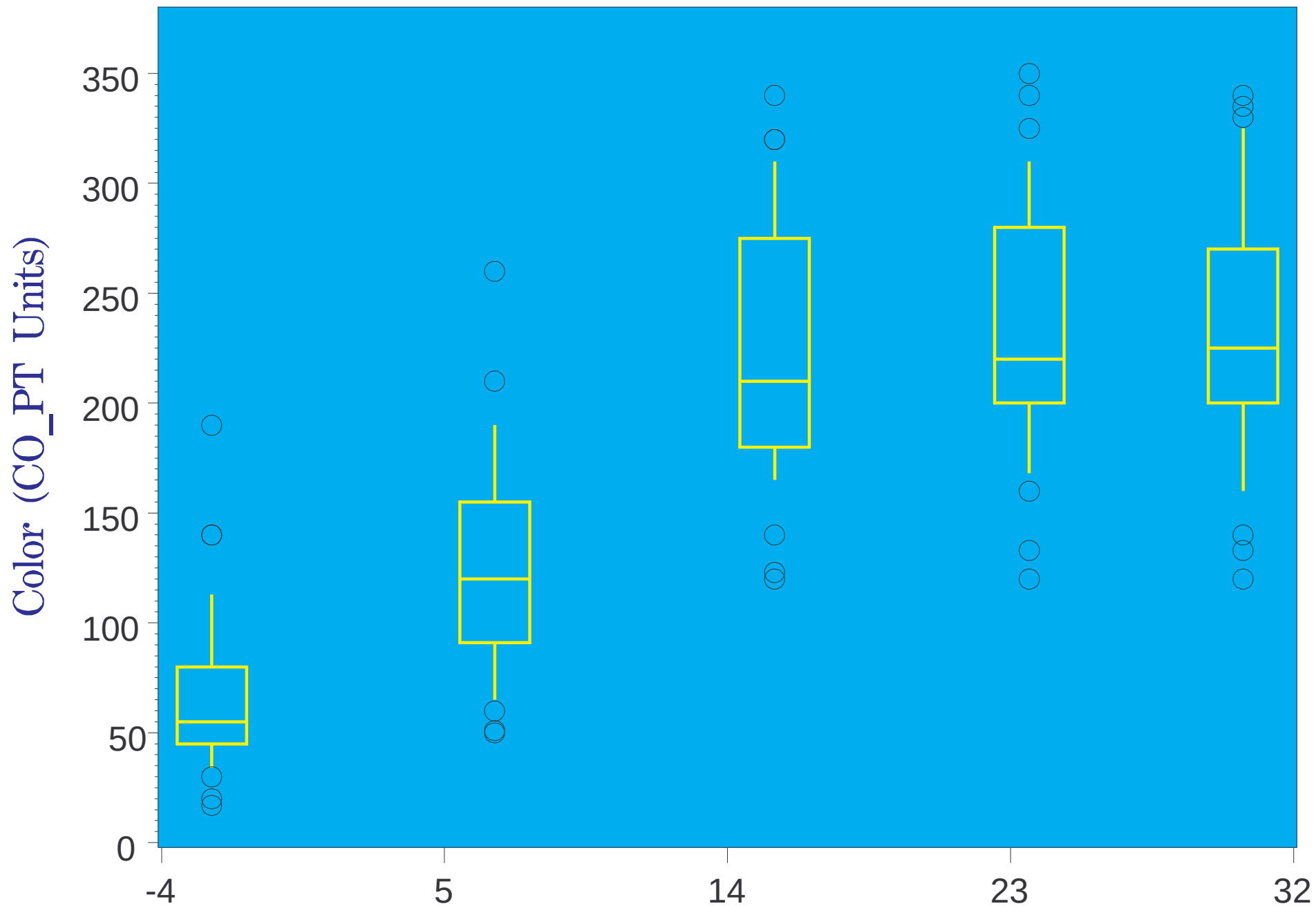


Figure 4.5.274 Box & whiskers of surface color by river kilometer (920 to 2100 cfs)

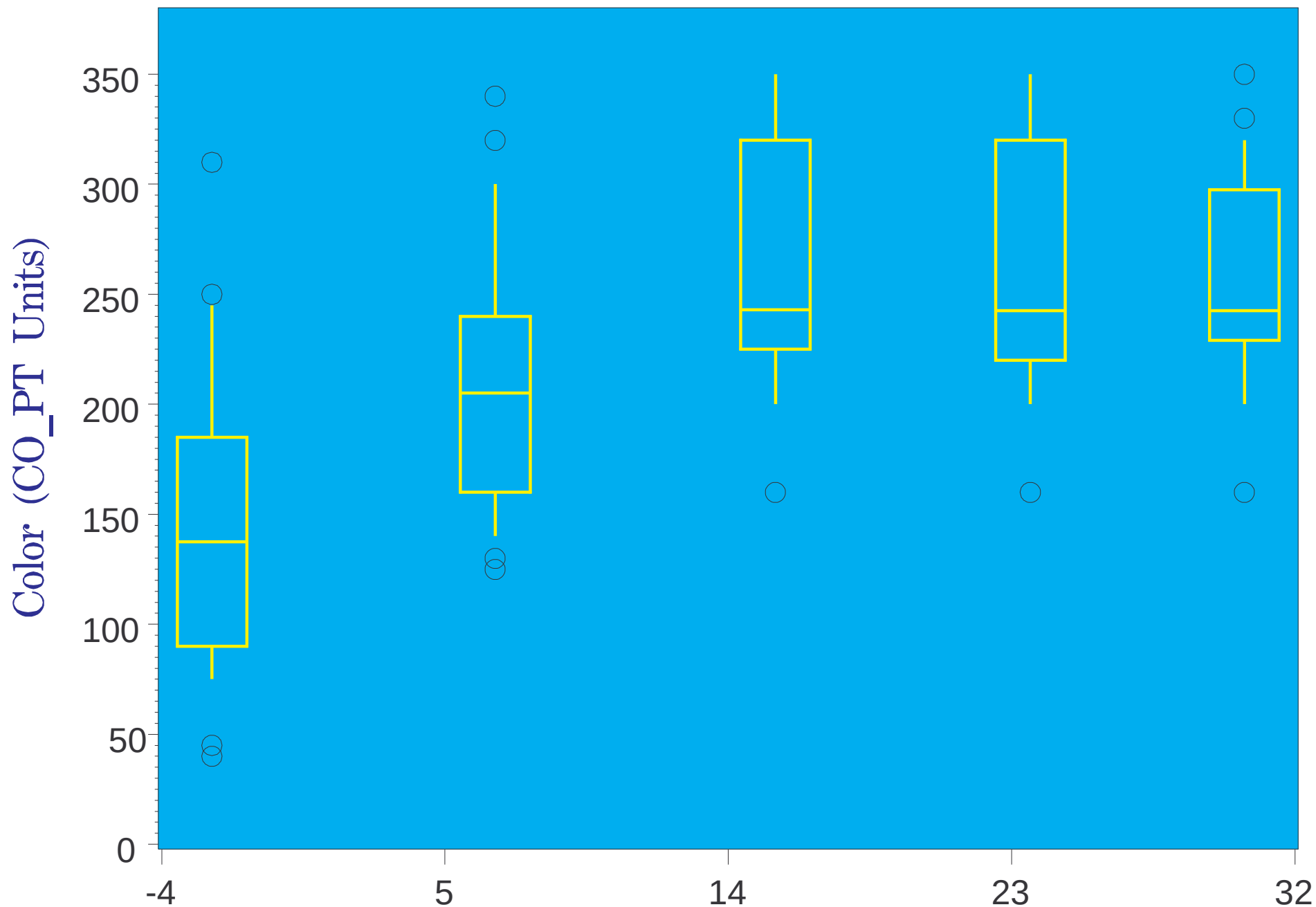


Figure 4.5.275 Box & whiskers of surface color by river kilometer (> 2100 cfs)

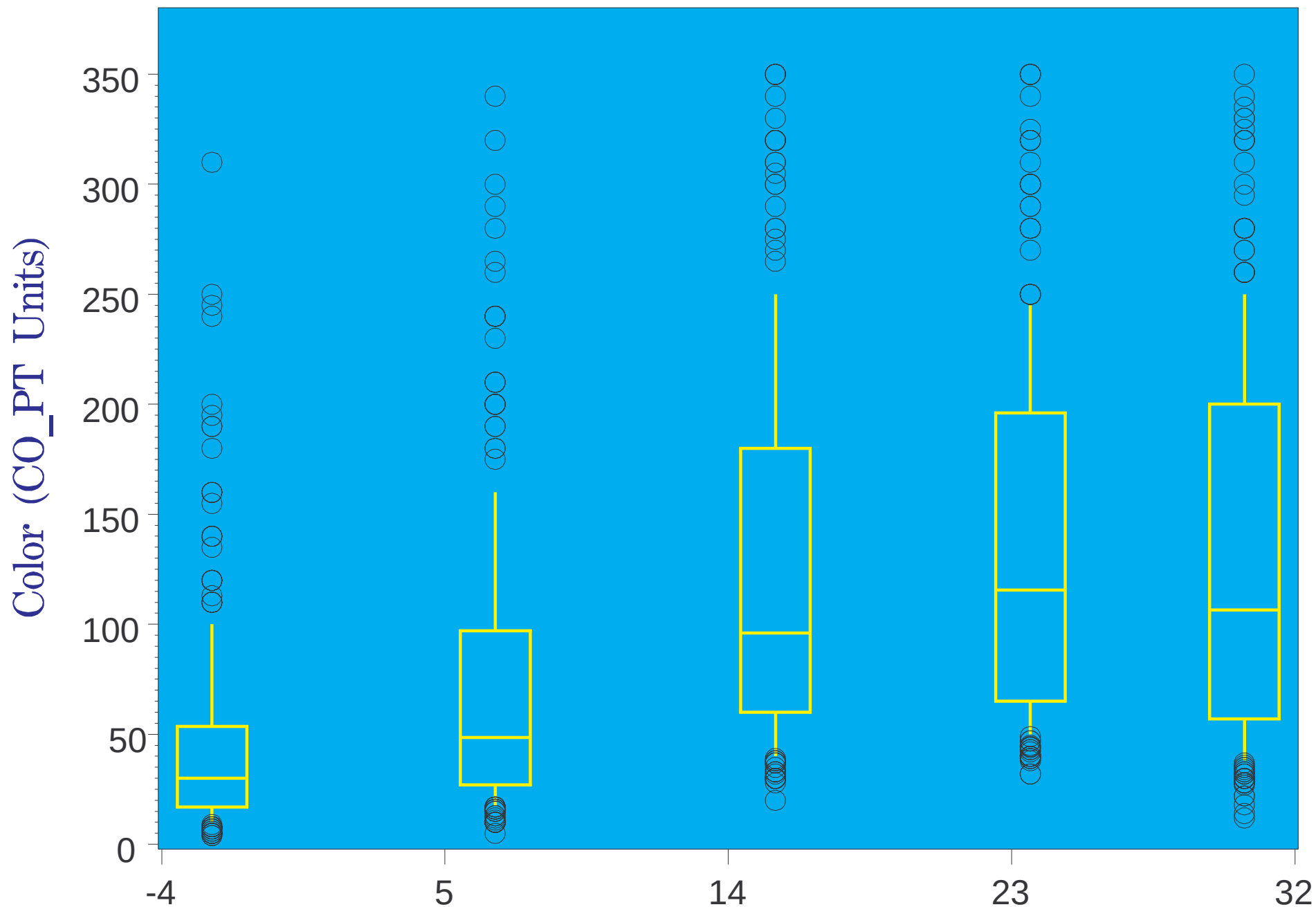


Figure 4.5.276 Box & whiskers of surface color by river kilometer (all flows)

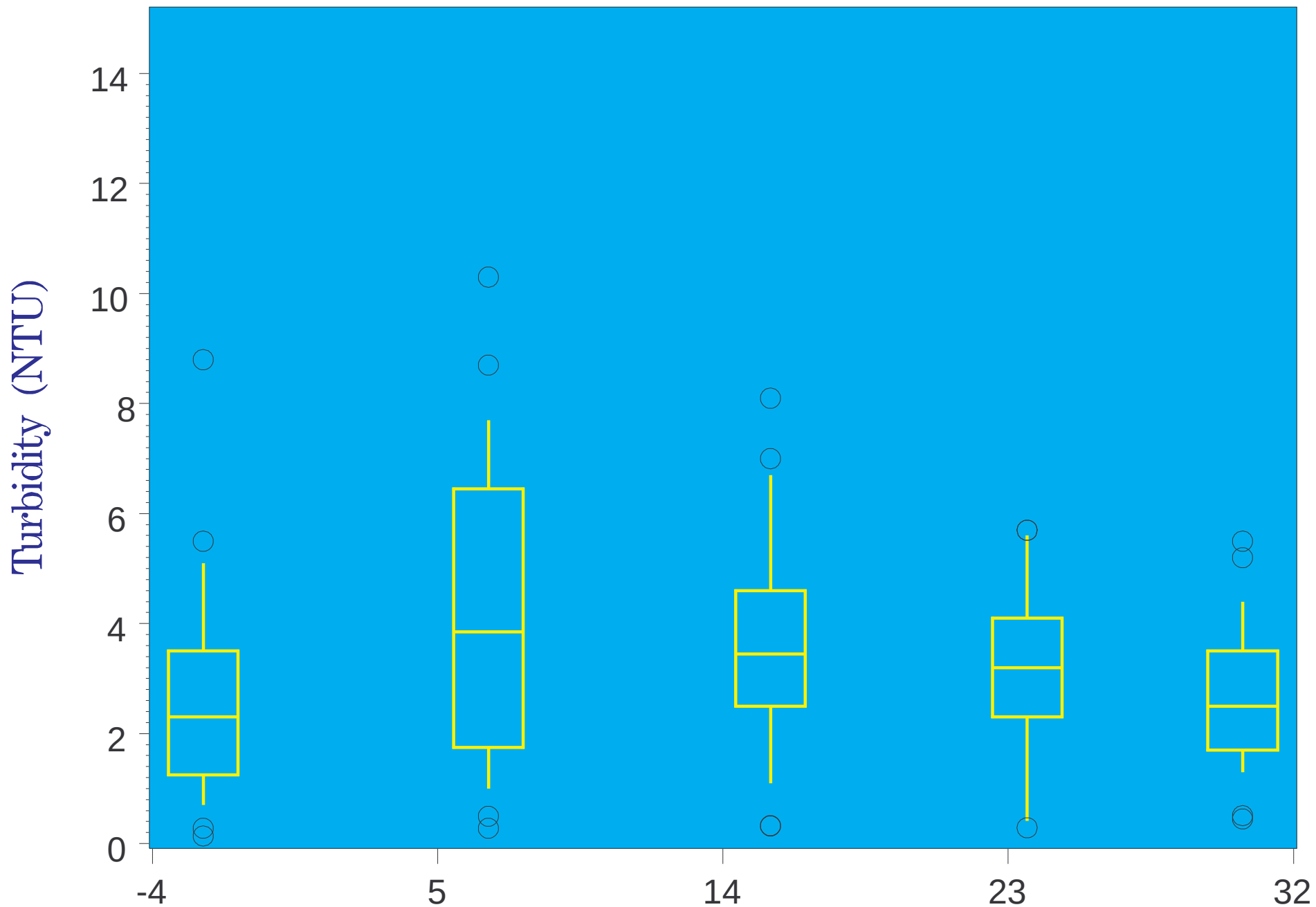


Figure 4.5.277 Box & whiskers of surface turbidity by river kilometer (0 to 90 cfs)

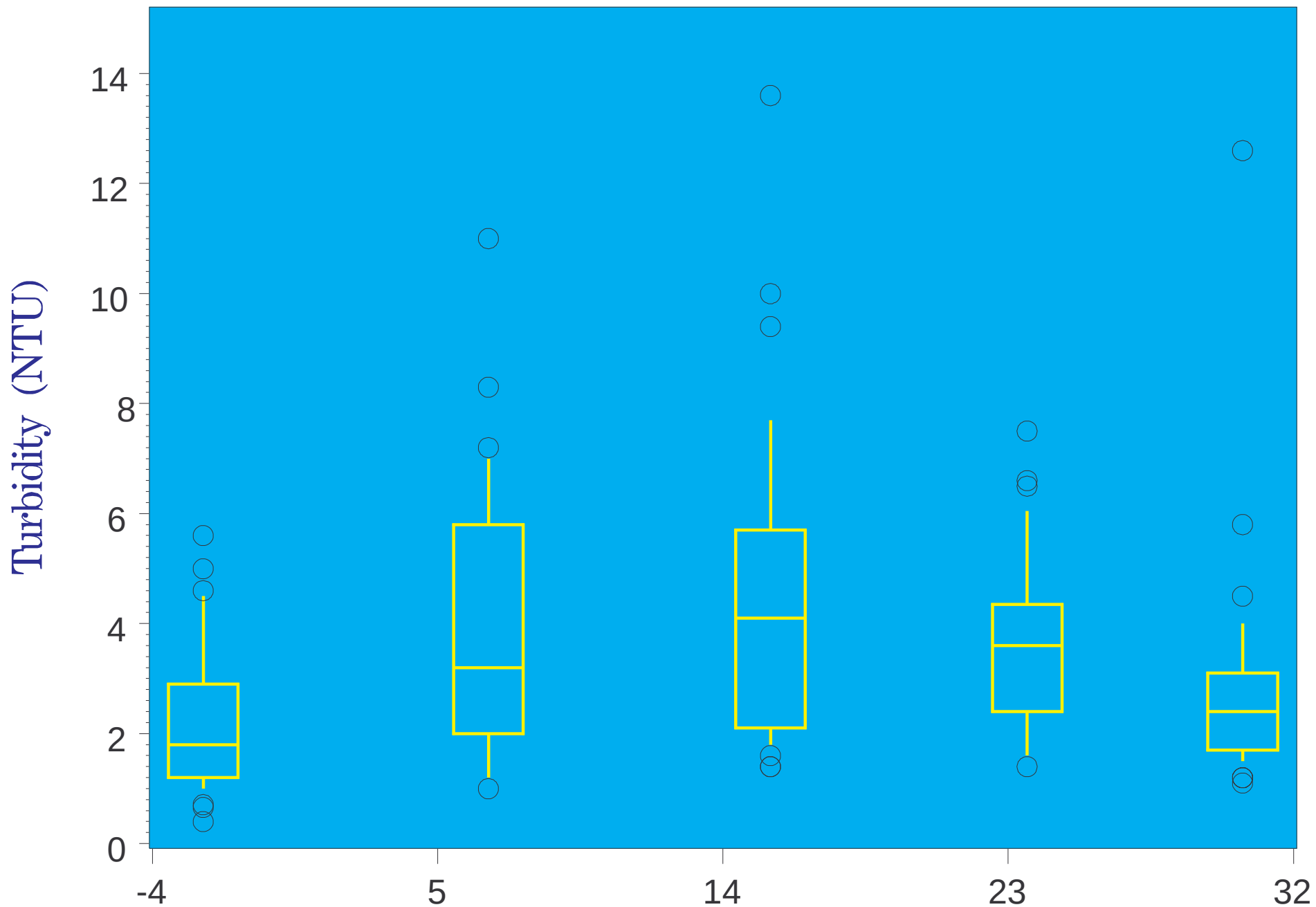
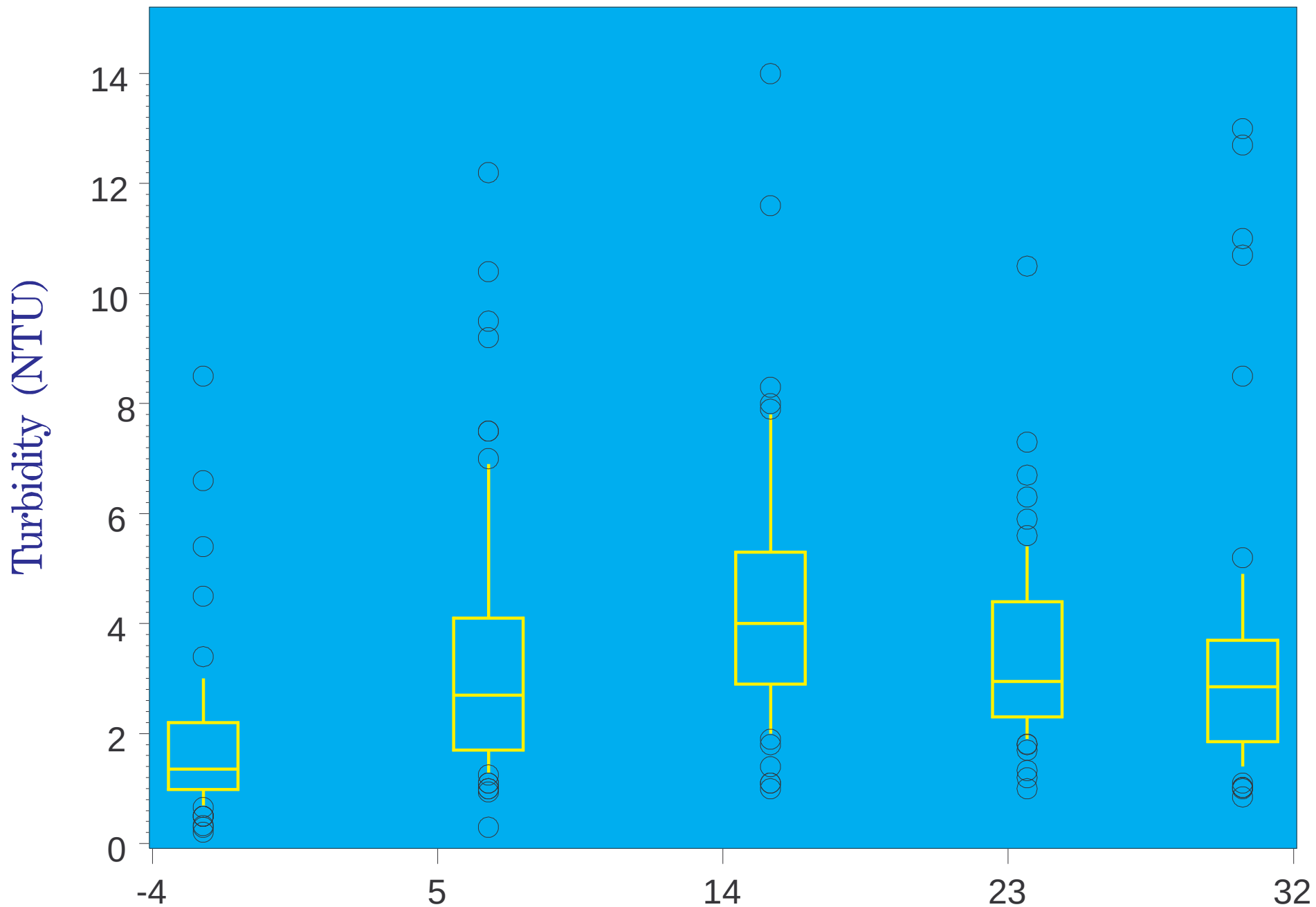


Figure 4.5.278 Box & whiskers of surface turbidity by river kilometer (90 to 160 cfs)



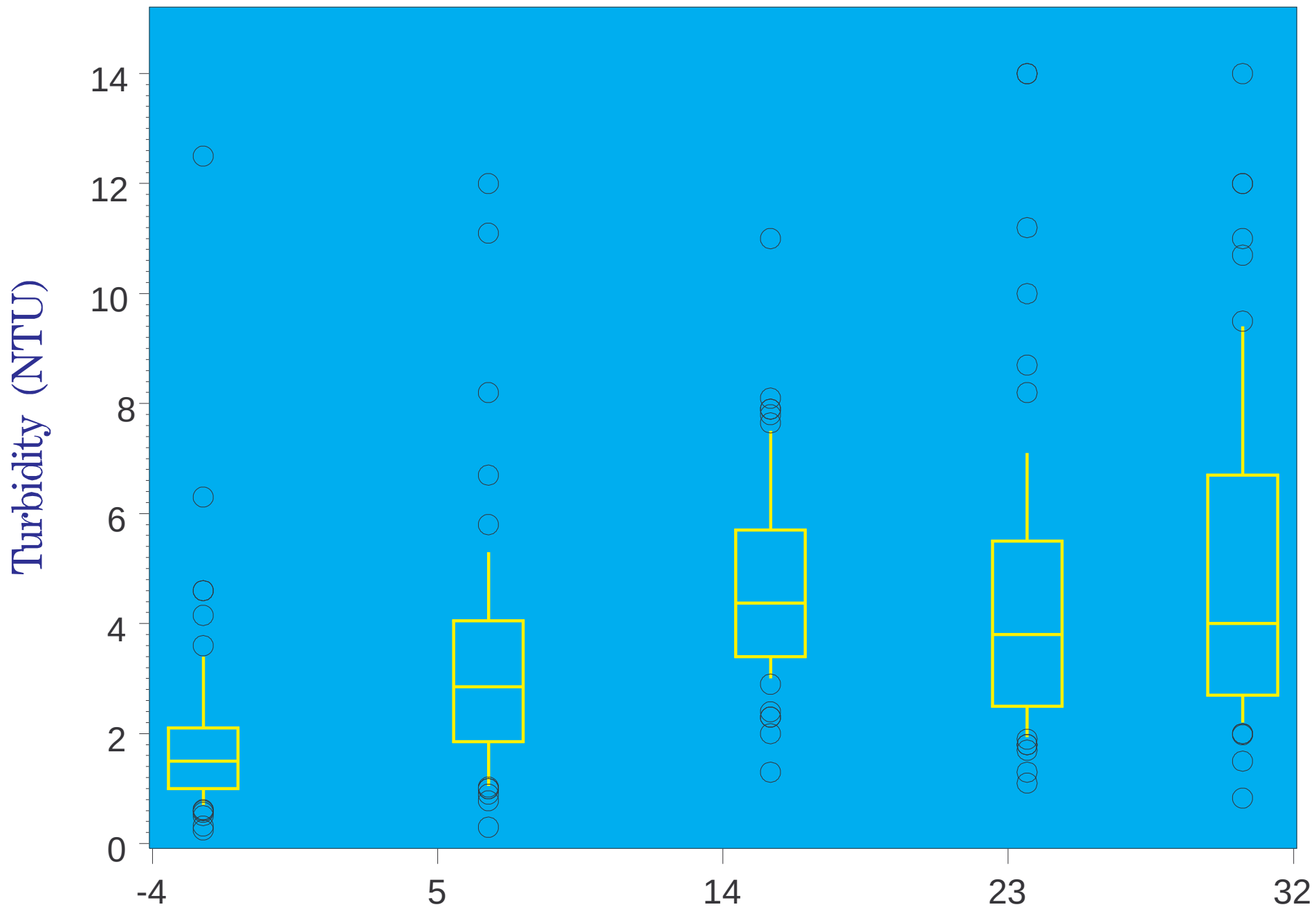


Figure 4.5.280 Box & whiskers of surface turbidity by river kilometer (360 to 920 cfs)

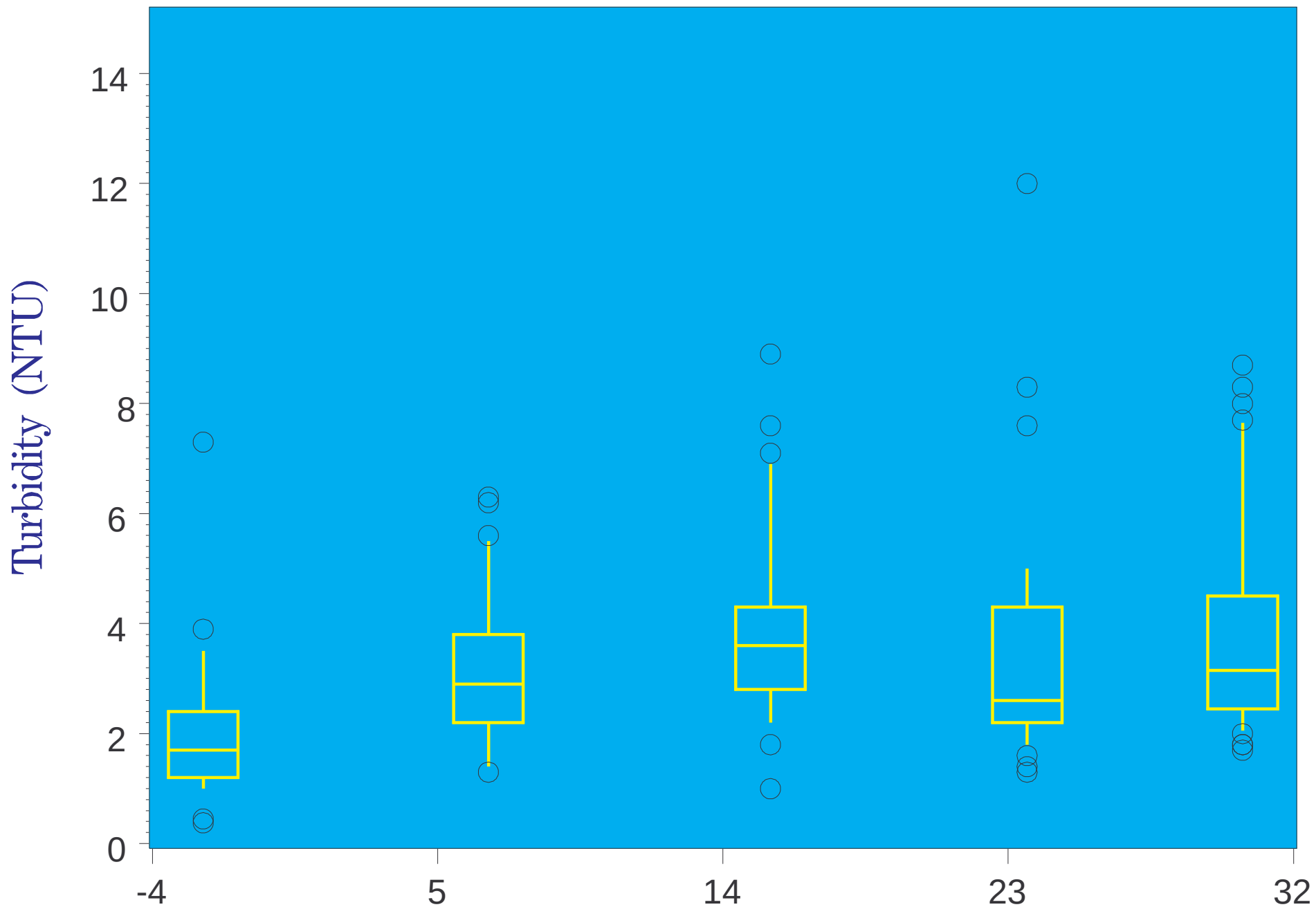


Figure 4.5.281 Box & whiskers of surface turbidity by river kilometer (920 to 2100 cfs)



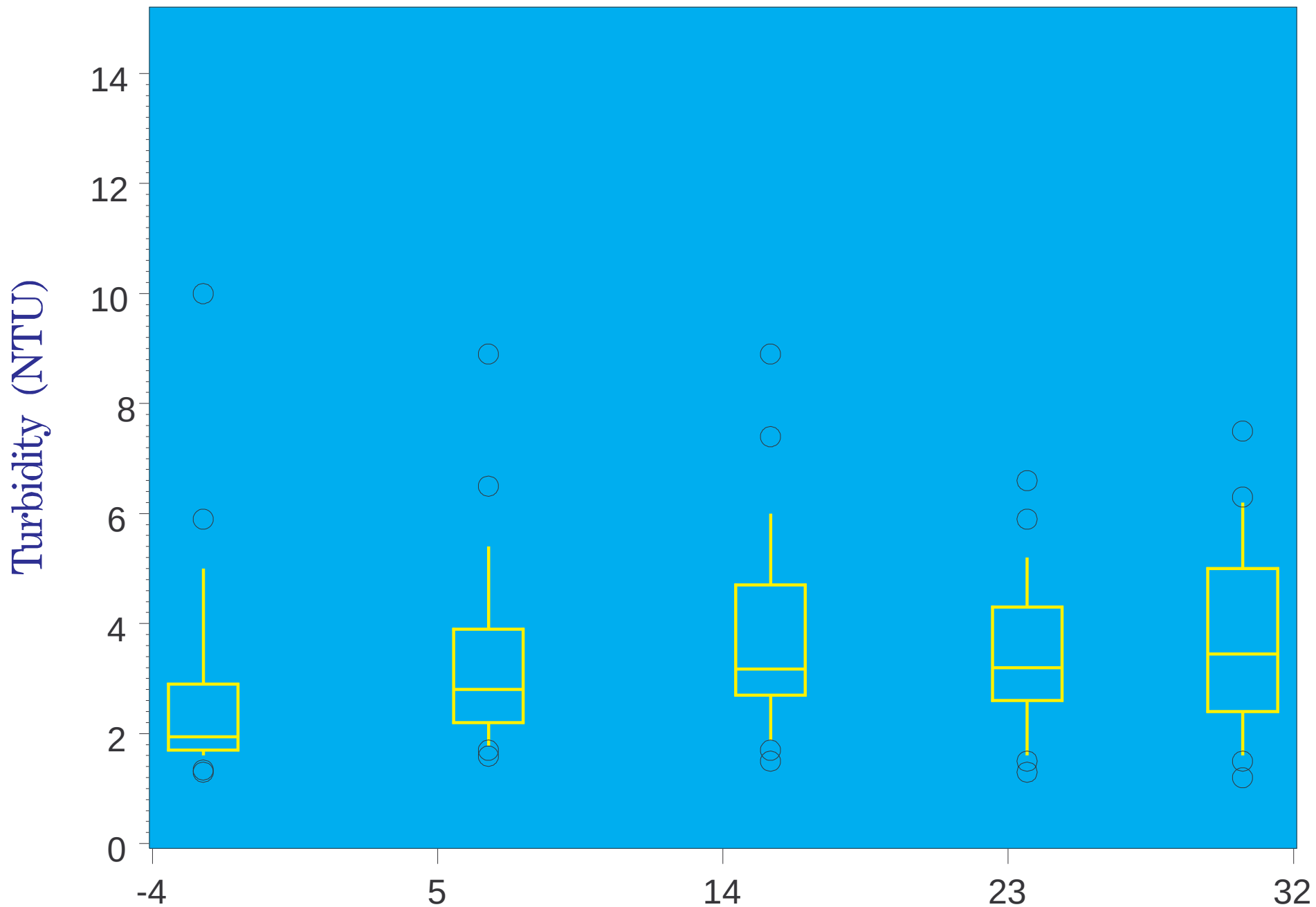


Figure 4.5.282 Box & whiskers of surface turbidity by river kilometer (> 2100 cfs)

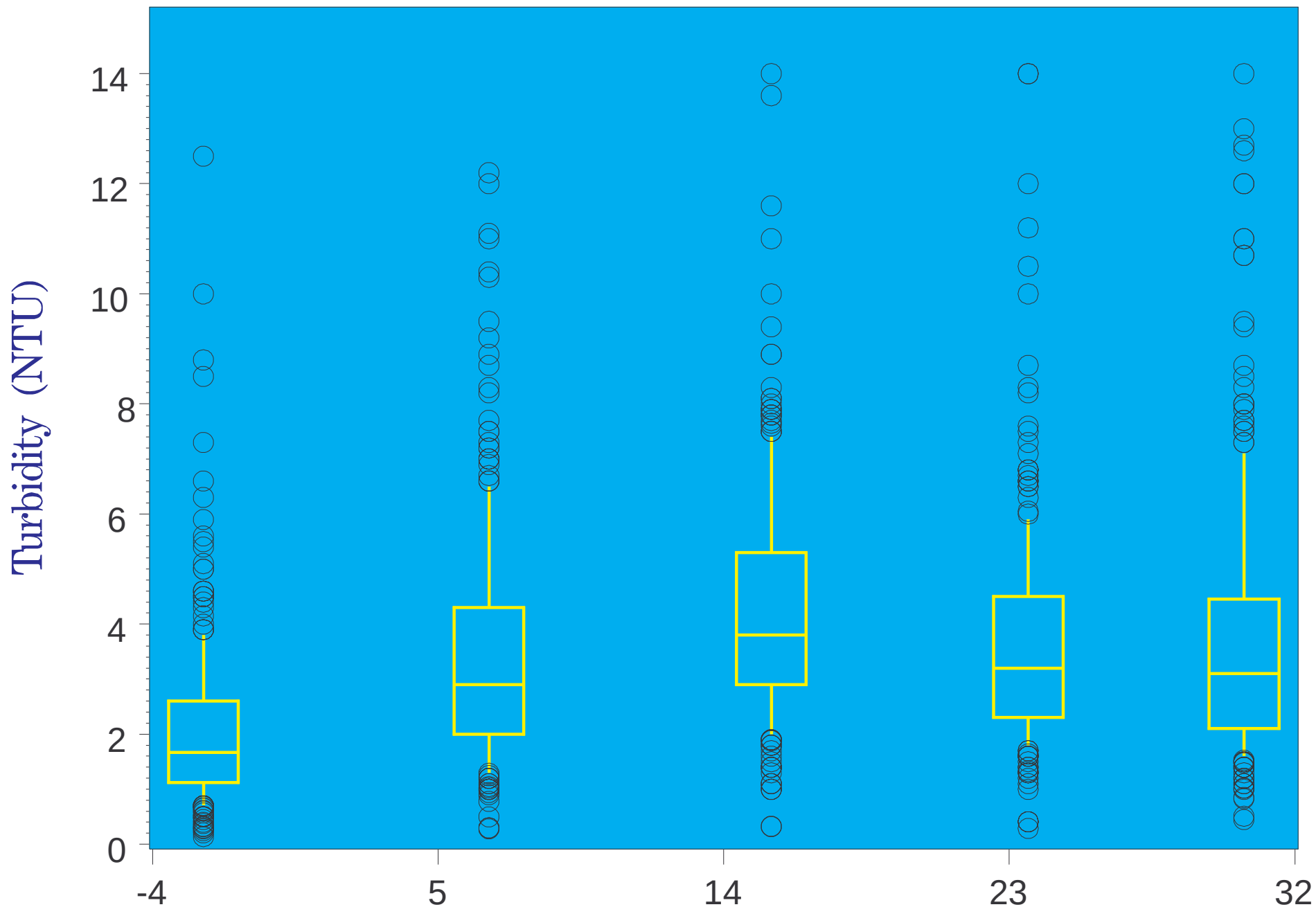


Figure 4.5.283 Box & whiskers of surface turbidity by river kilometer (all flows)

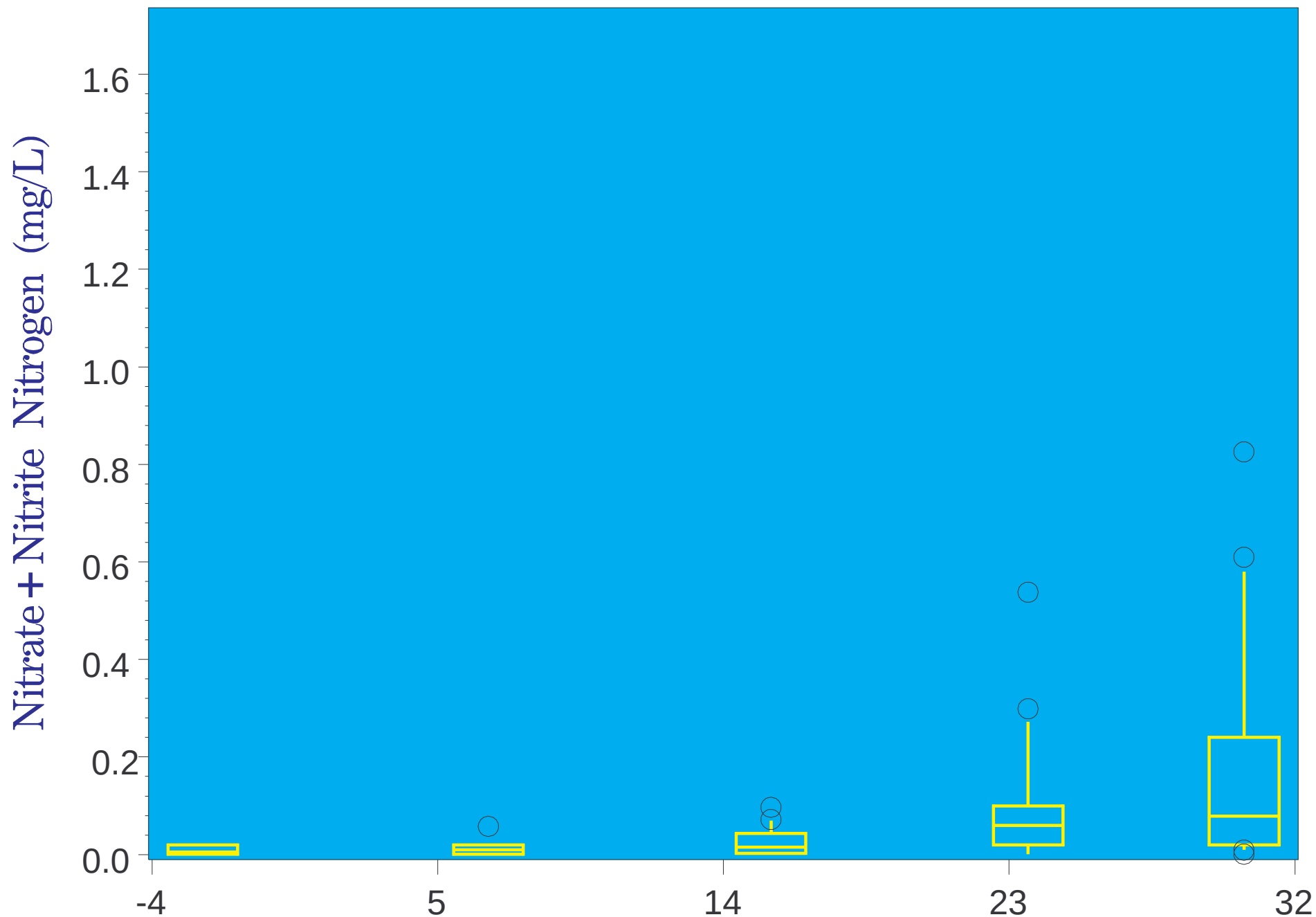


Figure 4.5.284 Box & whiskers of surface nitrate/nitrite nitrogen at river kilometer (0 to 90 cfs)

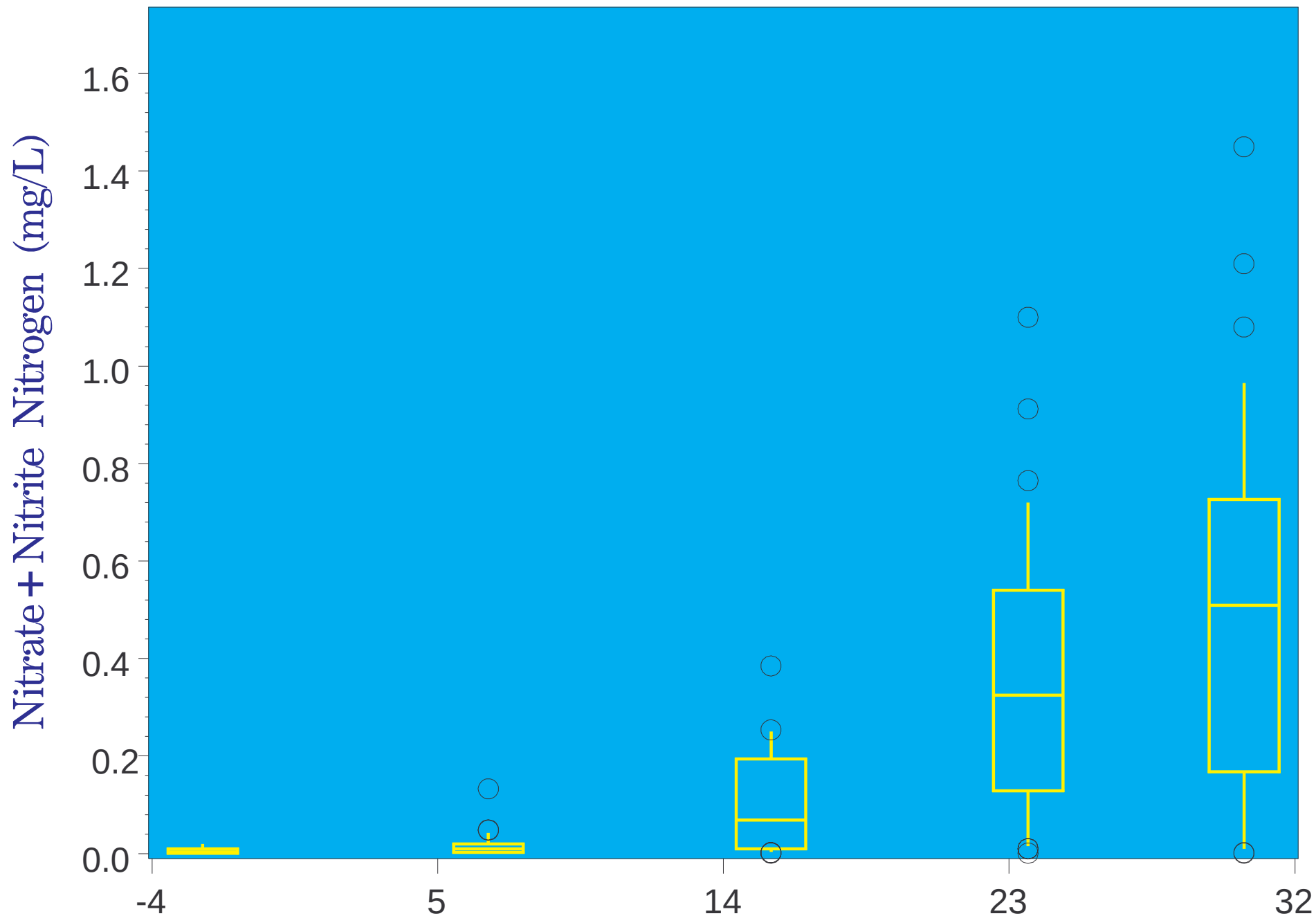


Figure 4.5.285 Box & whiskers of surface nitrate/nitrite nitrogen at river kilometer (90 to 160 cfs)

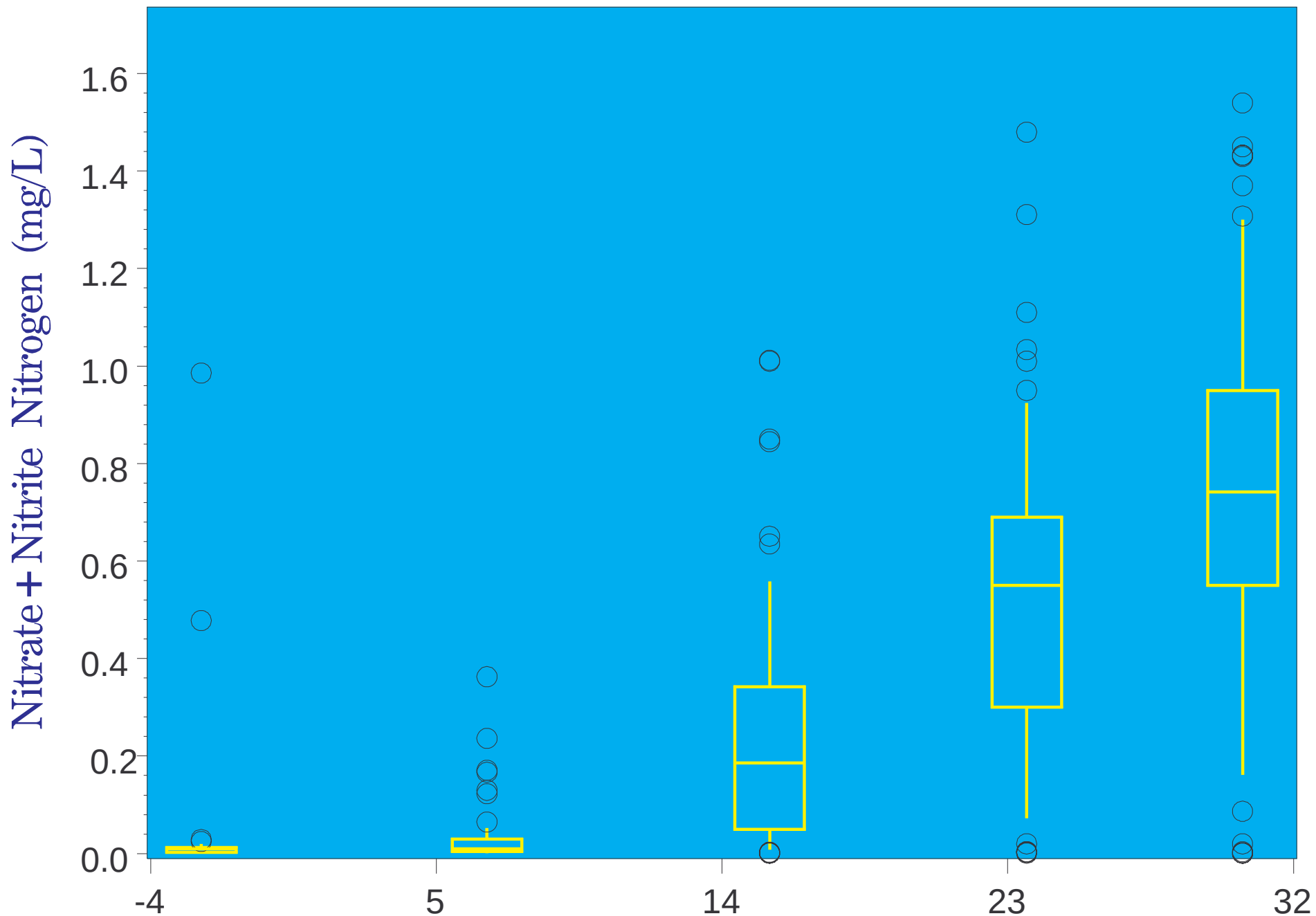


Figure 4.5.286 Box & whiskers of surface nitrate/nitrite nitrogen at river kilometer (160 to 360 cfs)

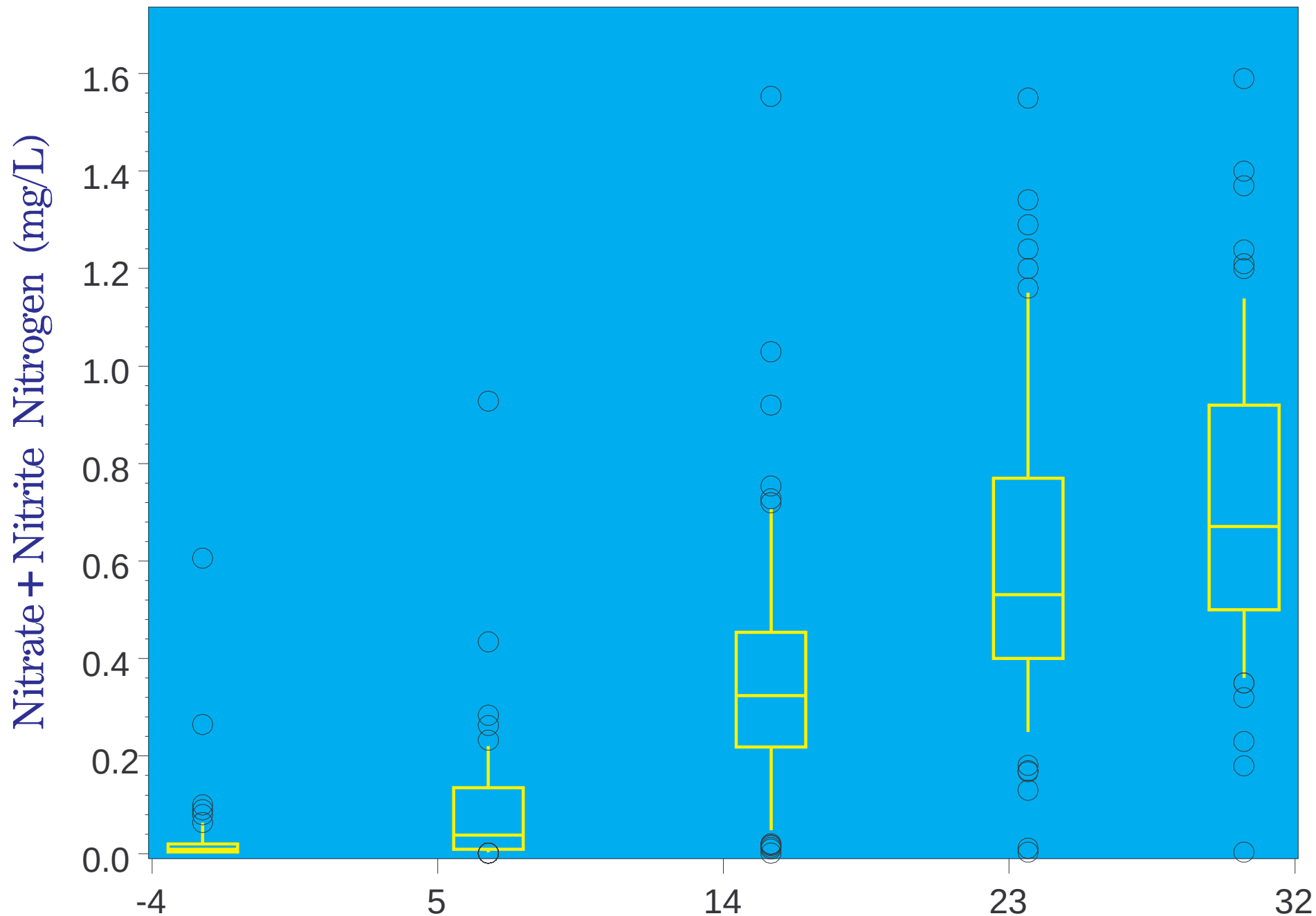


Figure 4.5.287 Box & whiskers of surface nitrate/nitrite nitrogen at river kilometer (360 to 920 cfs)

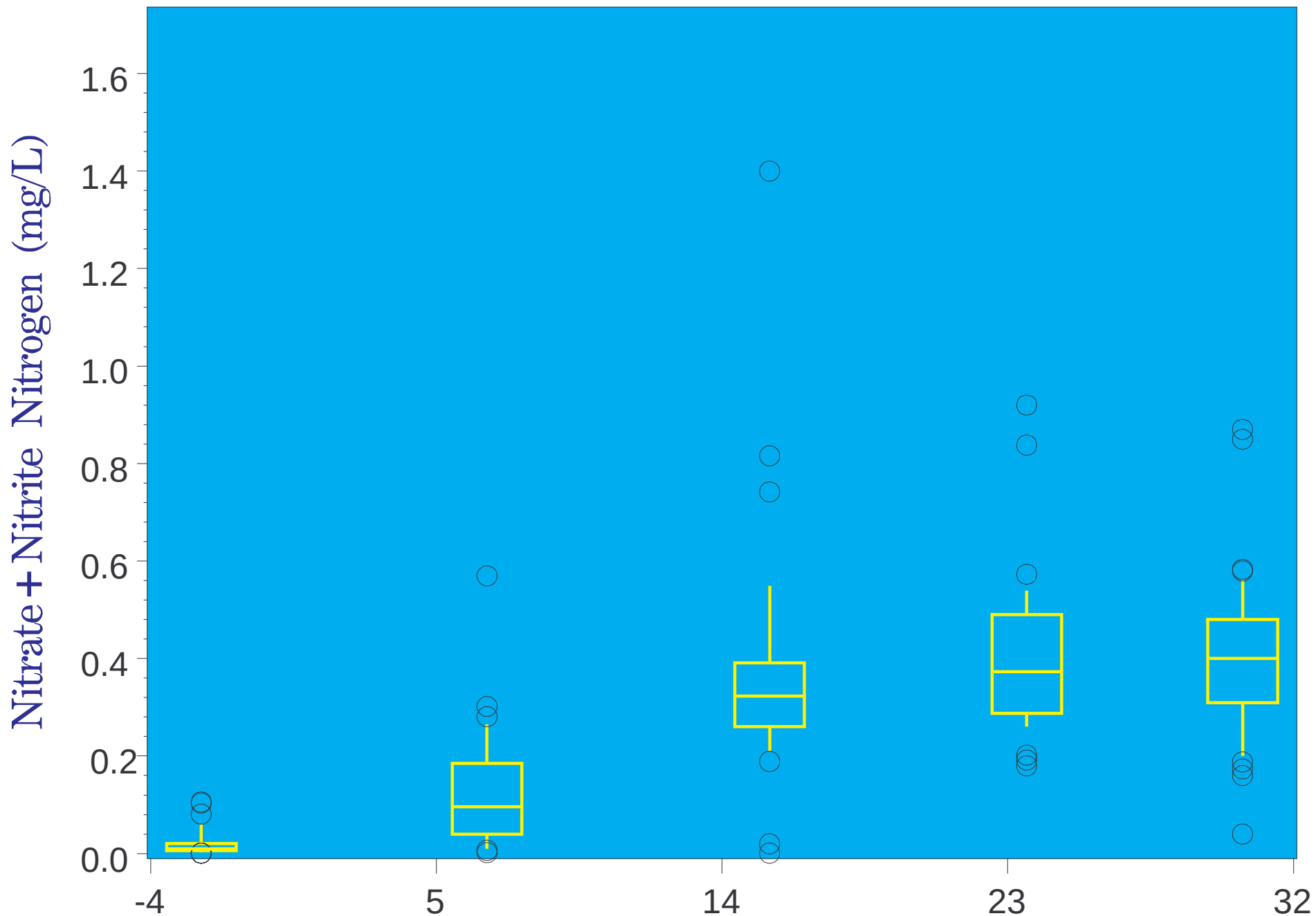


Figure 4.5.288 Box & whiskers of surface nitrate/nitrite nitrogen at river kilometer (920 to 2100 cfs)

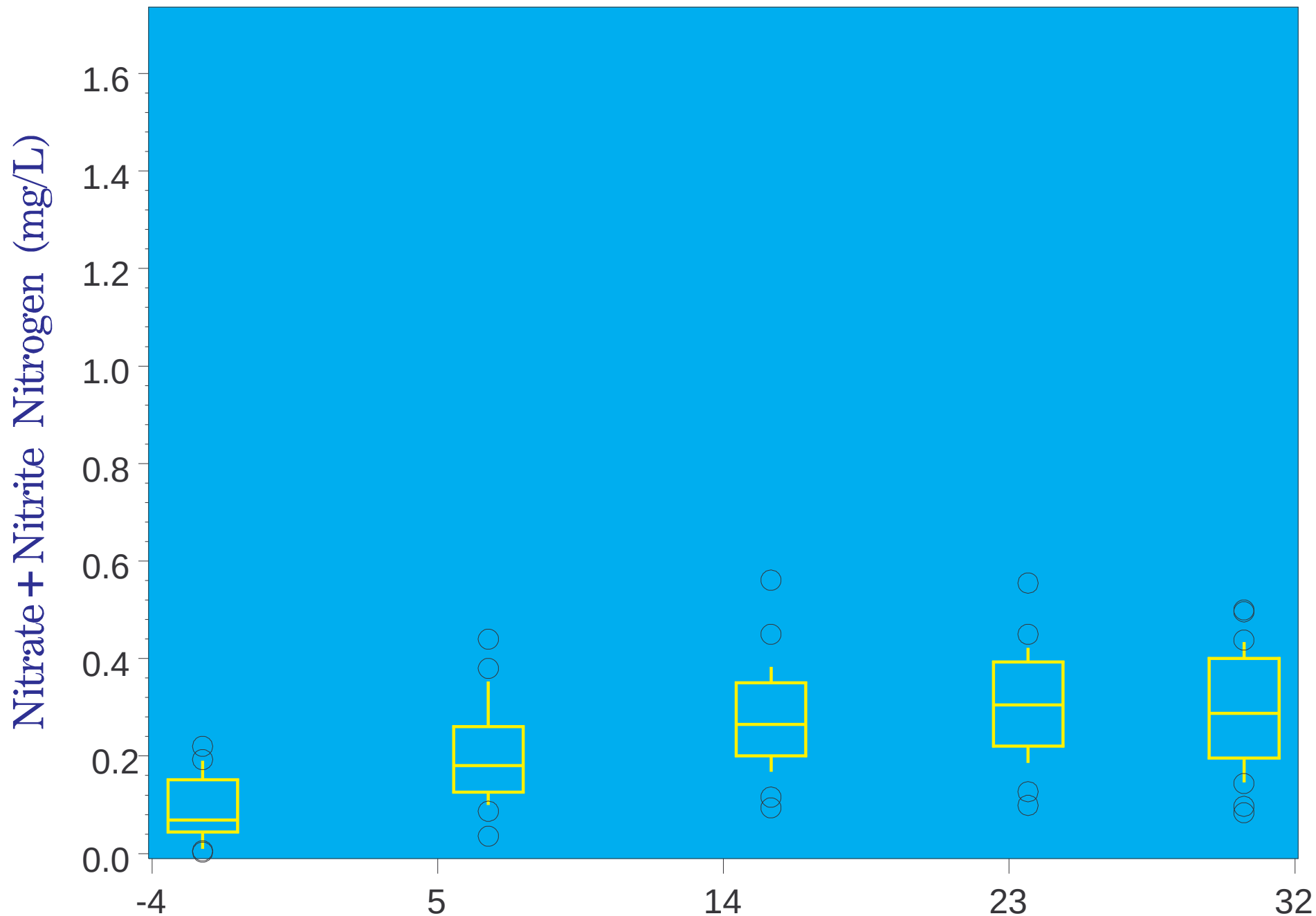


Figure 4.5.289 Box & whiskers of surface nitrate/nitrite nitrogen at river kilometer (> 2100 cfs)



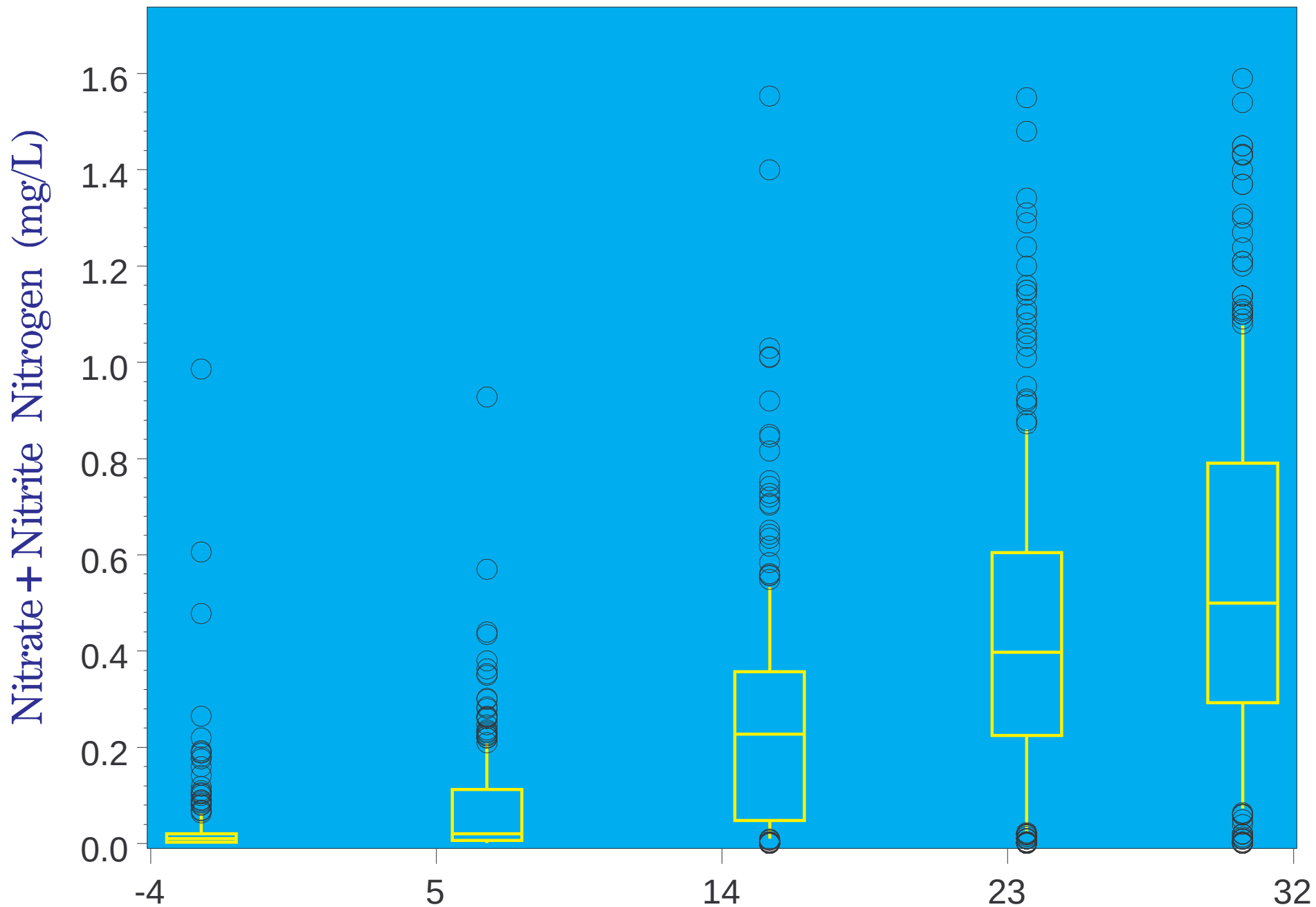


Figure 4.5.290 Box & whiskers of surface nitrate/nitrite nitrogen at river kilometer (all flows)

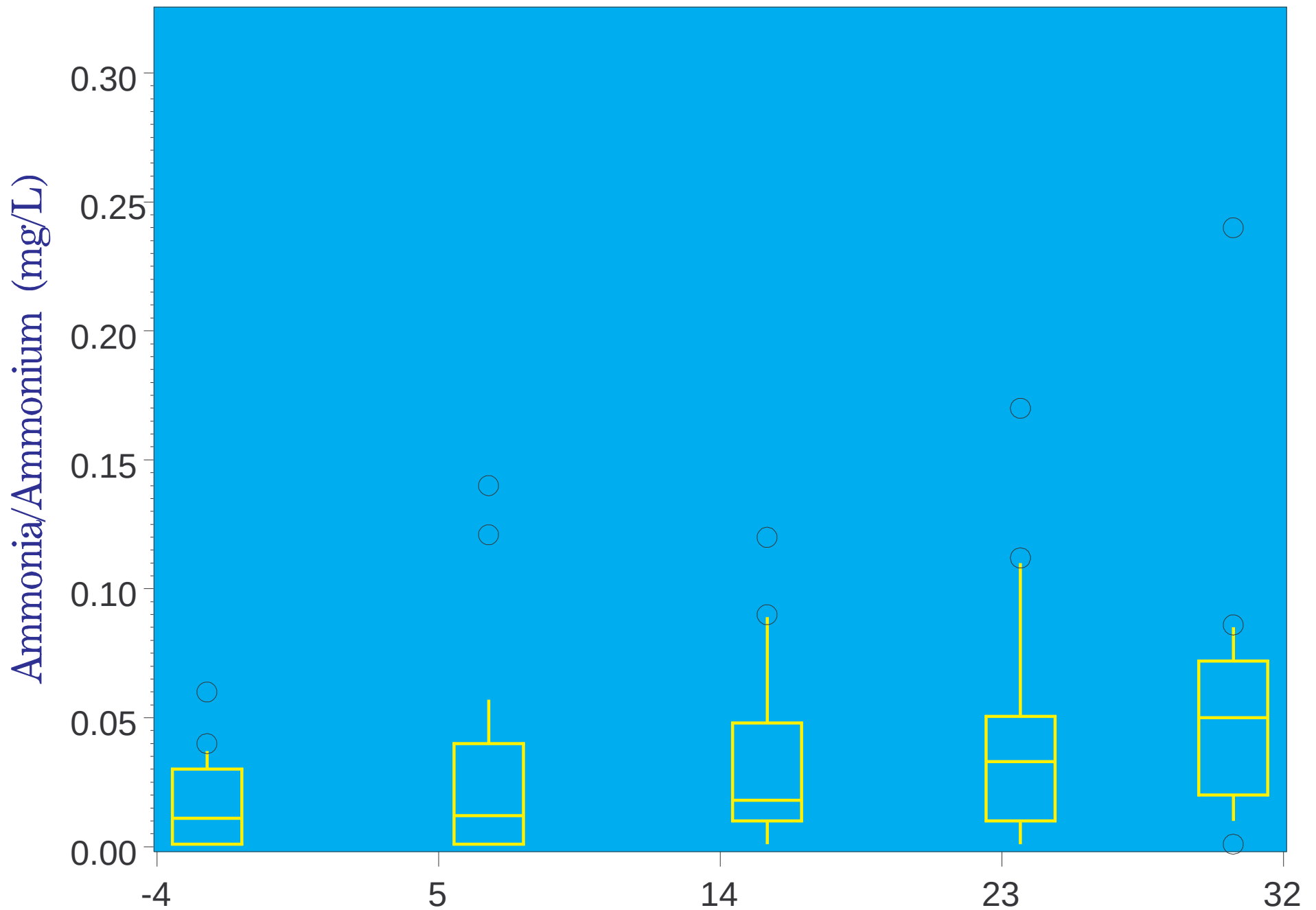


Figure 4.5.291 Box & whiskers of surface ammonia/ammonium by river kilometer (0 to 90 cfs)

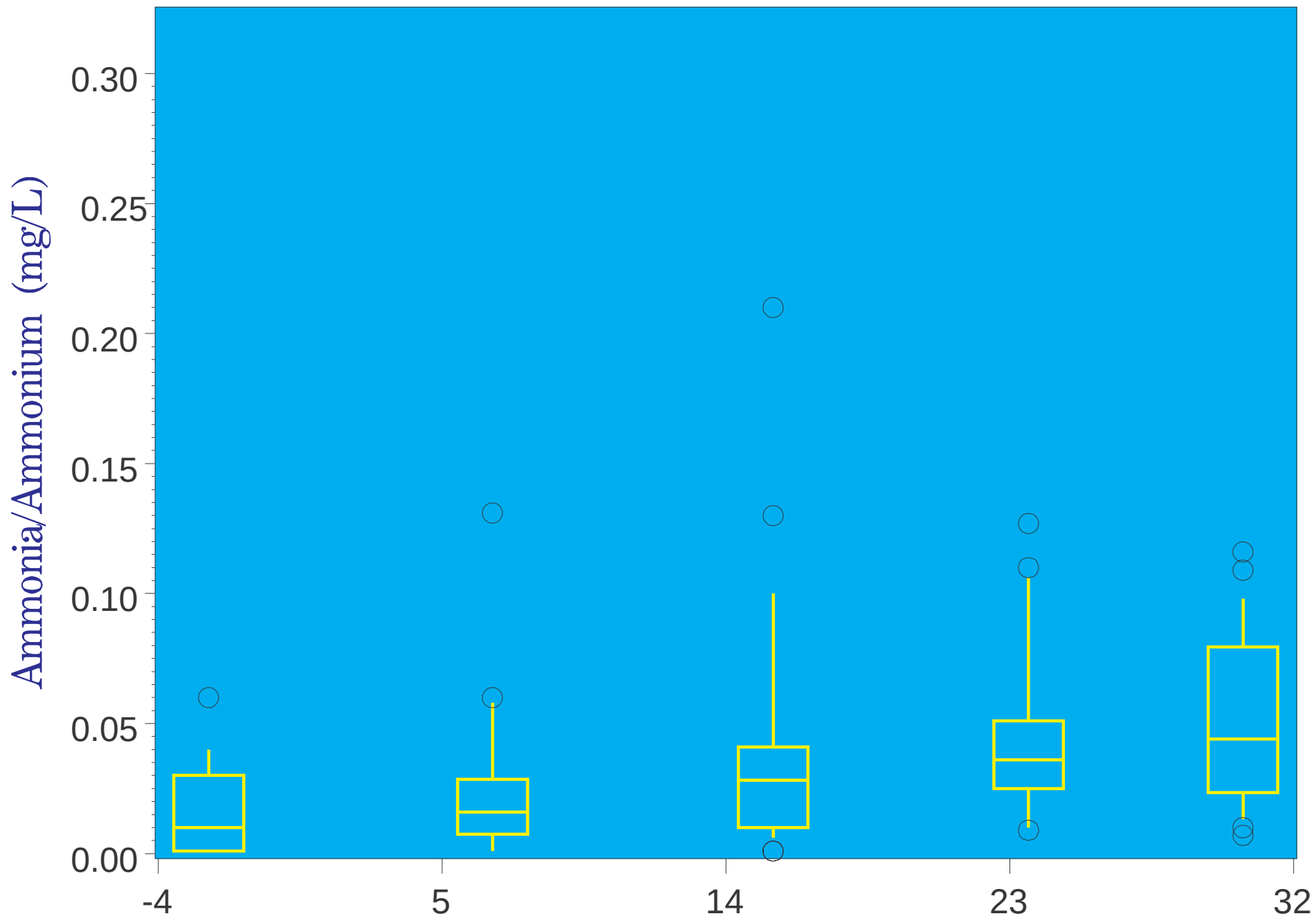


Figure 4.5.292 Box & whiskers of surface ammonia/ammonium by river kilometer (90 to 160 cfs)

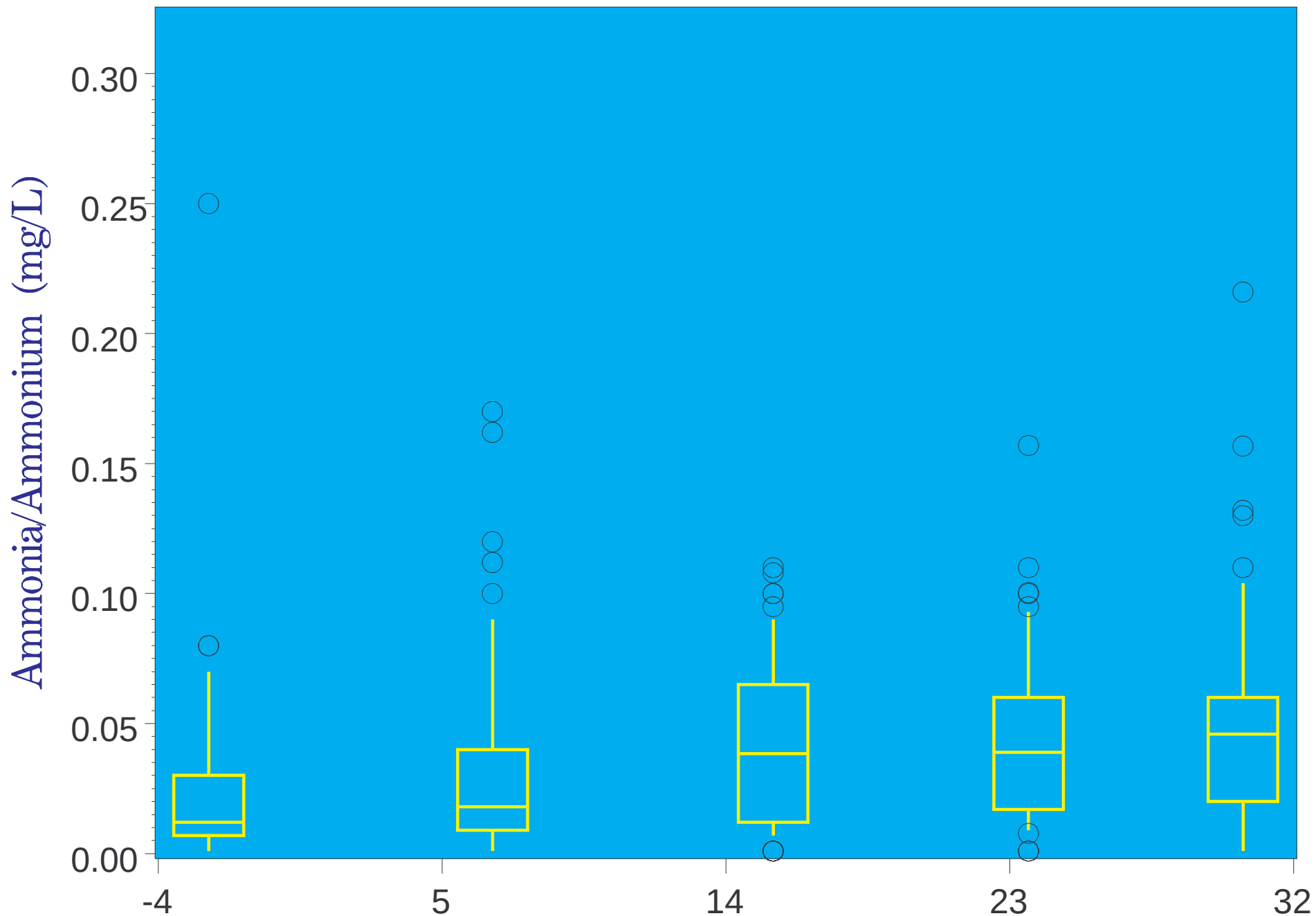


Figure 4.5.293 Box & whiskers of surface ammonia/ammonium by river kilometer (160 to 360 cfs)

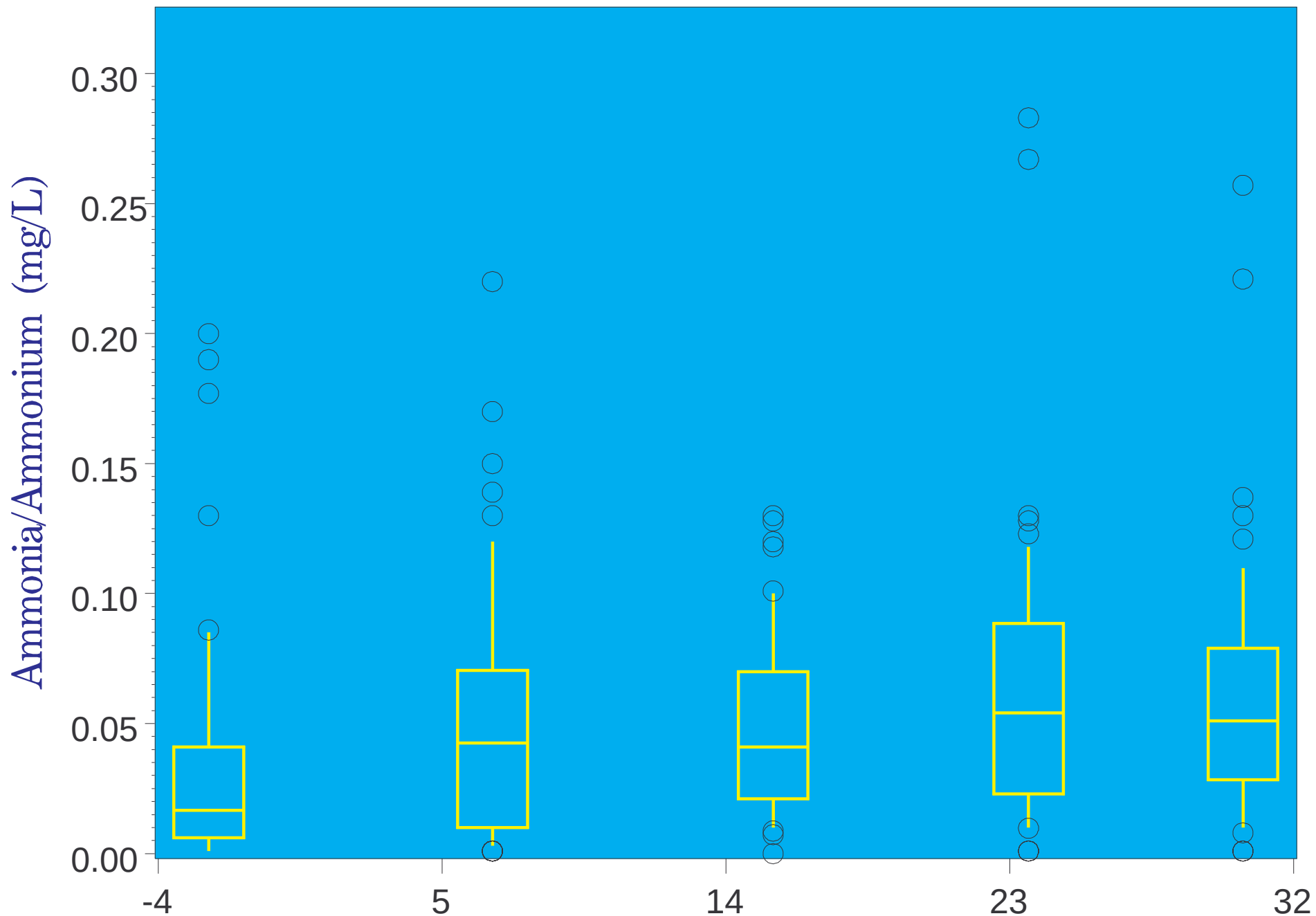


Figure 4.5.294 Box & whiskers of surface ammonia/ammonium by river kilometer (360 to 920 cfs)

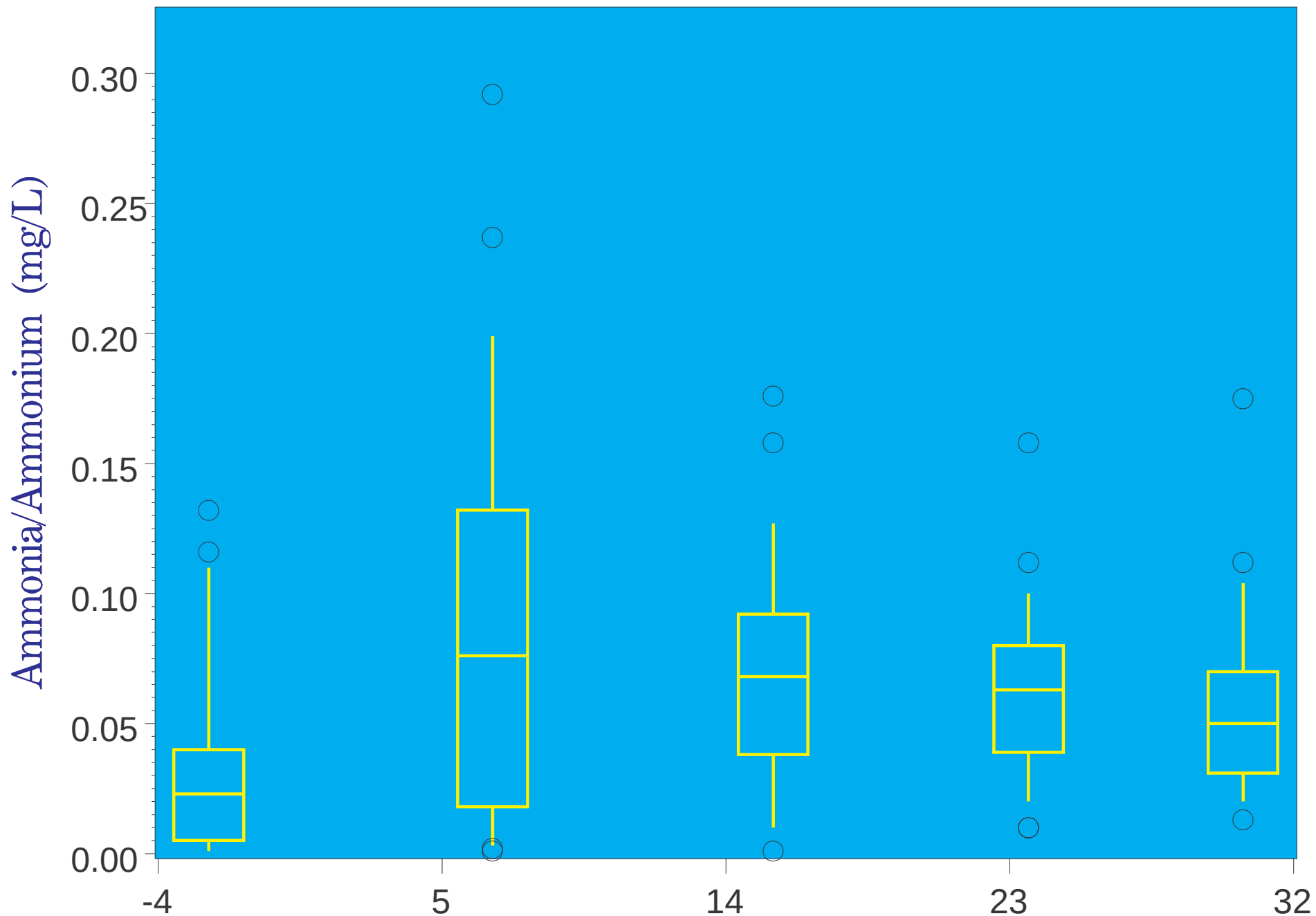


Figure 4.5.295 Box & whiskers of surface ammonia/ammonium by river kilometer (920 to 2100 cfs)

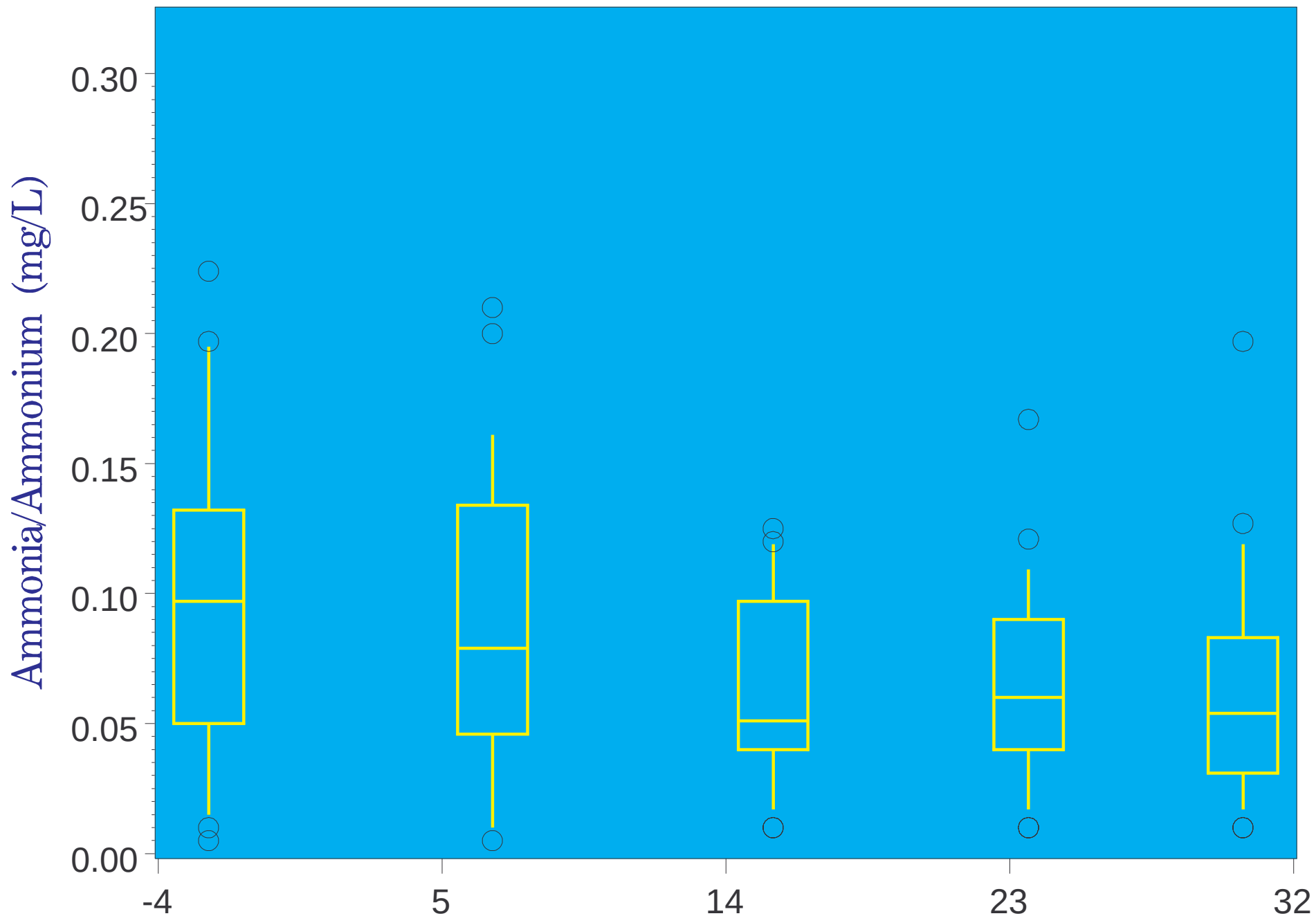


Figure 4.5.296 Box & whiskers of surface ammonia/ammonium by river kilometer (> 2100 cfs)

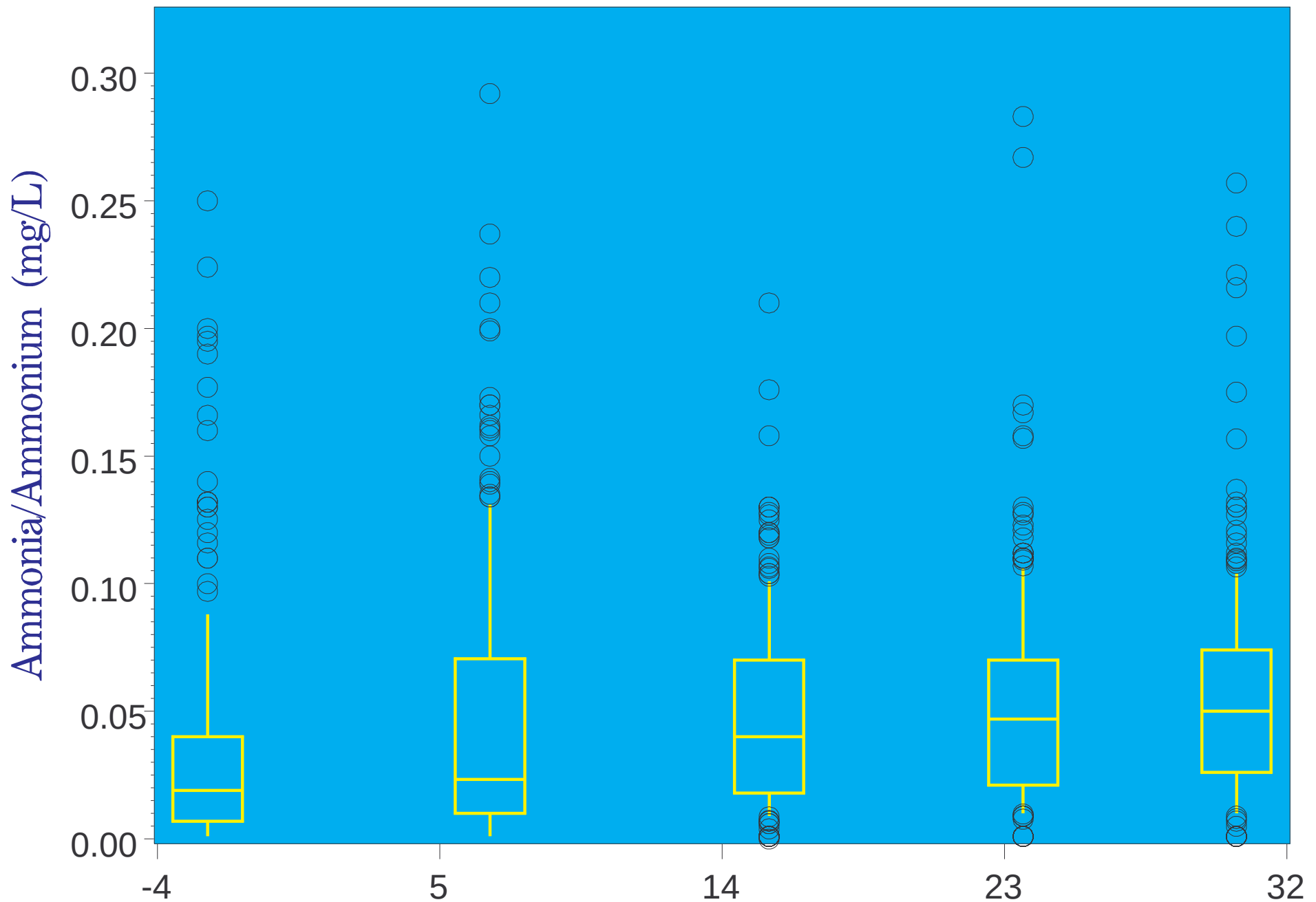


Figure 4.5.297 Box & whiskers of surface ammonia/ammonium by river kilometer (all flows)



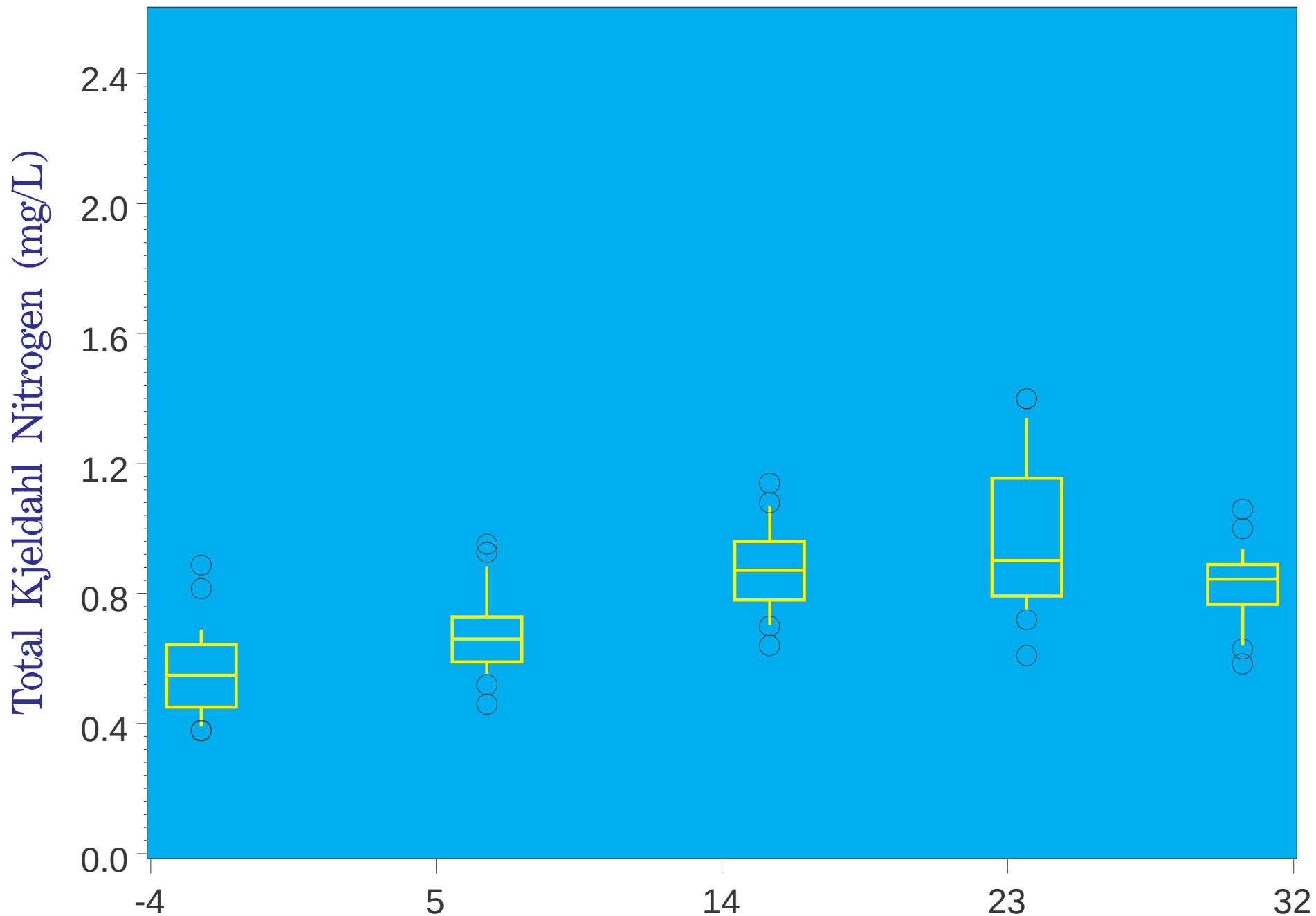


Figure 4.5.298 Box & whiskers of surface total Kjeldahl nitrogen by river kilometer (0 to 90 cfs)

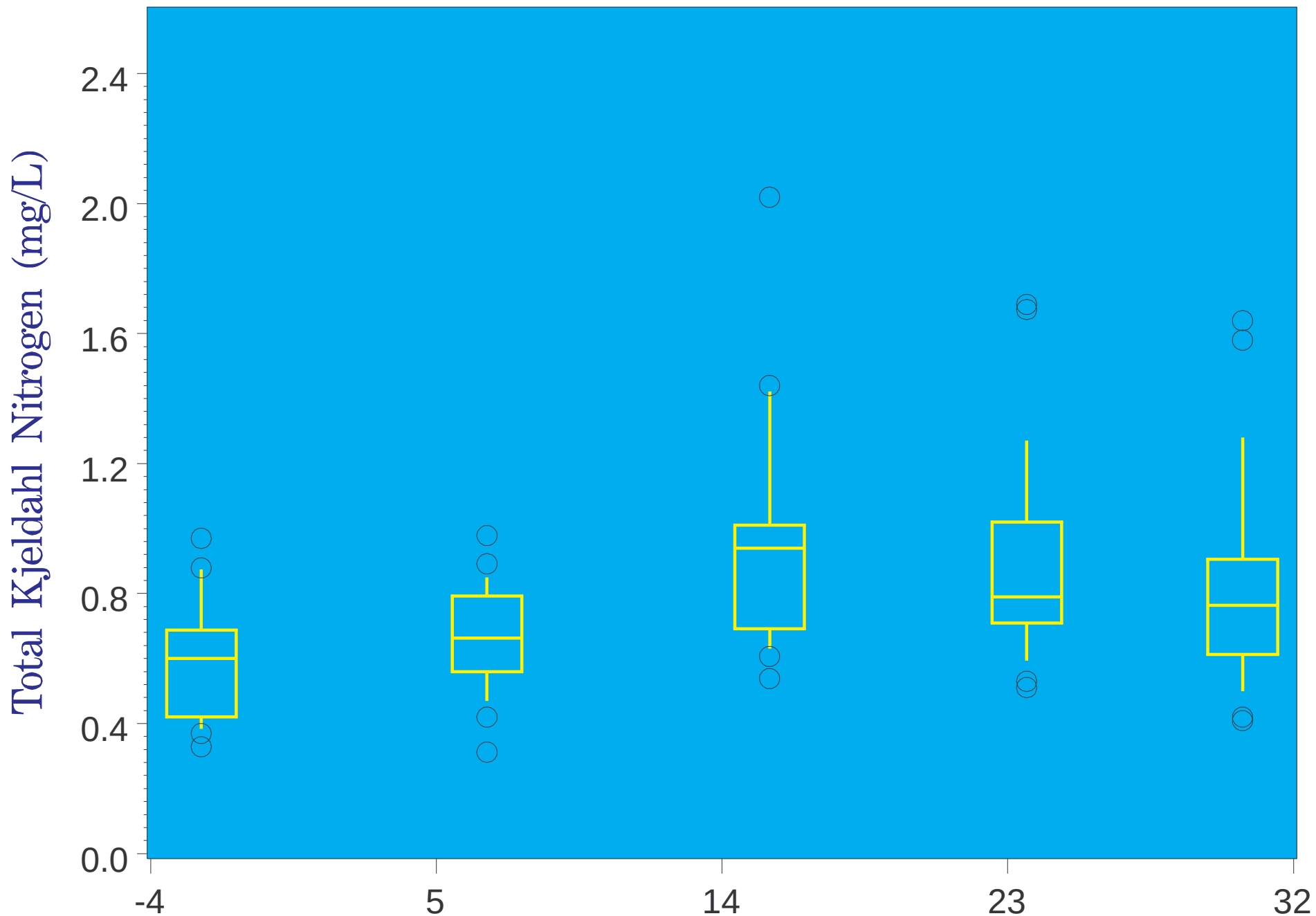


Figure 4.5.299 Box & whiskers of surface total Kjeldahl nitrogen by river kilometer (90 to 160 cfs)

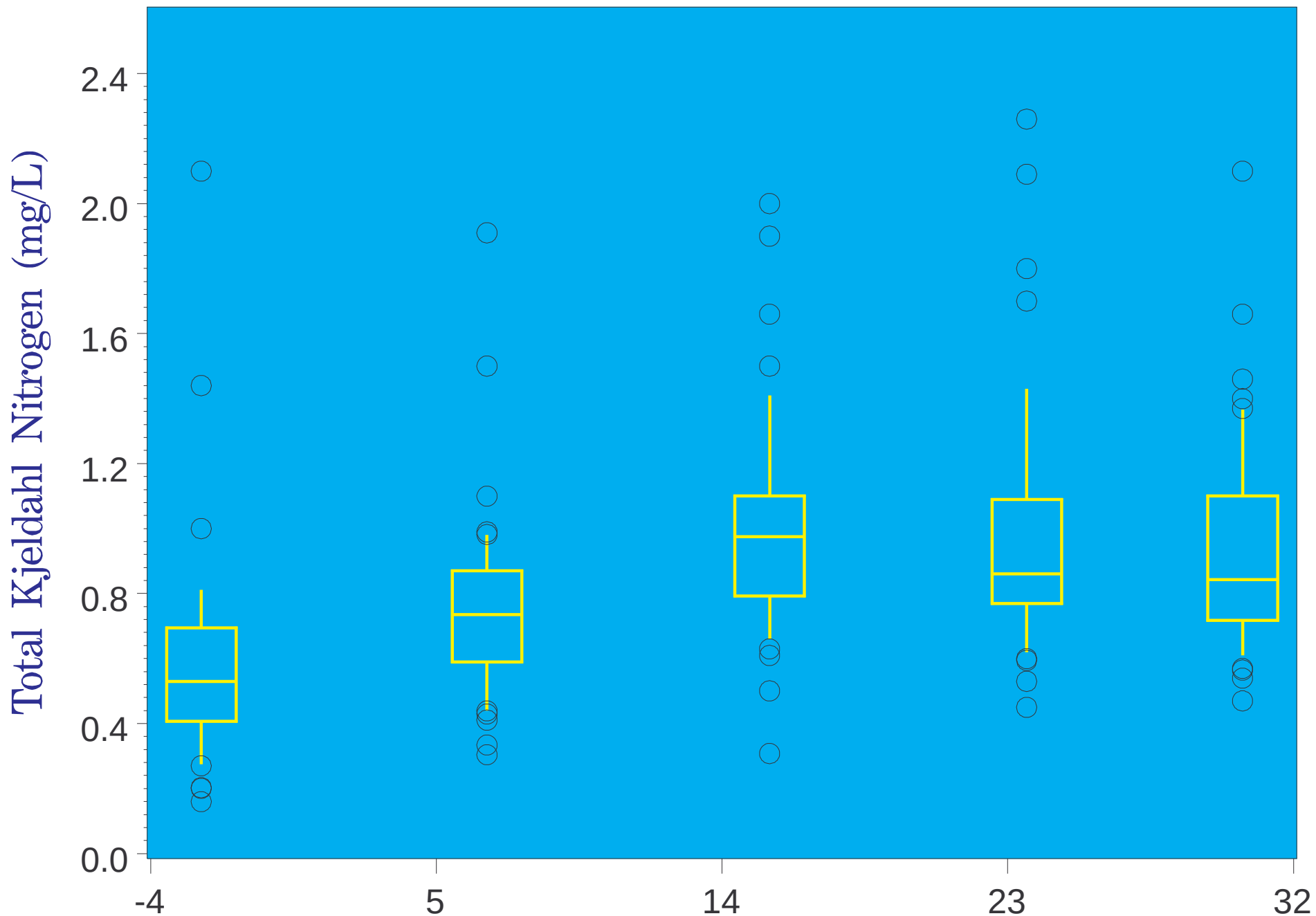


Figure 4.5.300 Box & whiskers of surface total Kjeldahl nitrogen by river kilometer (160 to 360 cfs)

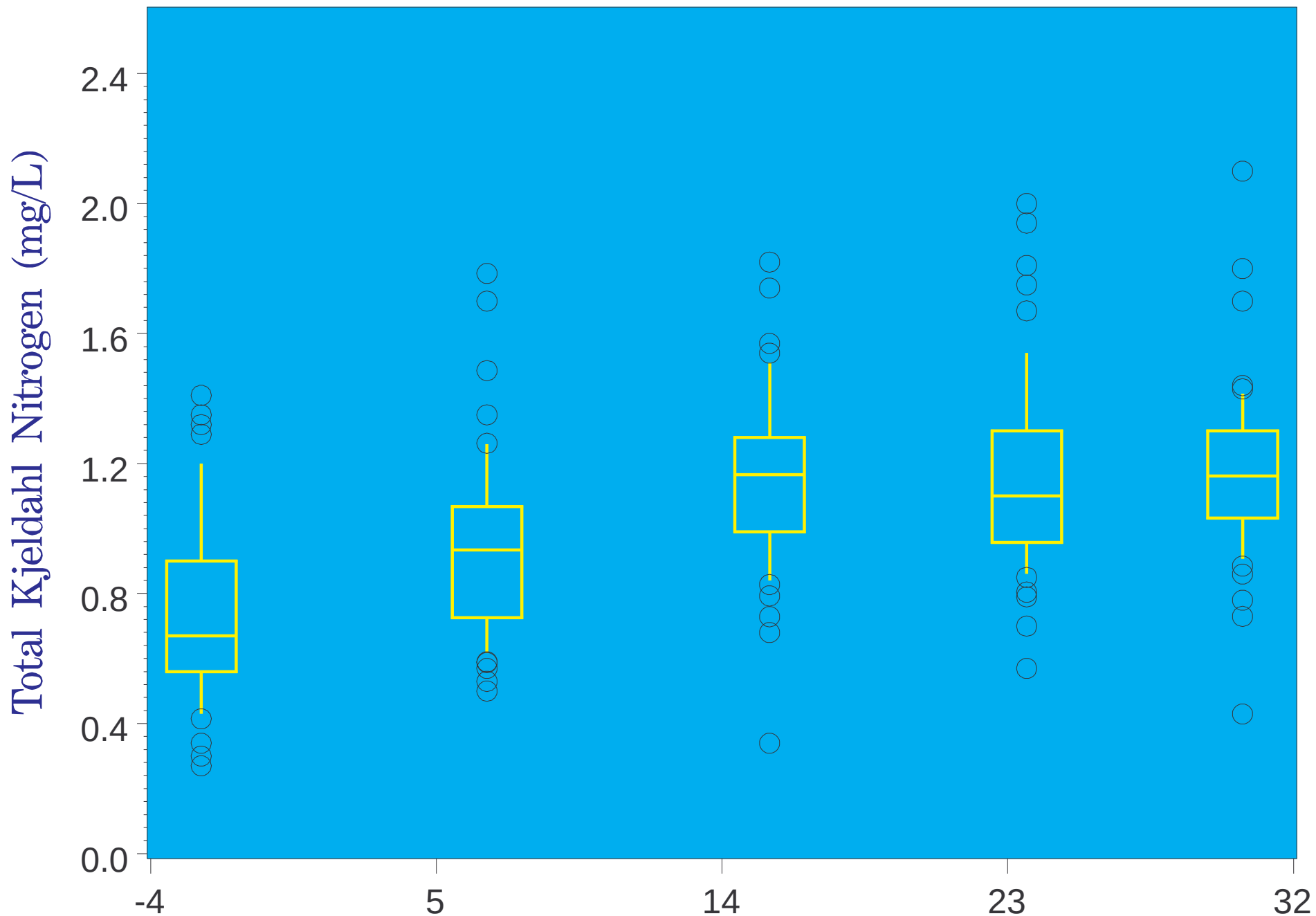


Figure 4.5.301 Box & whiskers of surface total Kjeldahl nitrogen by river kilometer (360 to 920 cfs)

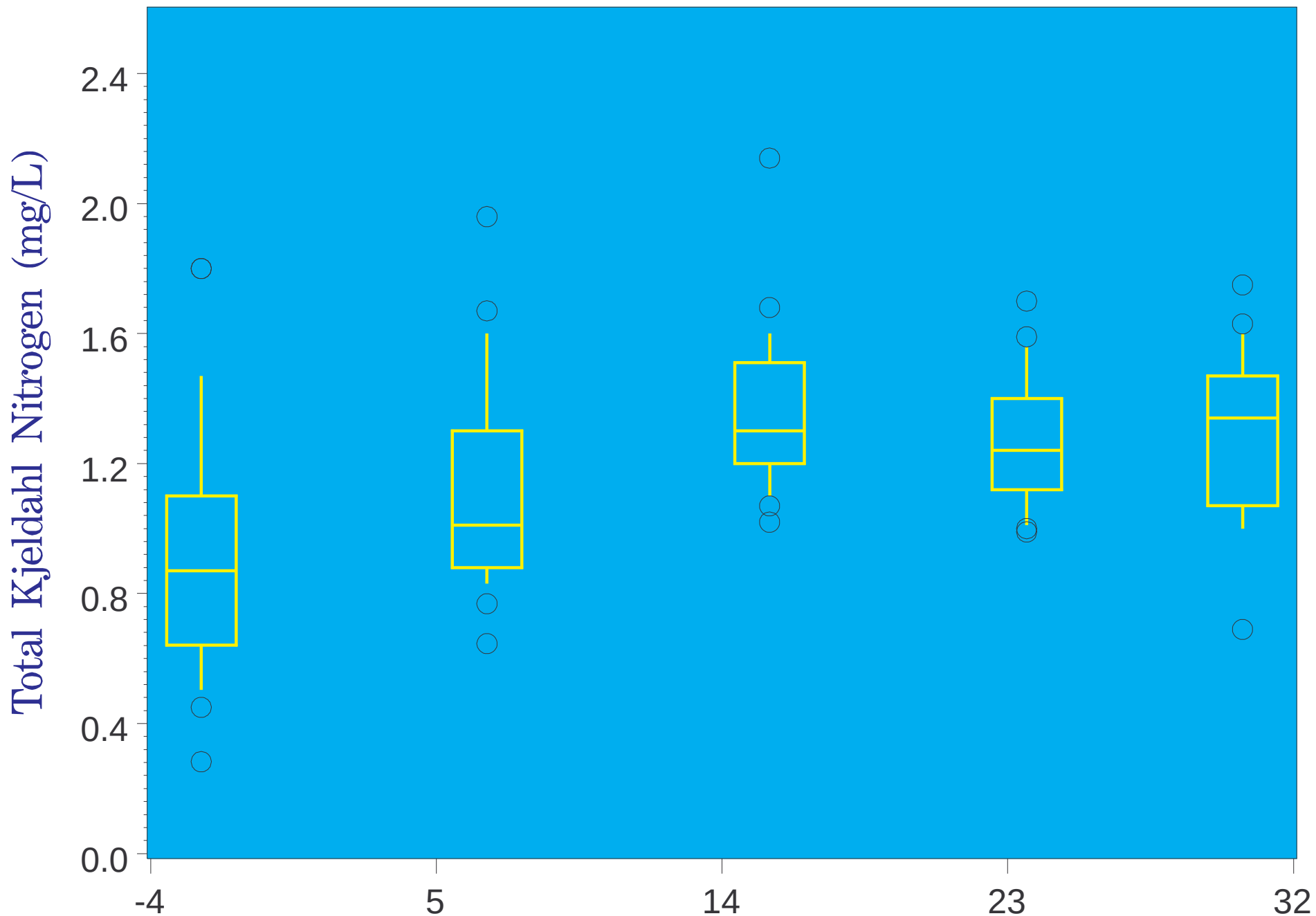


Figure 4.5.302 Box & whiskers of surface total Kjeldahl nitrogen by river kilometer (920 to 2100 cfs)

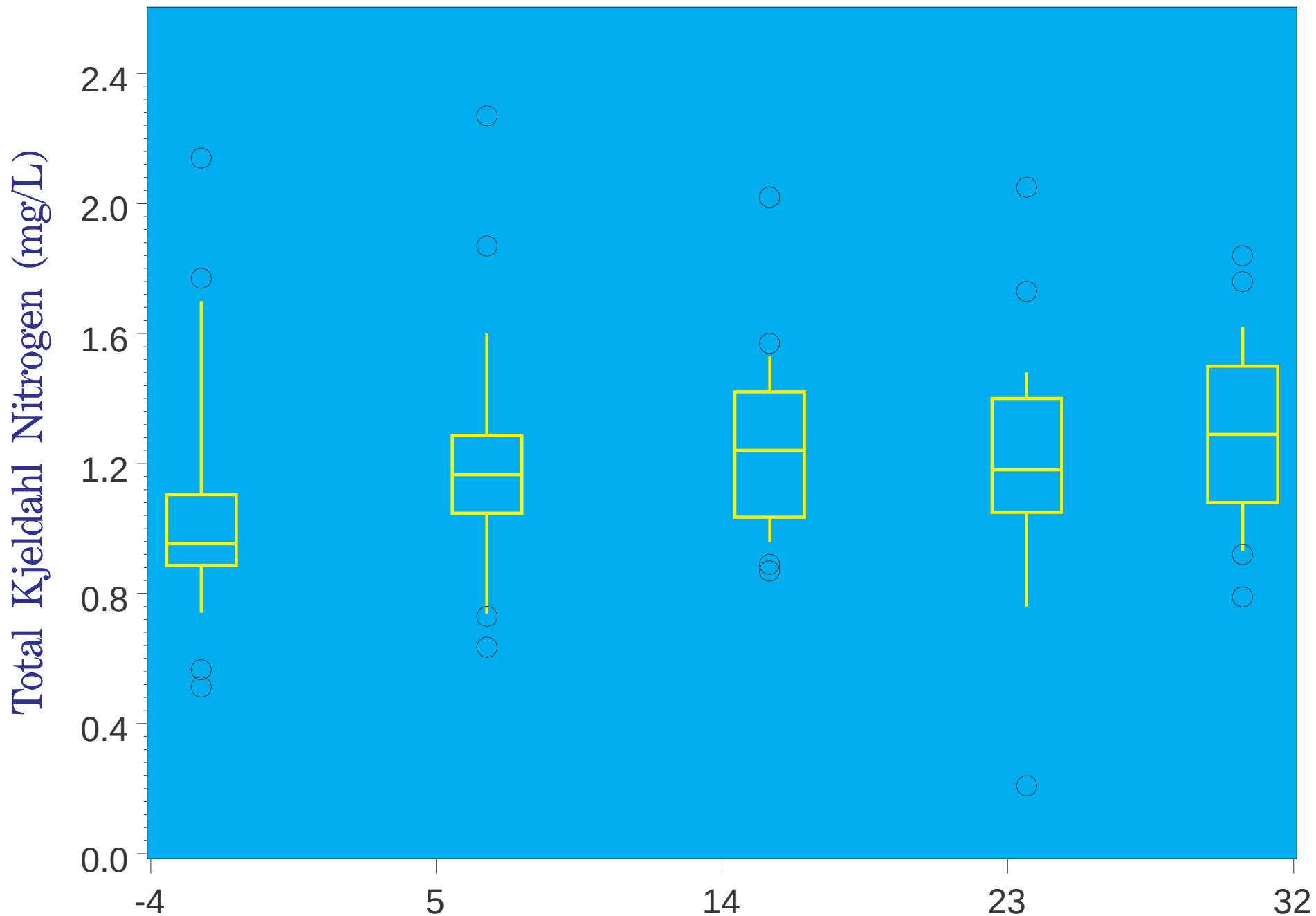


Figure 4.5.303 Box & whiskers of surface total Kjeldahl nitrogen by river kilometer (> 2100 cfs)

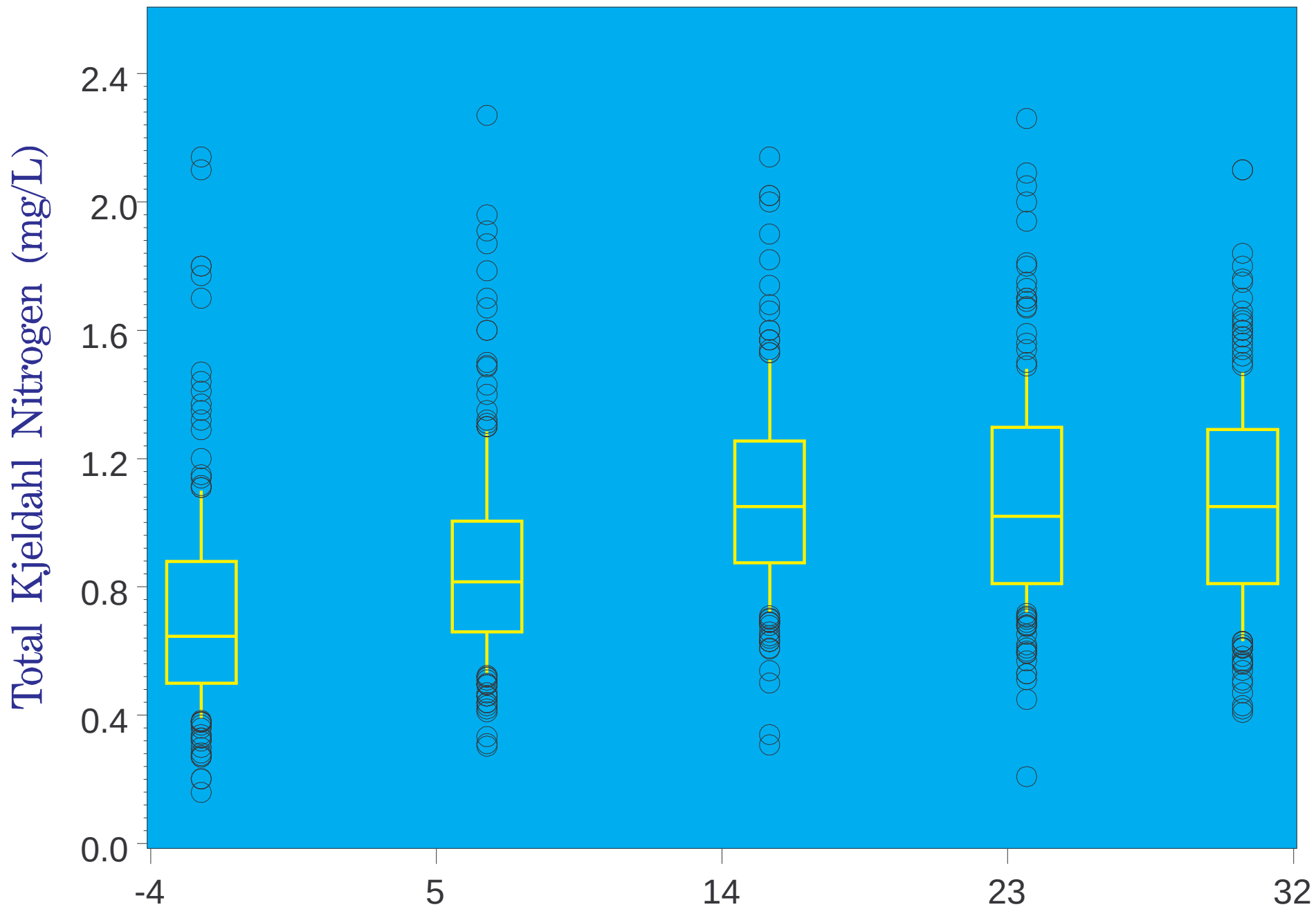


Figure 4.5.304 Box & whiskers of surface total Kjeldahl nitrogen by river kilometer (all flows)

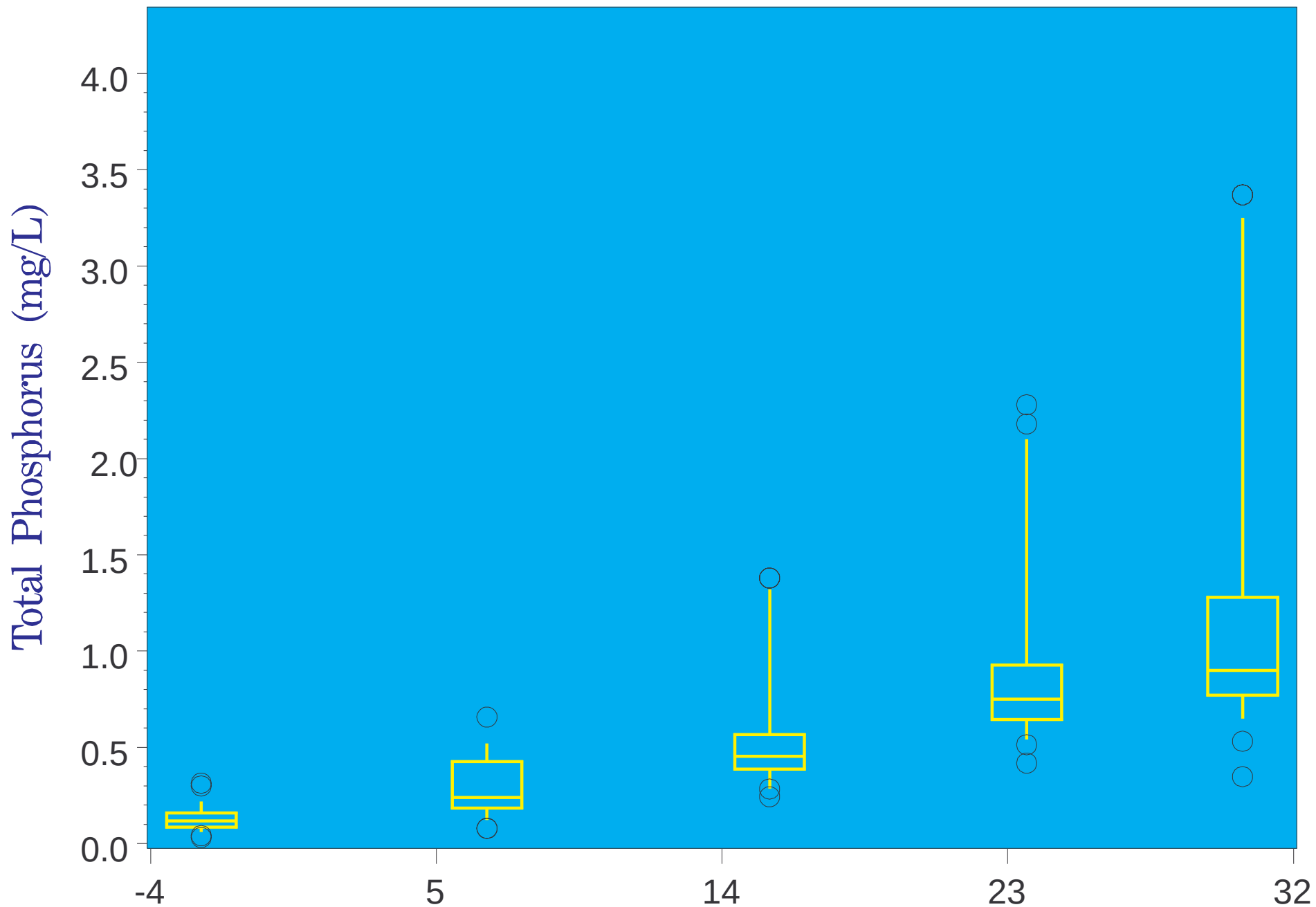


Figure 4.5.305 Box & whiskers of surface total phosphorus by river kilometer (0 to 90 cfs)



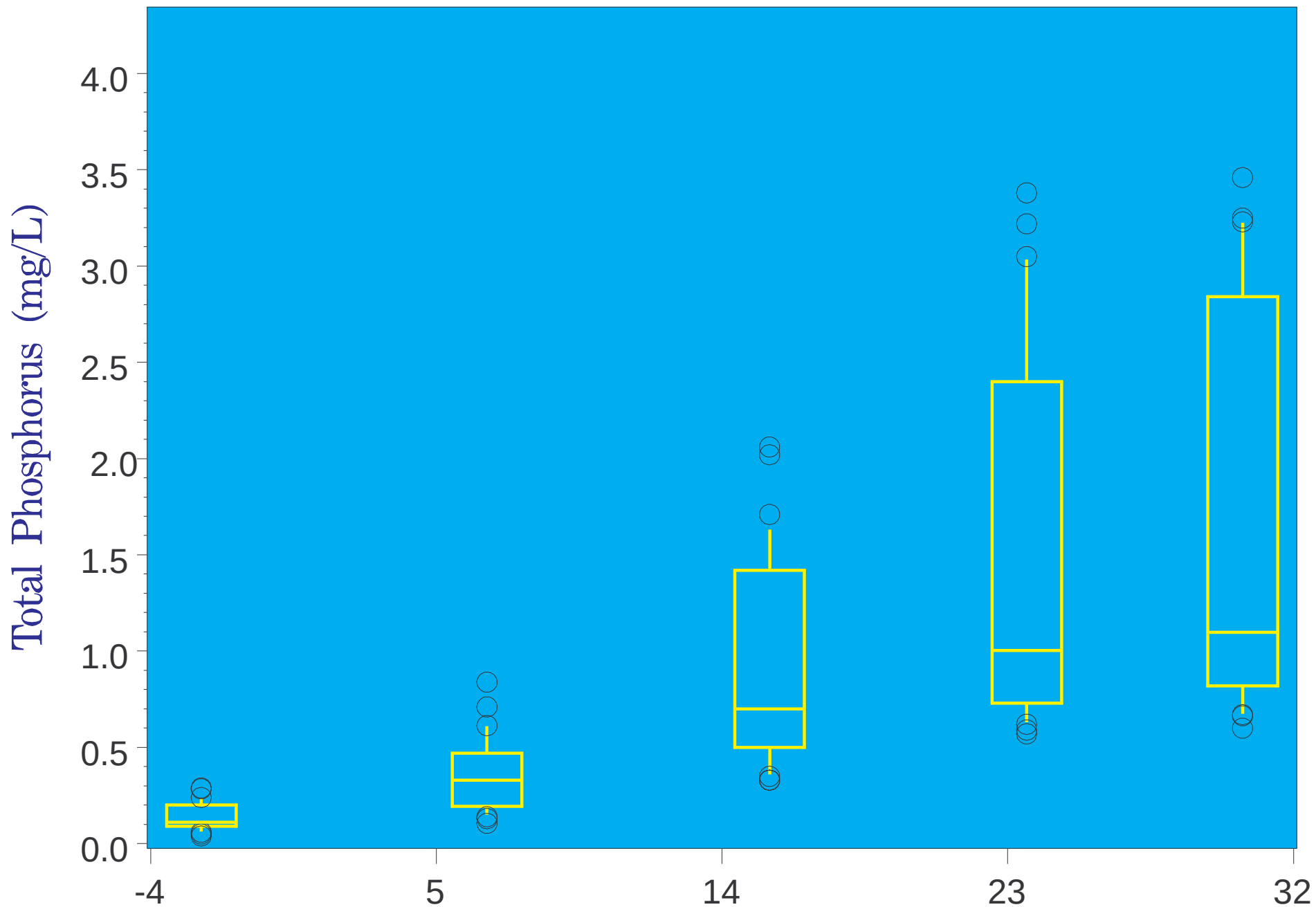


Figure 4.5.306 Box & whiskers of surface total phosphorus by river kilometer (90 to 160 cfs)

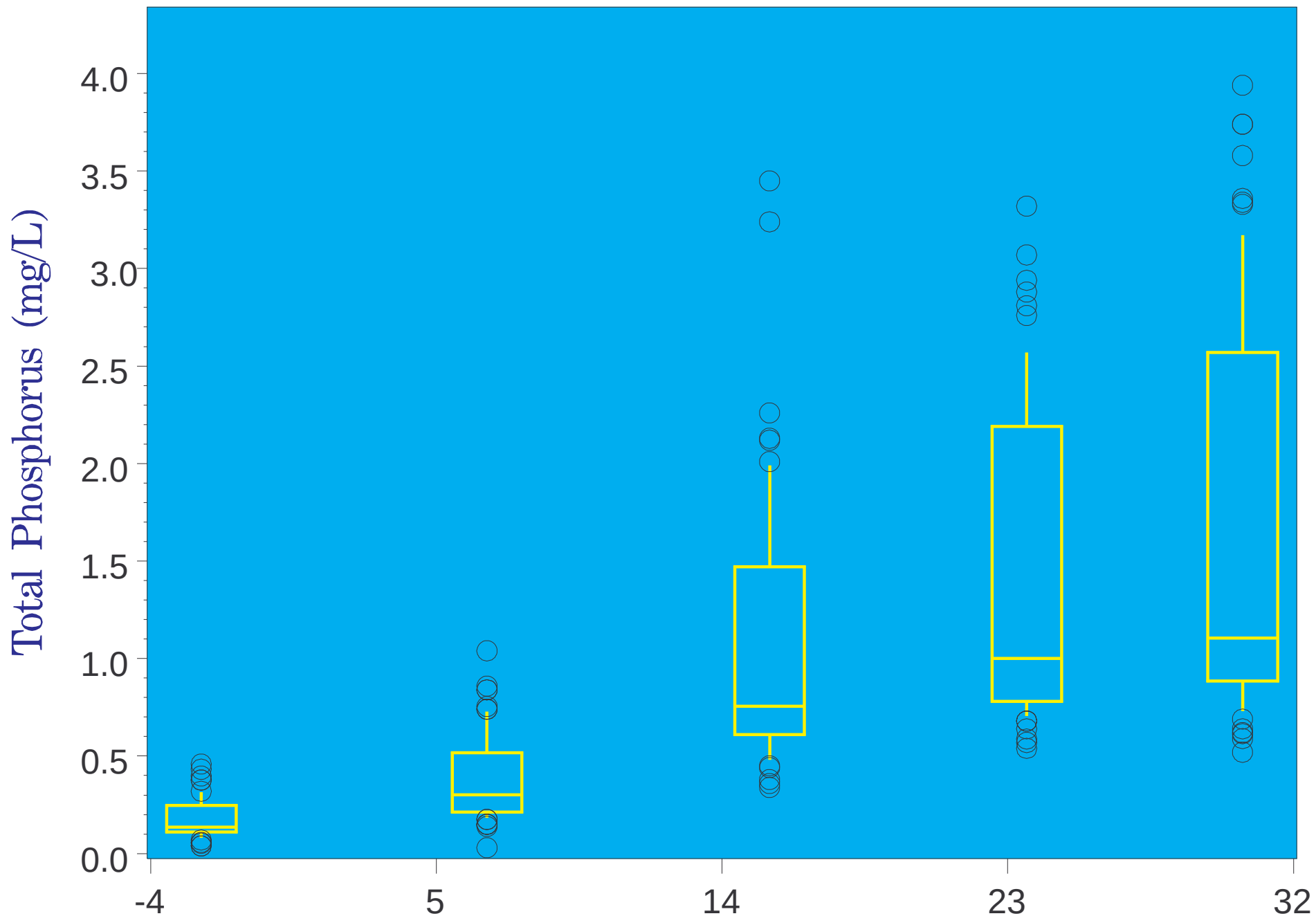


Figure 4.5.307 Box & whiskers of surface total phosphorus by river kilometer (160 to 360 cfs)

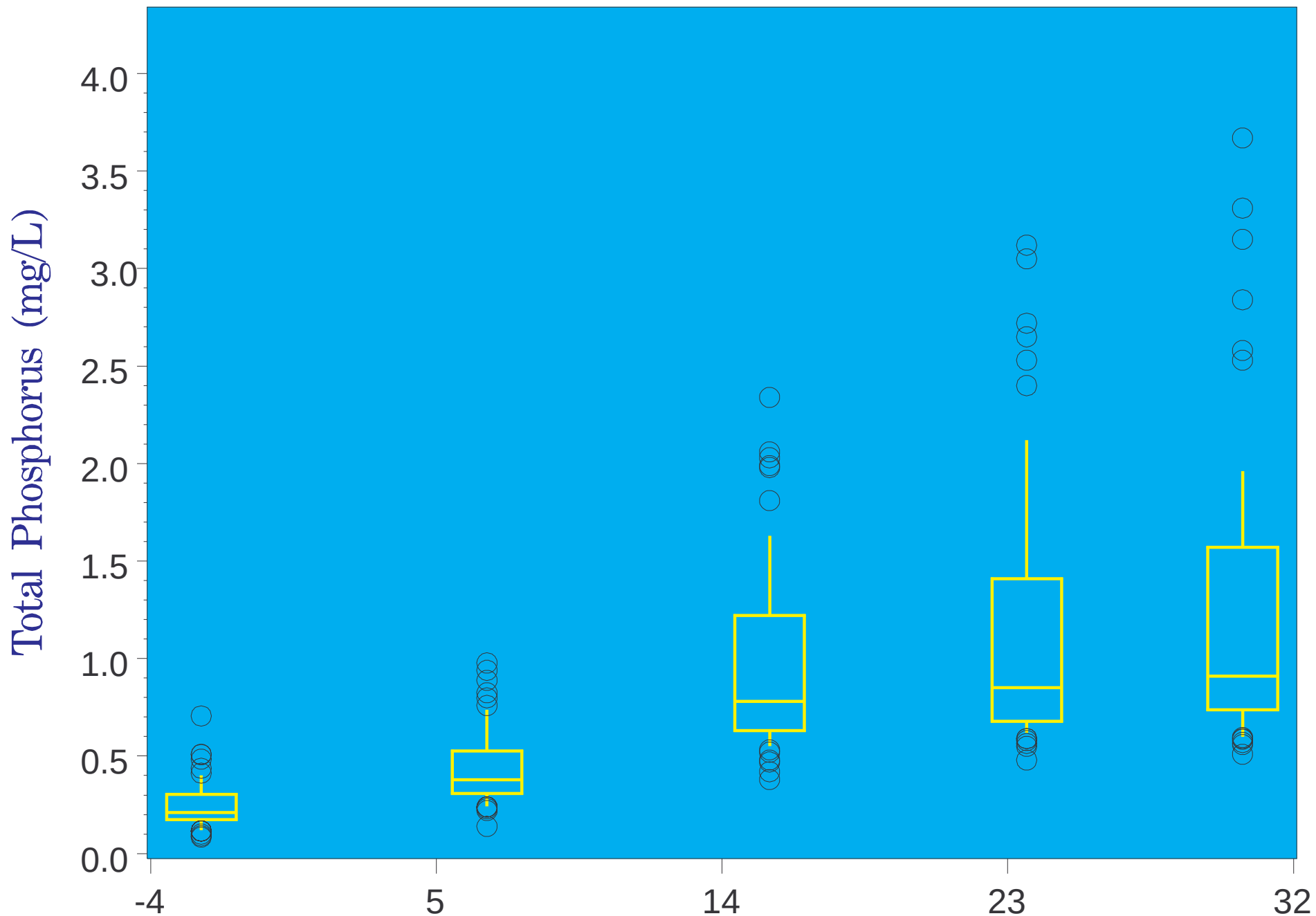


Figure 4.5.308 Box & whiskers of surface total phosphorus by river kilometer (360 to 920 cfs)

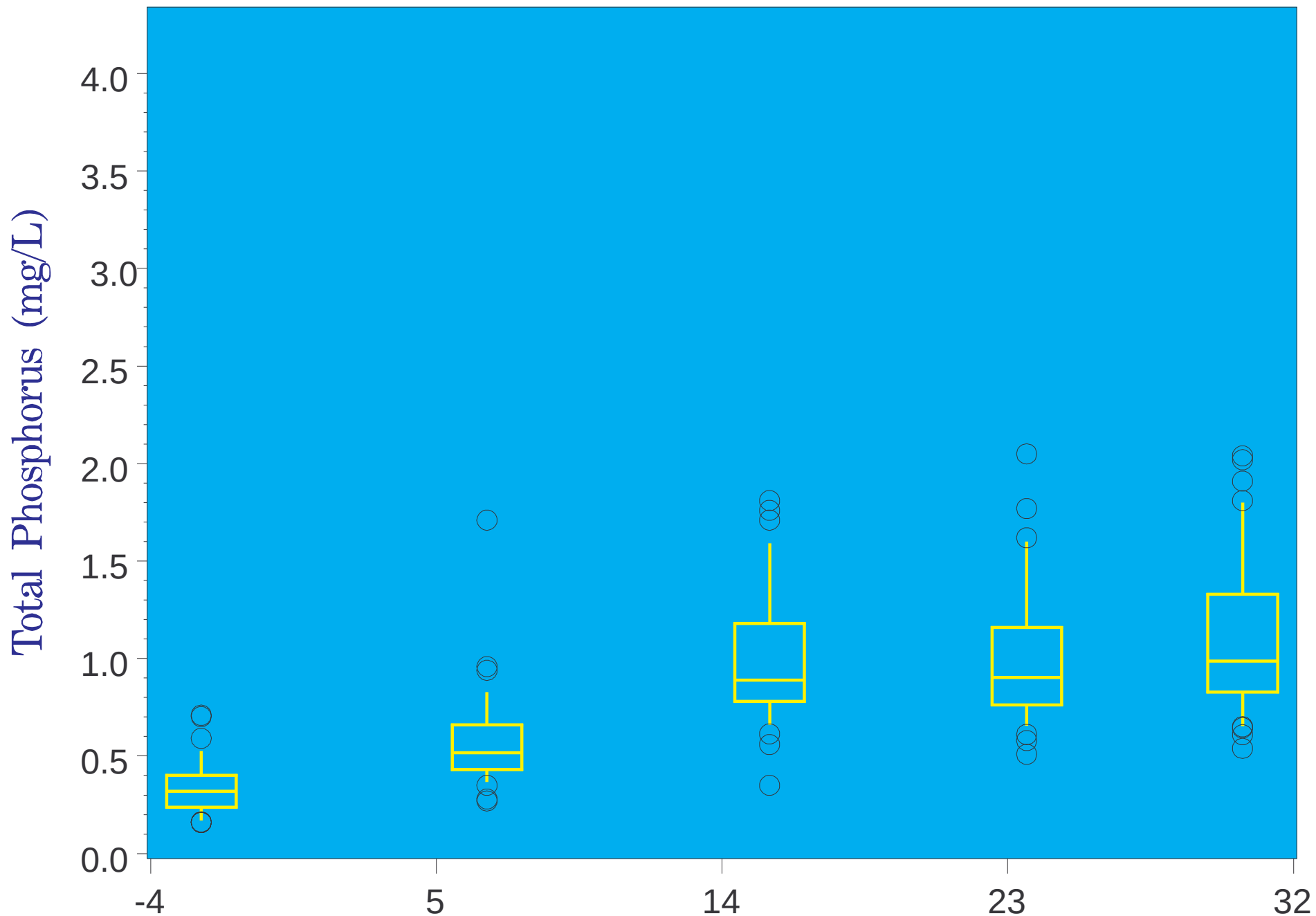


Figure 4.5.309 Box & whiskers of surface total phosphorus by river kilometer (920 to 2100 cfs)

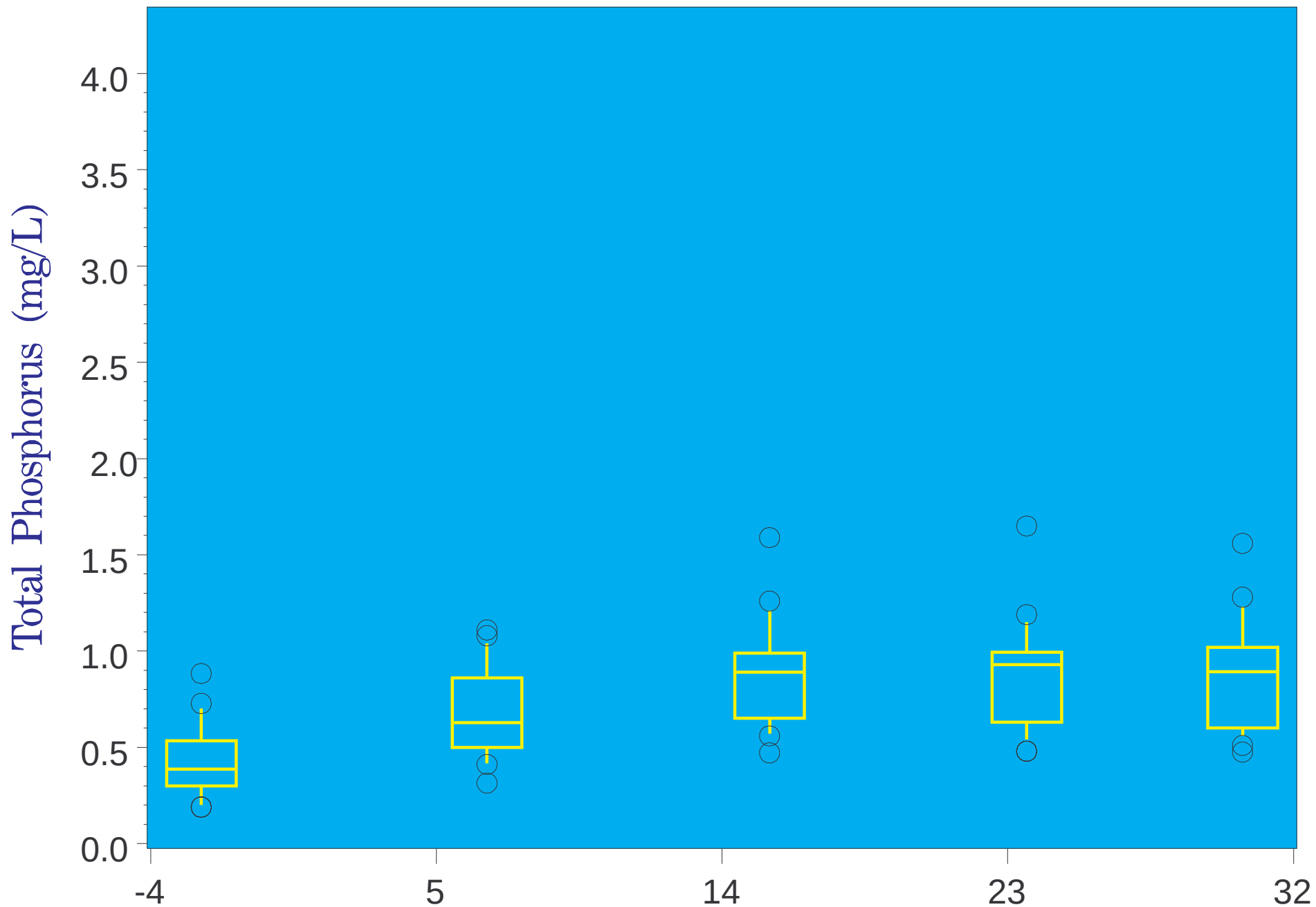


Figure 4.5.310 Box & whiskers of surface total phosphorus by river kilometer (> 2100 cfs)

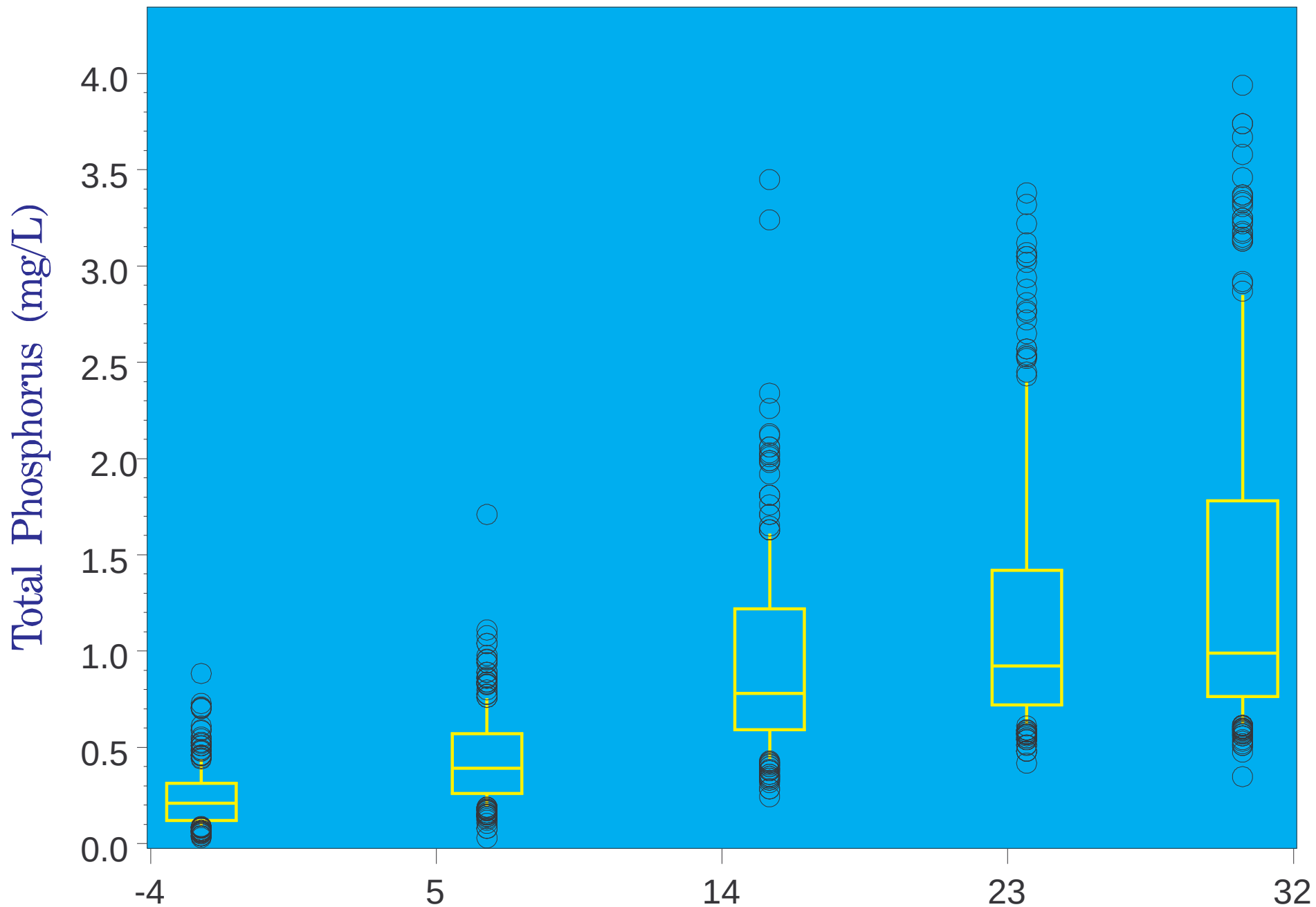


Figure 4.5.311 Box & whiskers of surface total phosphorus by river kilometer (all flows)

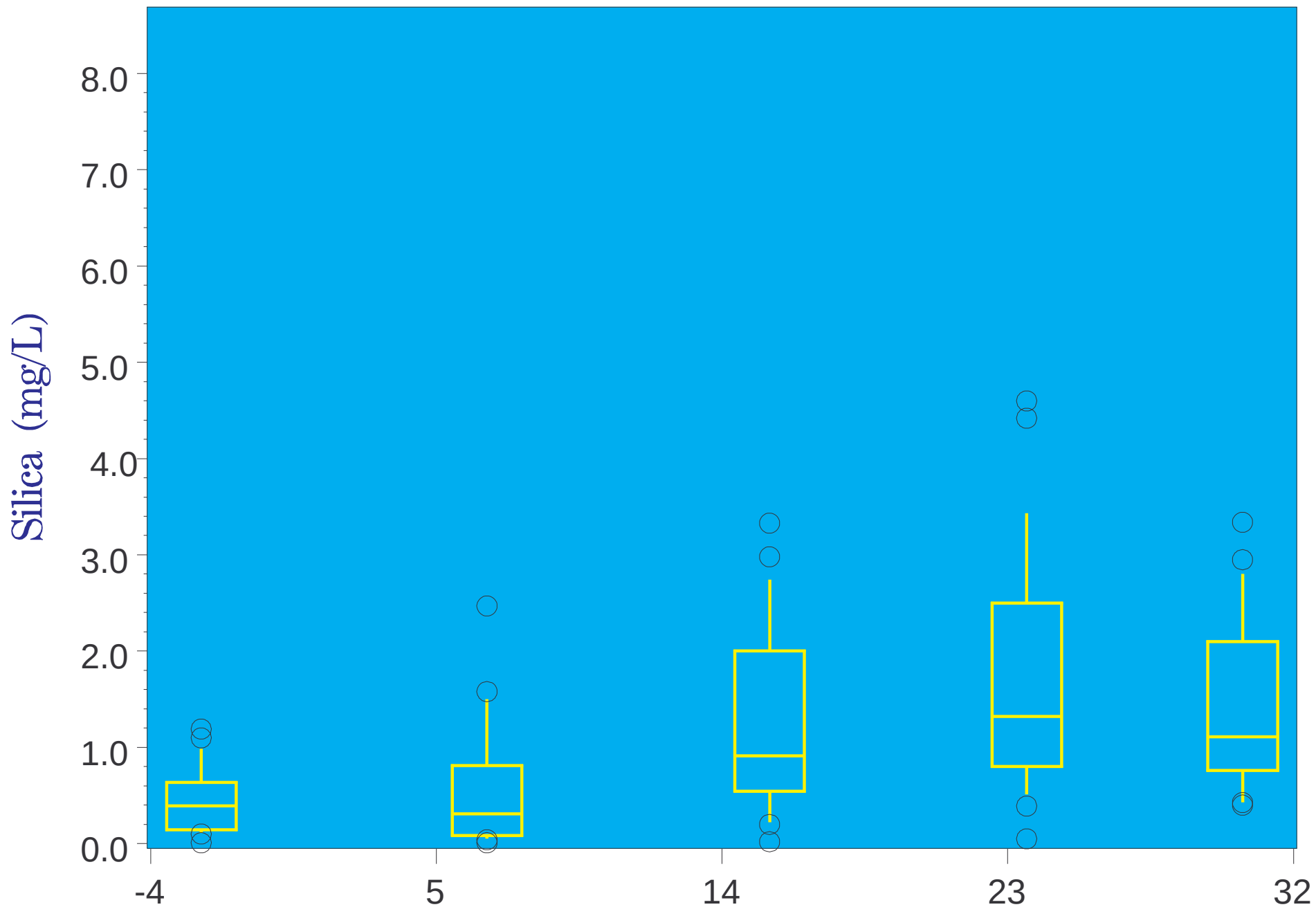


Figure 4.5.312 Box & whiskers of surface silica by river kilometer (0 to 90 cfs)

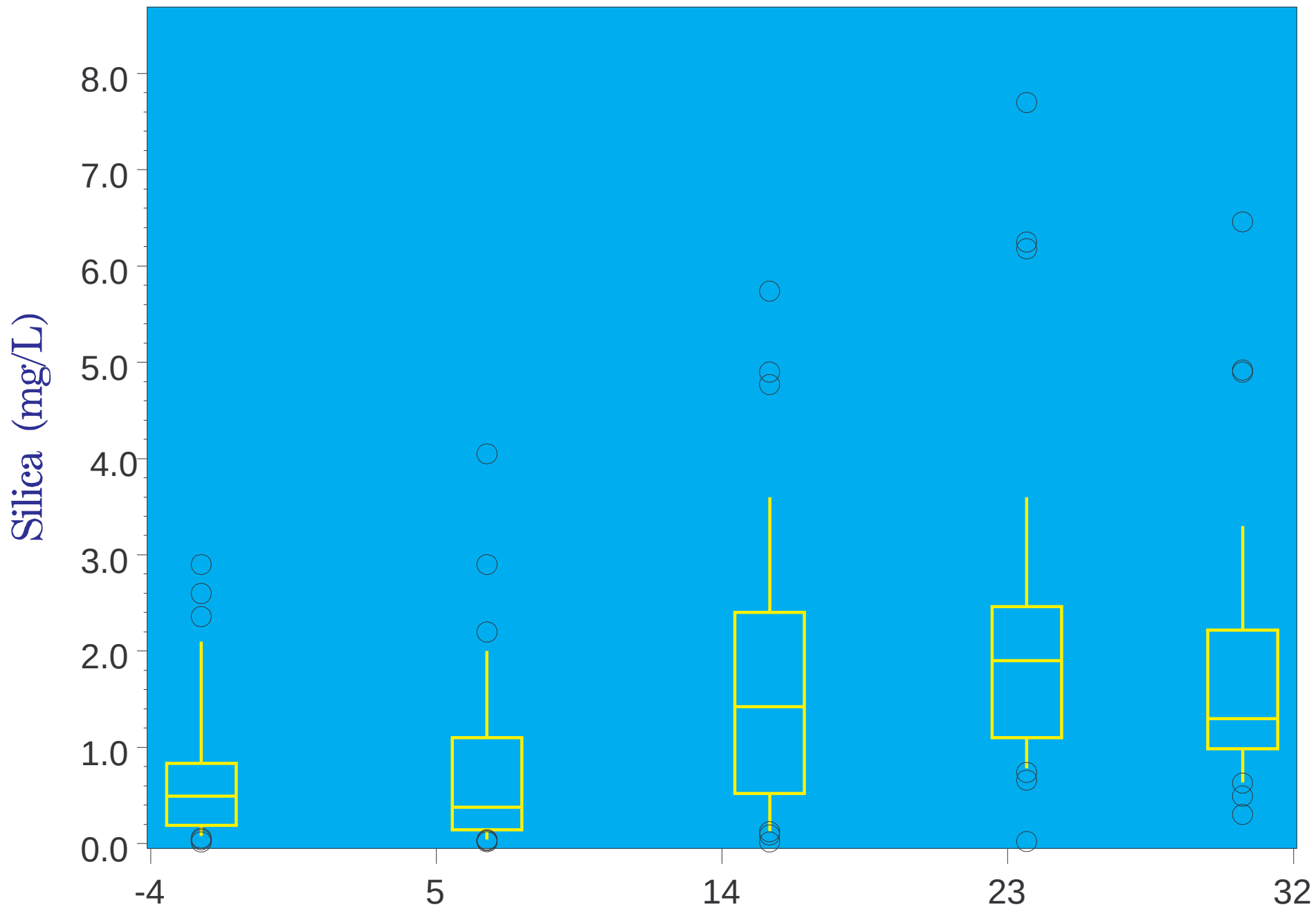


Figure 4.5.313 Box & whiskers of surface silica by river kilometer (90 to 160 cfs)



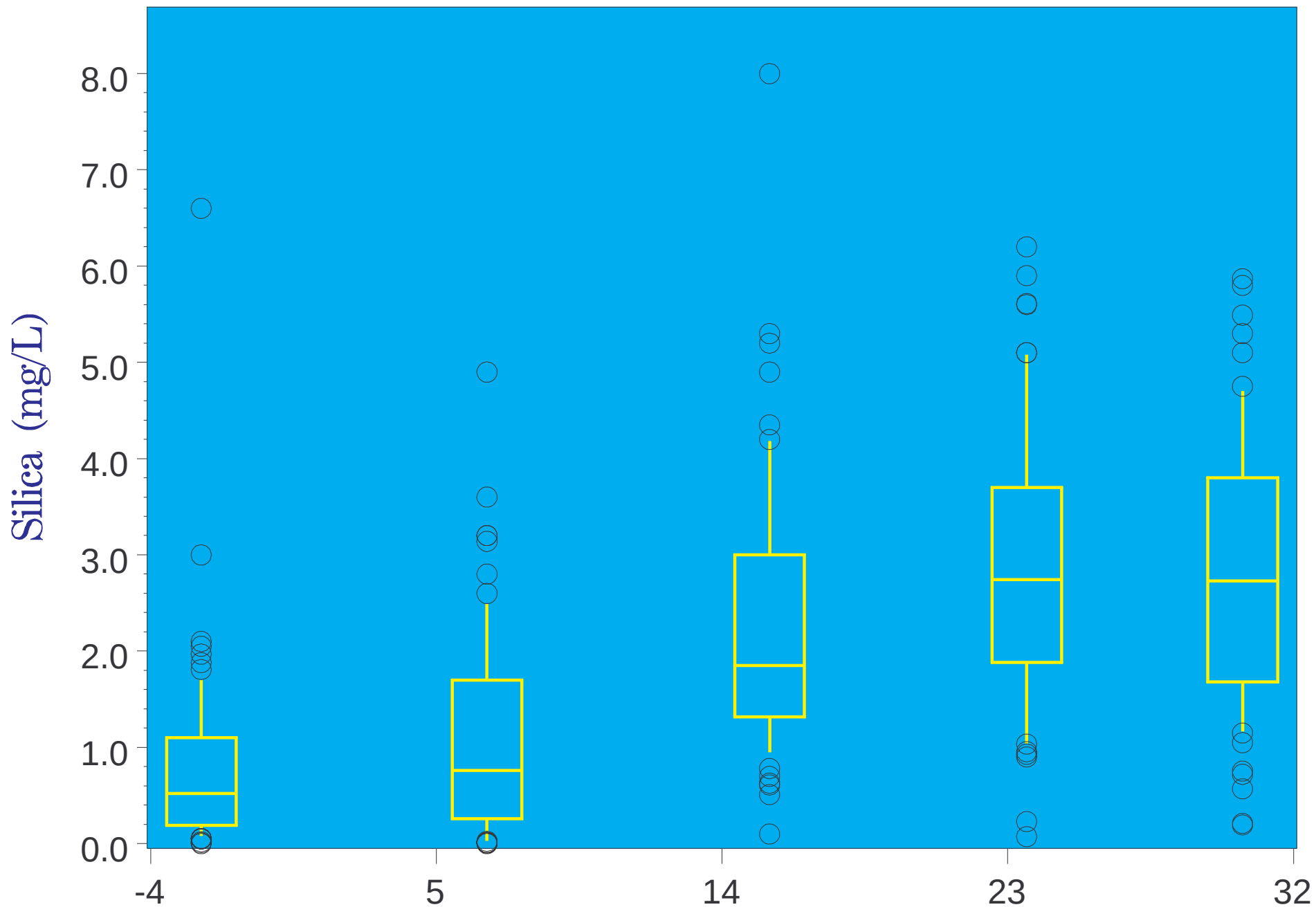


Figure 4.5.314 Box & whiskers of surface silica by river kilometer (160 to 360 cfs)

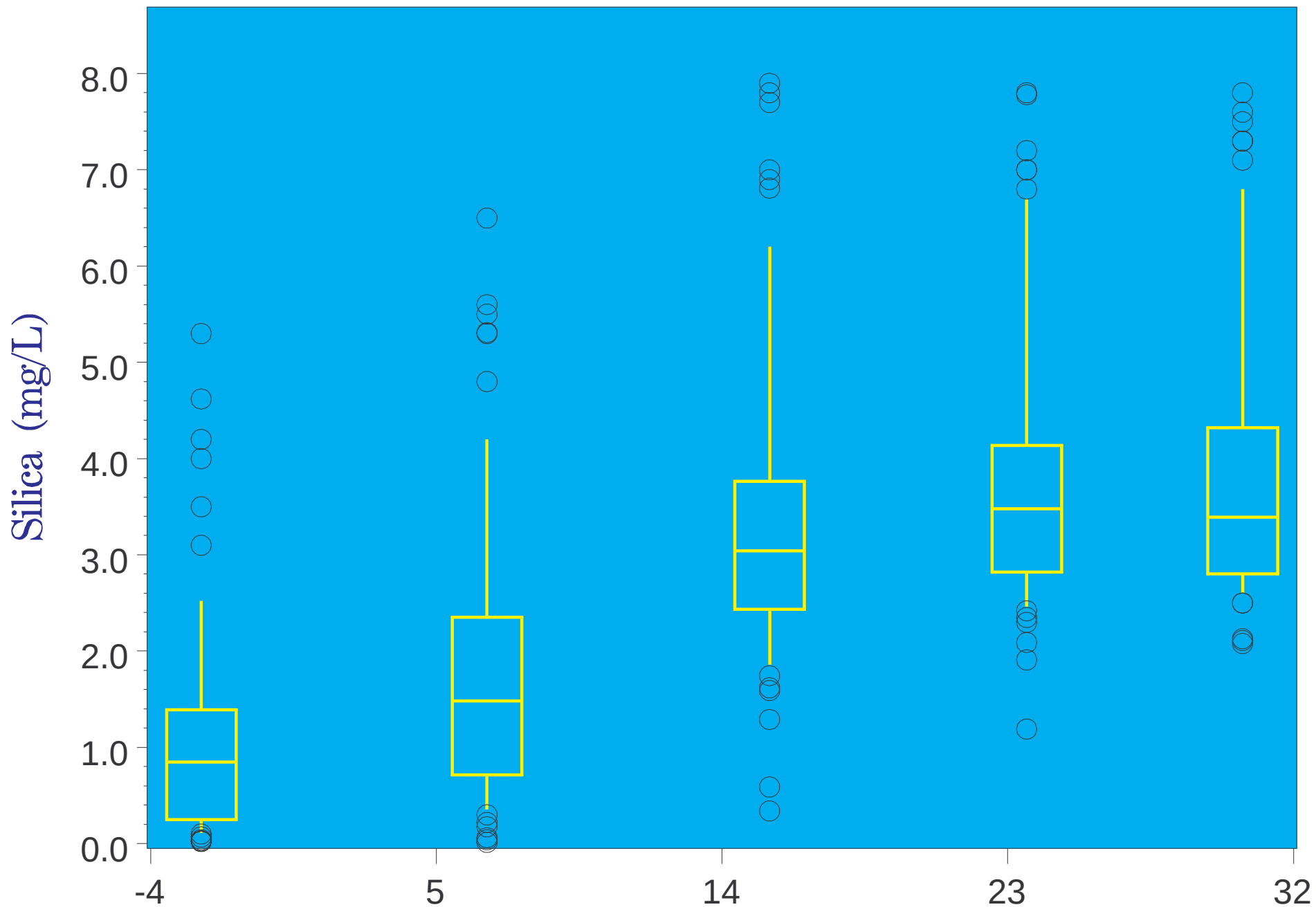


Figure 4.5.315 Box & whiskers of surface silica by river kilometer (360 to 920 cfs)

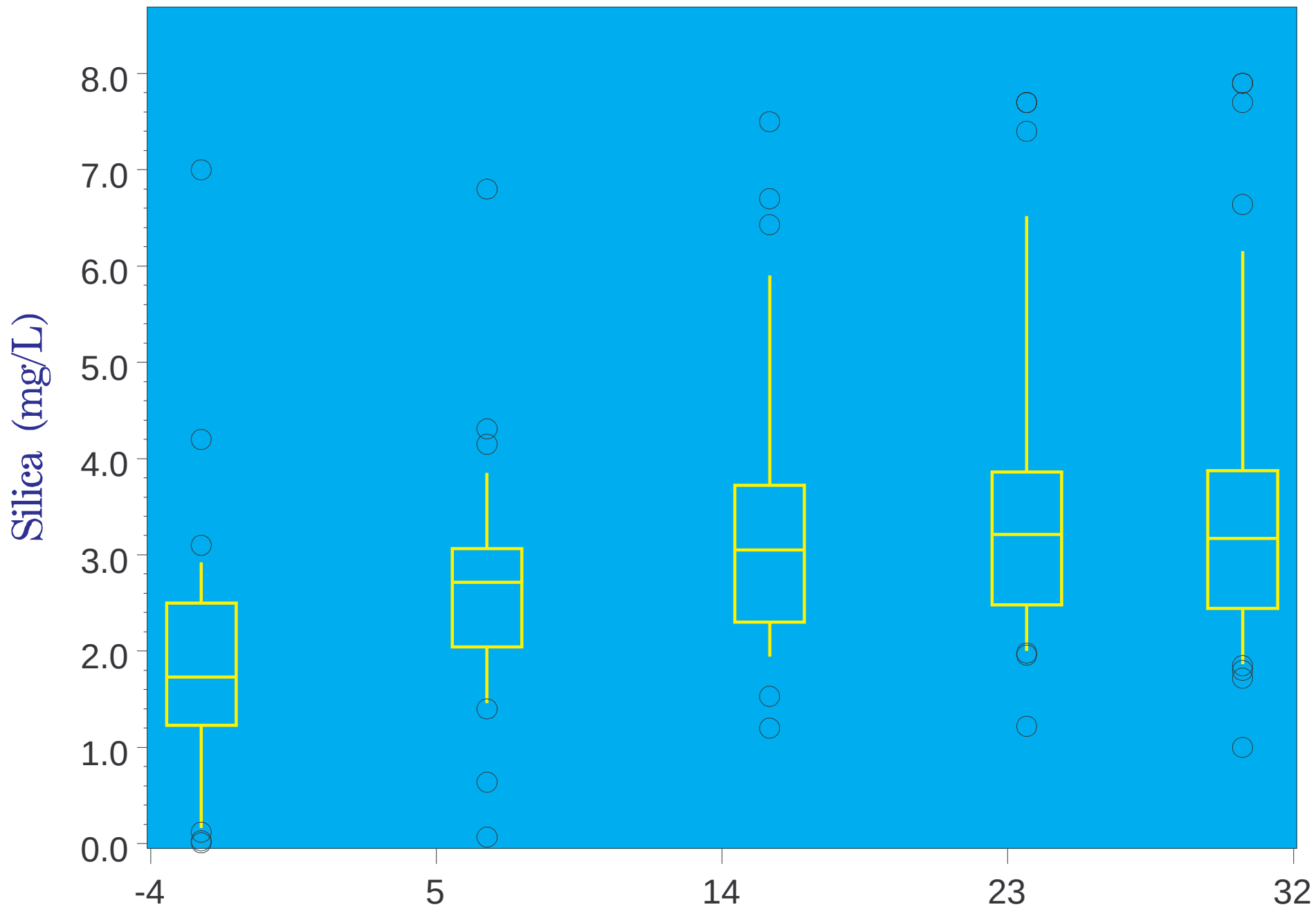


Figure 4.5.316 Box & whiskers of surface silica by river kilometer (920 to 2100 cfs)

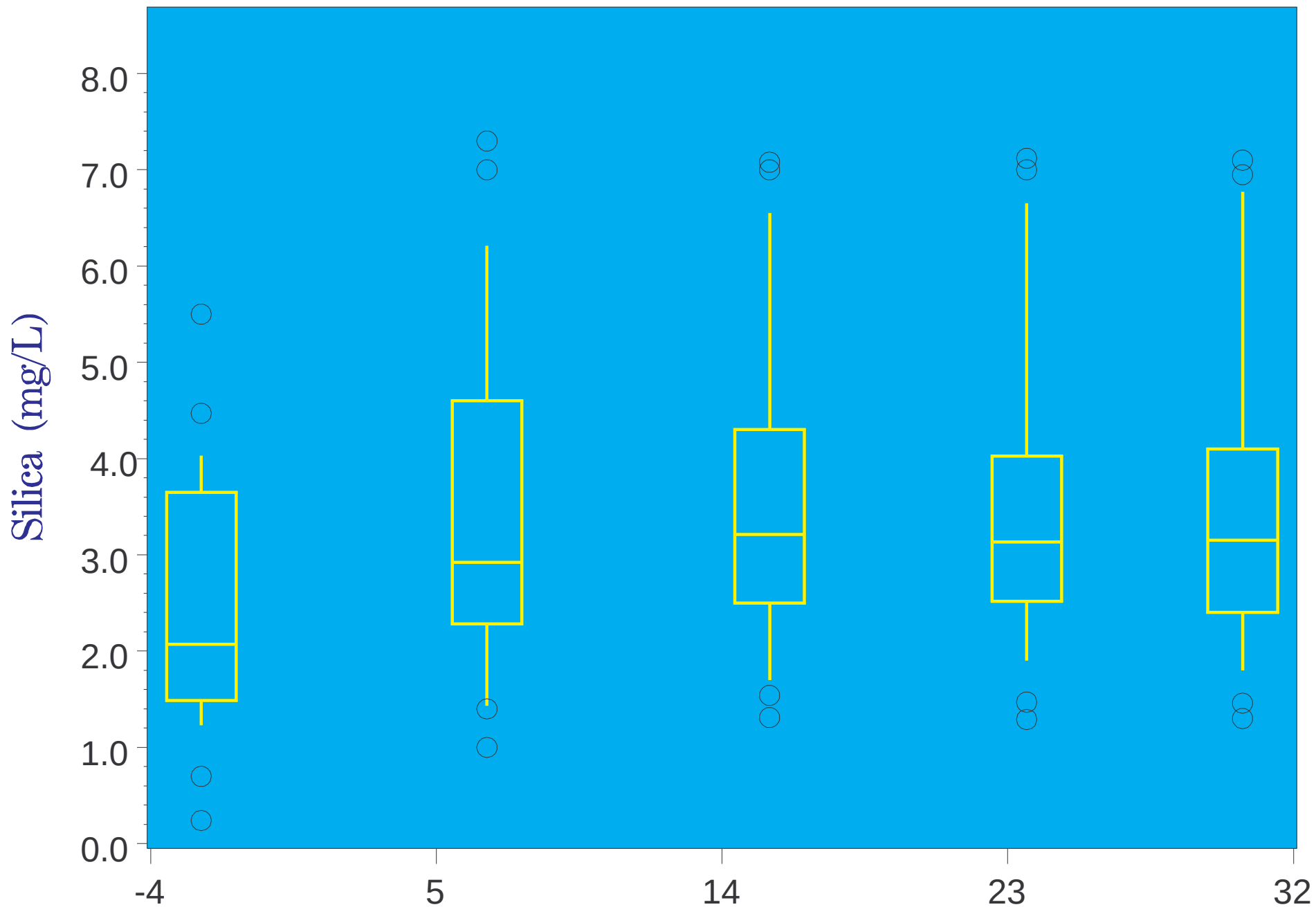


Figure 4.5.317 Box & whiskers of surface silica by river kilometer (> 2100 cfs)

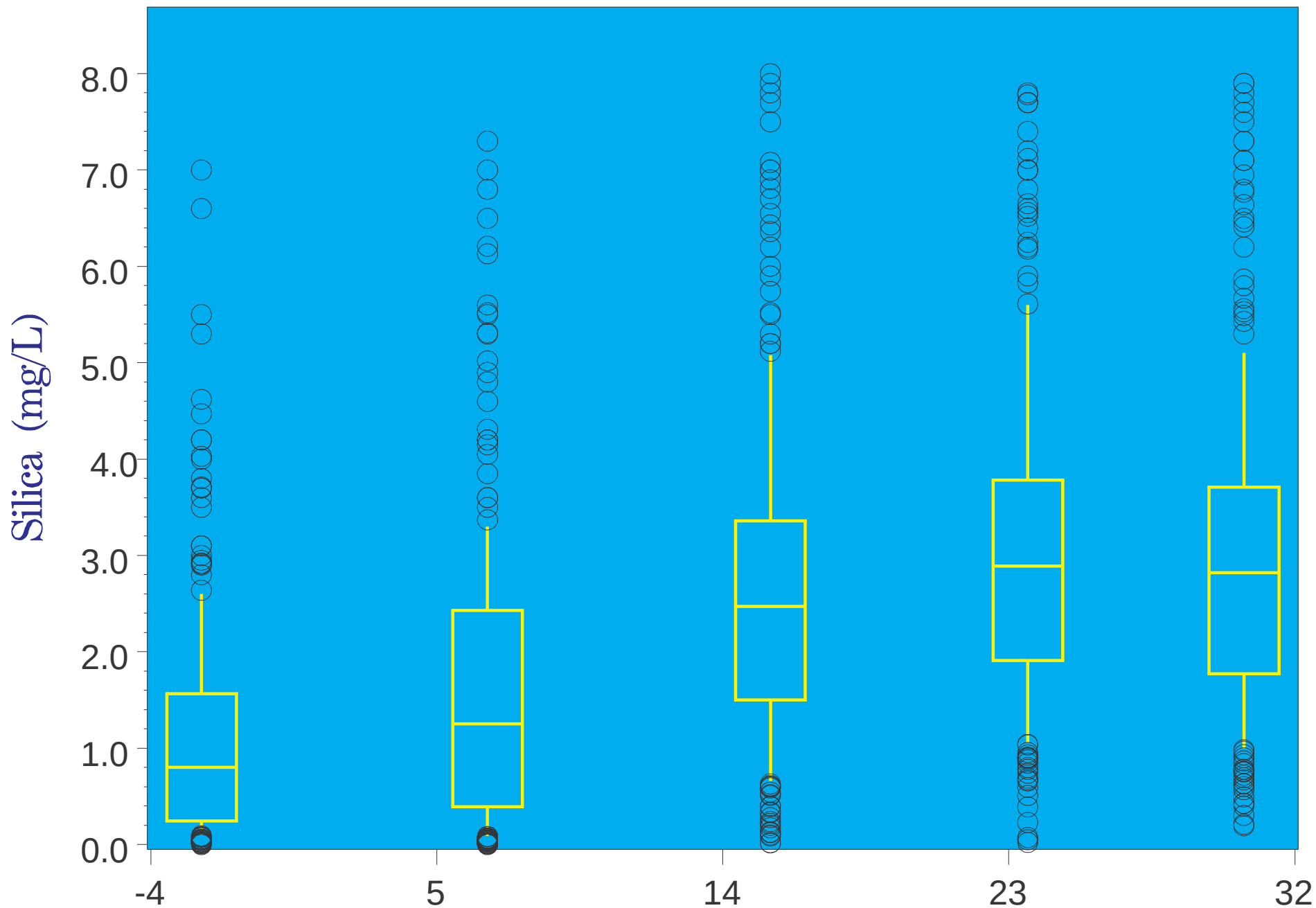


Figure 4.5.318 Box & whiskers of surface silica by river kilometer (all flows)

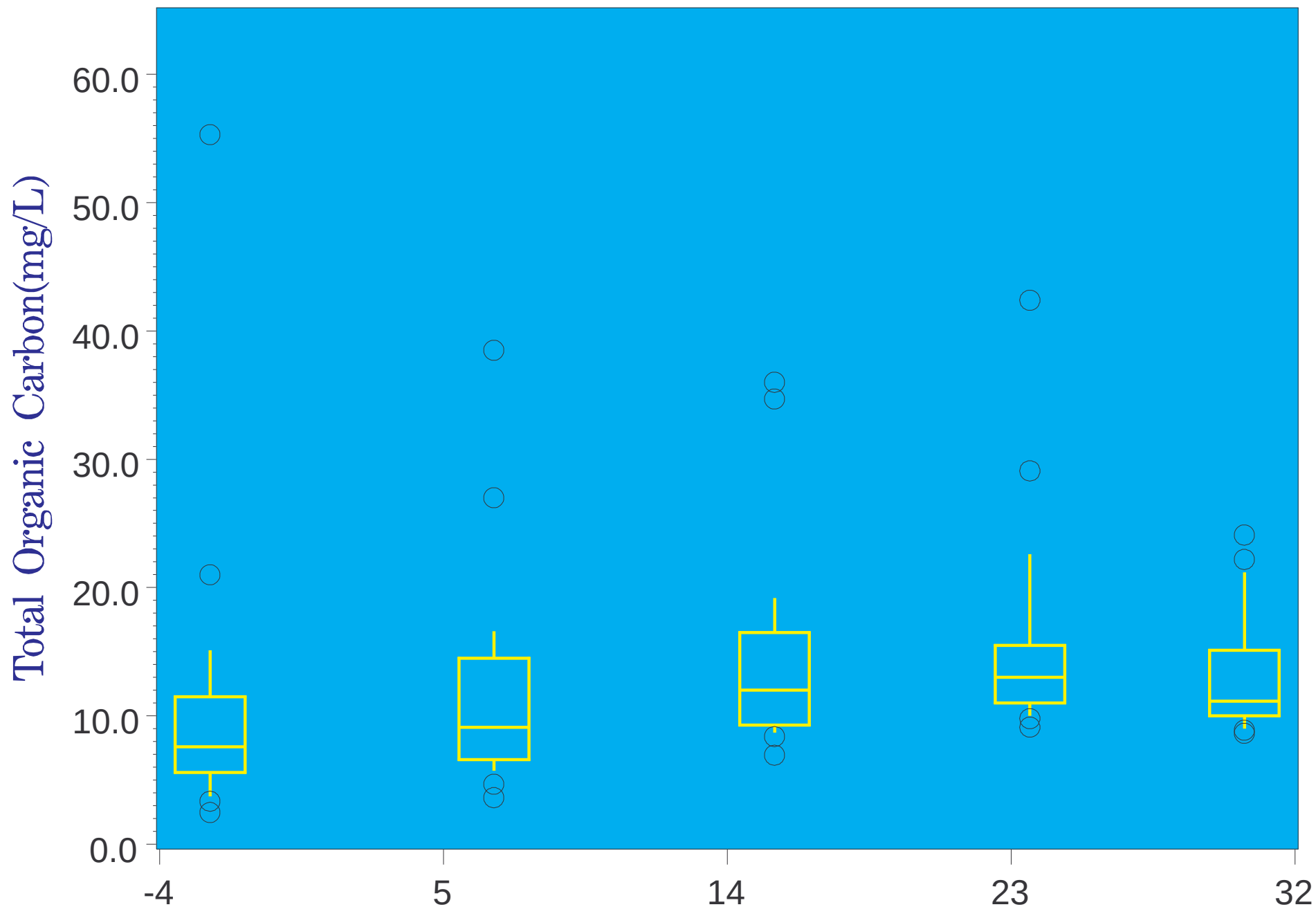


Figure 4.5.319 Box & whiskers of surface total organic carbon by river kilometer (0 to 90 cfs)

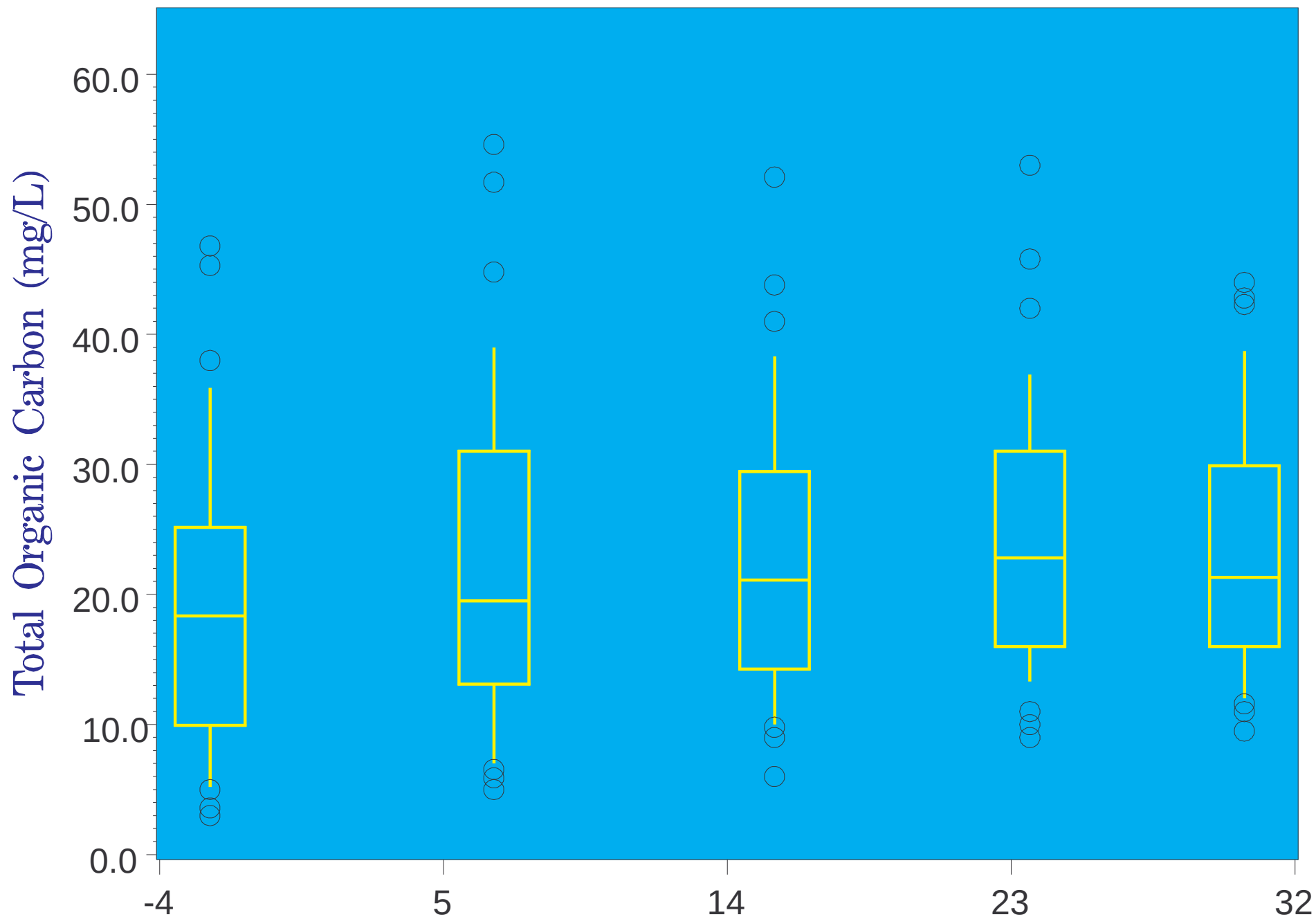


Figure 4.5.320 Box & whiskers of surface total organic carbon by river kilometer (90 to 160 cfs)

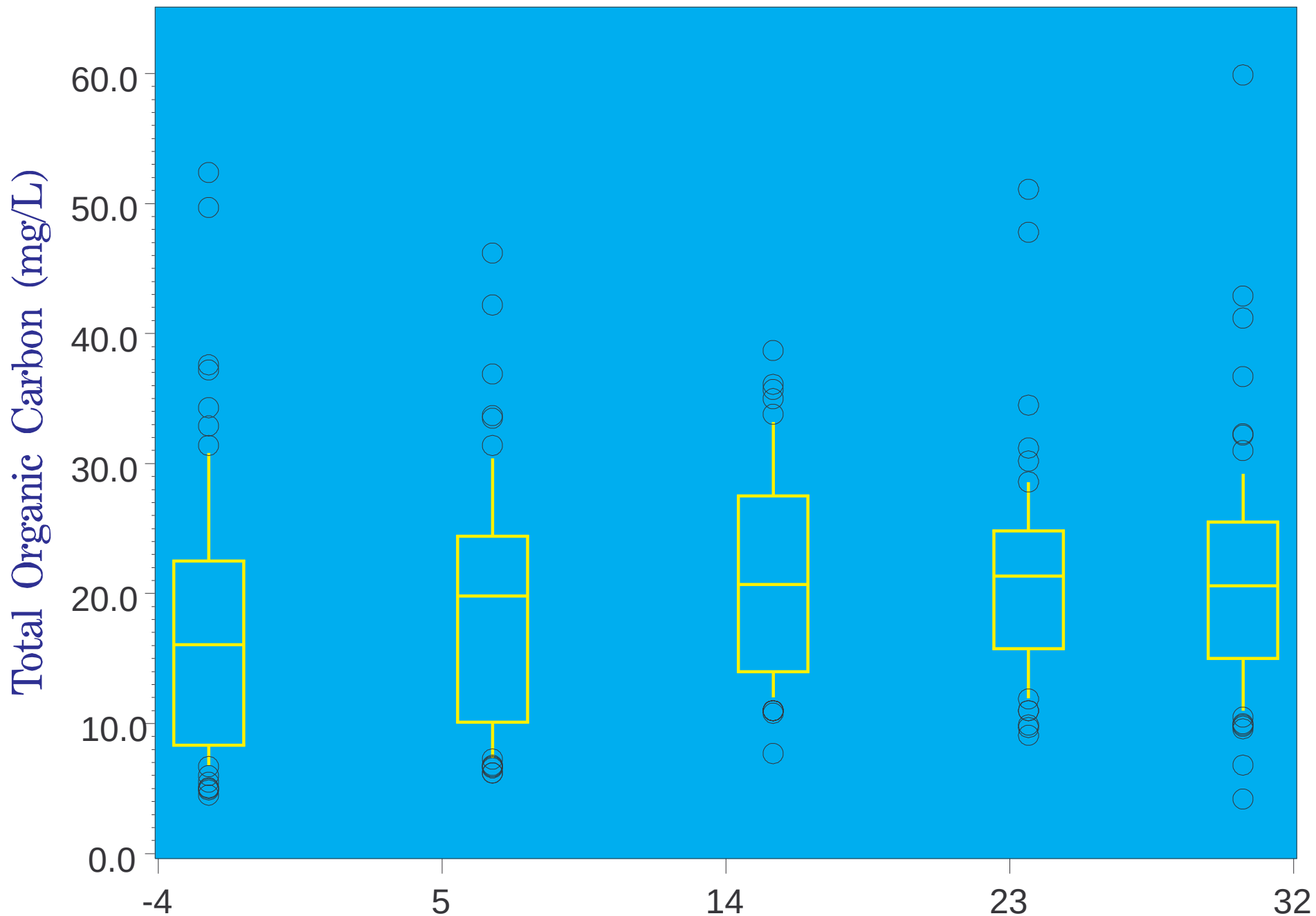


Figure 4.5.321 Box & whiskers of surface total organic carbon by river kilometer (160 to 360 cfs)



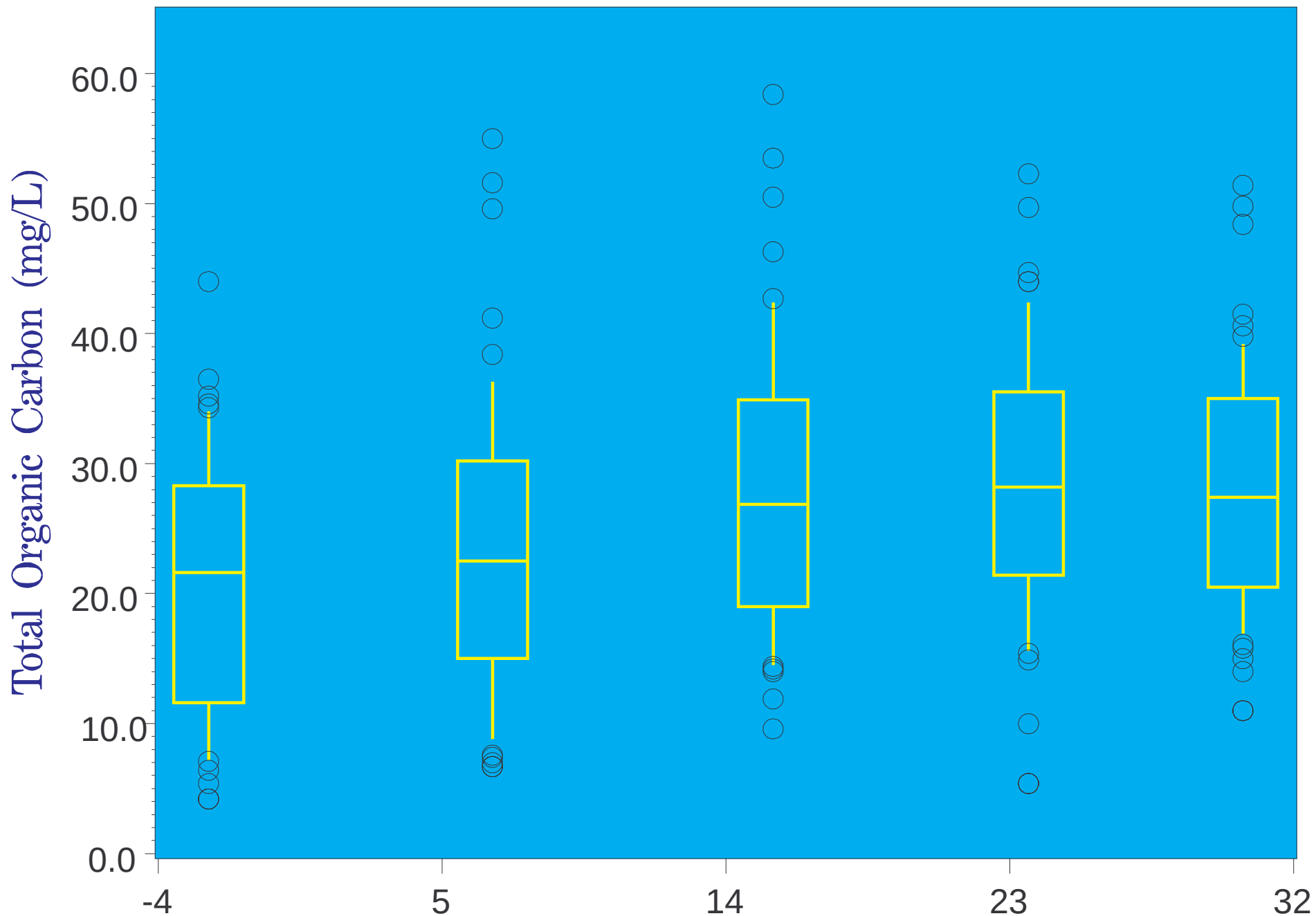


Figure 4.5.322 Box & whiskers of surface total organic carbon by river kilometer (360 to 920 cfs)

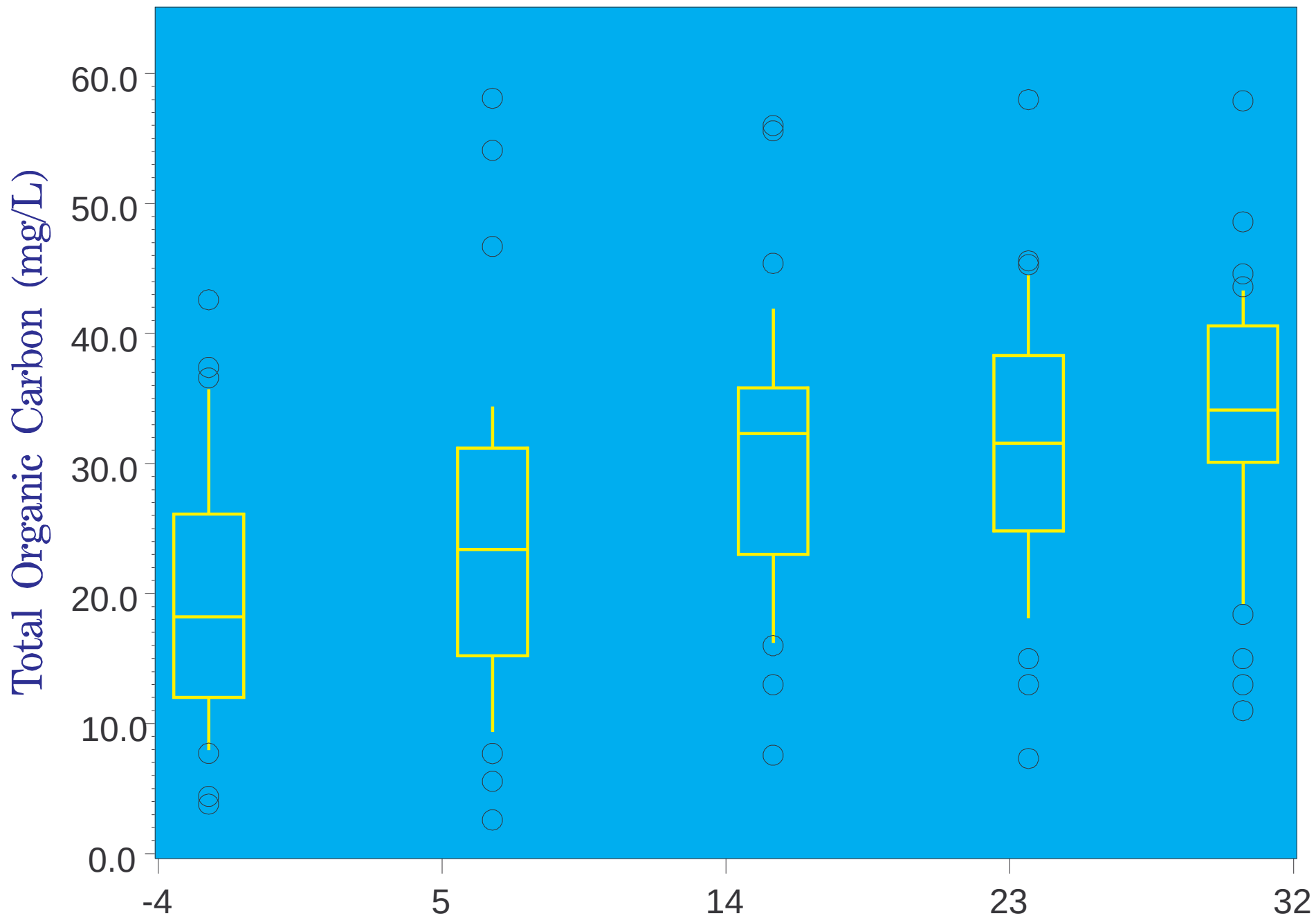


Figure 4.5.323 Box & whiskers of surface total organic carbon by river kilometer (920 to 2100 cfs)

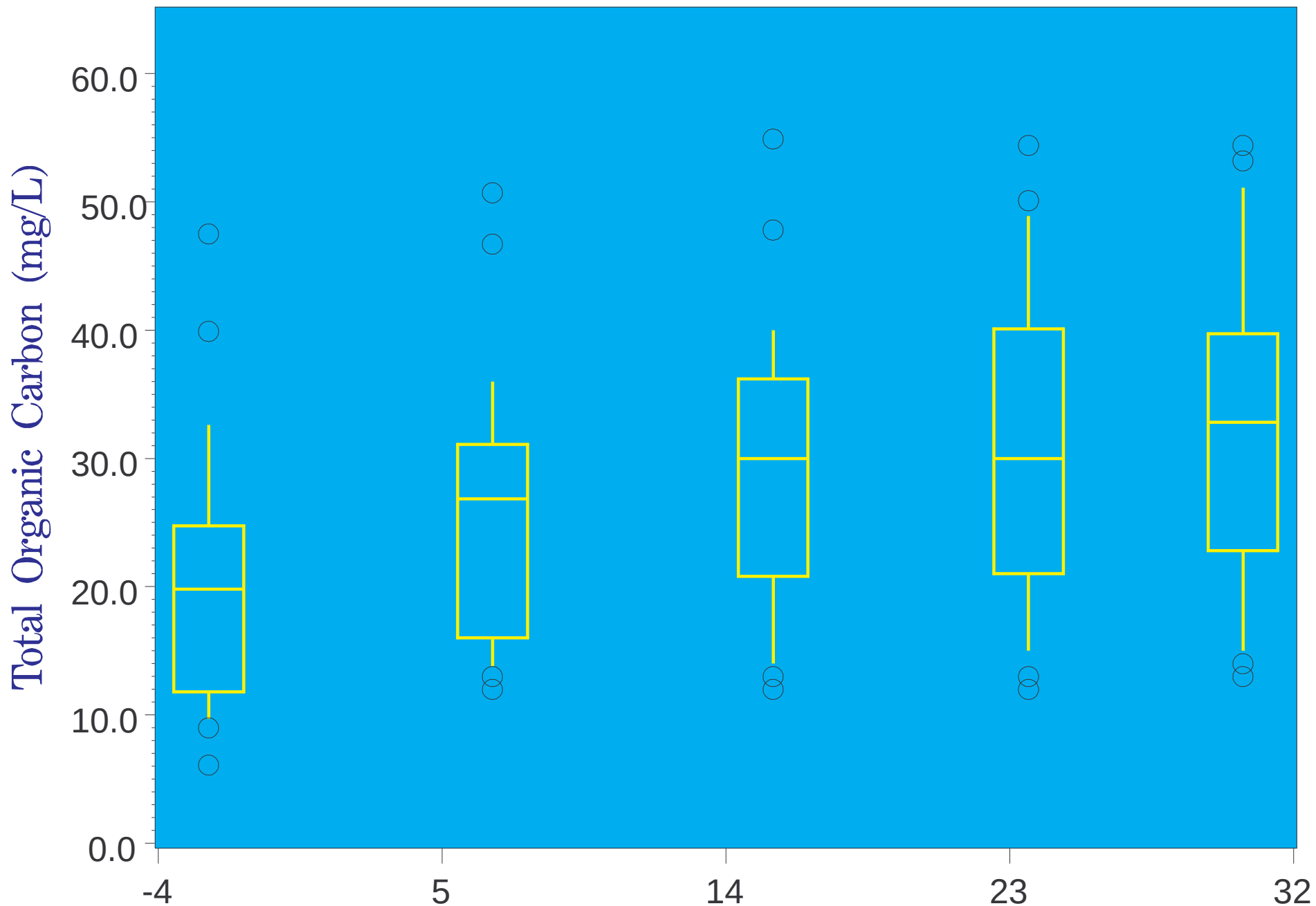


Figure 4.5.324 Box & whiskers of surface total organic carbon by river kilometer (> 2100 cfs)

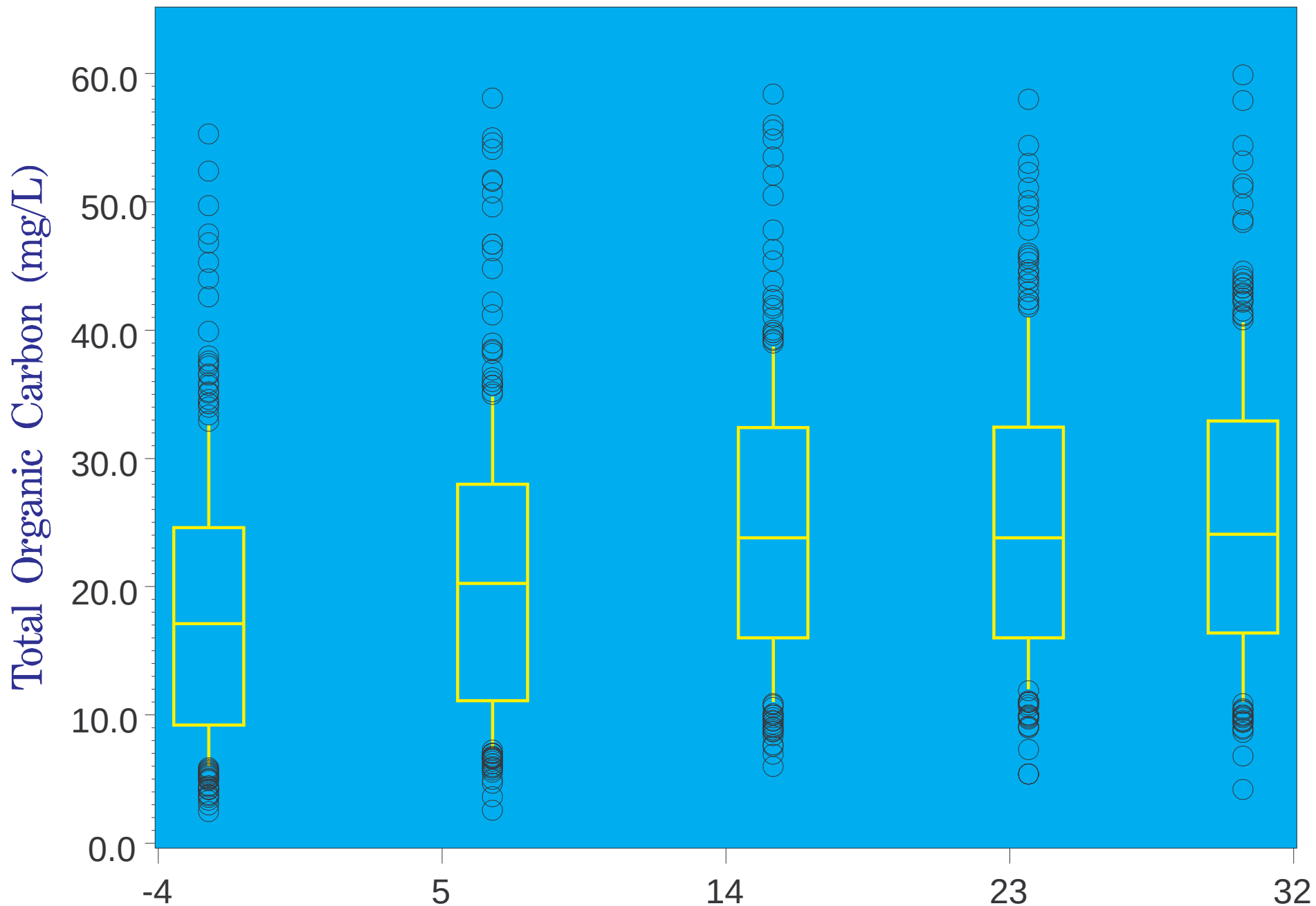


Figure 4.5.325 Box & whiskers of surface total organic carbon by river kilometer (all flows)

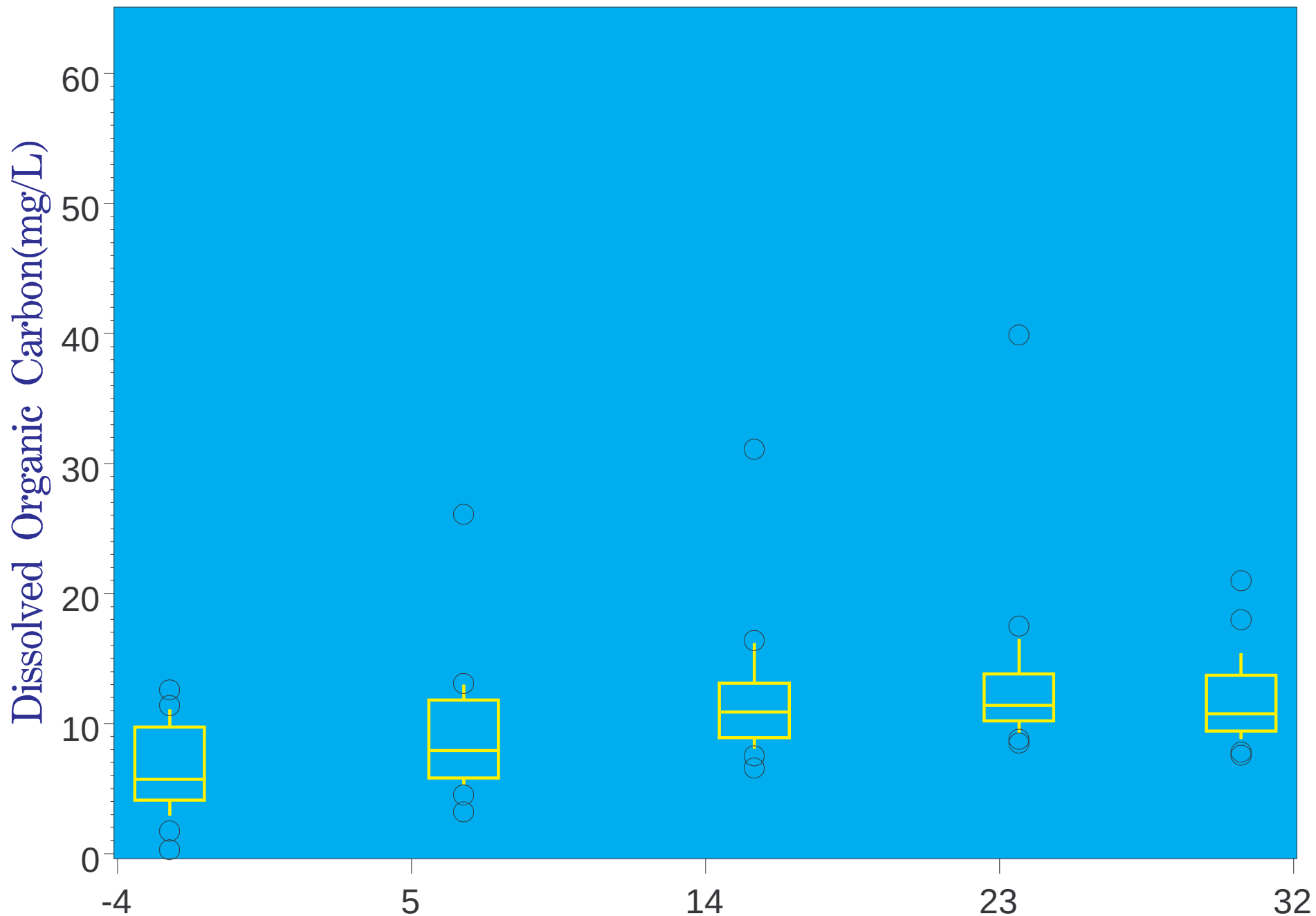


Figure 4.5.326 Box & whiskers of surface dissolved organic carbon by river kilometer (0 to 90 cfs)

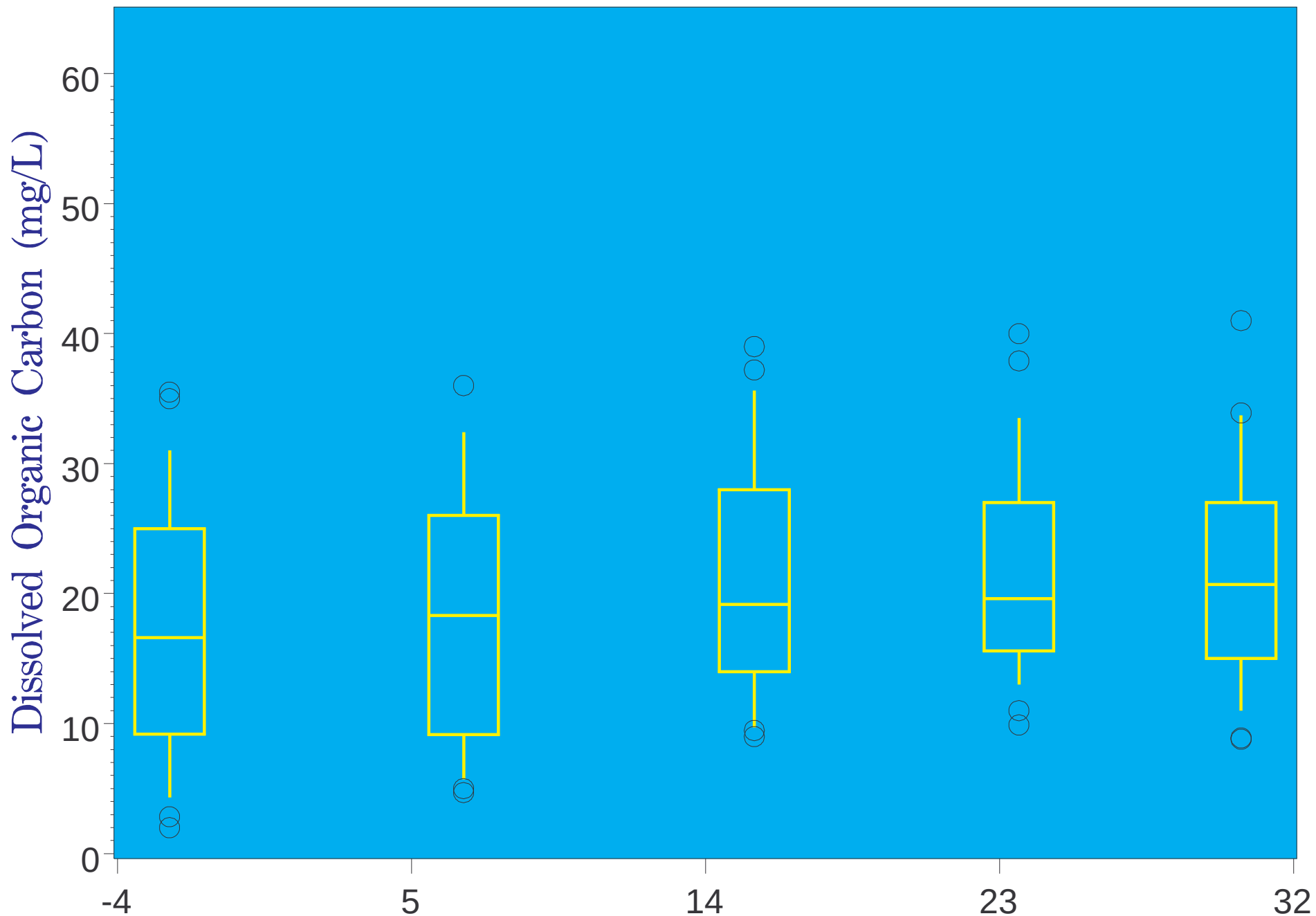


Figure 4.5.327 Box & whiskers of surface dissolved organic carbon by river kilometer (90 to 160 cfs)

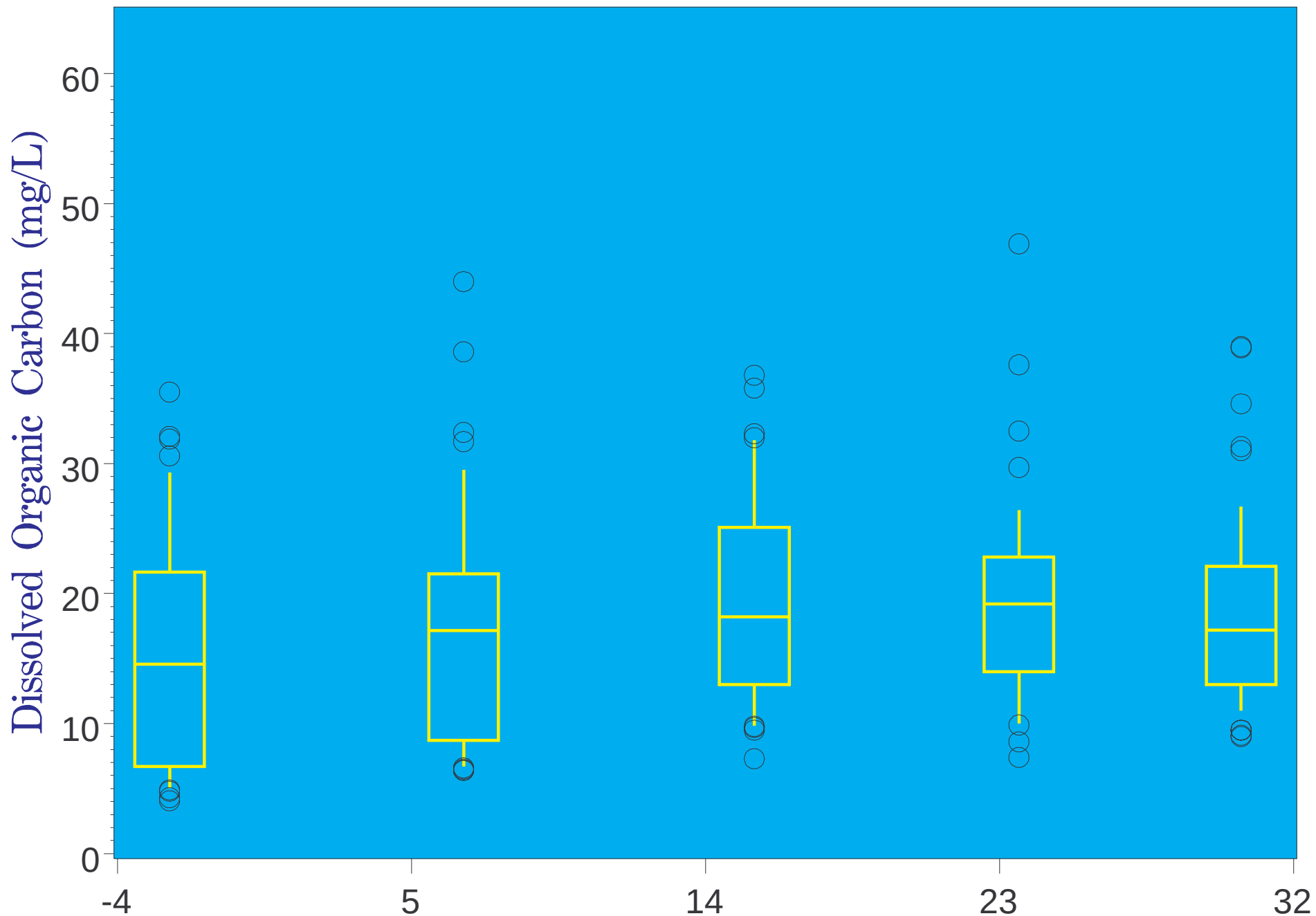


Figure 4.5.328 Box & whiskers of surface dissolved organic carbon by river kilometer (160 to 360 cfs)

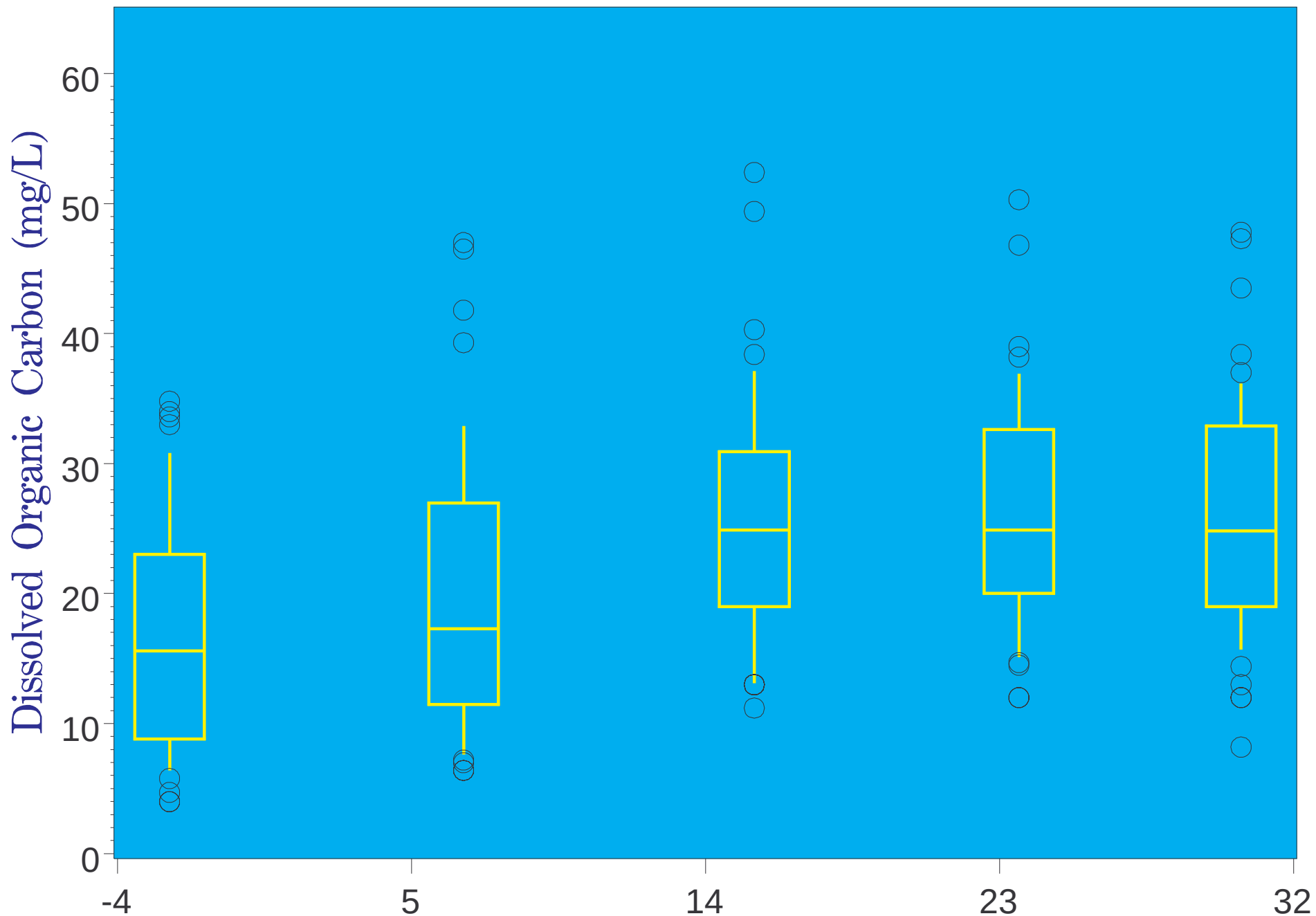


Figure 4.5.329 Box & whiskers of surface dissolved organic carbon by river kilometer (360 to 920 cfs)



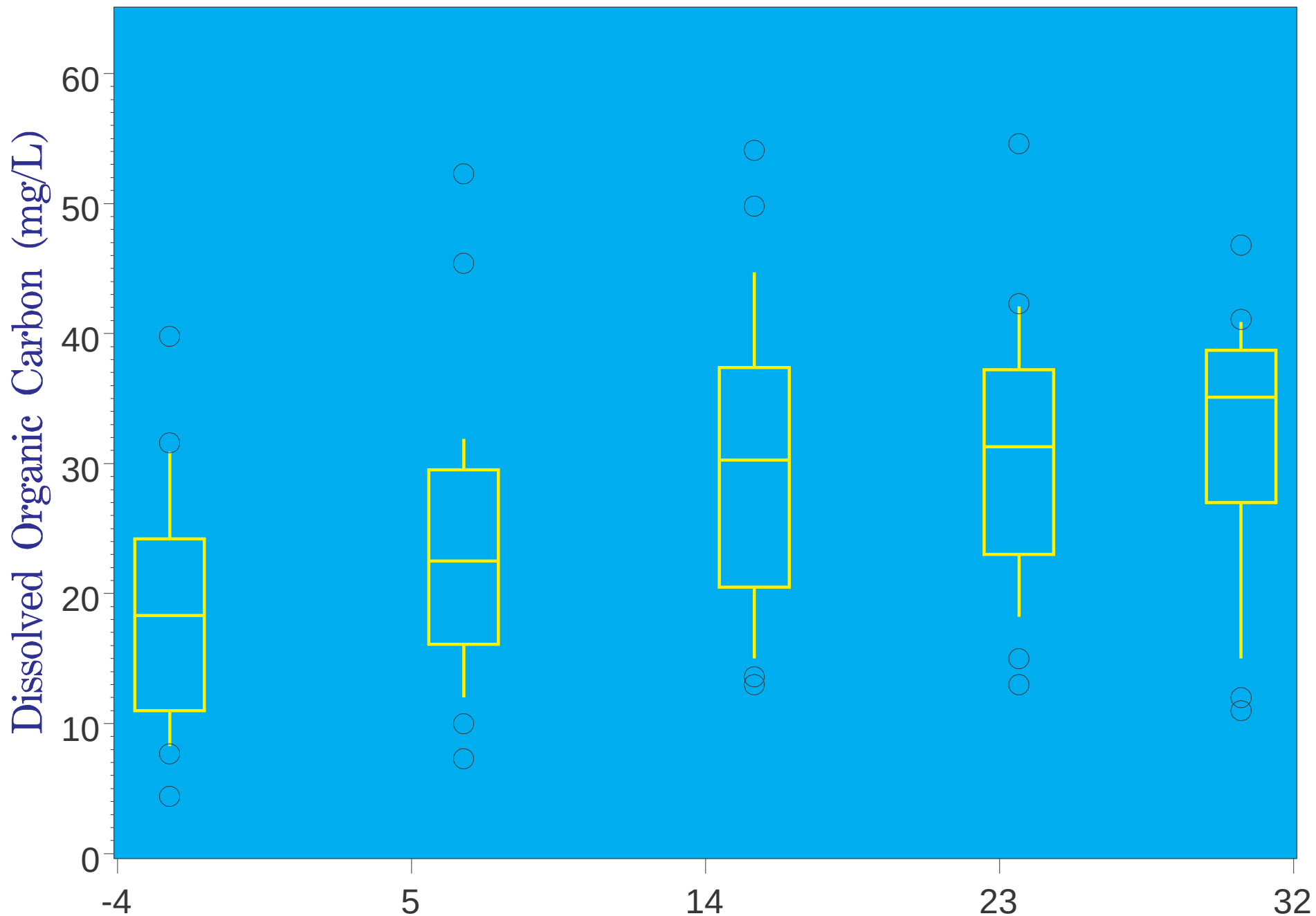


Figure 4.5.330 Box & whiskers of surface dissolved organic carbon by river kilometer (920 to 2100 cfs)

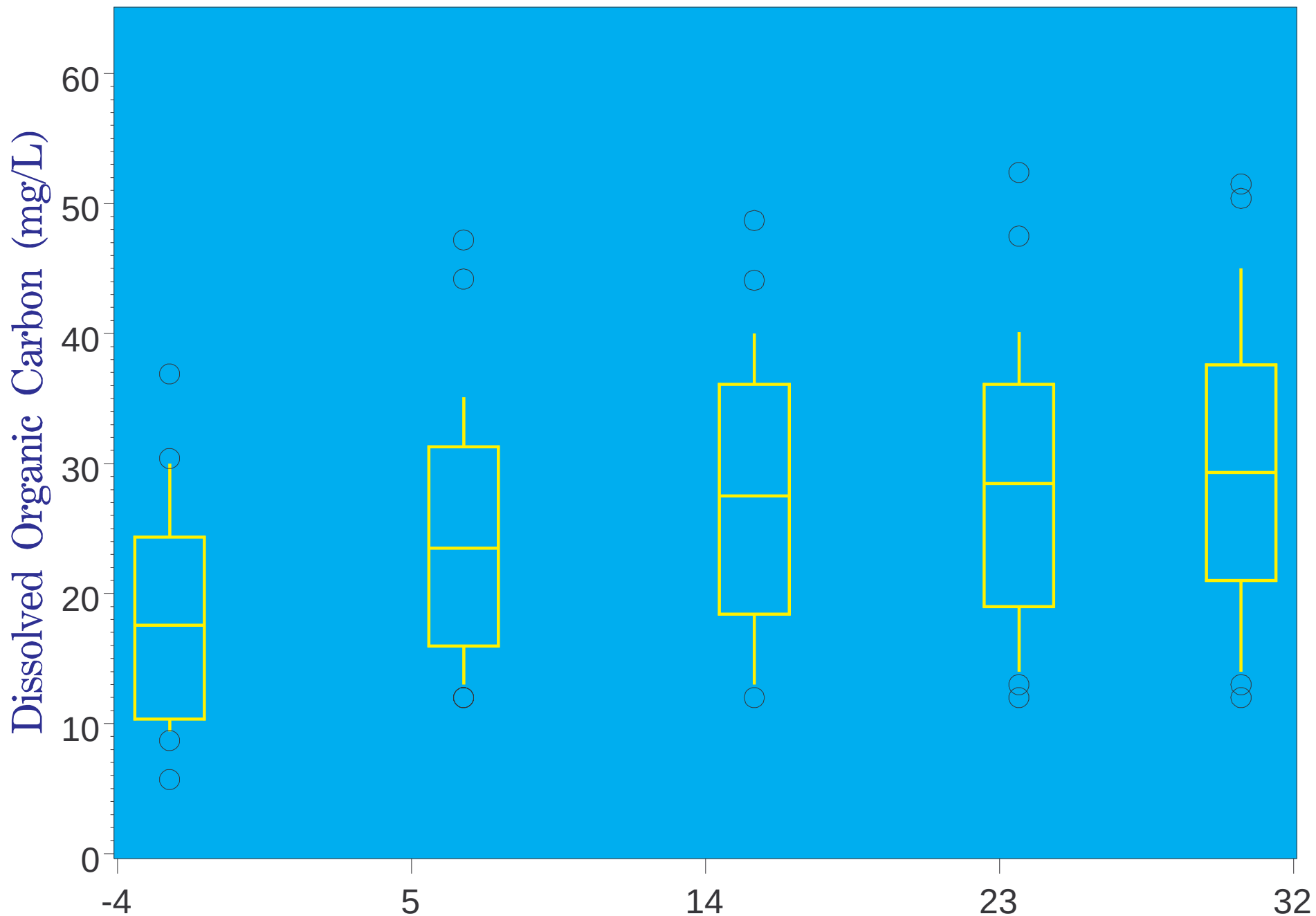


Figure 4.5.331 Box & whiskers of surface dissolved organic carbon by river kilometer (> 2100 cfs)

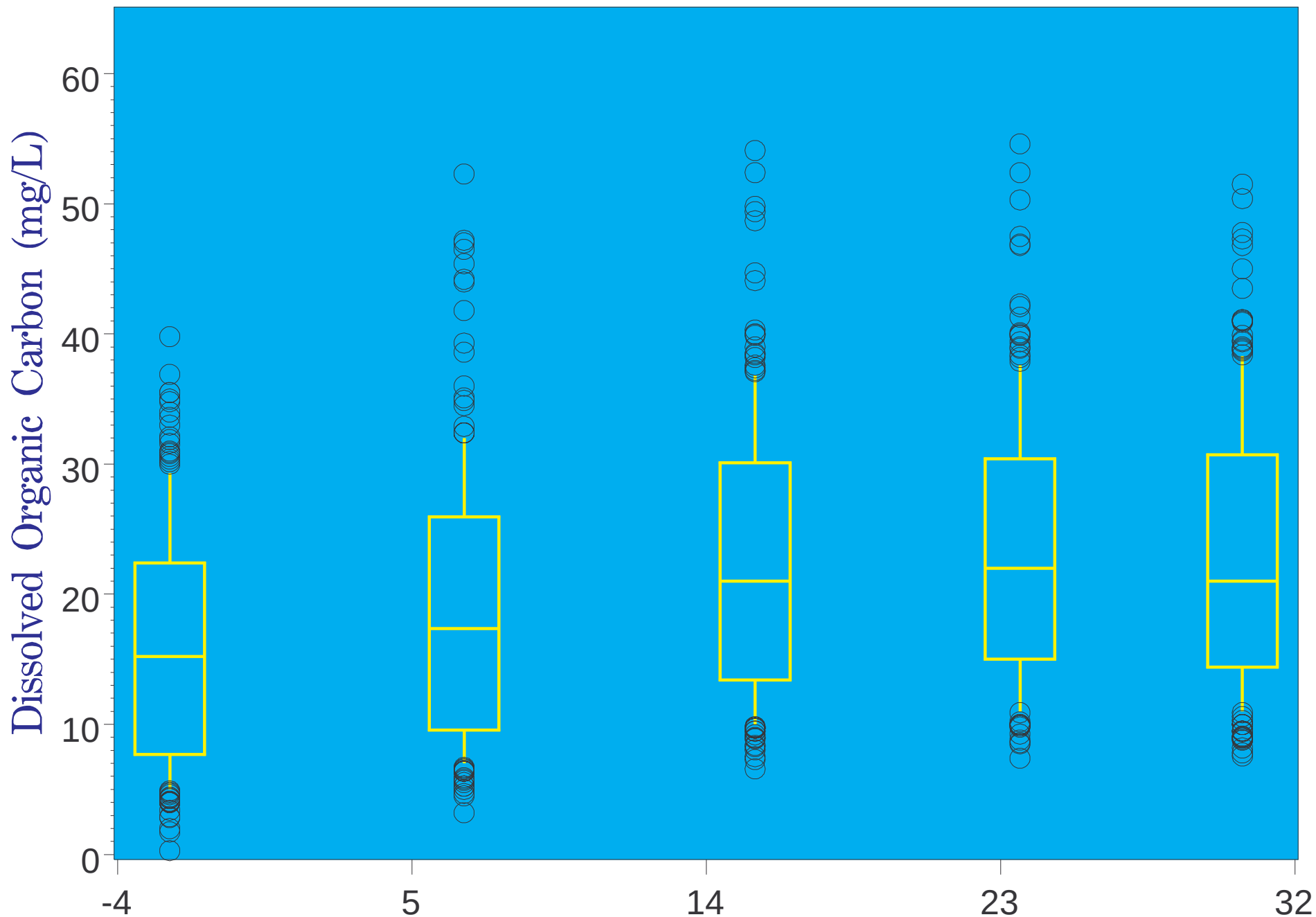


Figure 4.5.332 Box & whiskers of surface dissolved organic carbon by river kilometer (all flows)

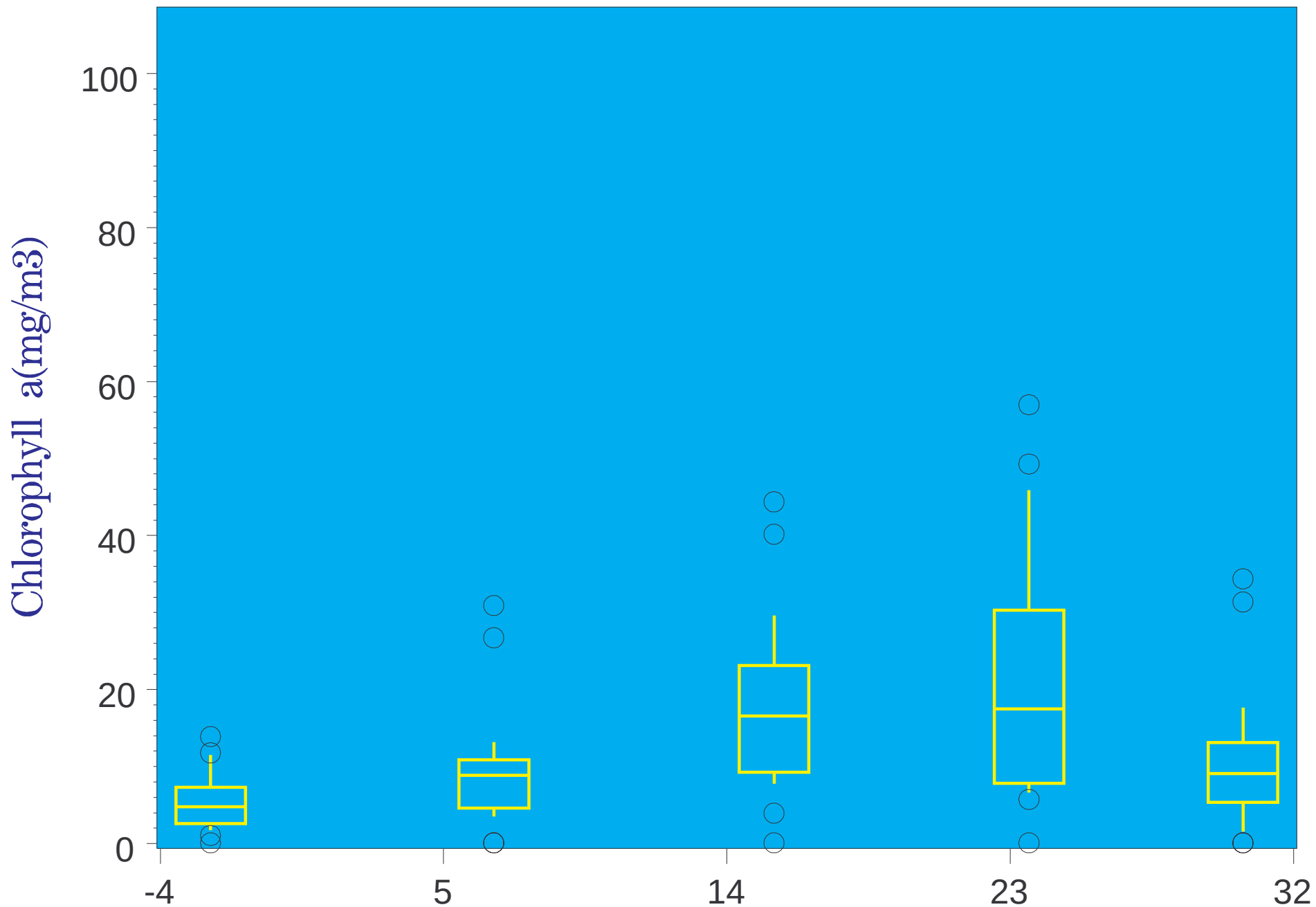


Figure 4.5.333 Box & whiskers of surface chlorophyll a by river kilometer (0 to 90 cfs)

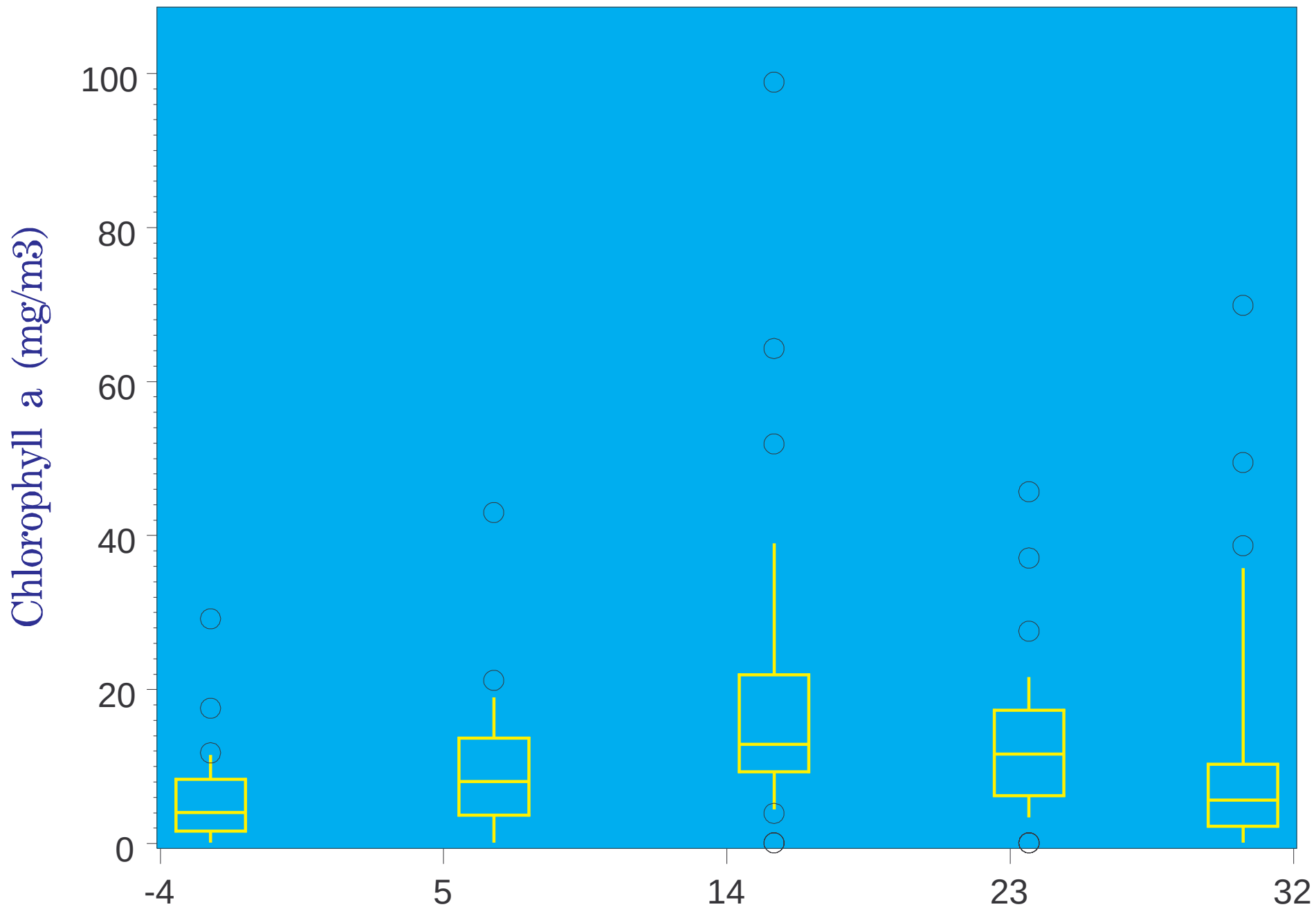


Figure 4.5.334 Box & whiskers of surface chlorophyll a by river kilometer (90 to 160 cfs)

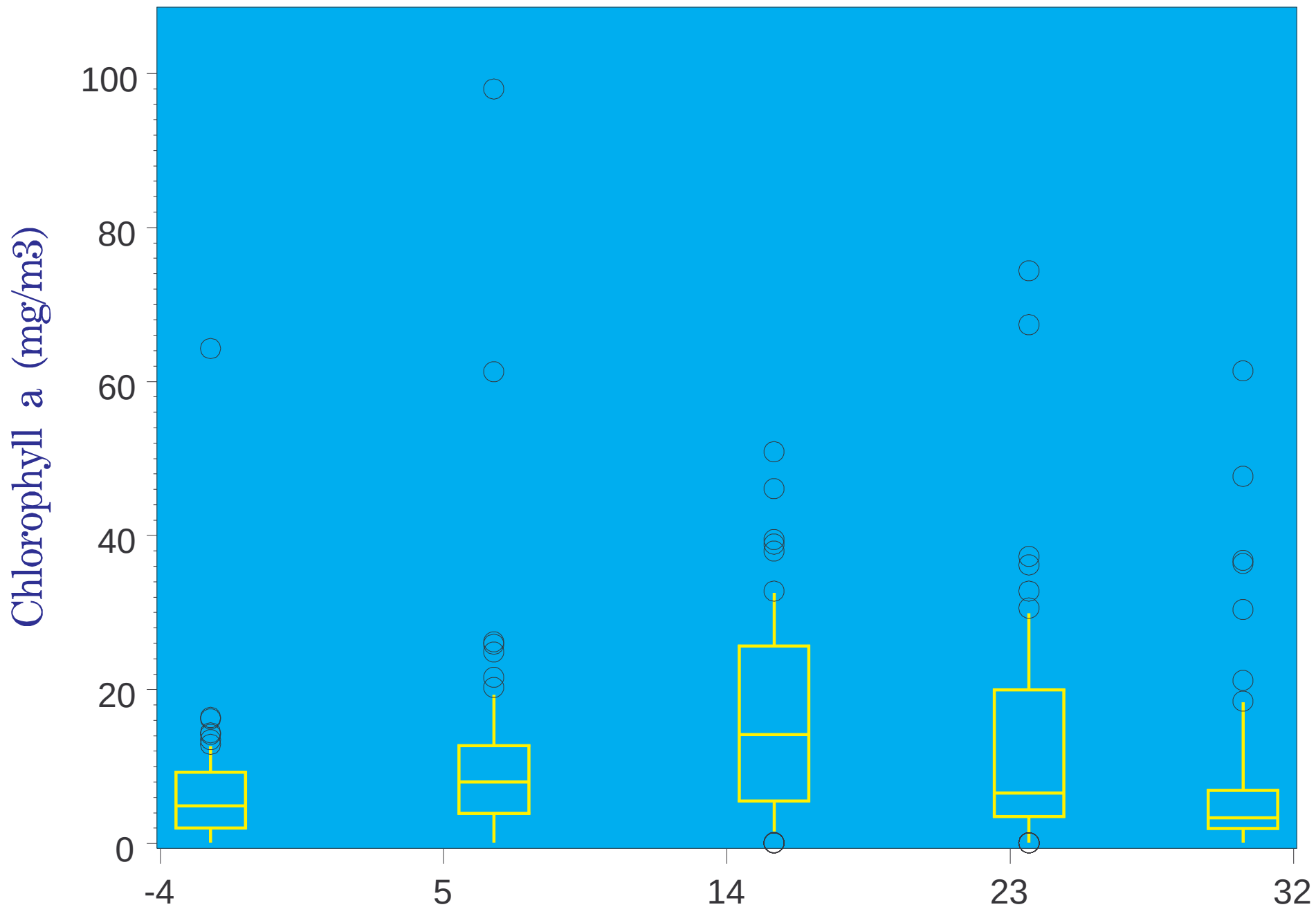


Figure 4.5.335 Box & whiskers of surface chlorophyll a by river kilometer (160 to 360 cfs)

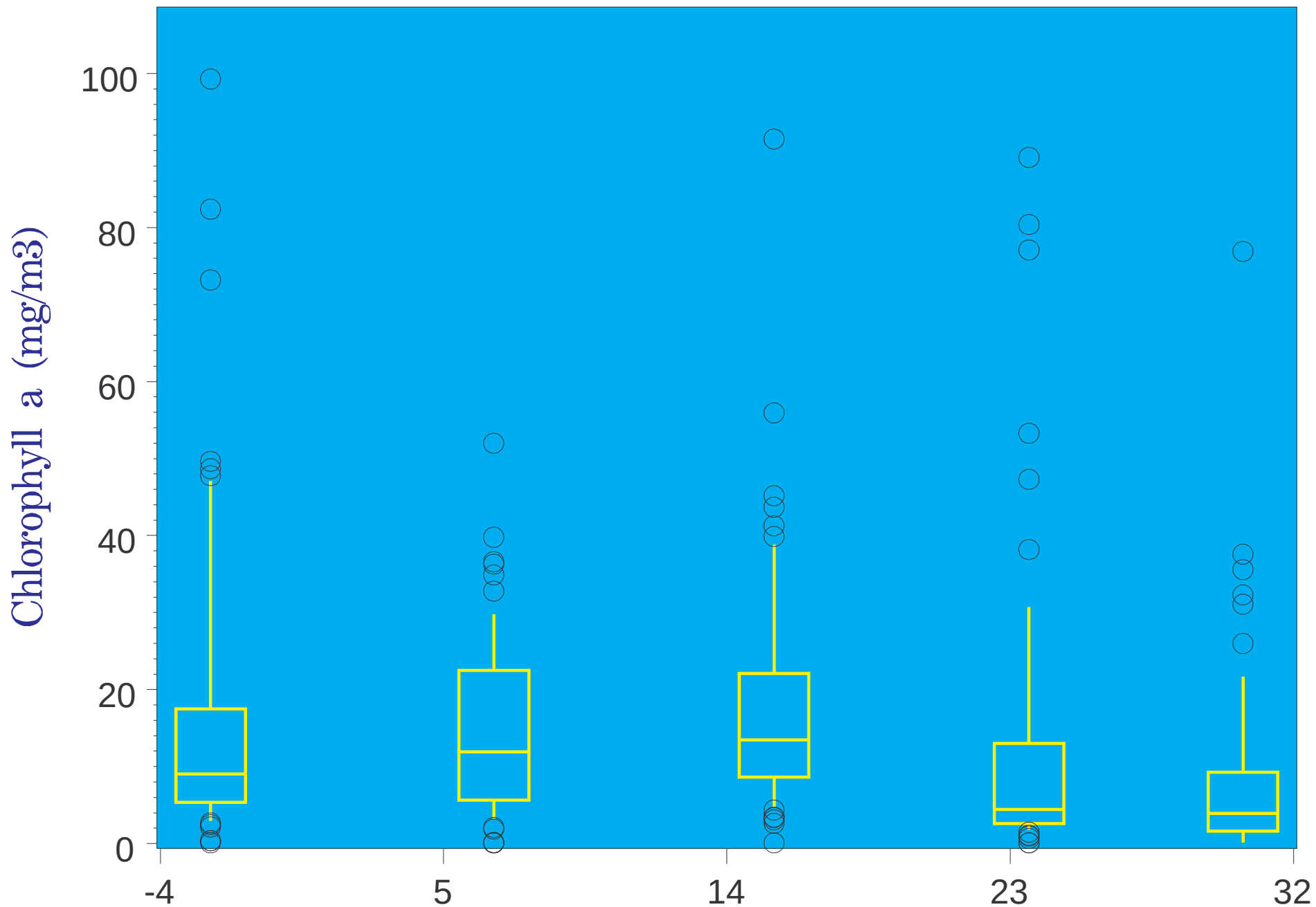


Figure 4.5.336 Box & whiskers of surface chlorophyll a by river kilometer (360 to 920 cfs)

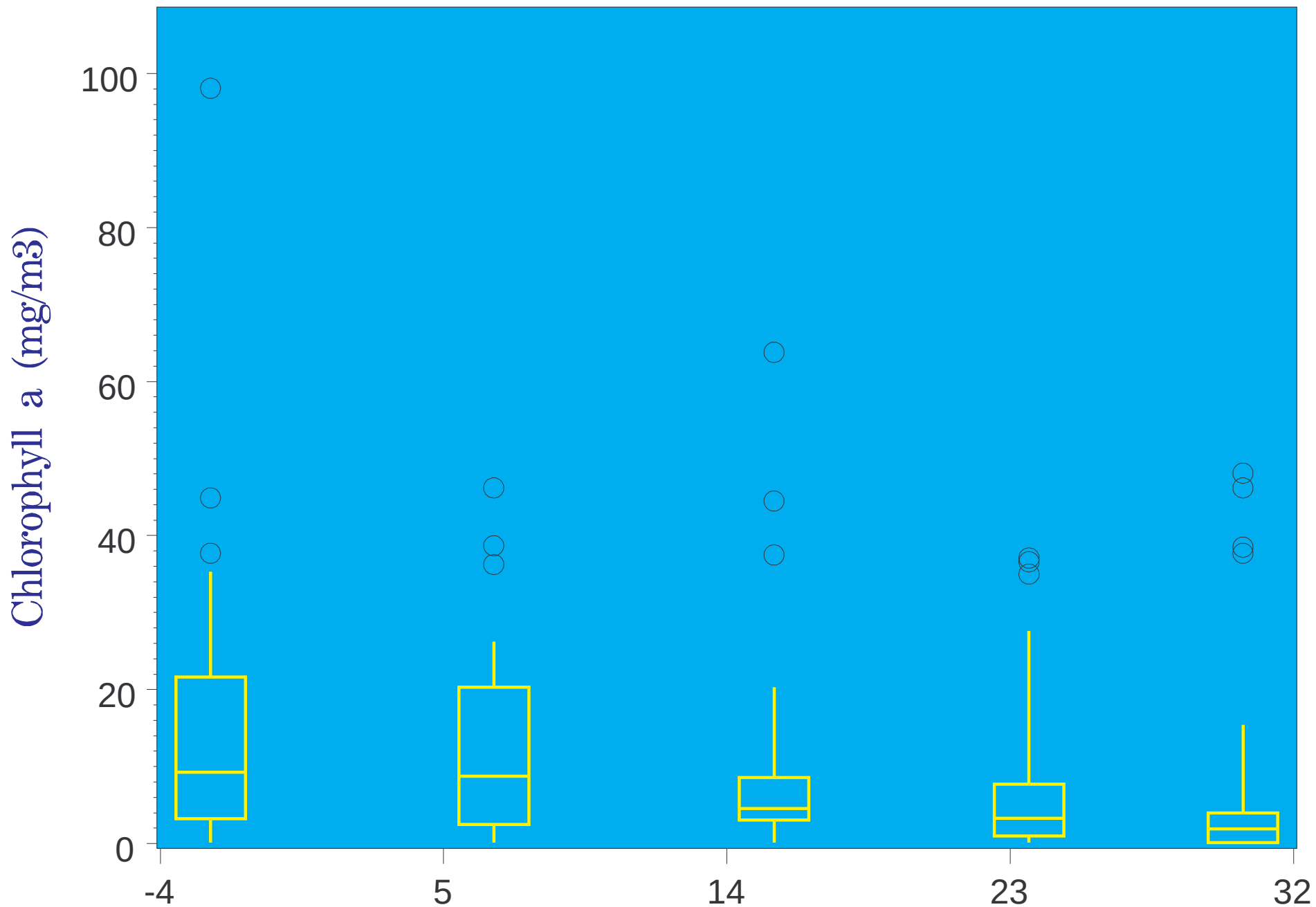


Figure 4.5.337 Box & whiskers of surface chlorophyll a by river kilometer (920 to 2100 cfs)



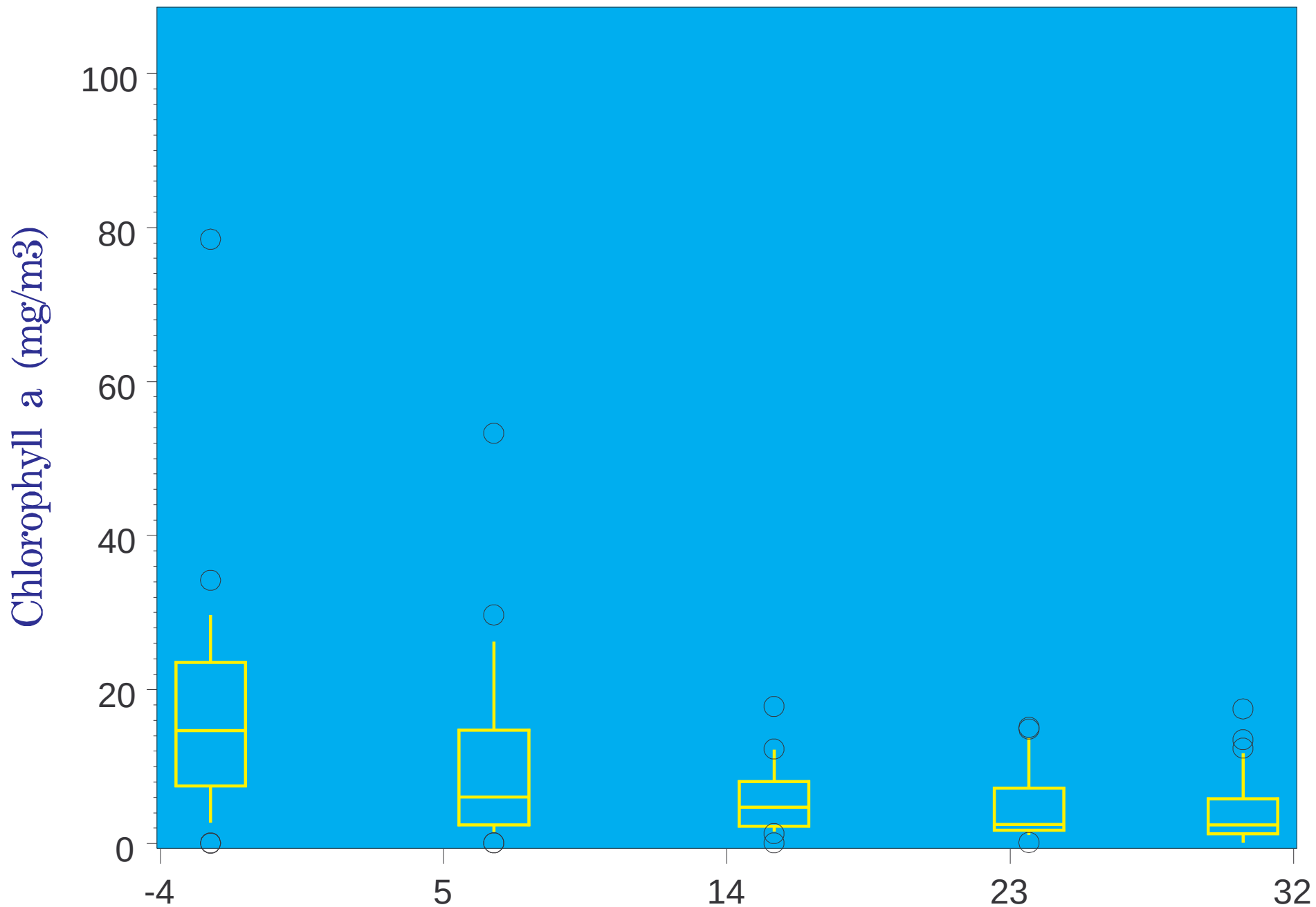


Figure 4.5.338 Box & whiskers of surface chlorophyll a by river kilometer (> 2100 cfs)

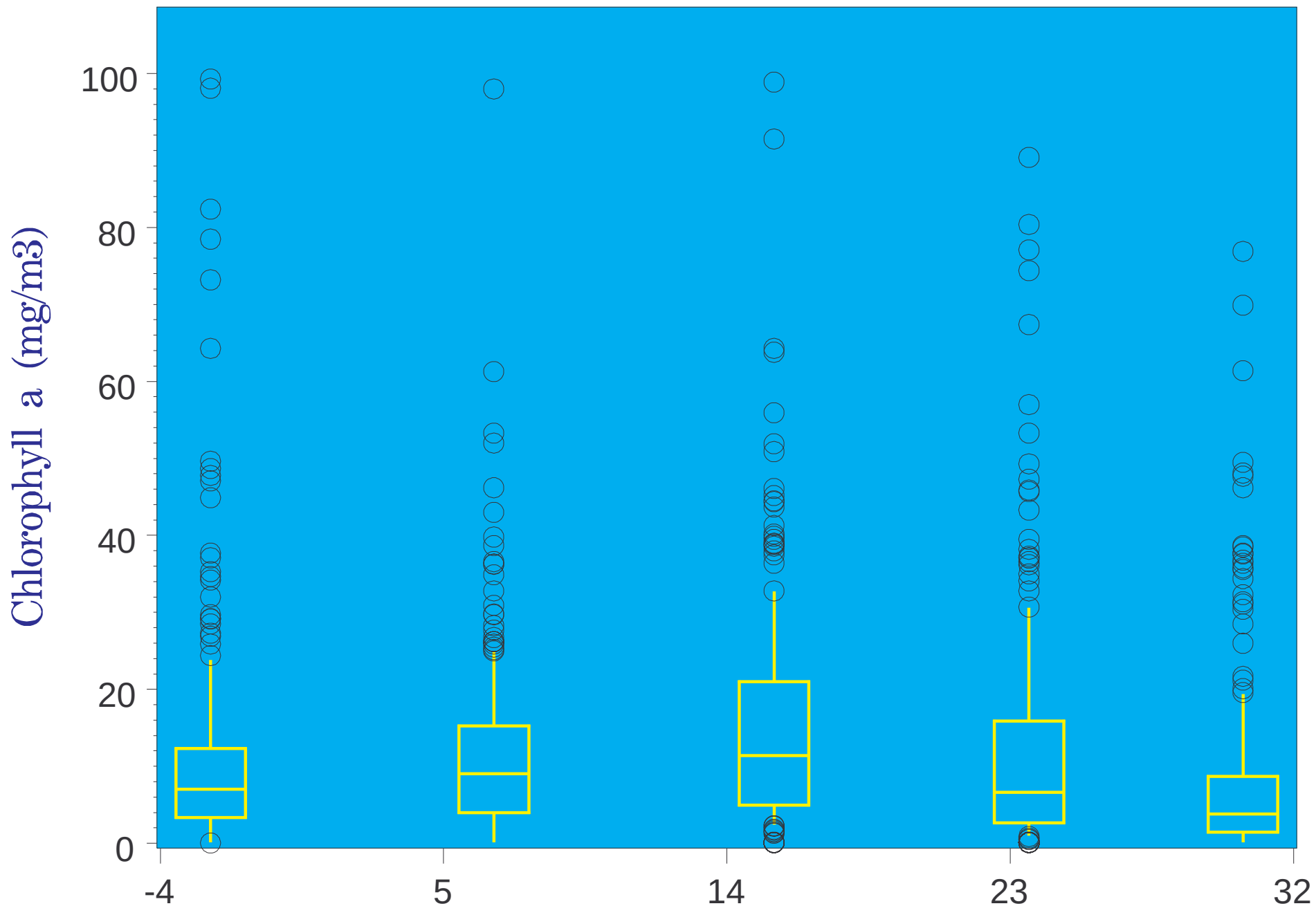


Figure 4.5.339 Box & whiskers of surface chlorophyll a by river kilometer (all flows)

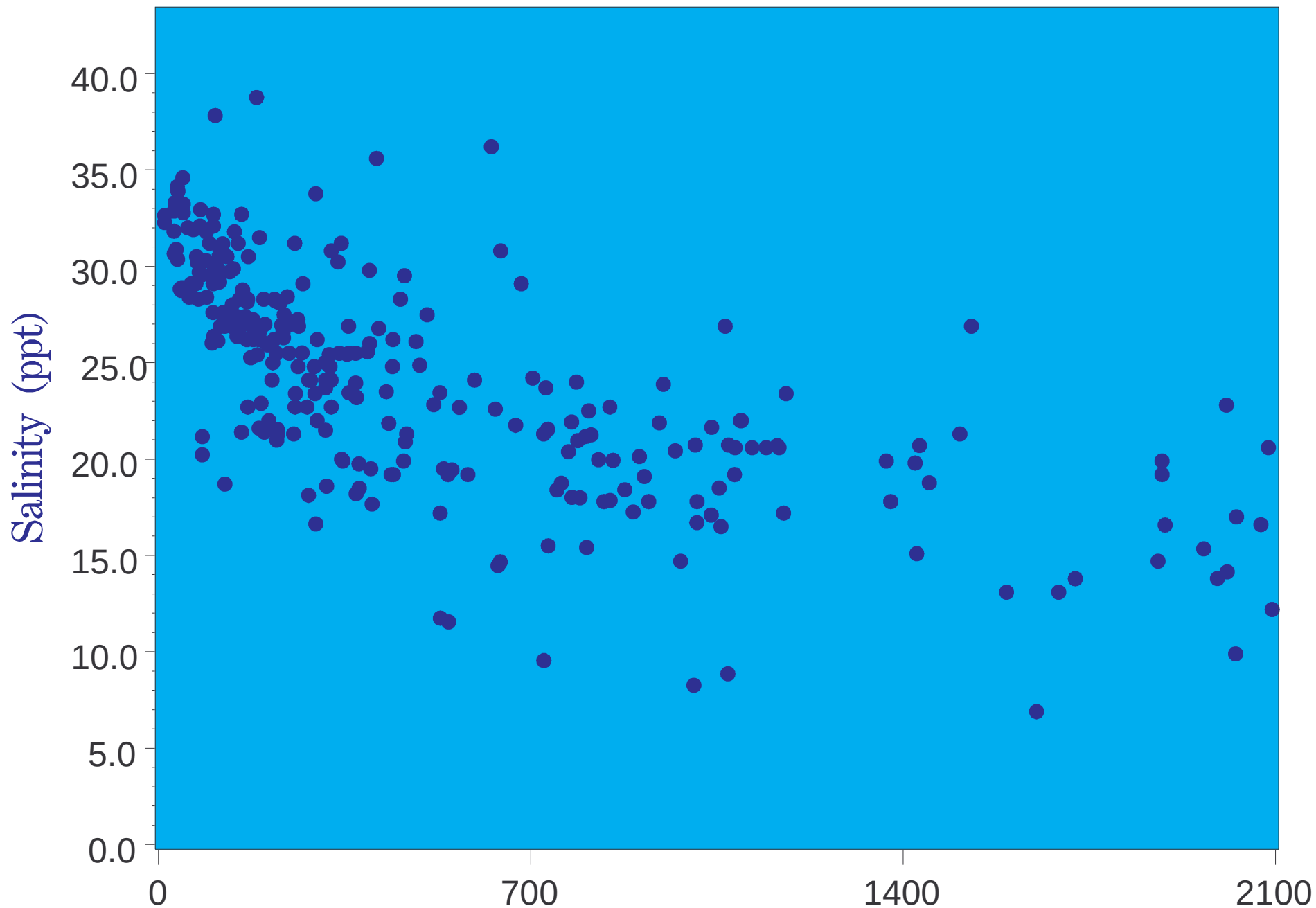


Figure 4.5.340 Surface salinity at river kilometer -2.4 versus flow

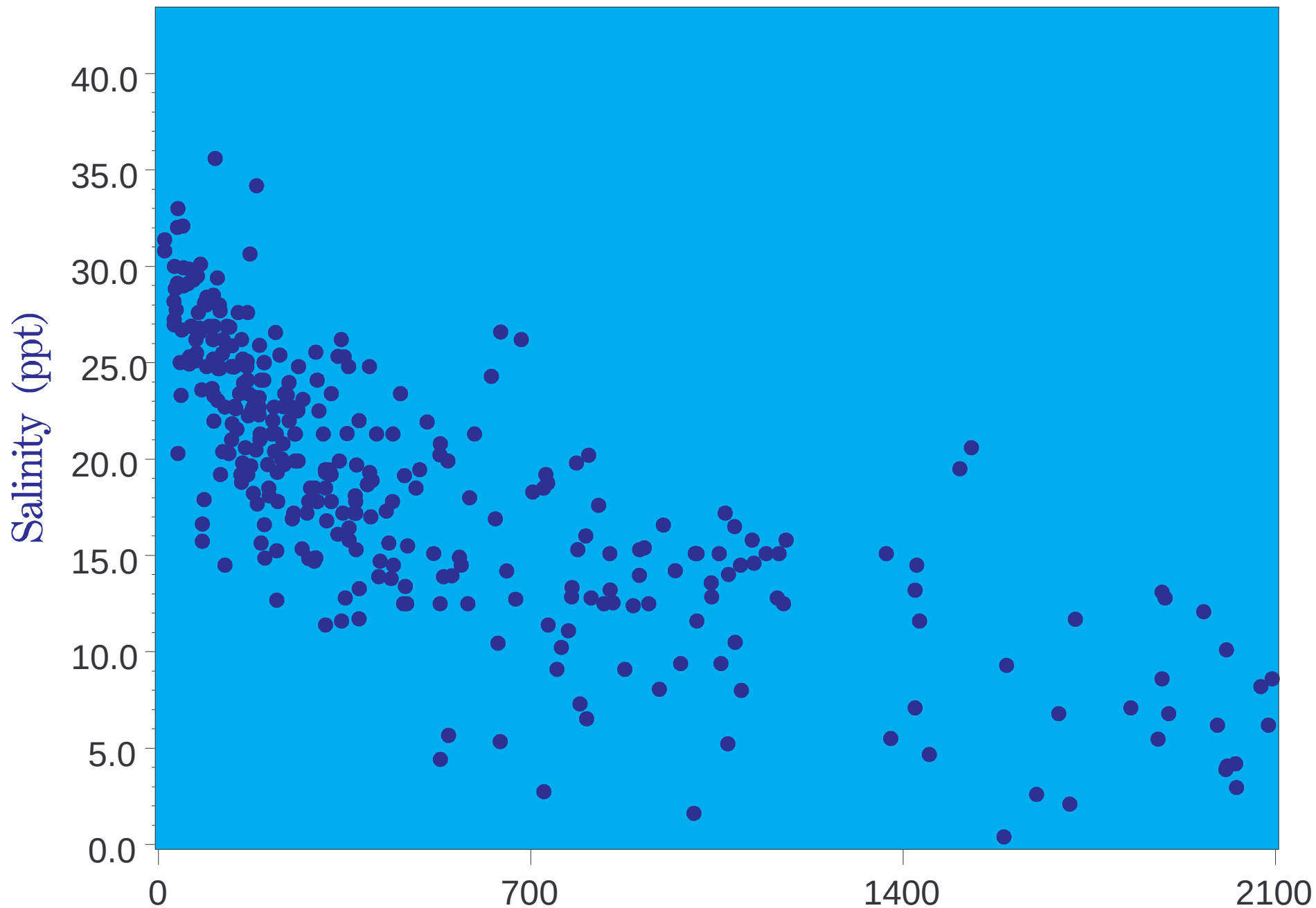


Figure 4.5.341 Surface salinity at river kilometer 6.6 versus flow

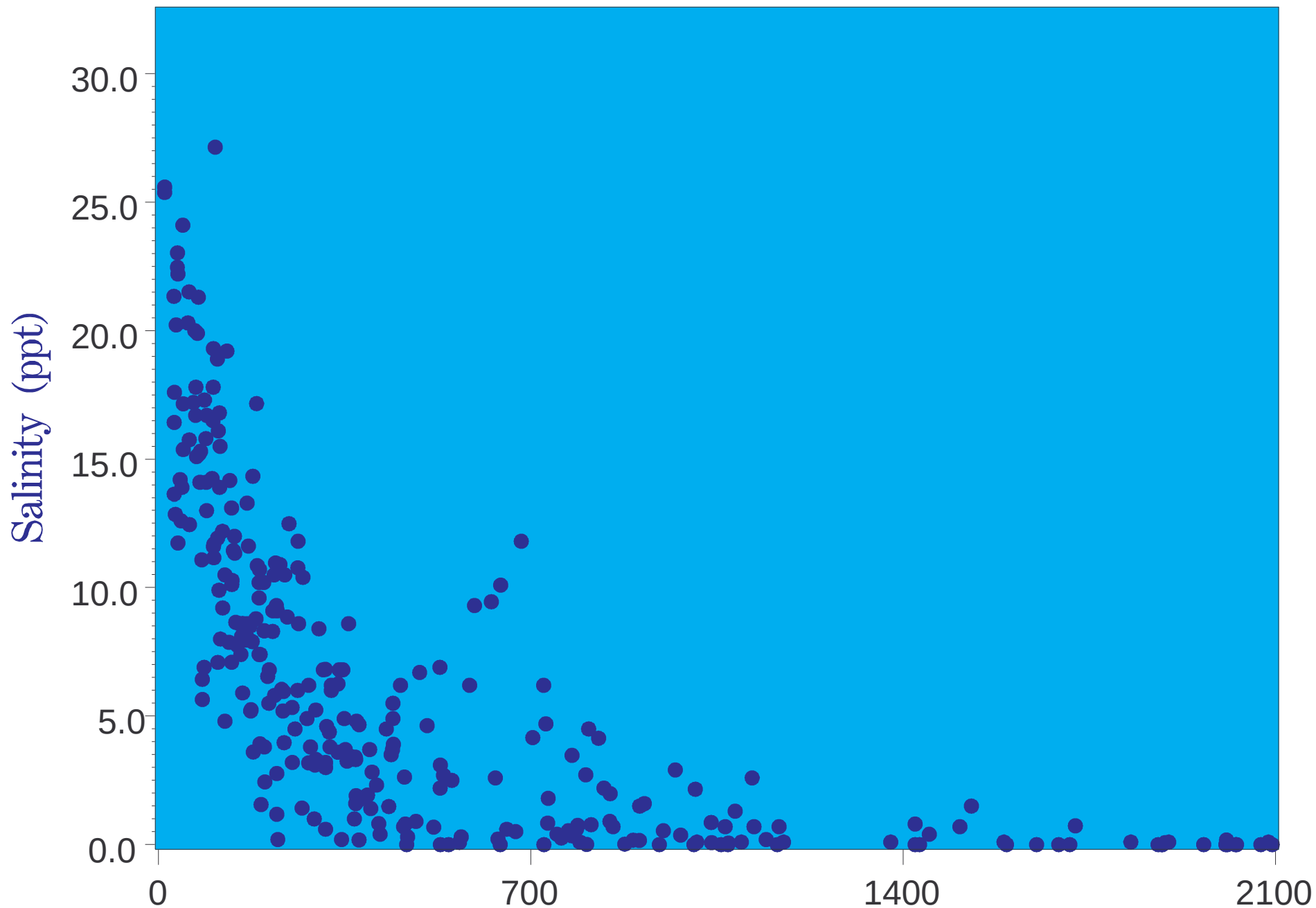


Figure 4.5.342 Surface salinity at river kilometer 15.5 versus flow

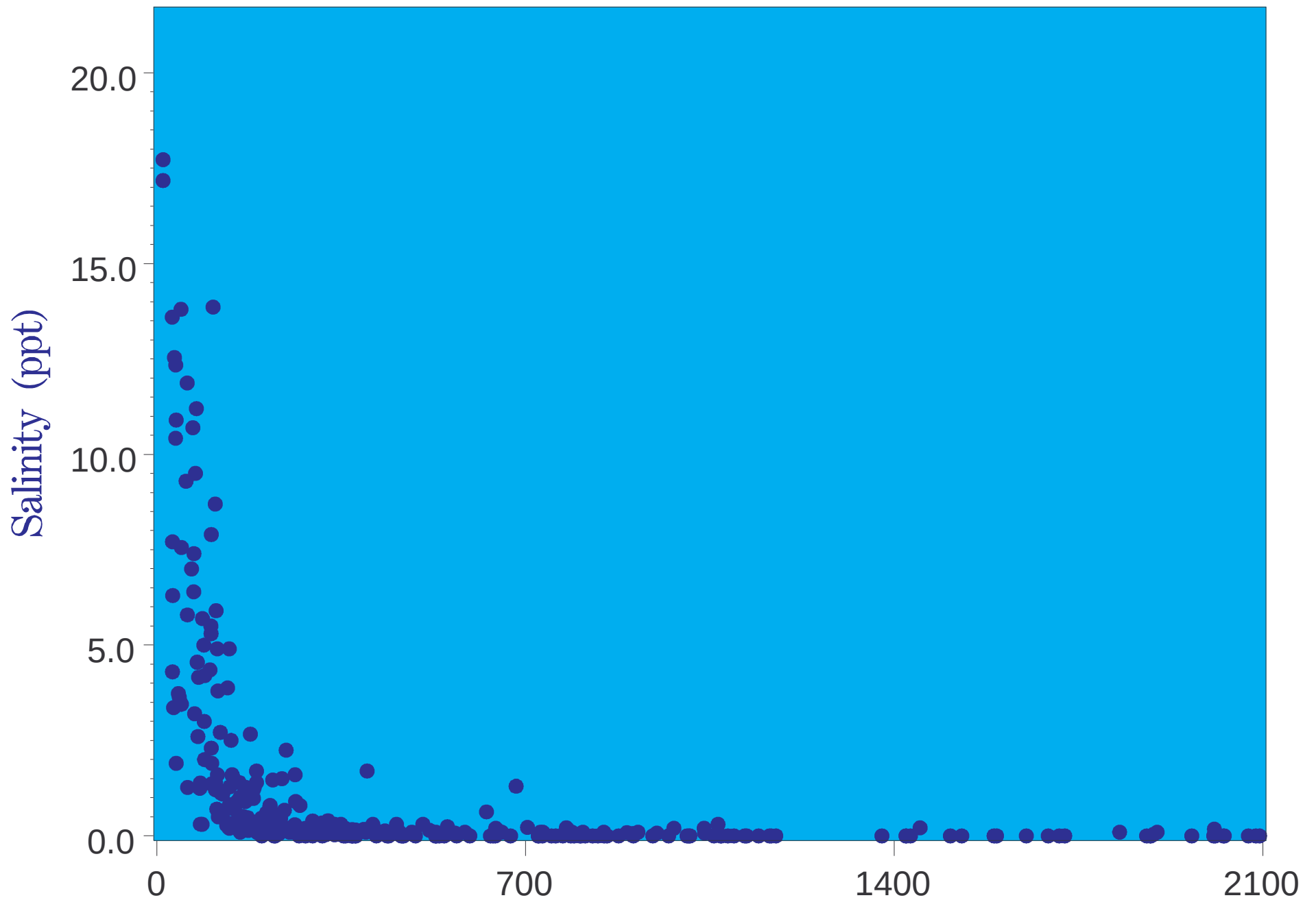


Figure 4.5.343 Surface salinity at river kilometer 23.6 versus flow

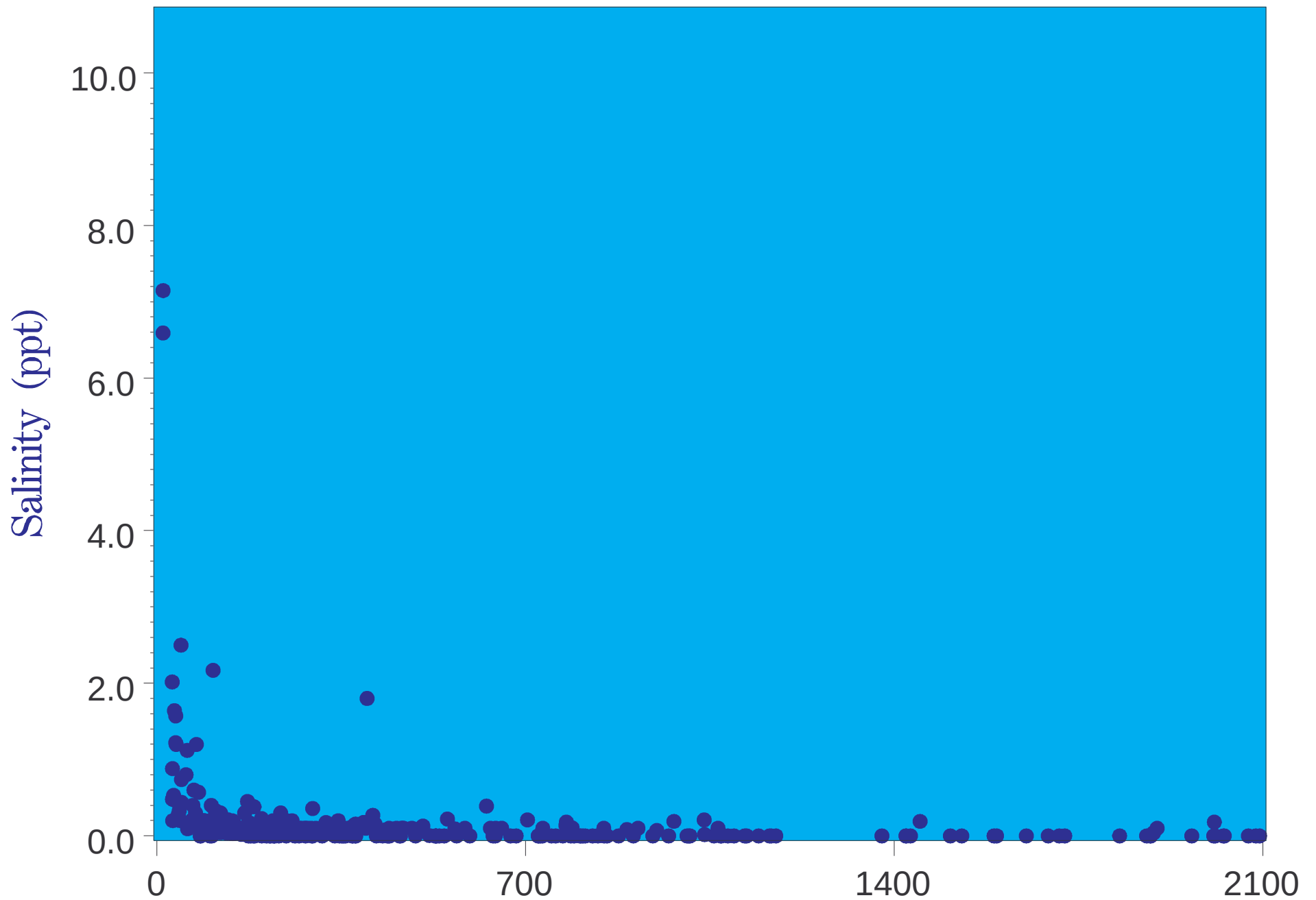


Figure 4.5.344 Surface salinity at river kilometer 30.4 versus flow

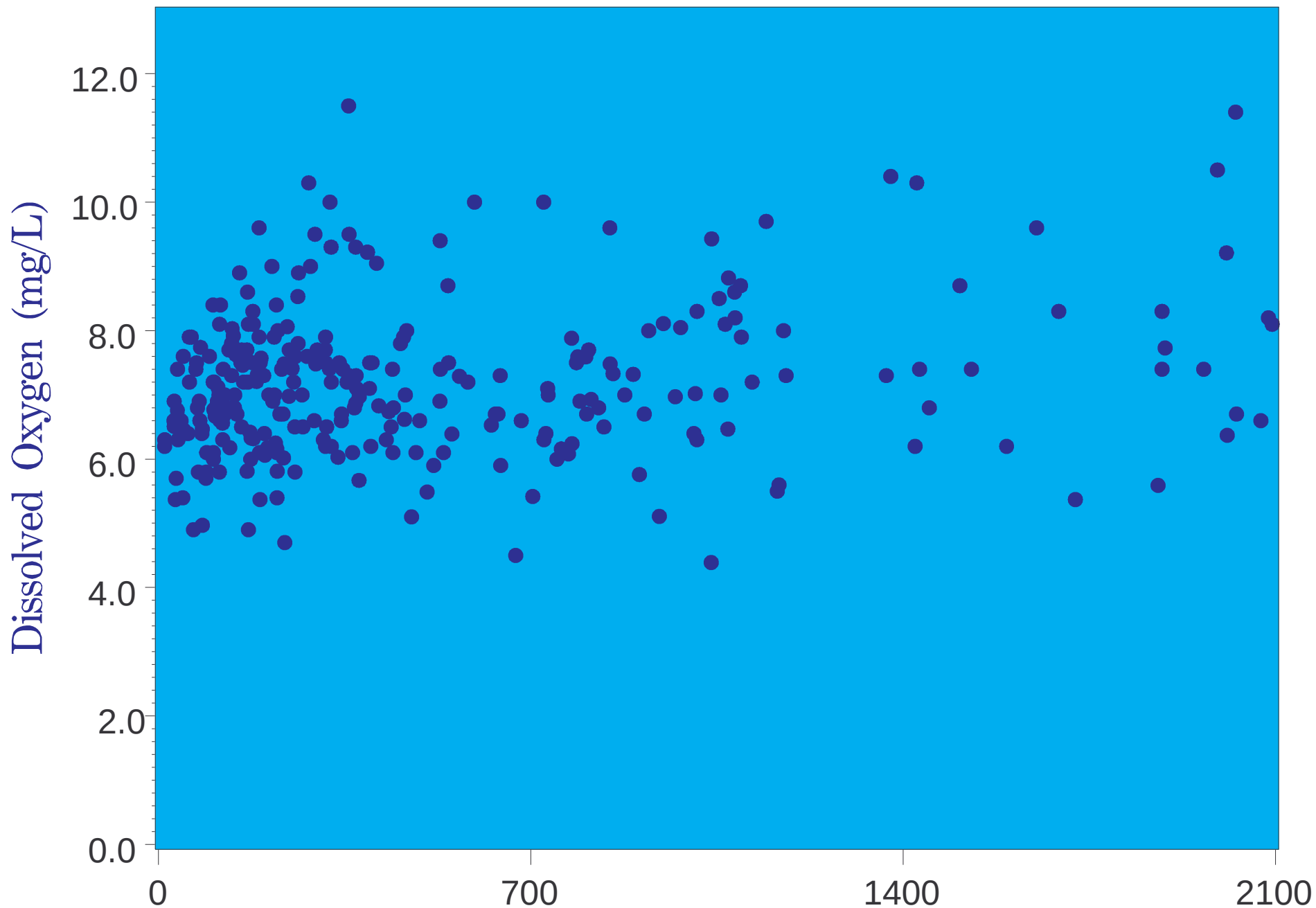


Figure 4.5.345 Surface dissolved oxygen at river kilometer -2.4 versus flow



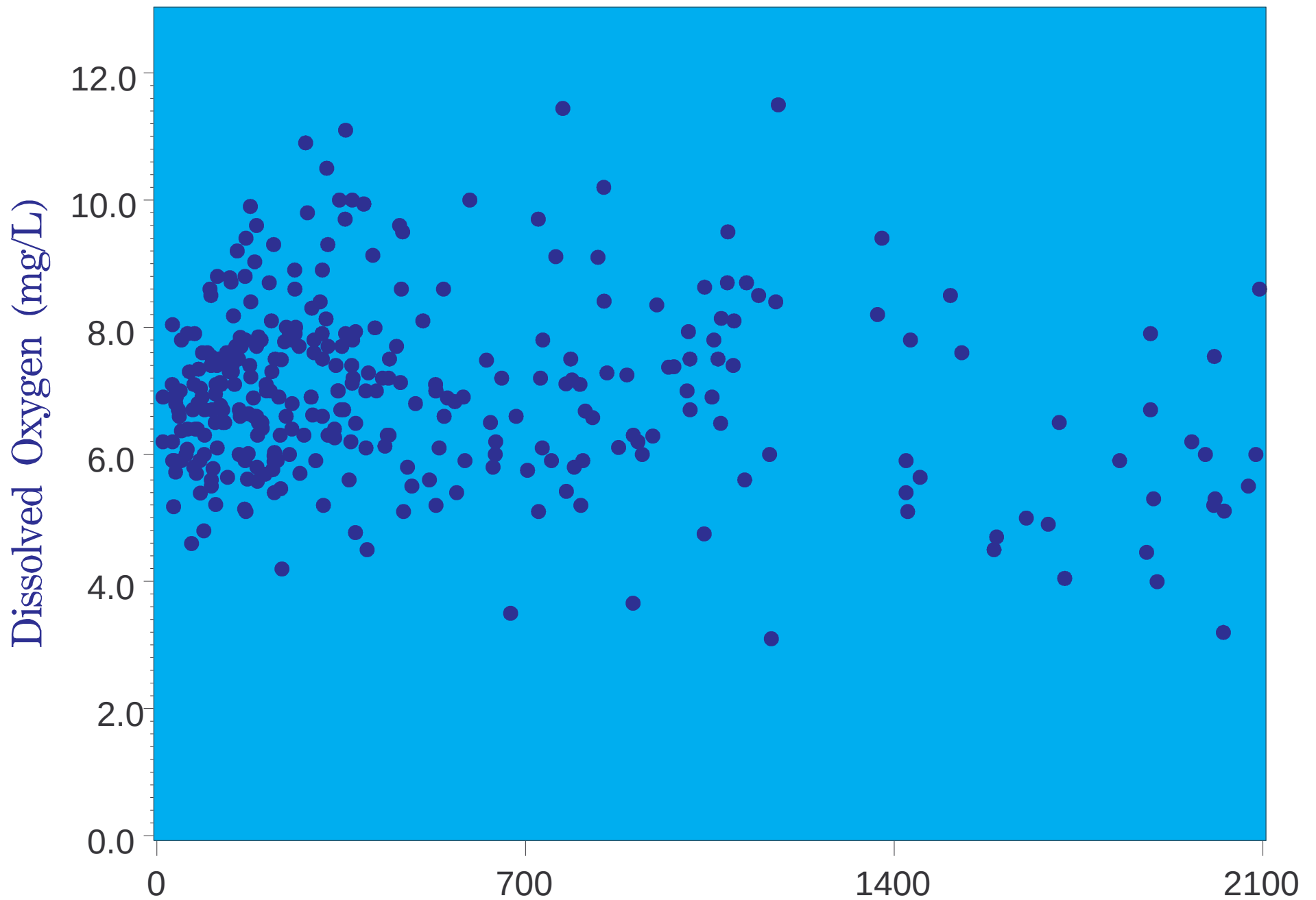


Figure 4.5.346 Surface dissolved oxygen at river kilometer 6.6 versus flow

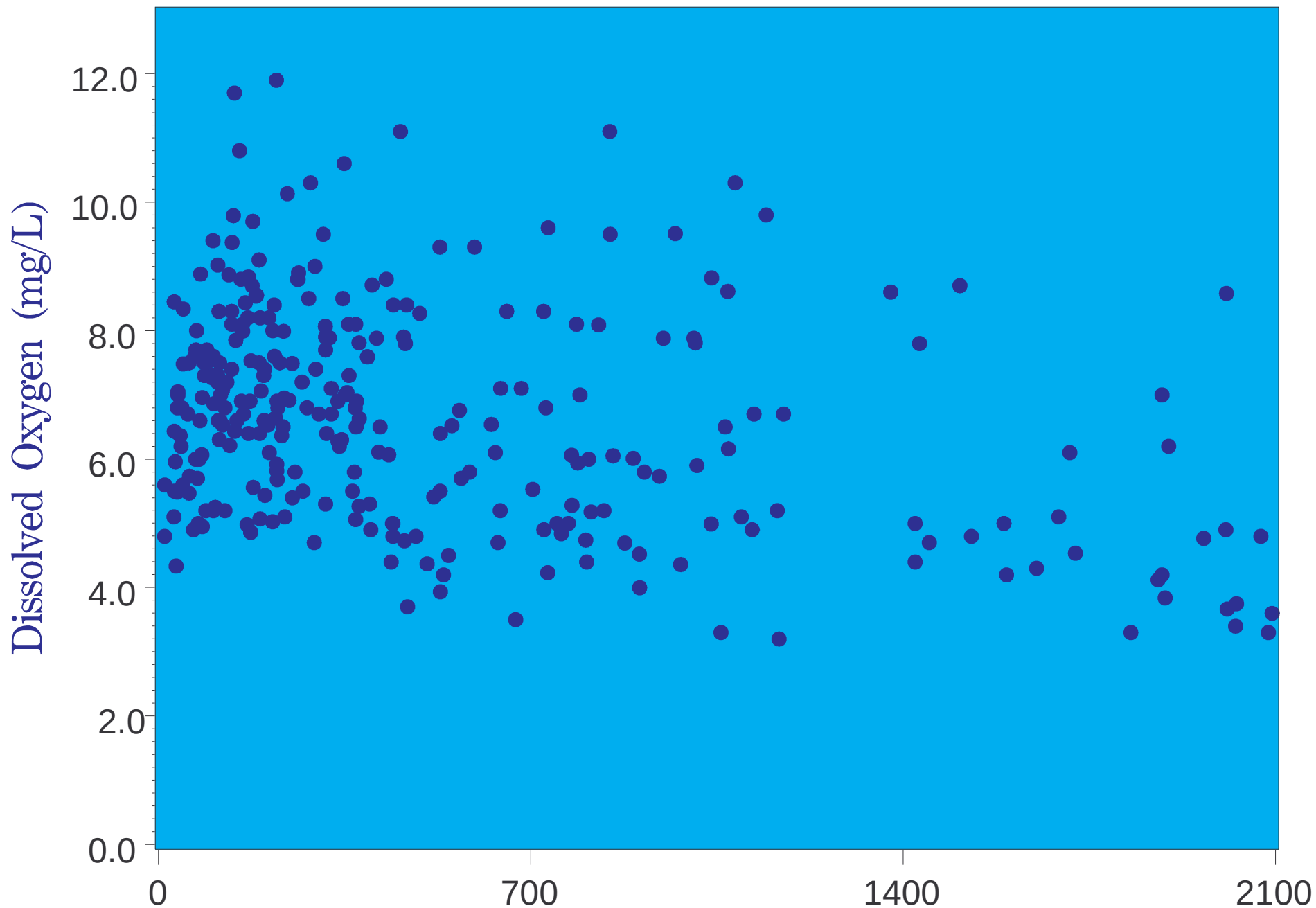


Figure 4.5.347 Surface dissolved oxygen at river kilometer 15.5 versus flow

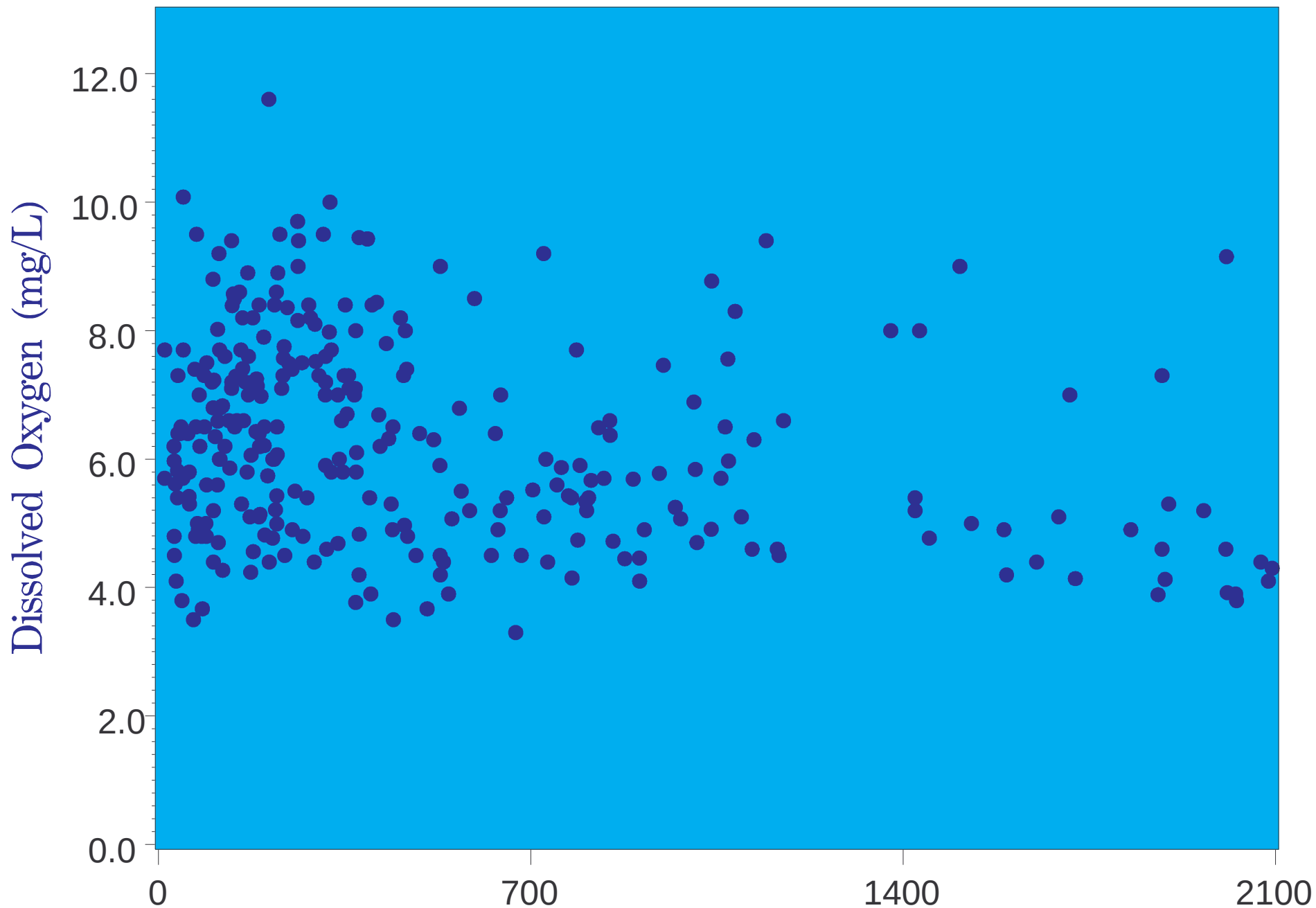


Figure 4.5.348 Surface dissolved oxygen at river kilometer 23.6 versus flow

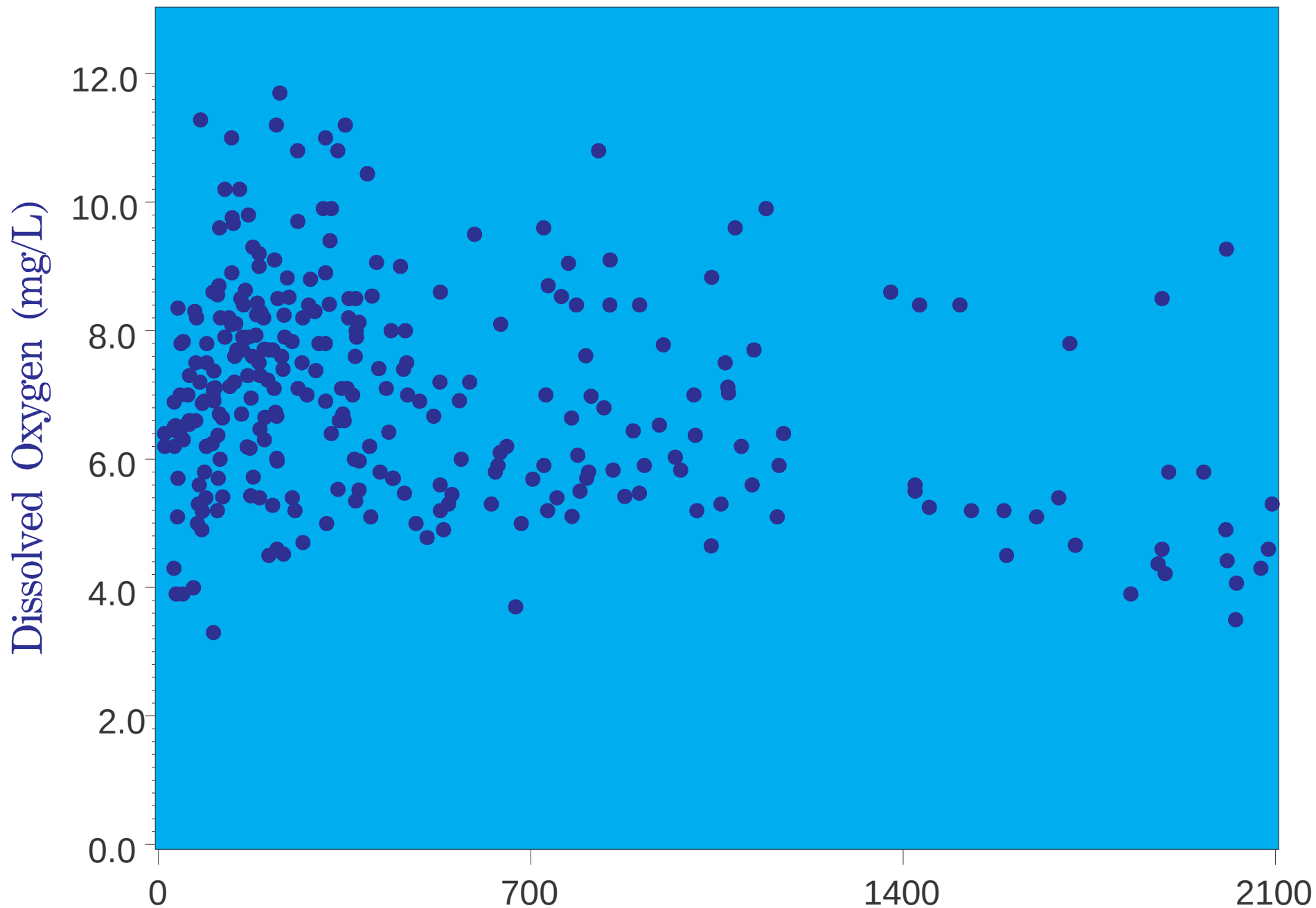


Figure 4.5.349 Surface dissolved oxygen at river kilometer 30.4 versus flow

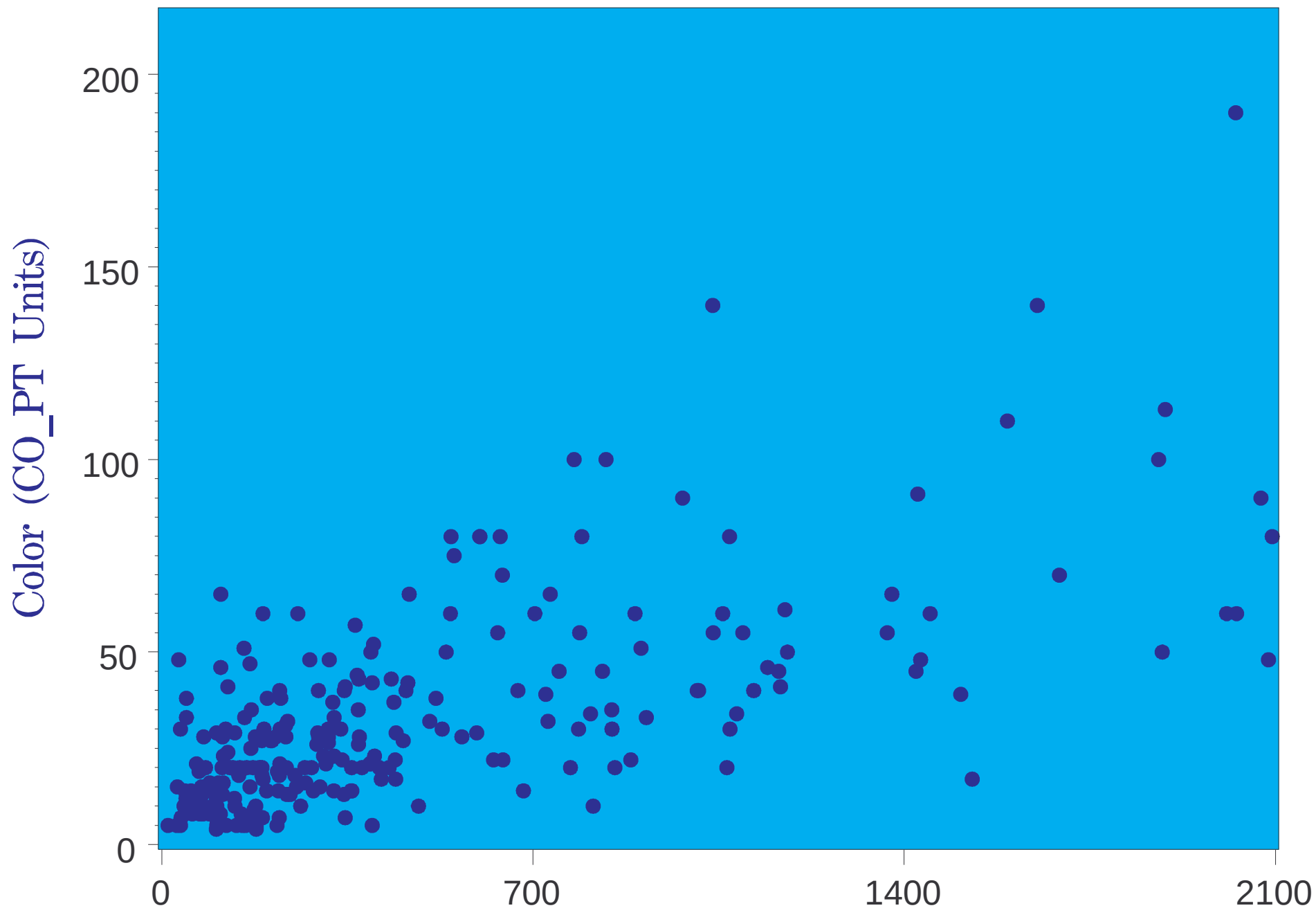


Figure 4.5.350 Surface color at river kilometer -2.4 versus flow

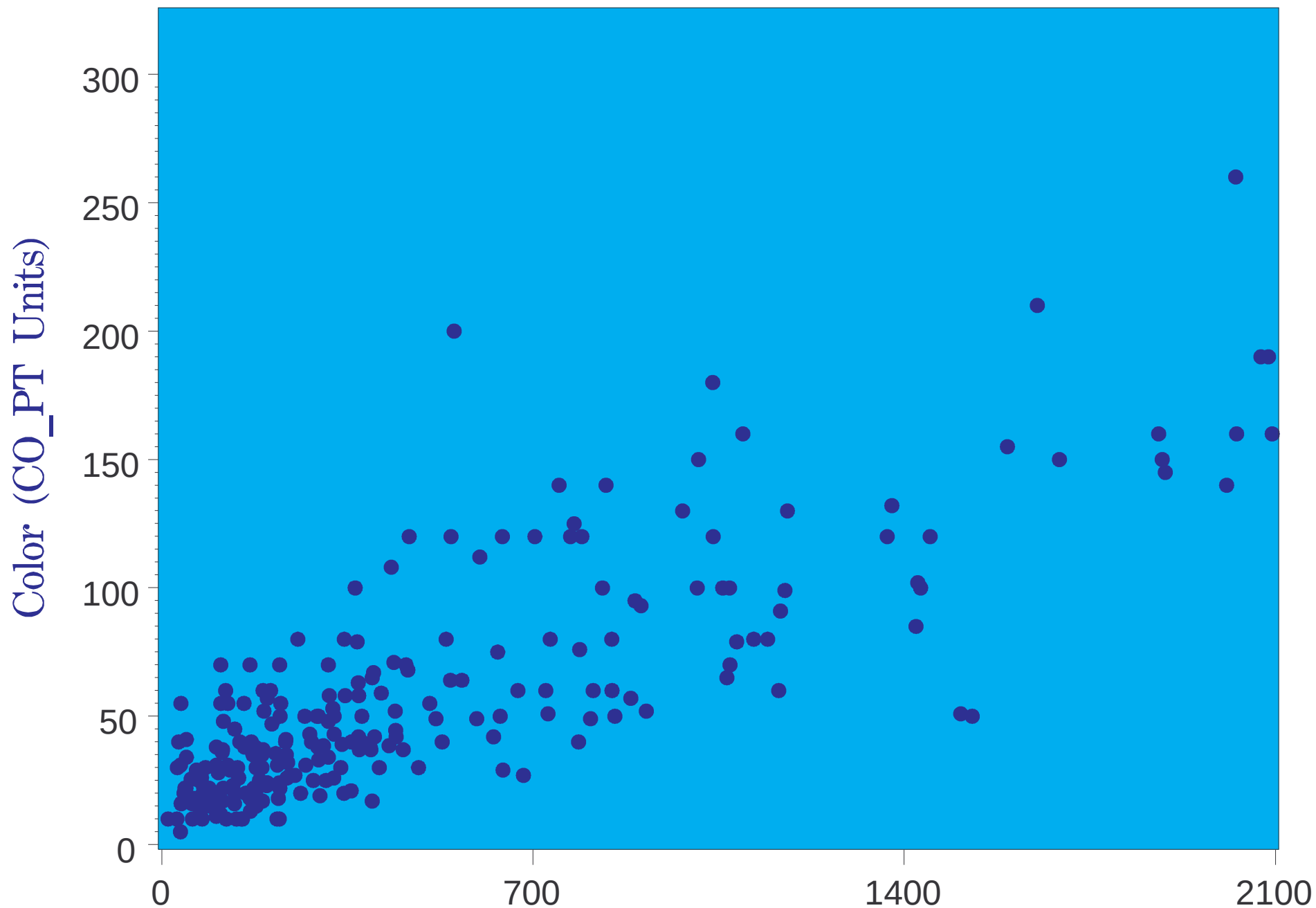


Figure 4.5.351 Surface color at river kilometer 6.6 versus flow

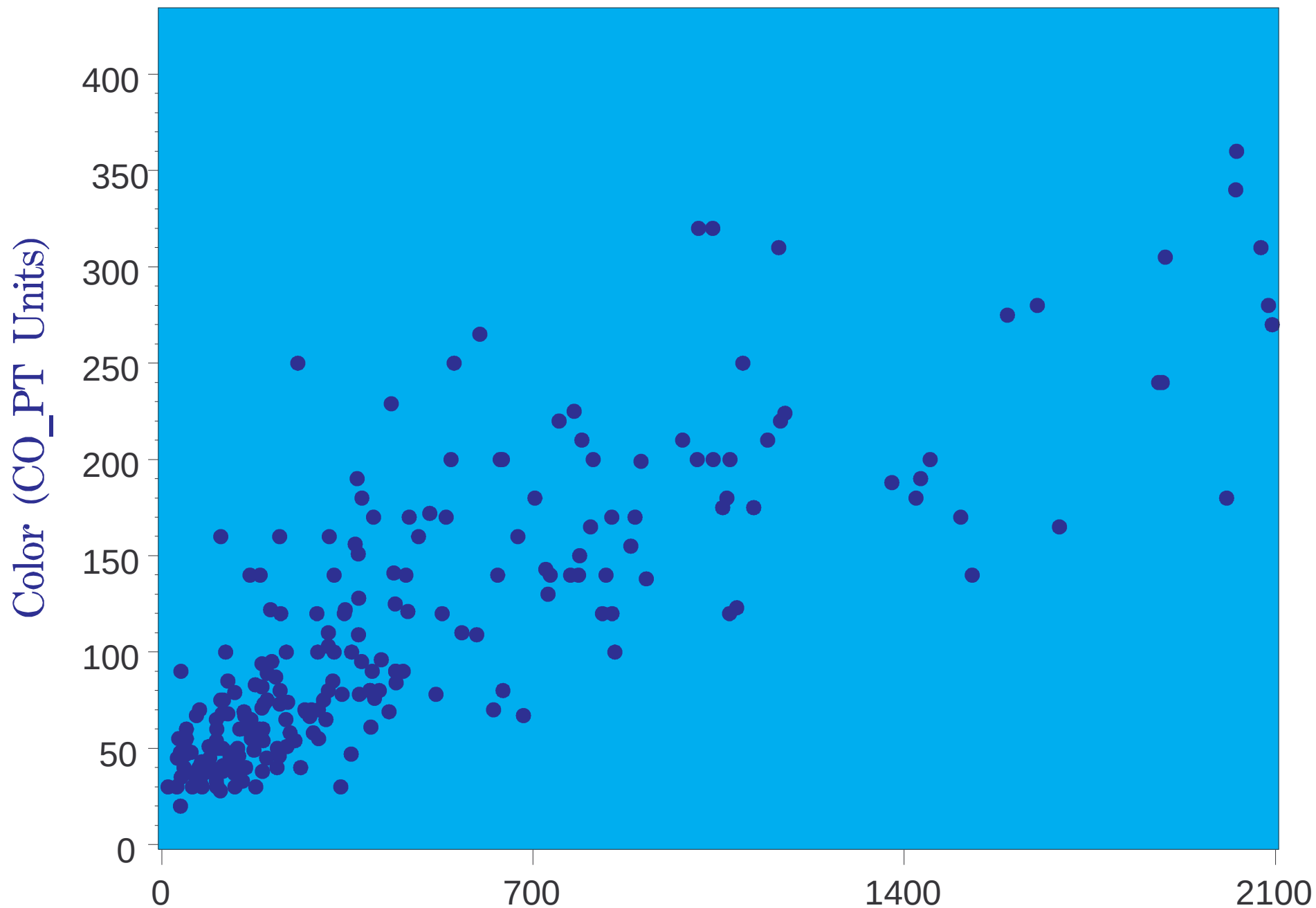


Figure 4.5.352 Surface color at river kilometer 15.5 versus flow

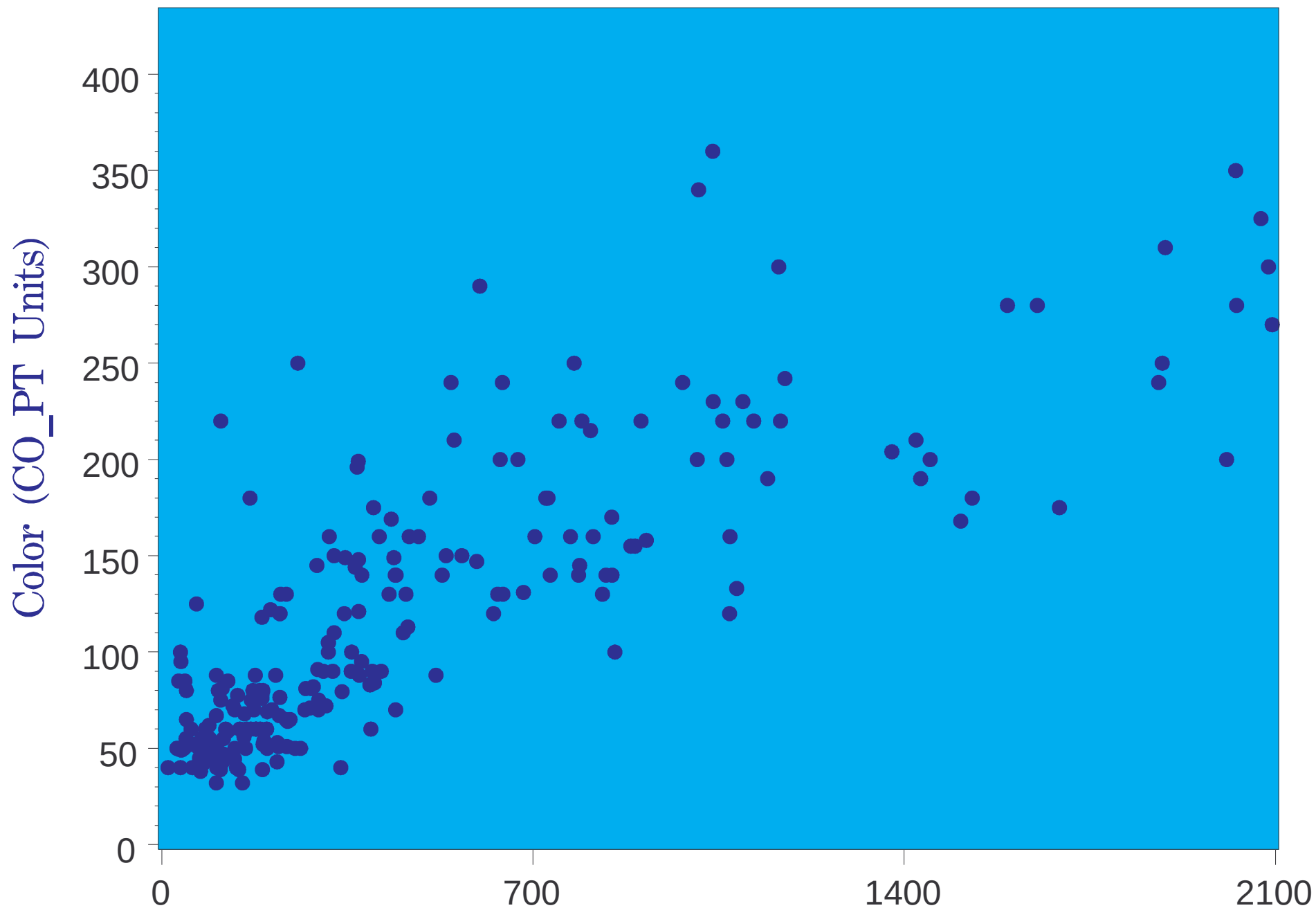


Figure 4.5.353 Surface color at river kilometer 23.6 versus flow



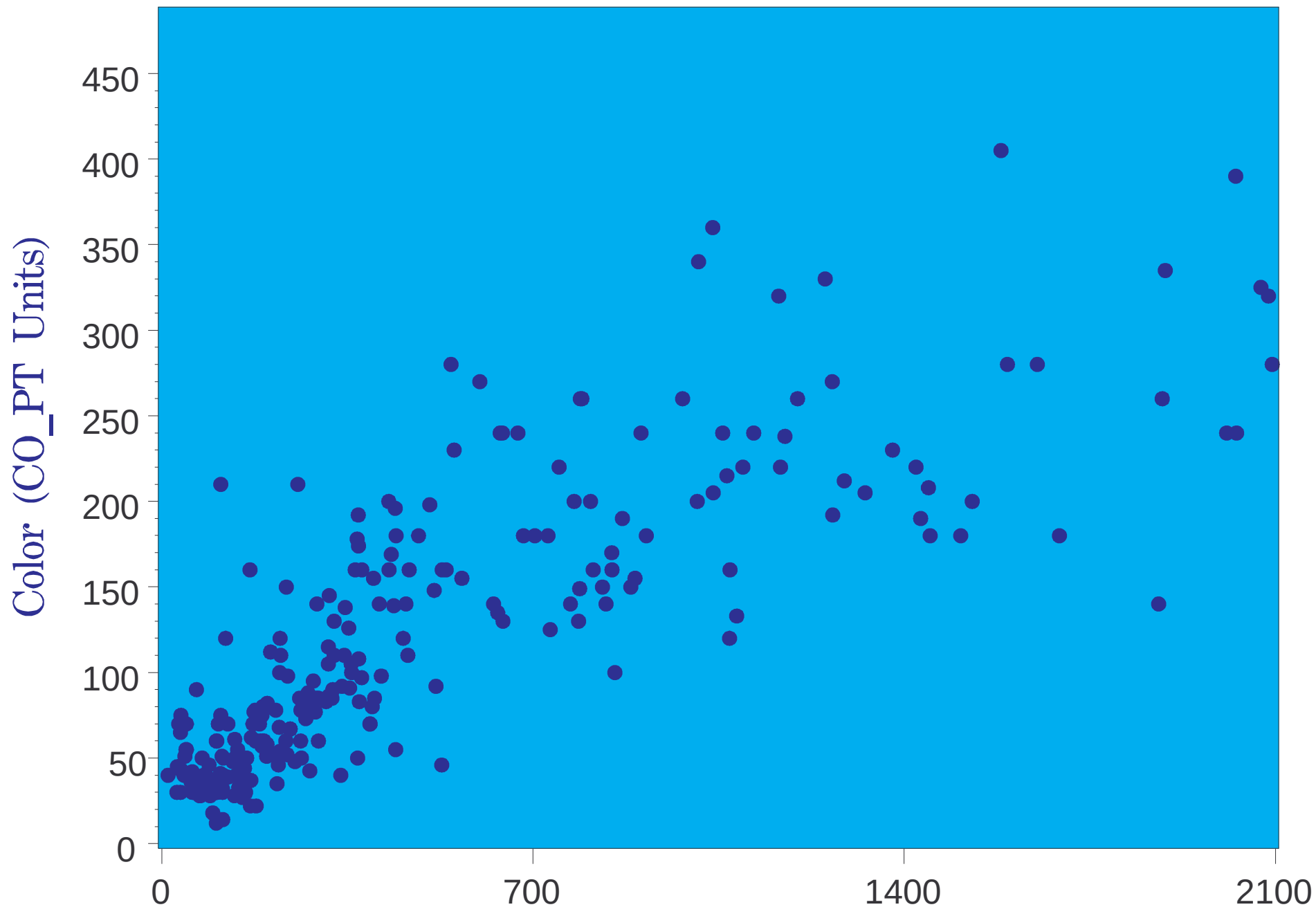


Figure 4.5.354 Surface color at river kilometer 30.4 versus flow

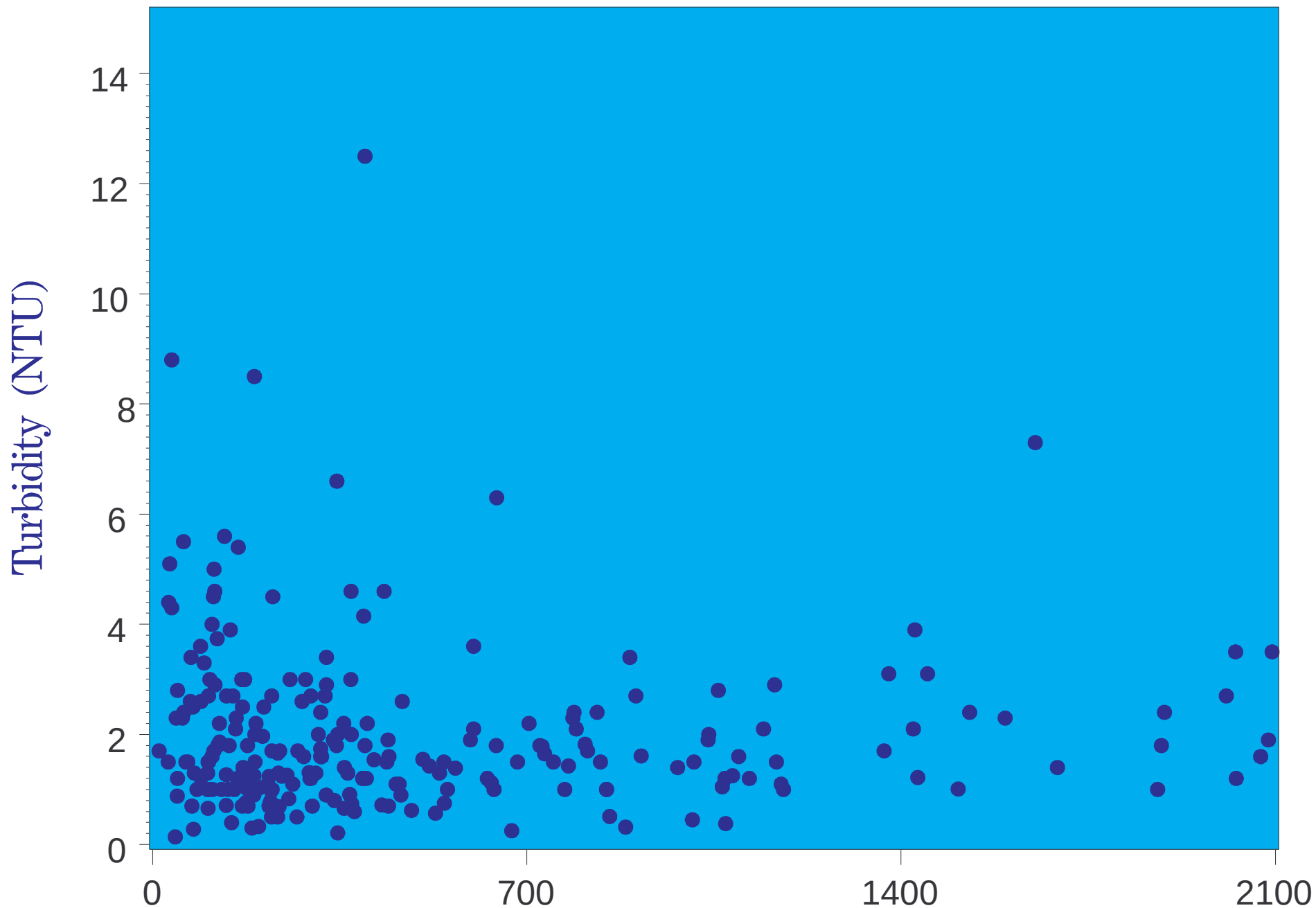


Figure 4.5.355 Surface turbidity at river kilometer -2.4 versus flow

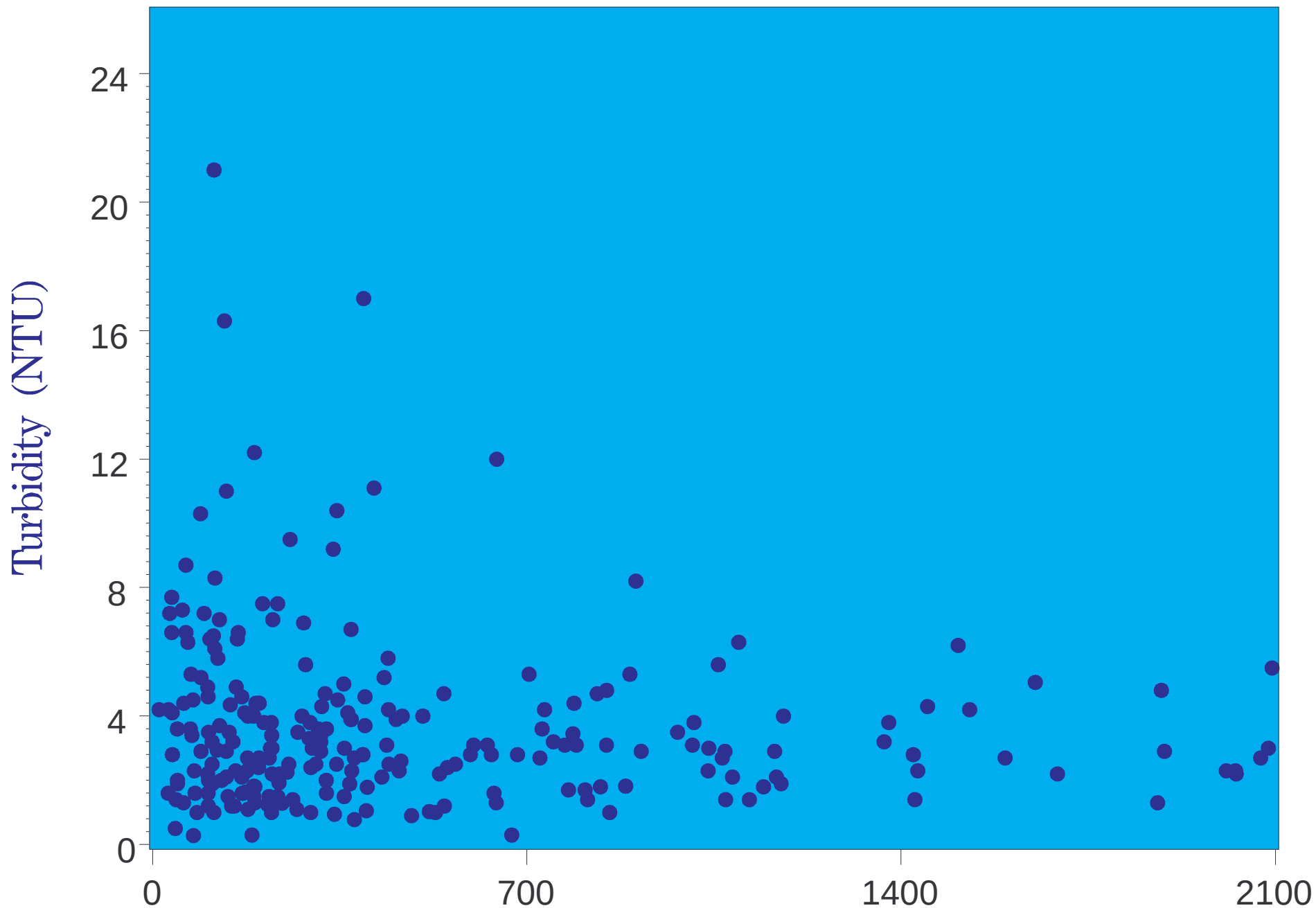


Figure 4.5.356 Surface turbidity at river kilometer 6.6 versus flow

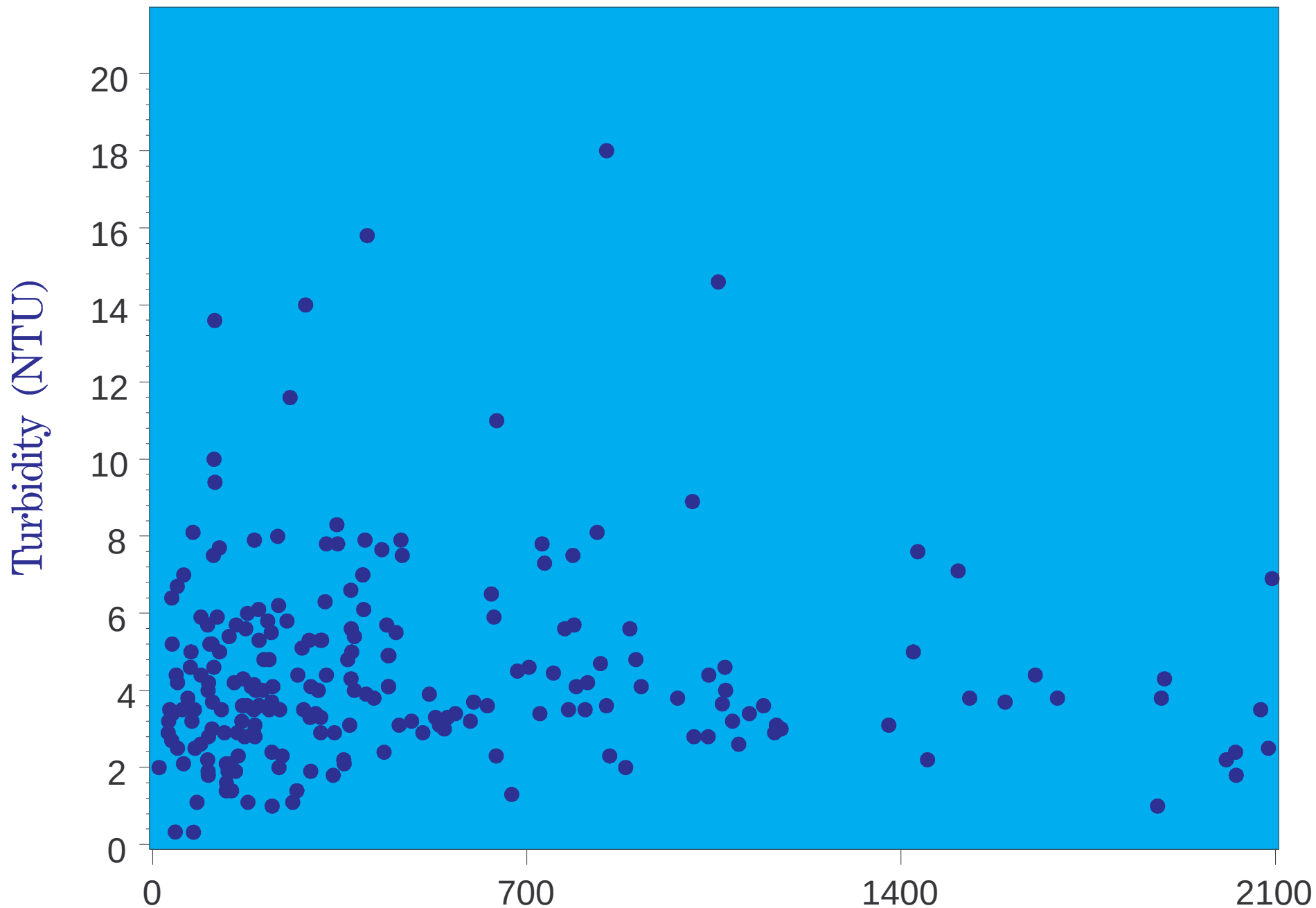


Figure 4.5.357 Surface turbidity at river kilometer 15.5 versus flow

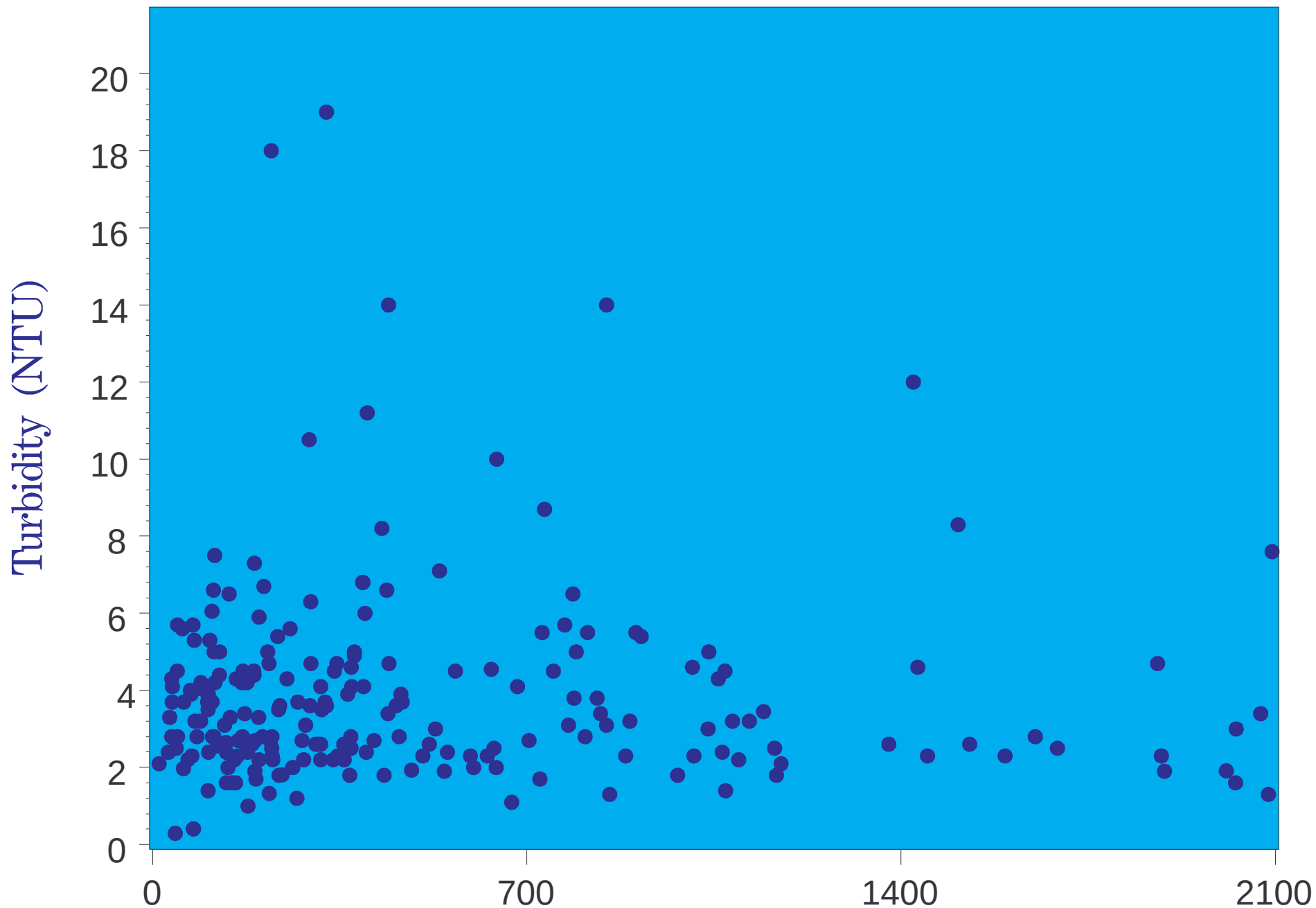


Figure 4.5.358 Surface turbidity at river kilometer 23.6 versus flow

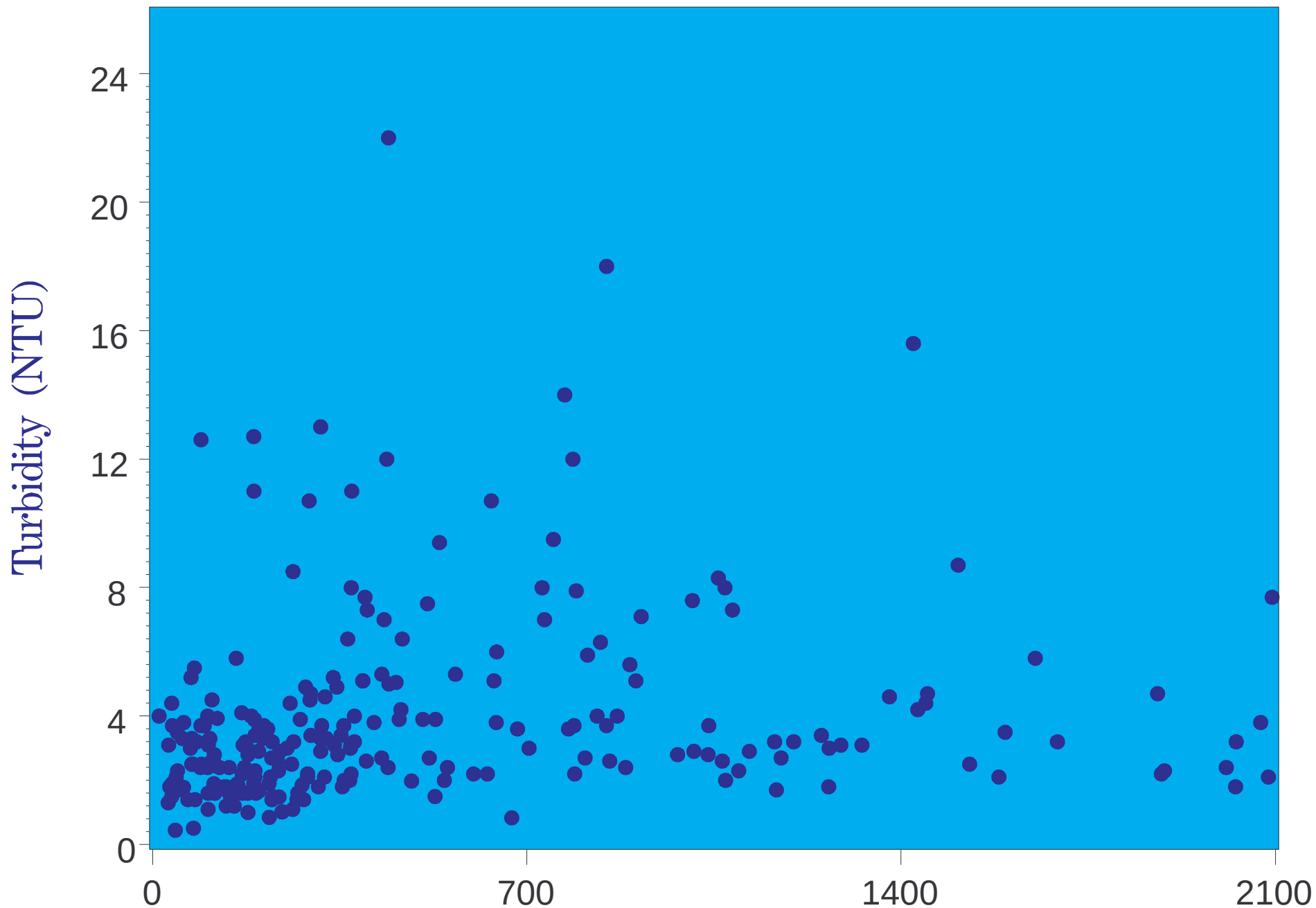


Figure 4.5.359 Surface turbidity at river kilometer 30.4 versus flow

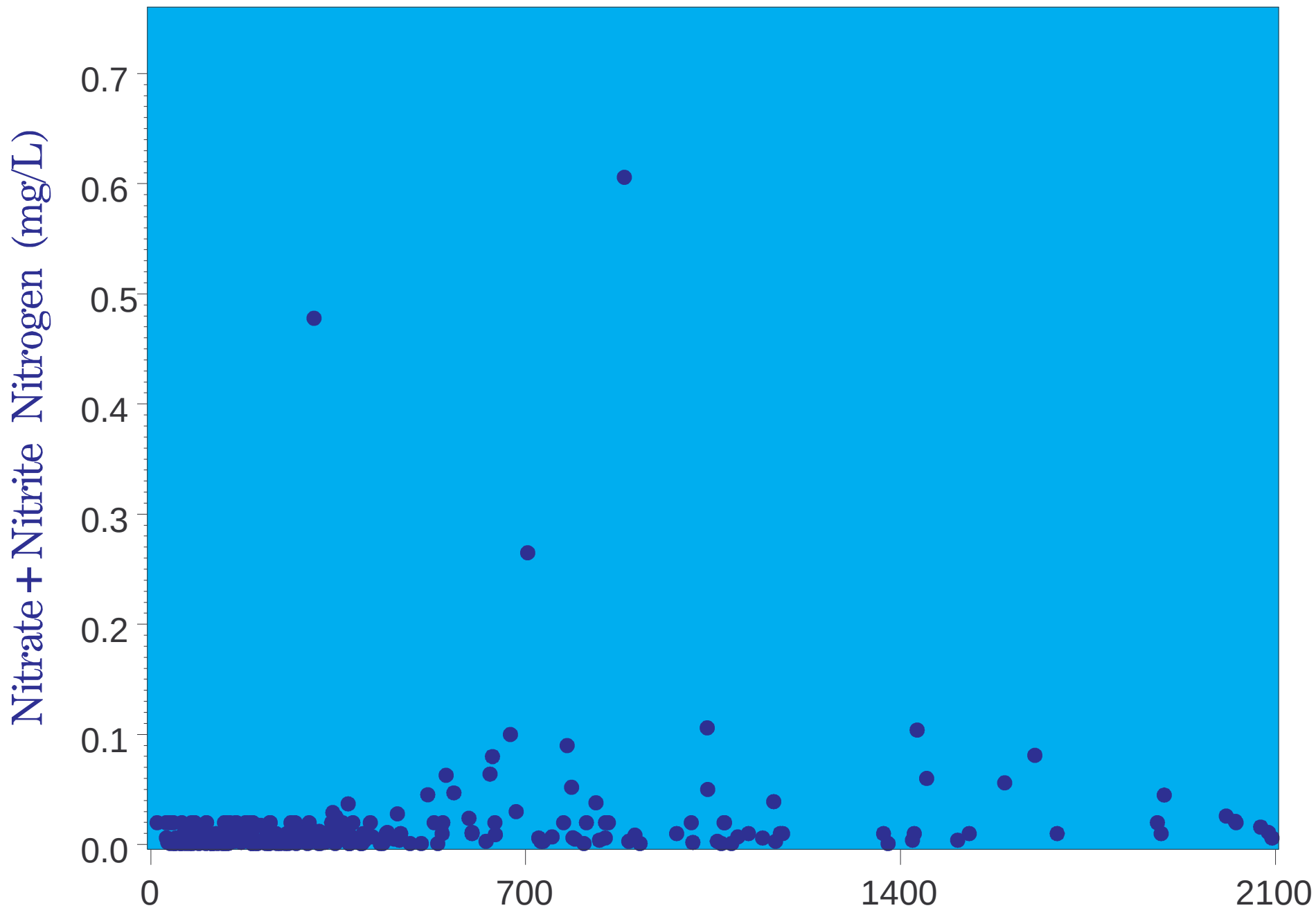


Figure 4.5.360 Surface nitrate/nitrite nitrogen at river kilometer -2.4 versus flow

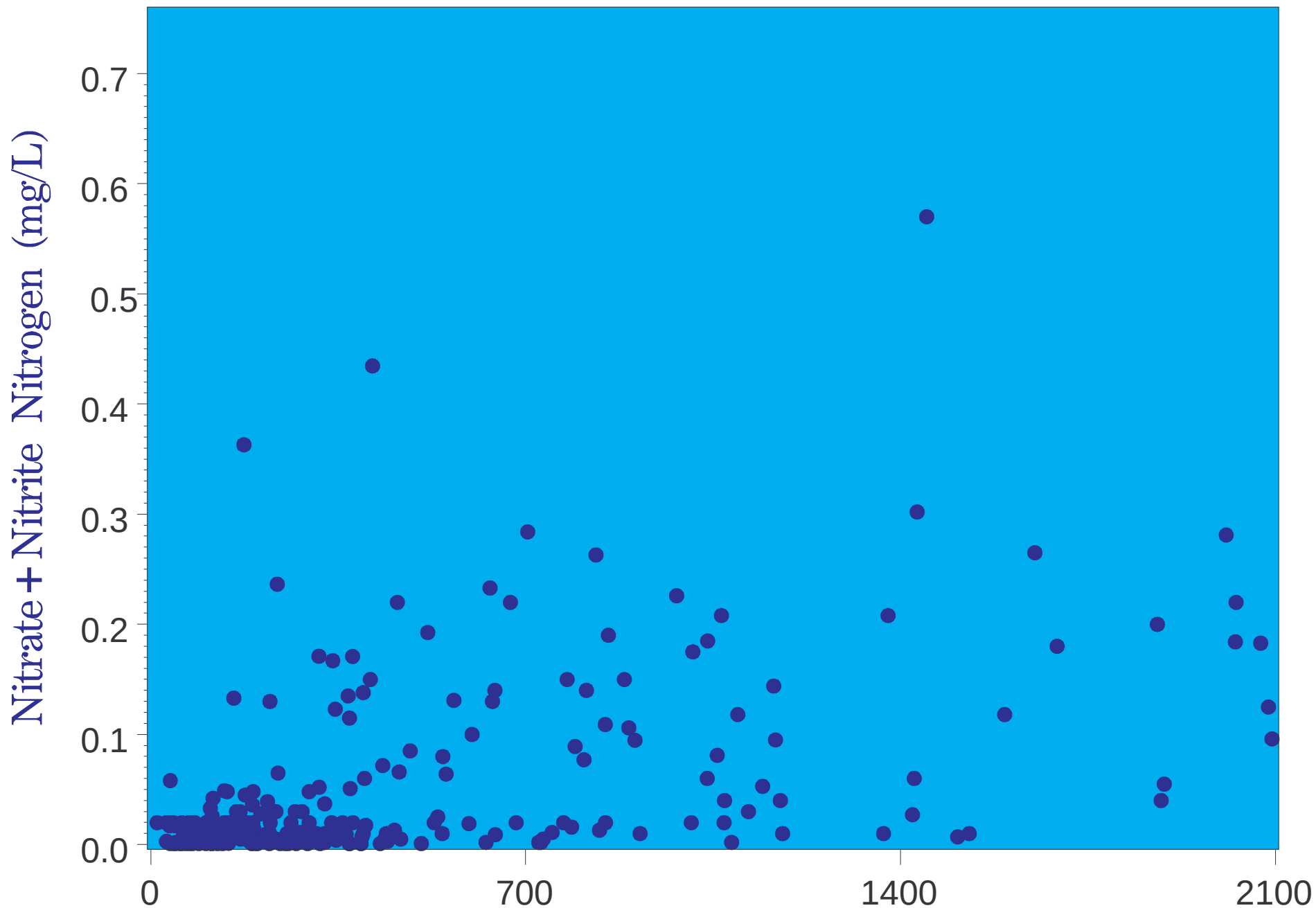


Figure 4.5.361 Surface nitrate/nitrite nitrogen at river kilometer 6.6 versus flow



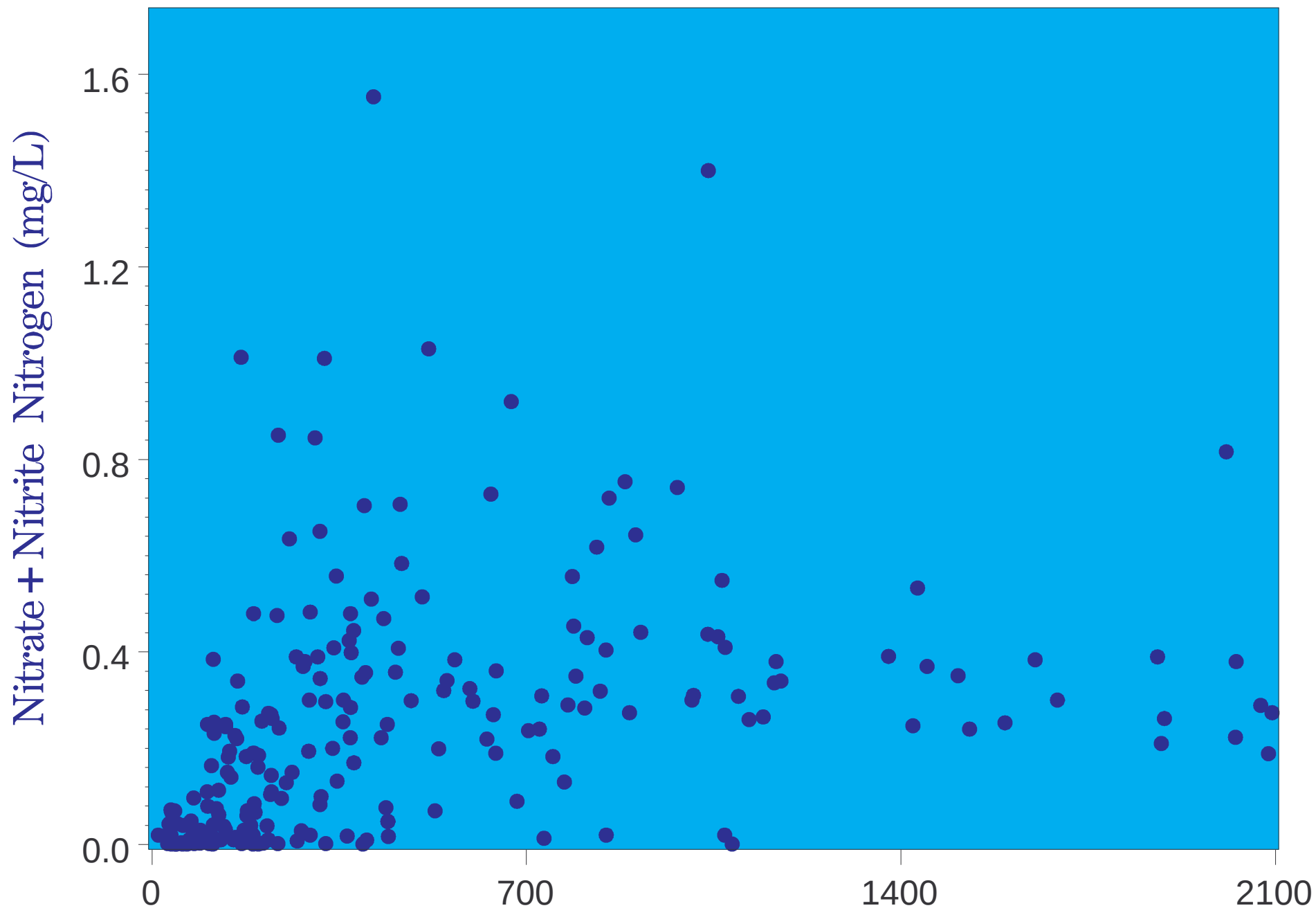


Figure 4.5.362 Surface nitrate/nitrite nitrogen at river kilometer 15.5 versus flow

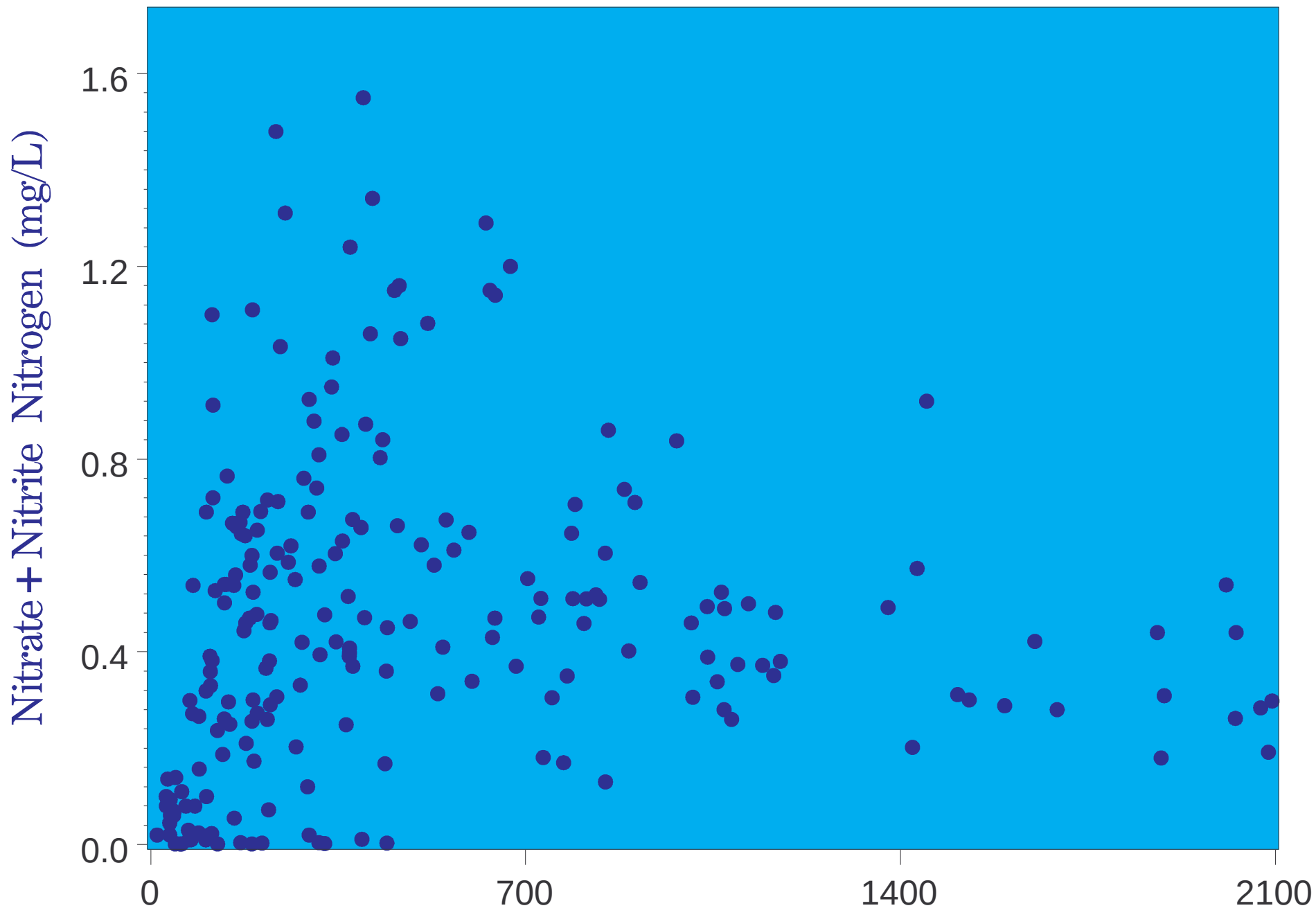


Figure 4.5.363 Surface nitrate/nitrite nitrogen at river kilometer 23.6 versus flow

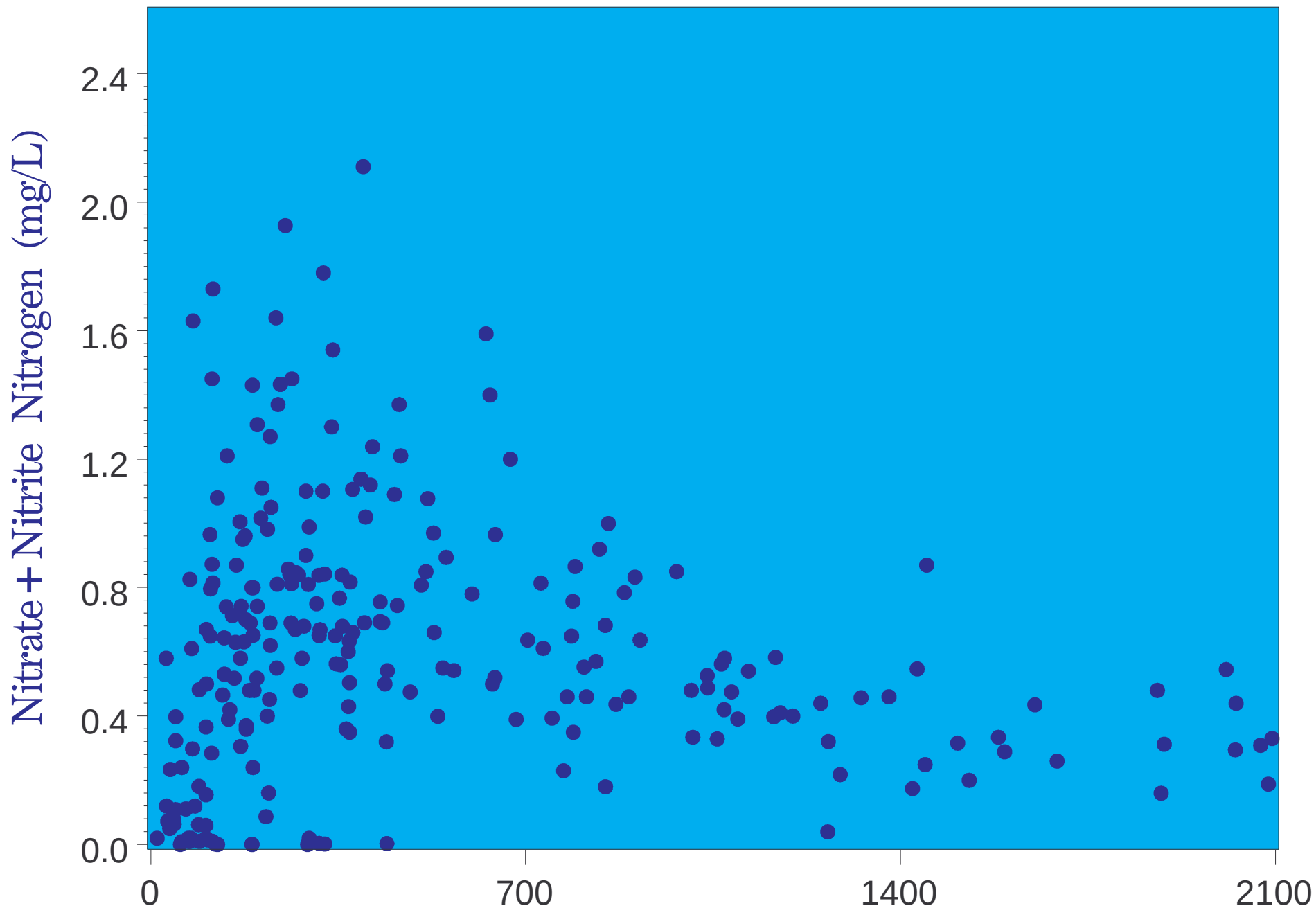


Figure 4.5.364 Surface nitrate/nitrite nitrogen at river kilometer 30.4 versus flow

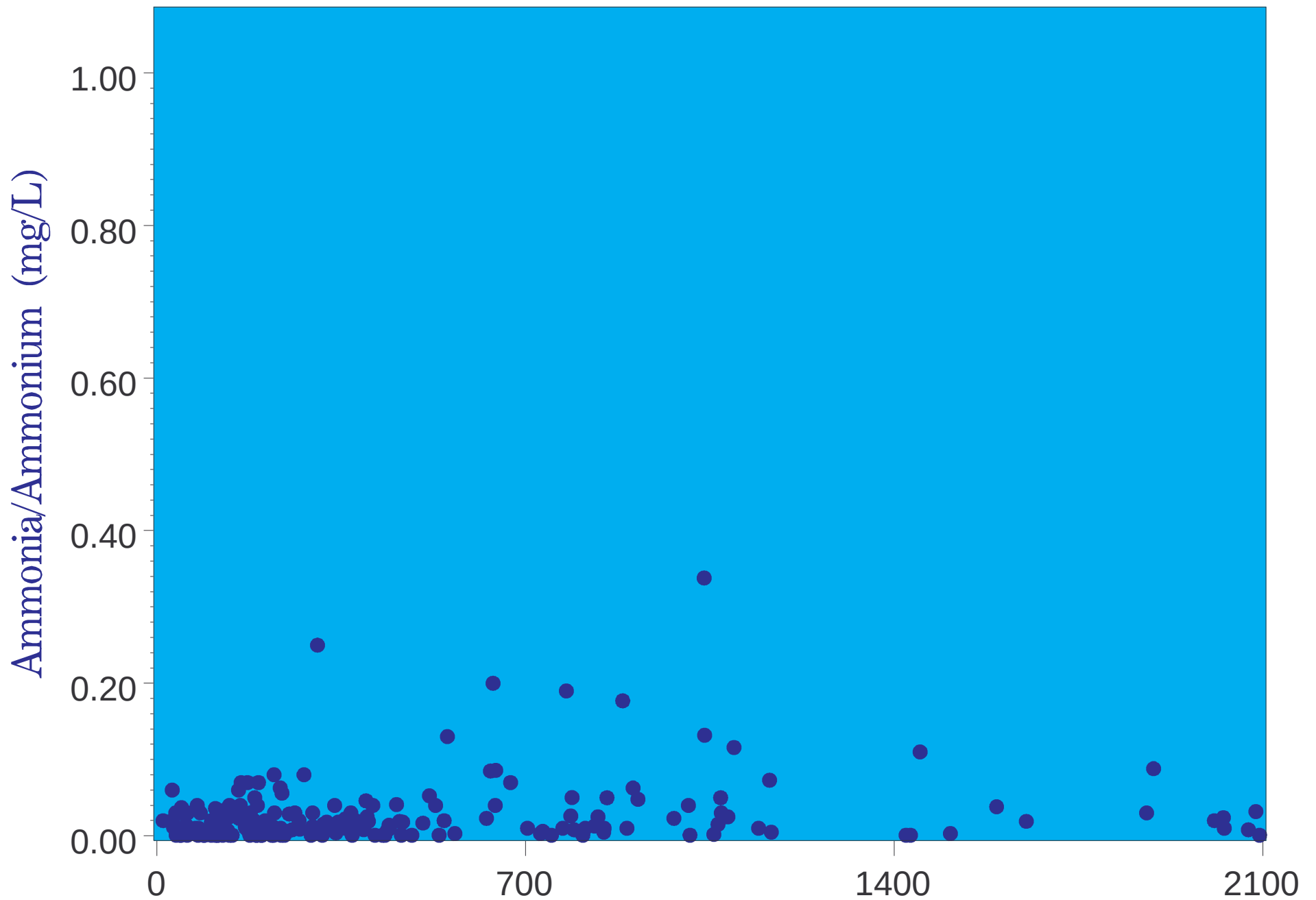


Figure 4.5.365 Surface ammonia/ammonium at river kilometer -2.4 versus flow

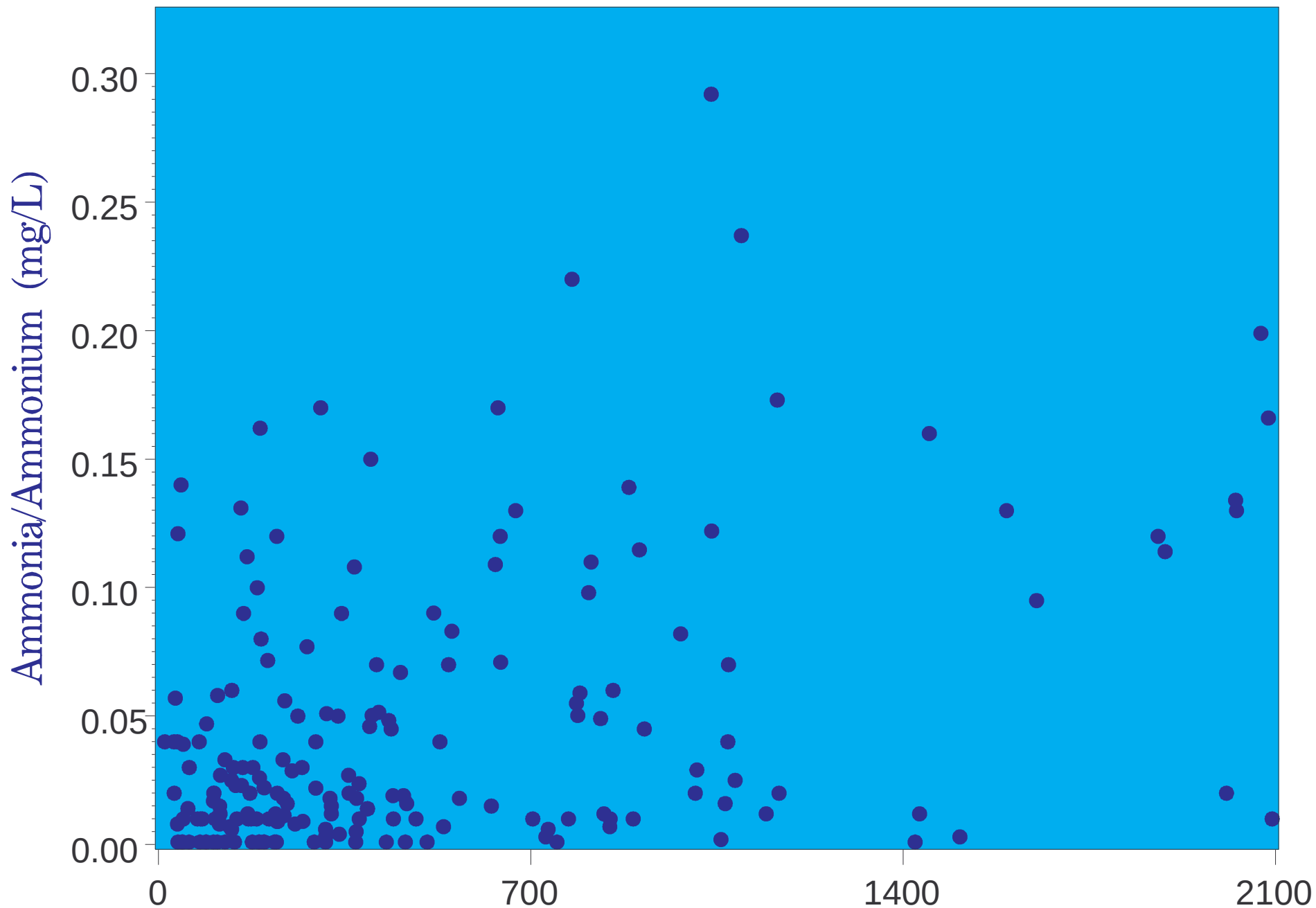


Figure 4.5.366 Surface ammonia/ammonium at river kilometer 6.6 versus flow

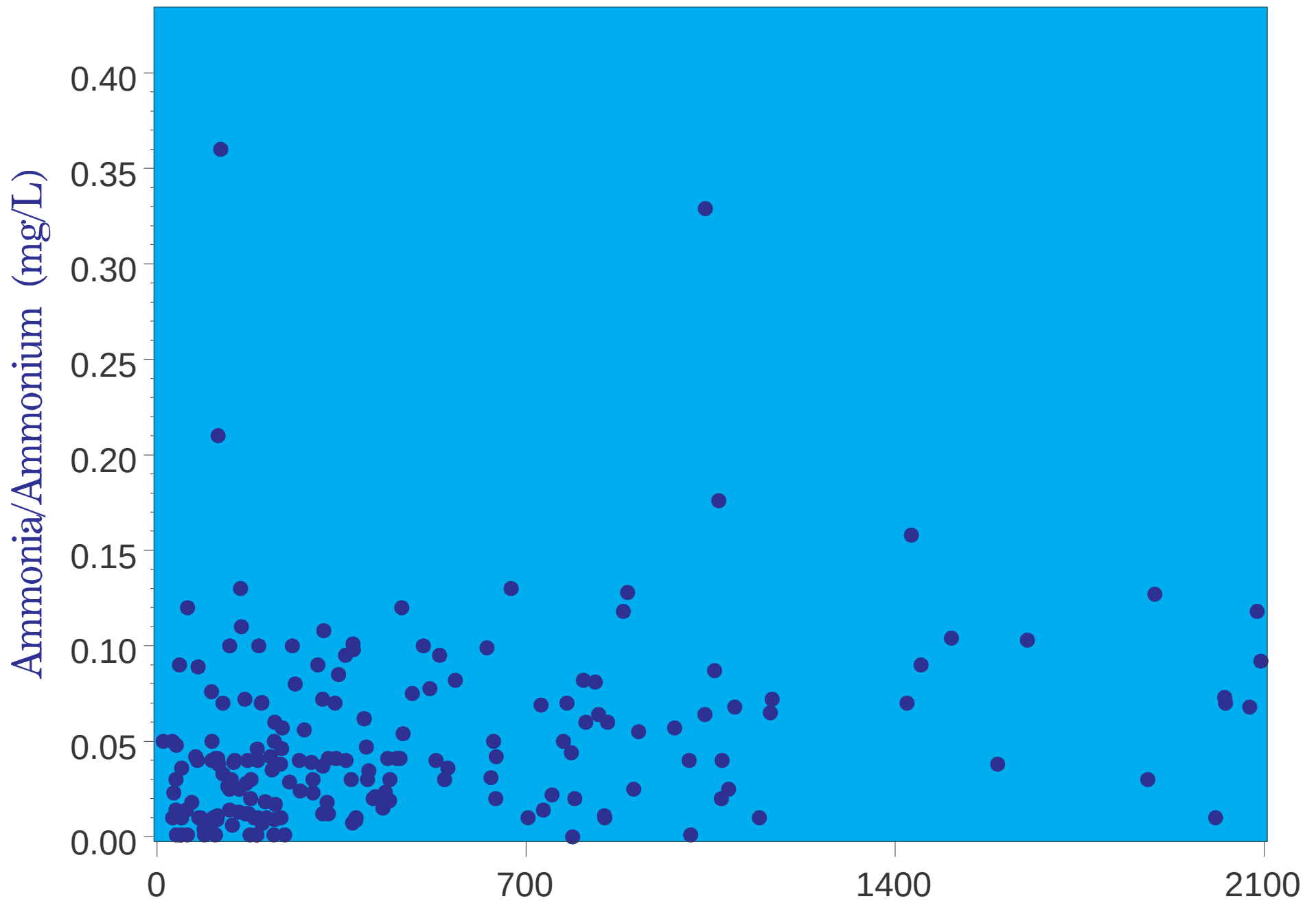


Figure 4.5.367 Surface ammonia/ammonium at river kilometer 15.5 versus flow

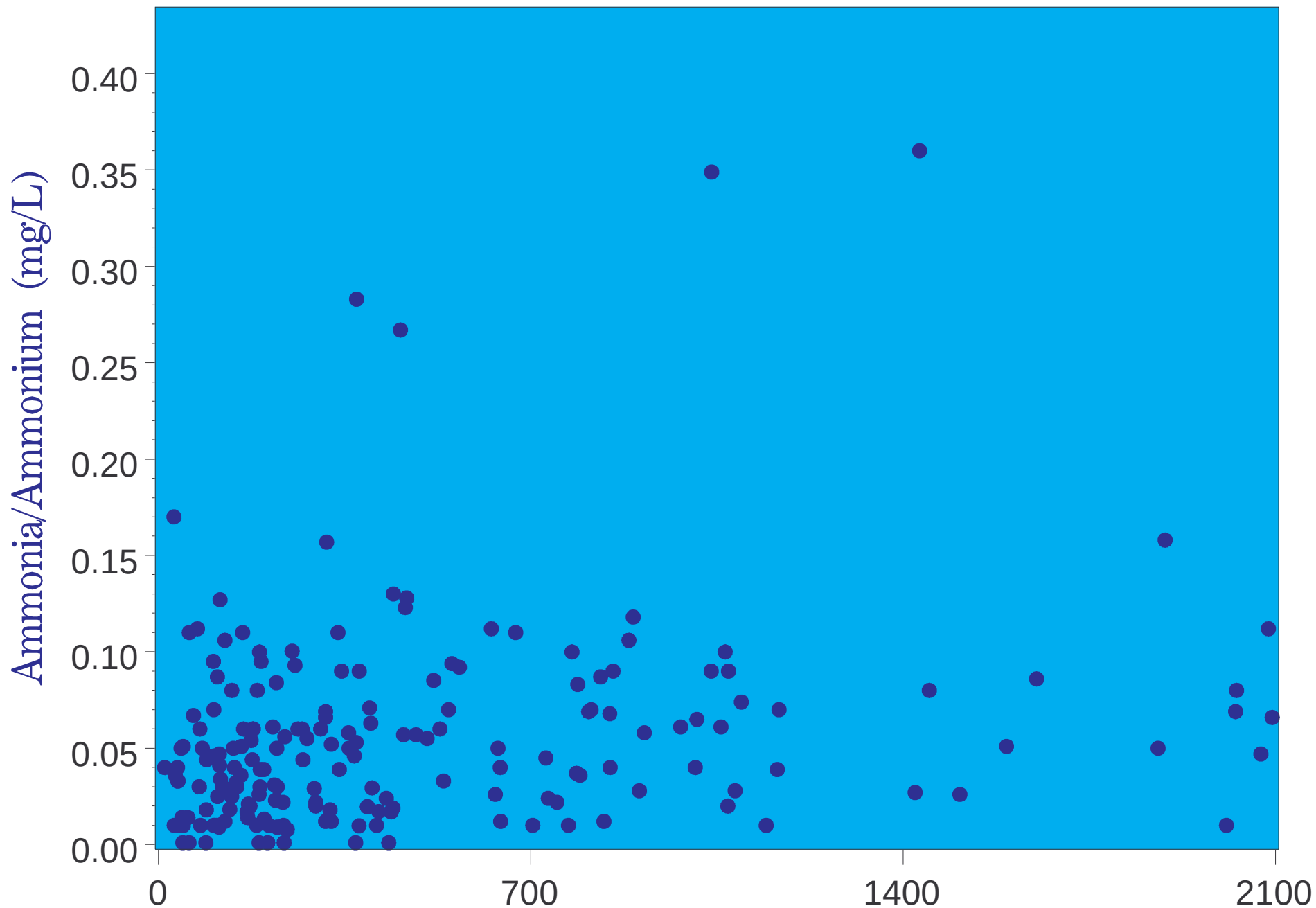


Figure 4.5.368 Surface ammonia/ammonium at river kilometer 23.6 versus flow

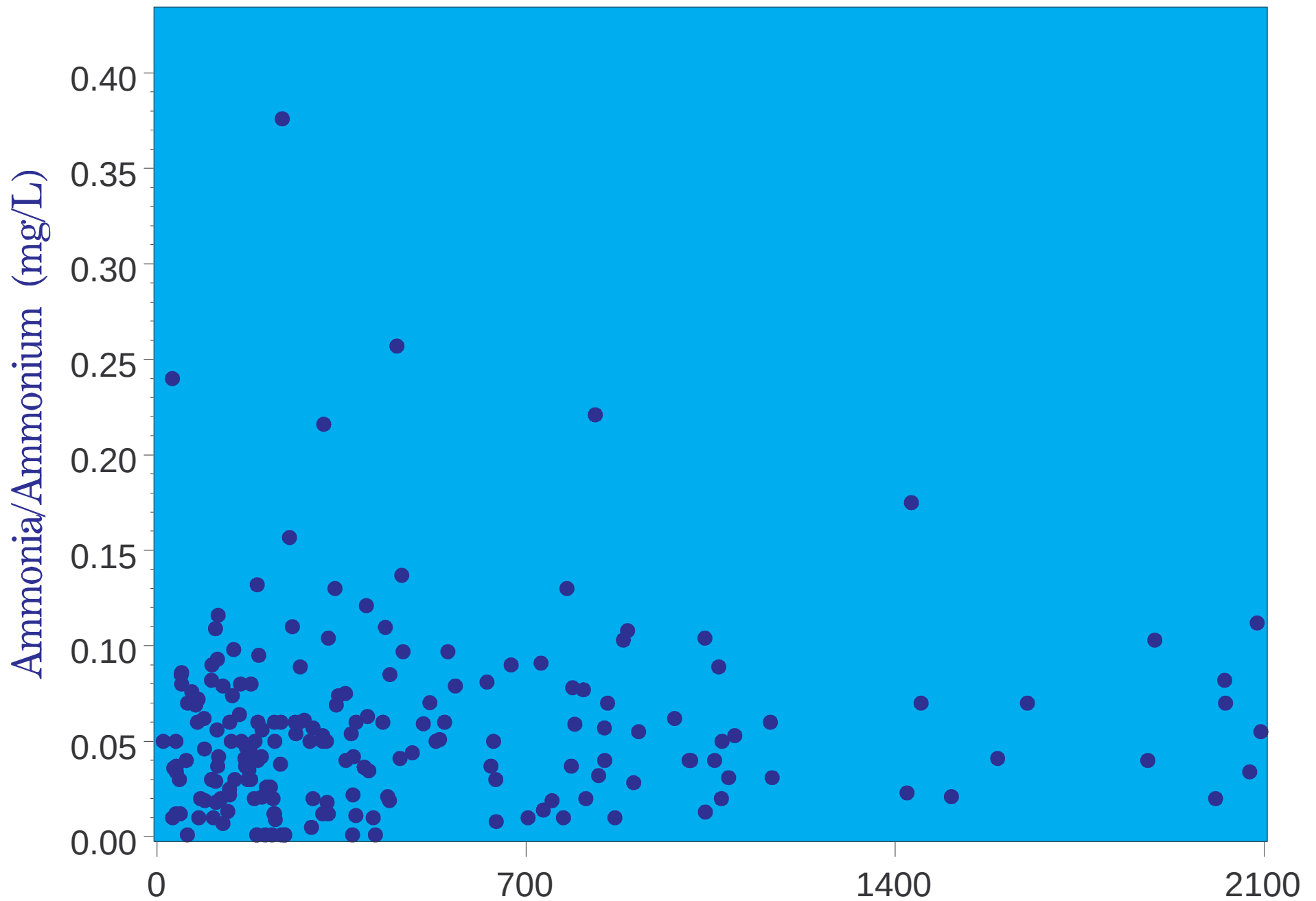


Figure 4.5.369 Surface ammonia/ammonium at river kilometer 30.4 versus flow



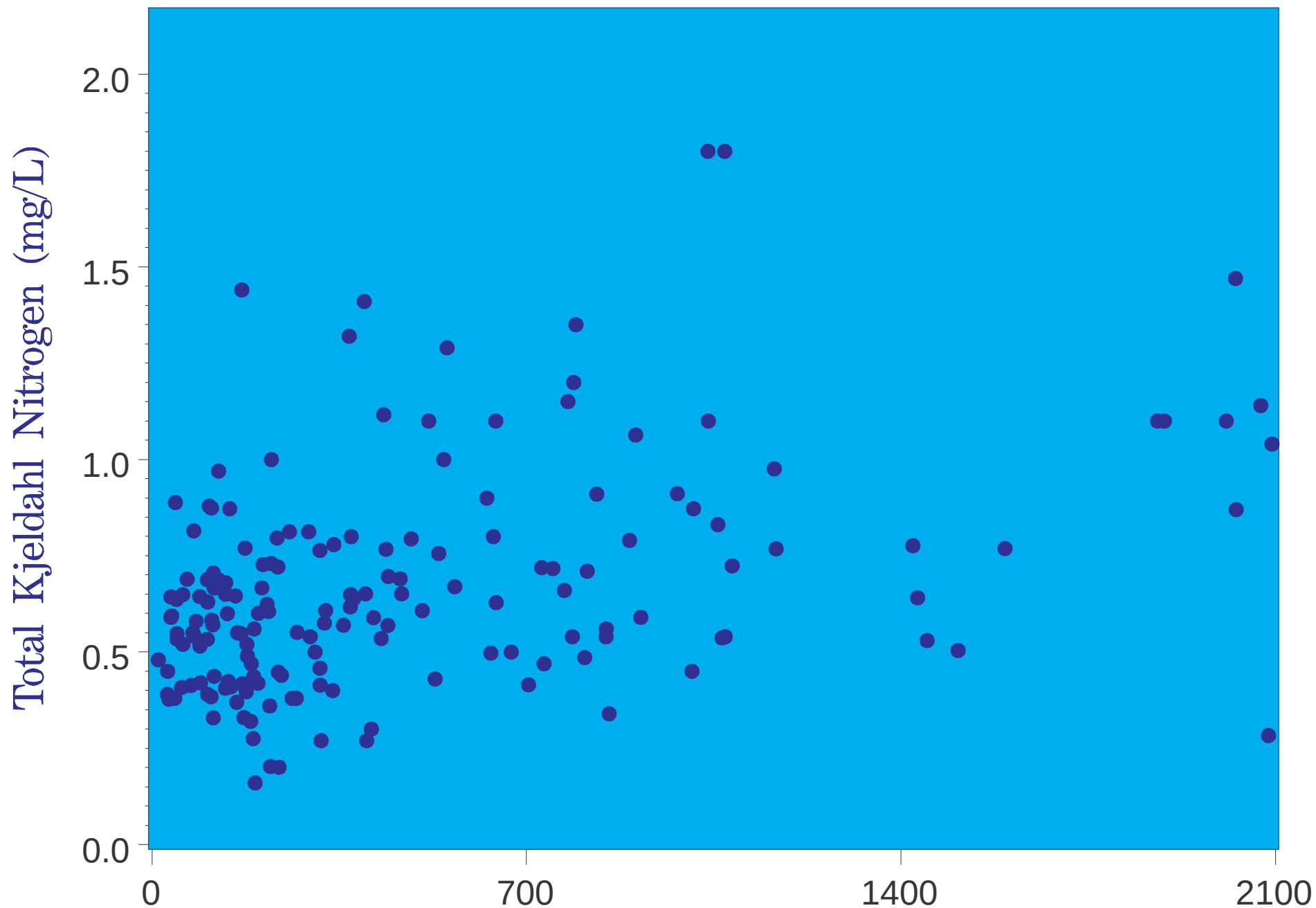


Figure 4.5.370 Surface total Kjeldahl nitrogen at river kilometer -2.4 versus flow

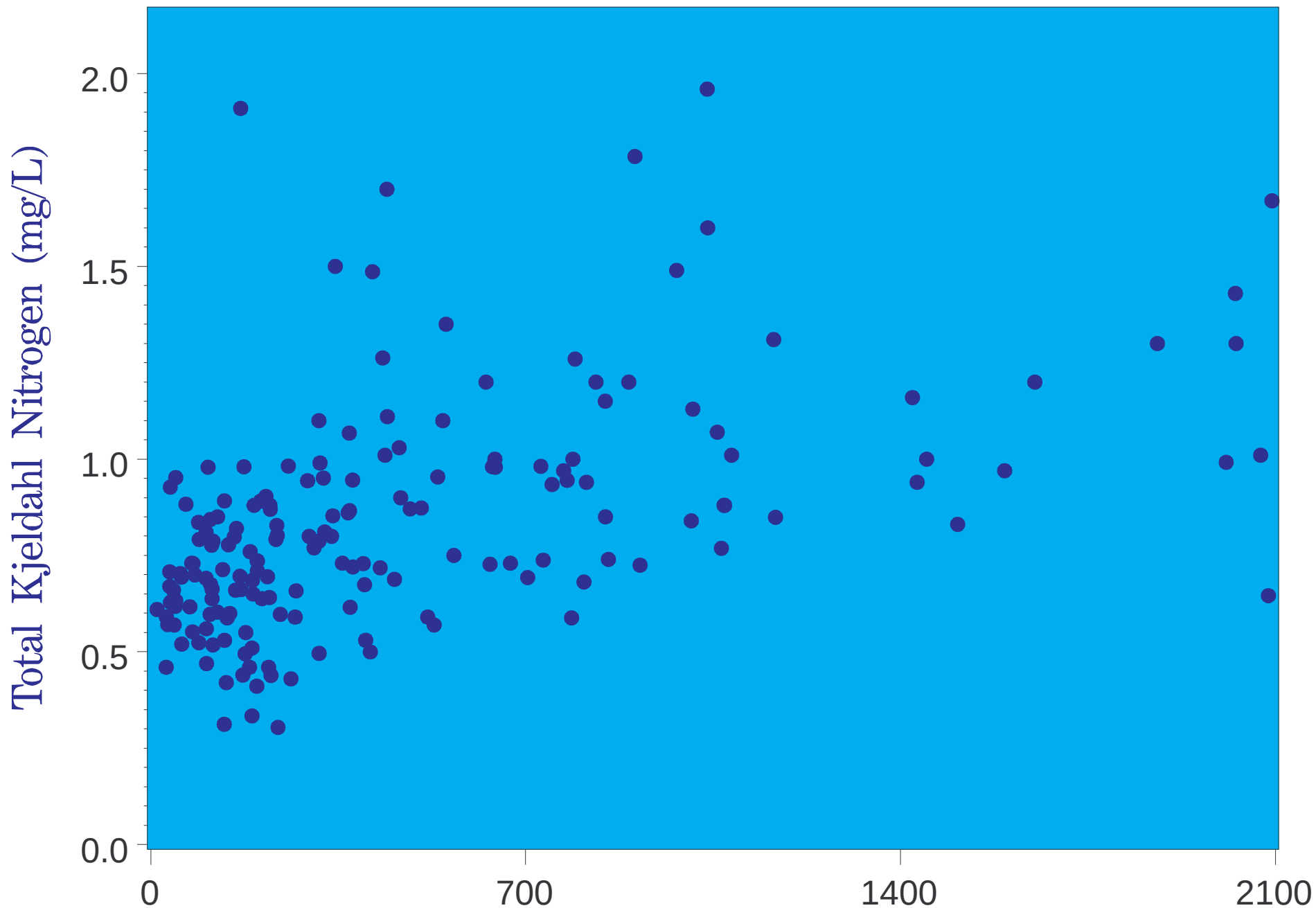


Figure 4.5.371 Surface total Kjeldahl nitrogen at river kilometer 6.6 versus flow

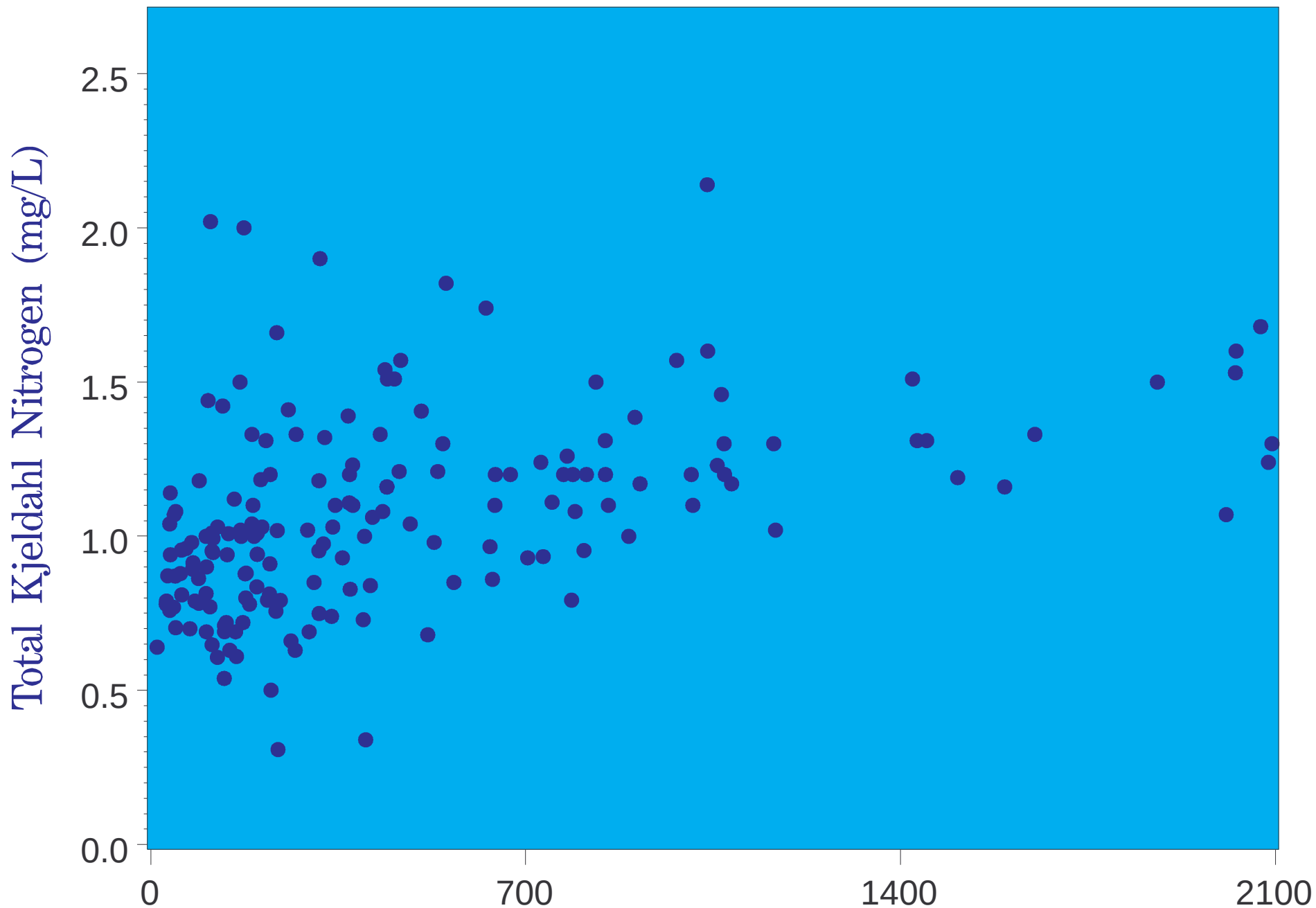


Figure 4.5.372 Surface total Kjeldahl nitrogen at river kilometer 15.5 versus flow

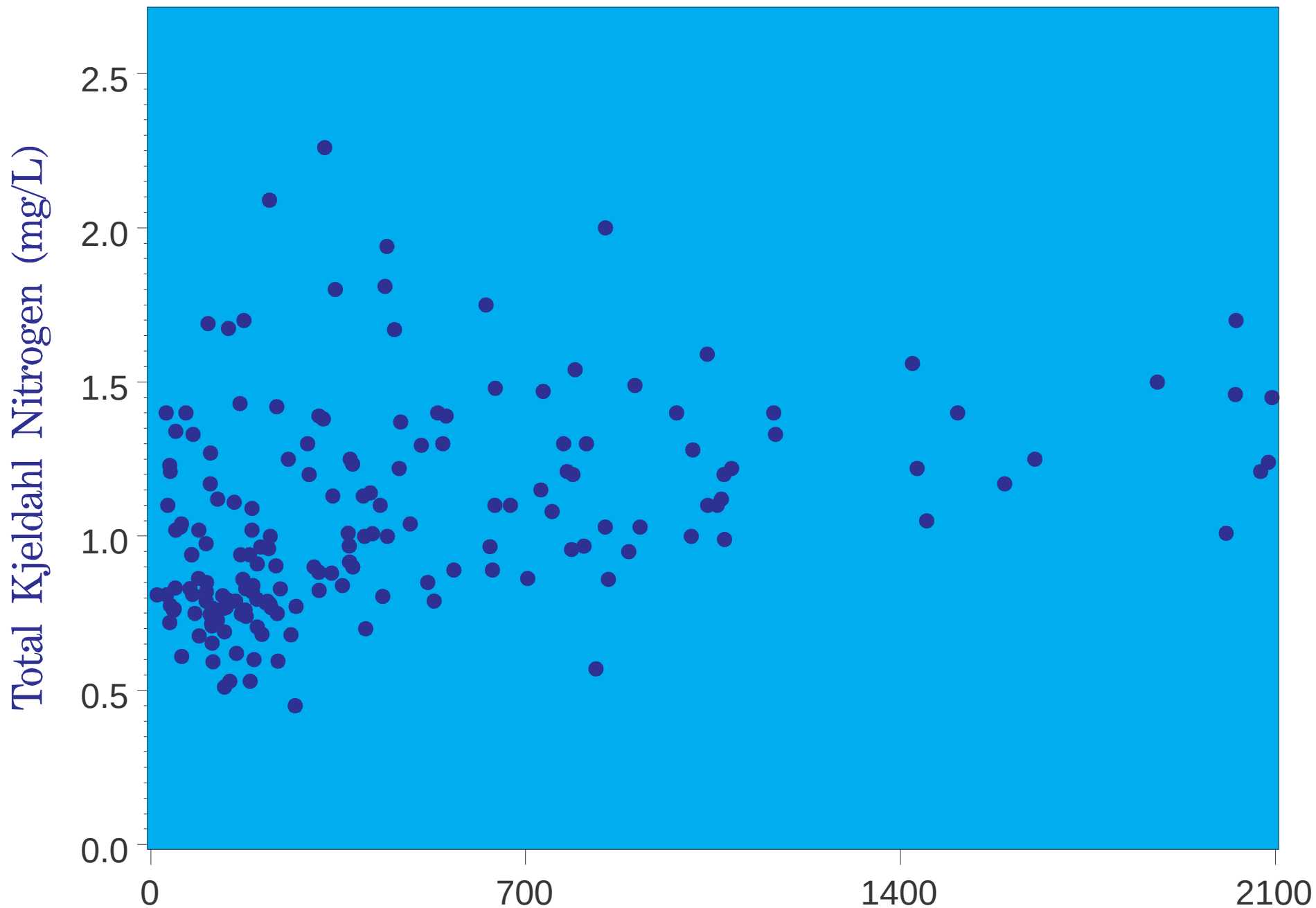


Figure 4.5.373 Surface total Kjeldahl nitrogen at river kilometer 23.6 versus flow

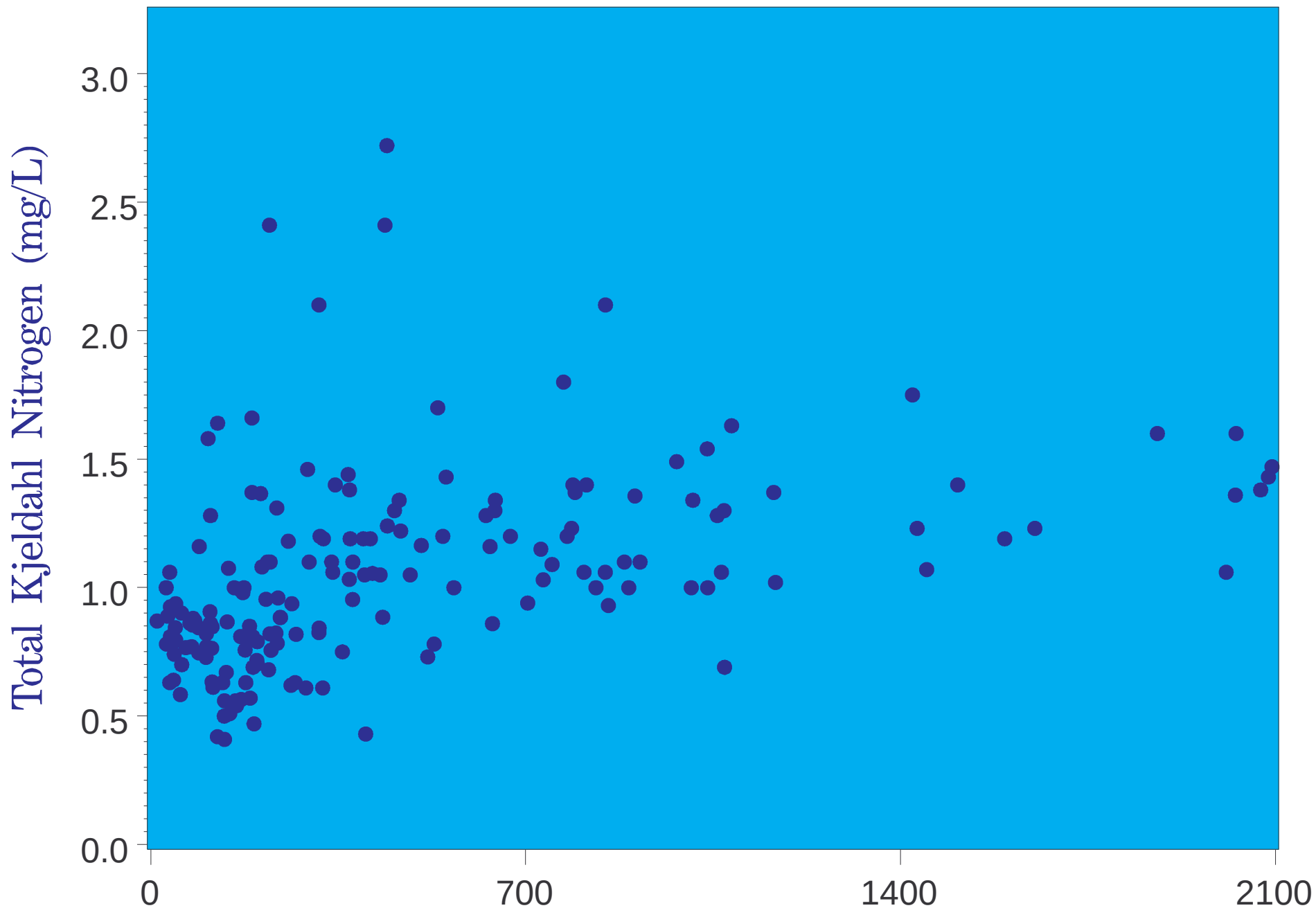


Figure 4.5.374 Surface total Kjeldahl nitrogen at river kilometer 30.4 versus flow

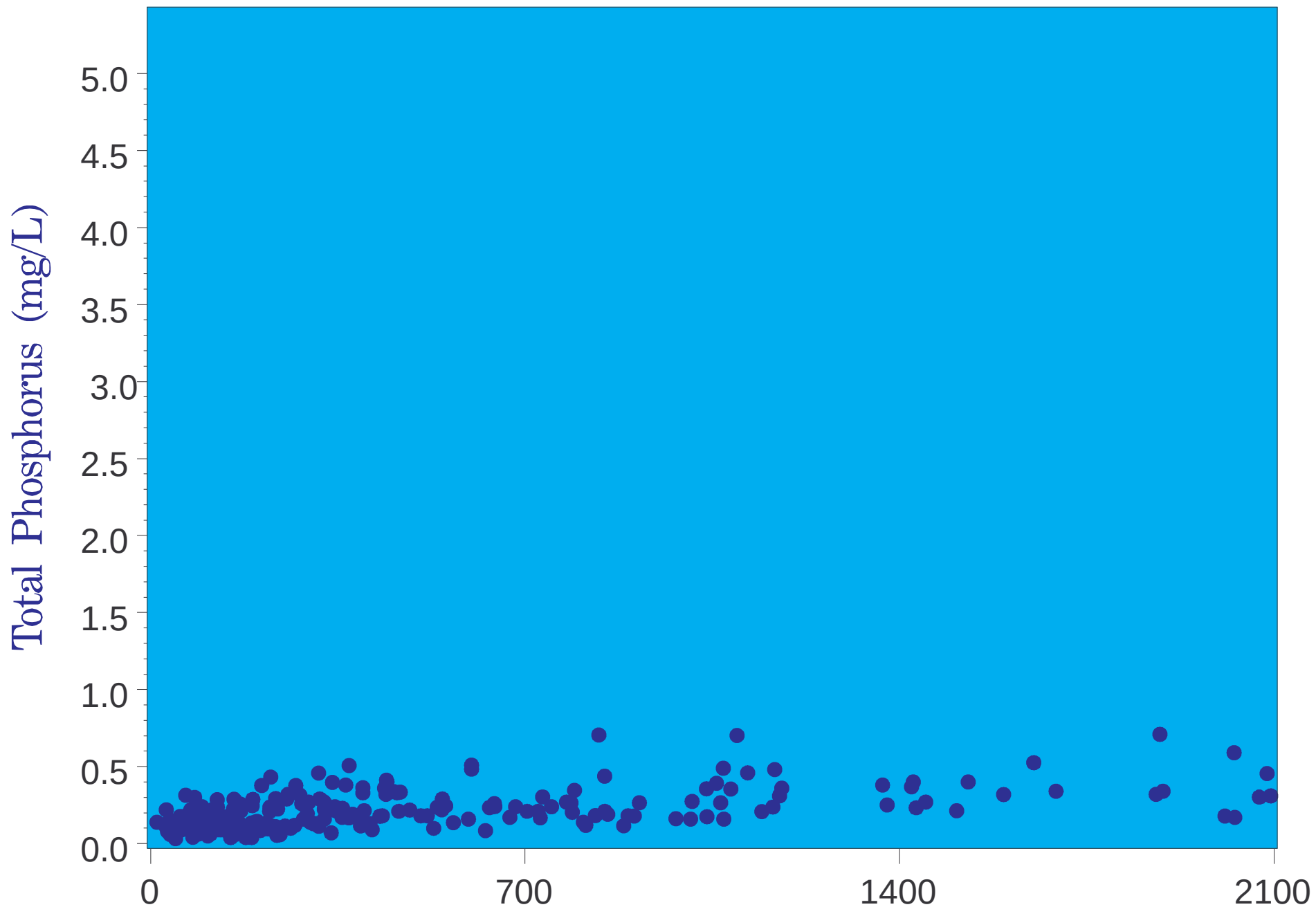


Figure 4.5.375 Surface total phosphorus at river kilometer -2.4 versus flow

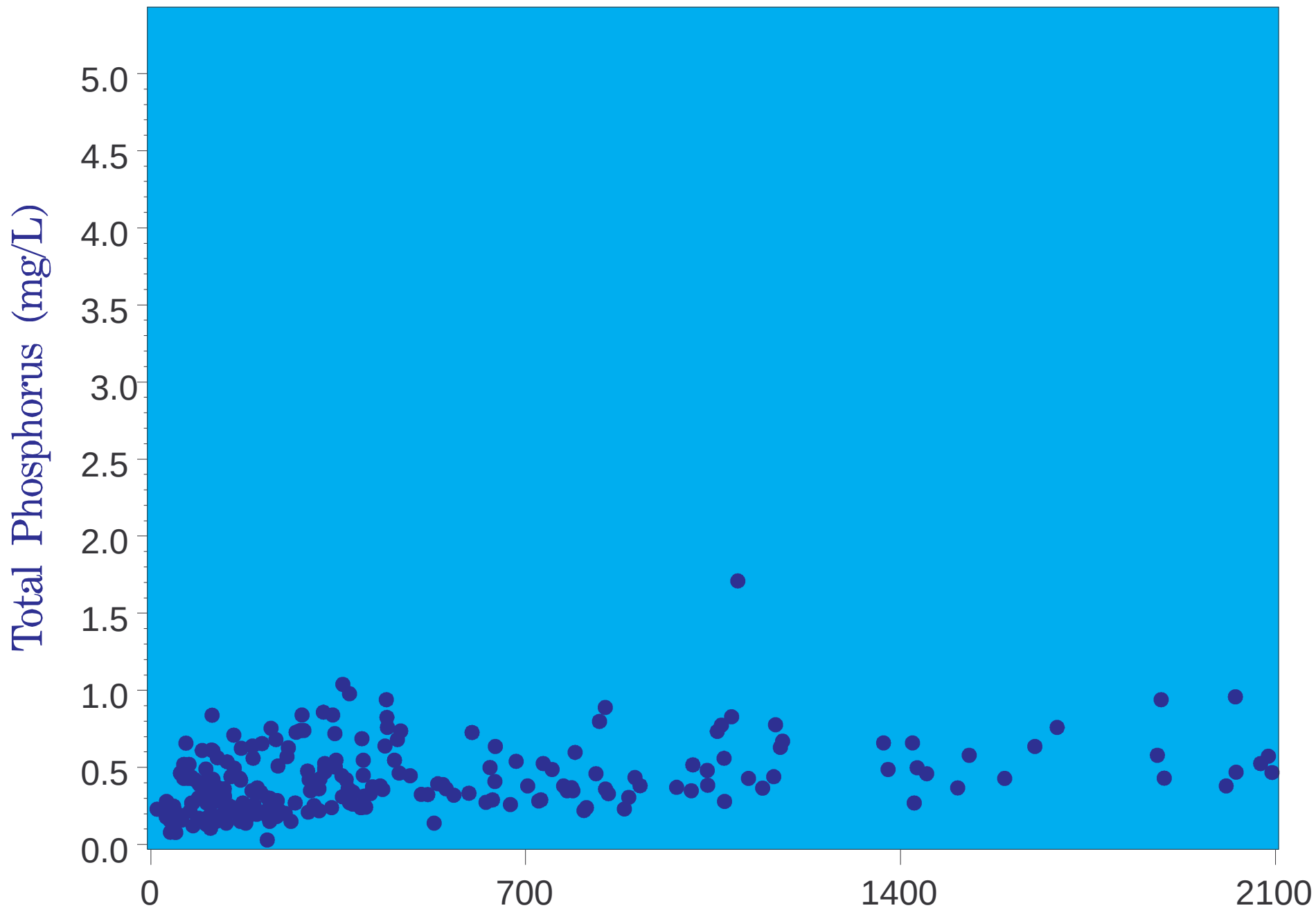


Figure 4.5.376 Surface total phosphorus at river kilometer 6.6 versus flow

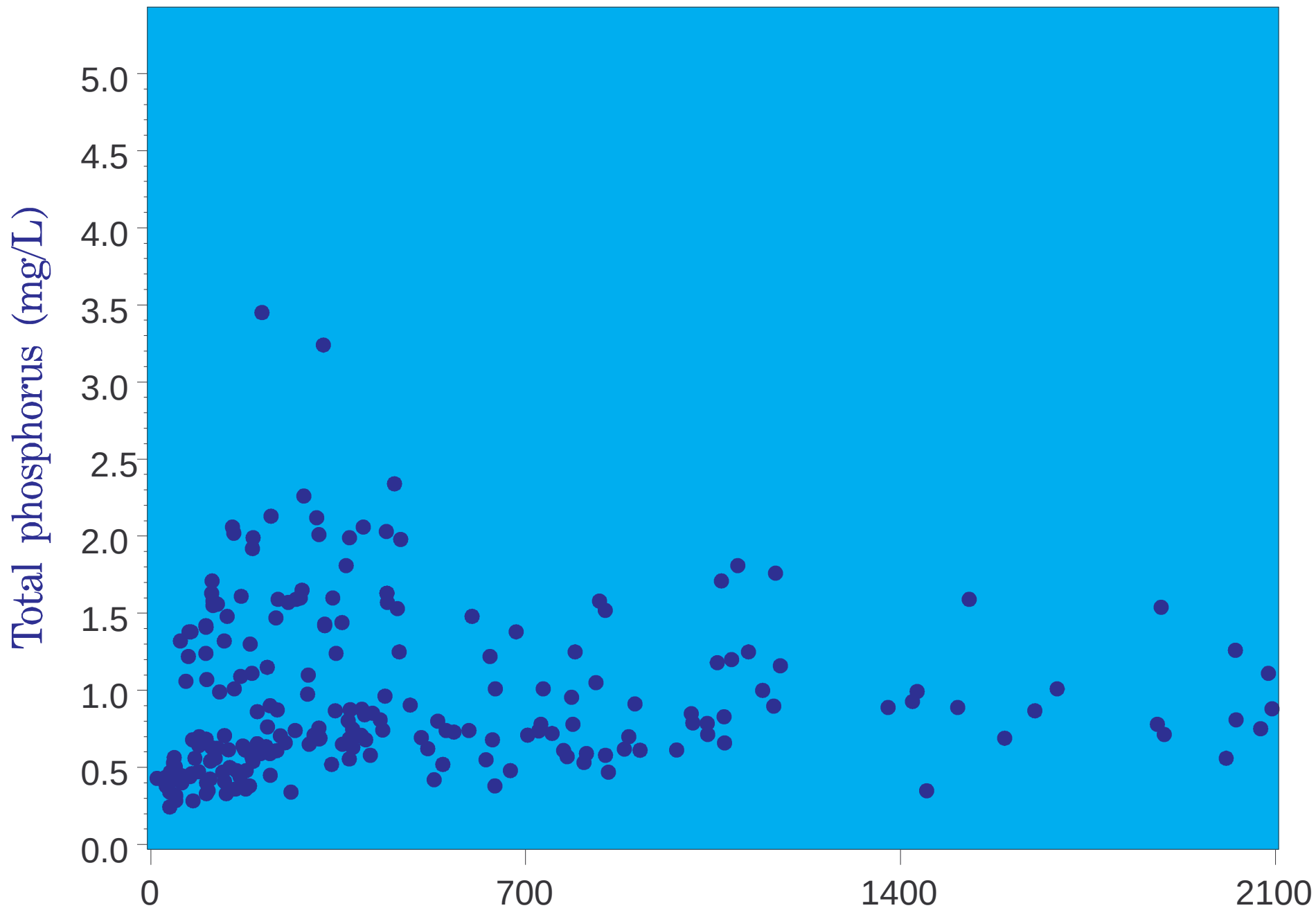


Figure 4.5.377 Surface total phosphorus at river kilometer 15.5 versus flow



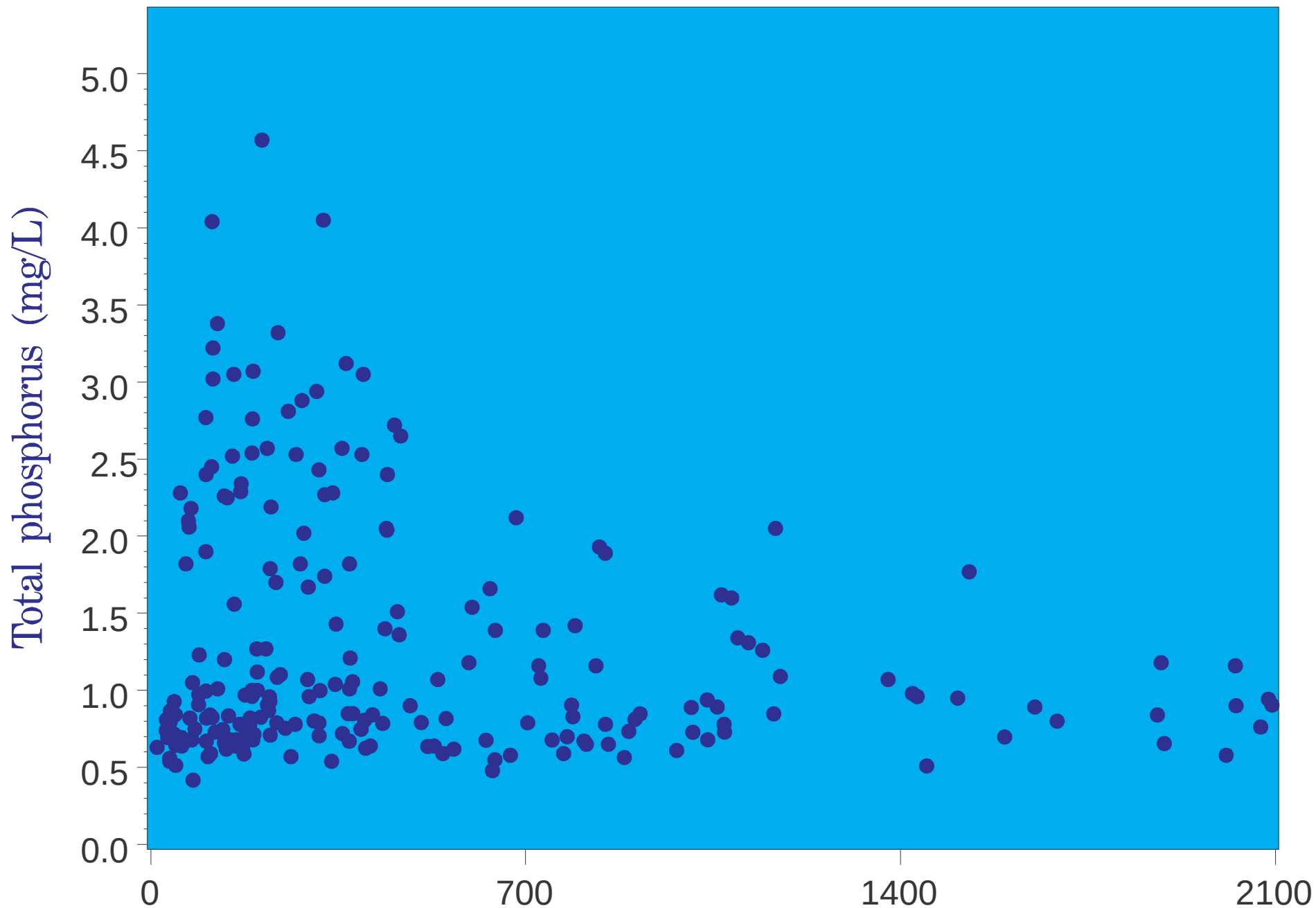


Figure 4.5.378 Surface total phosphorus at river kilometer 23.6 versus flow

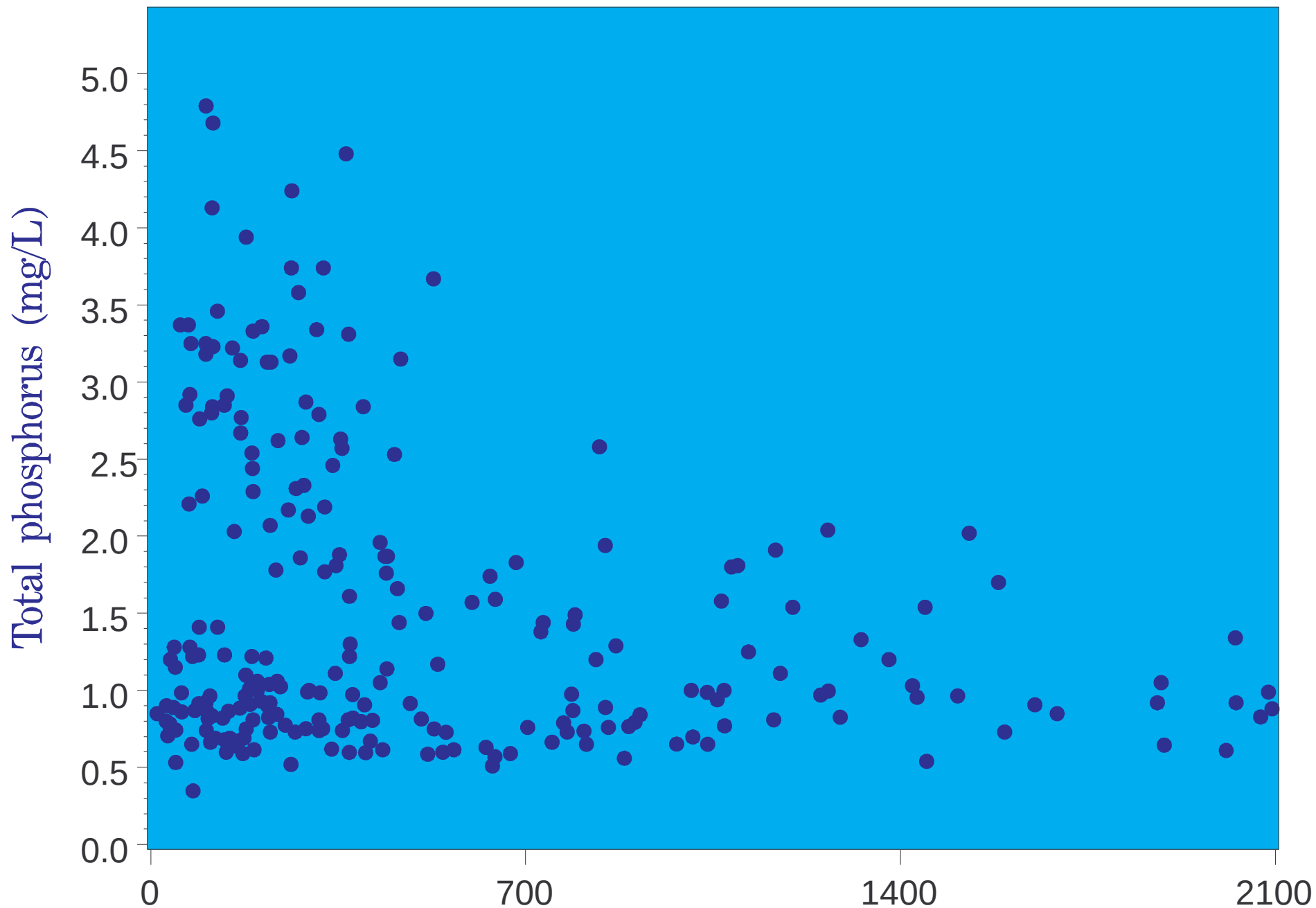


Figure 4.5.379 Surface total phosphorus at river kilometer 30.4 versus flow

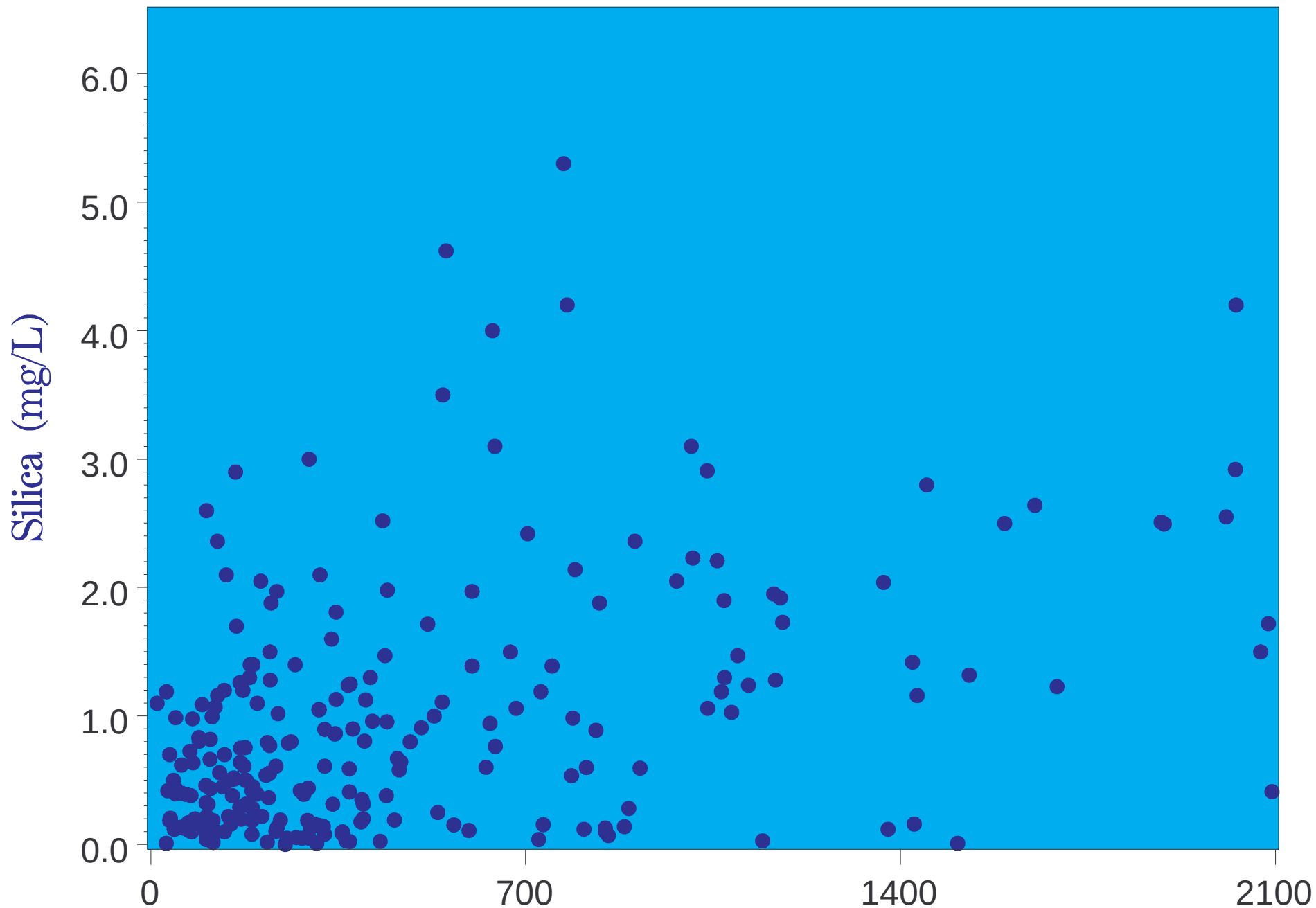


Figure 4.5.380 Surface silica at river kilometer -2.4 versus flow

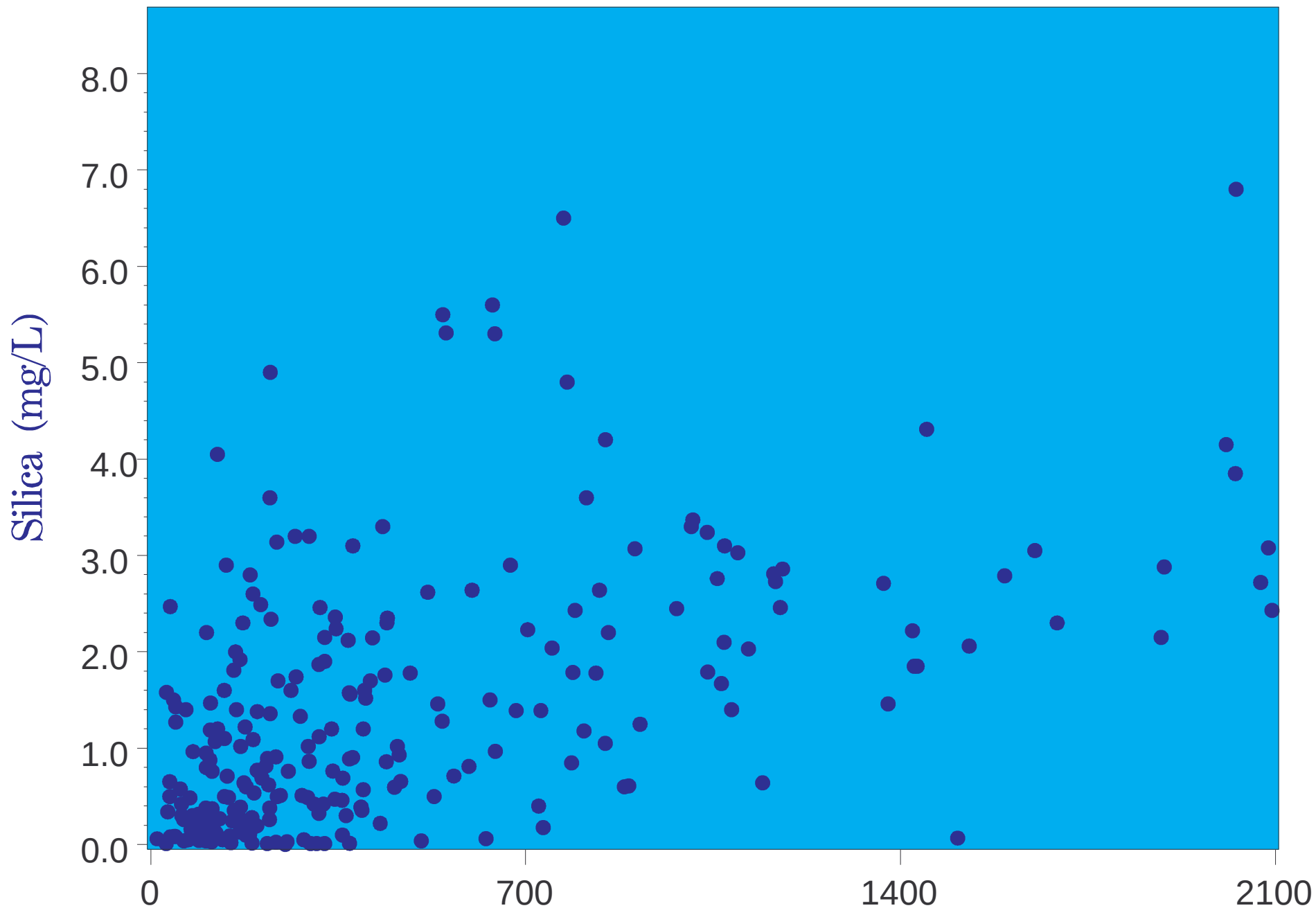


Figure 4.5.381 Surface silica at river kilometer 6.6 versus flow

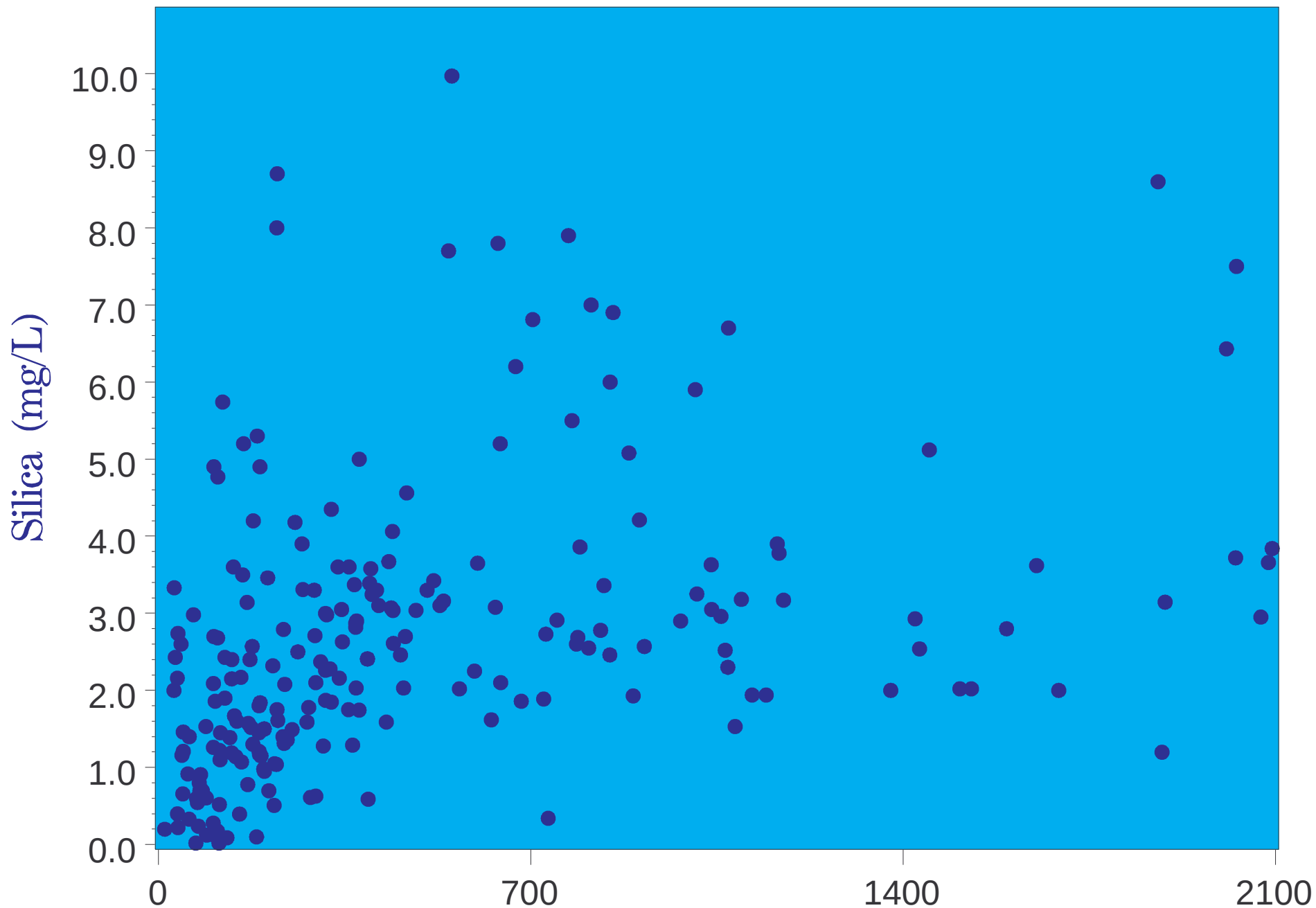


Figure 4.5.382 Surface silica at river kilometer 15.5 versus flow

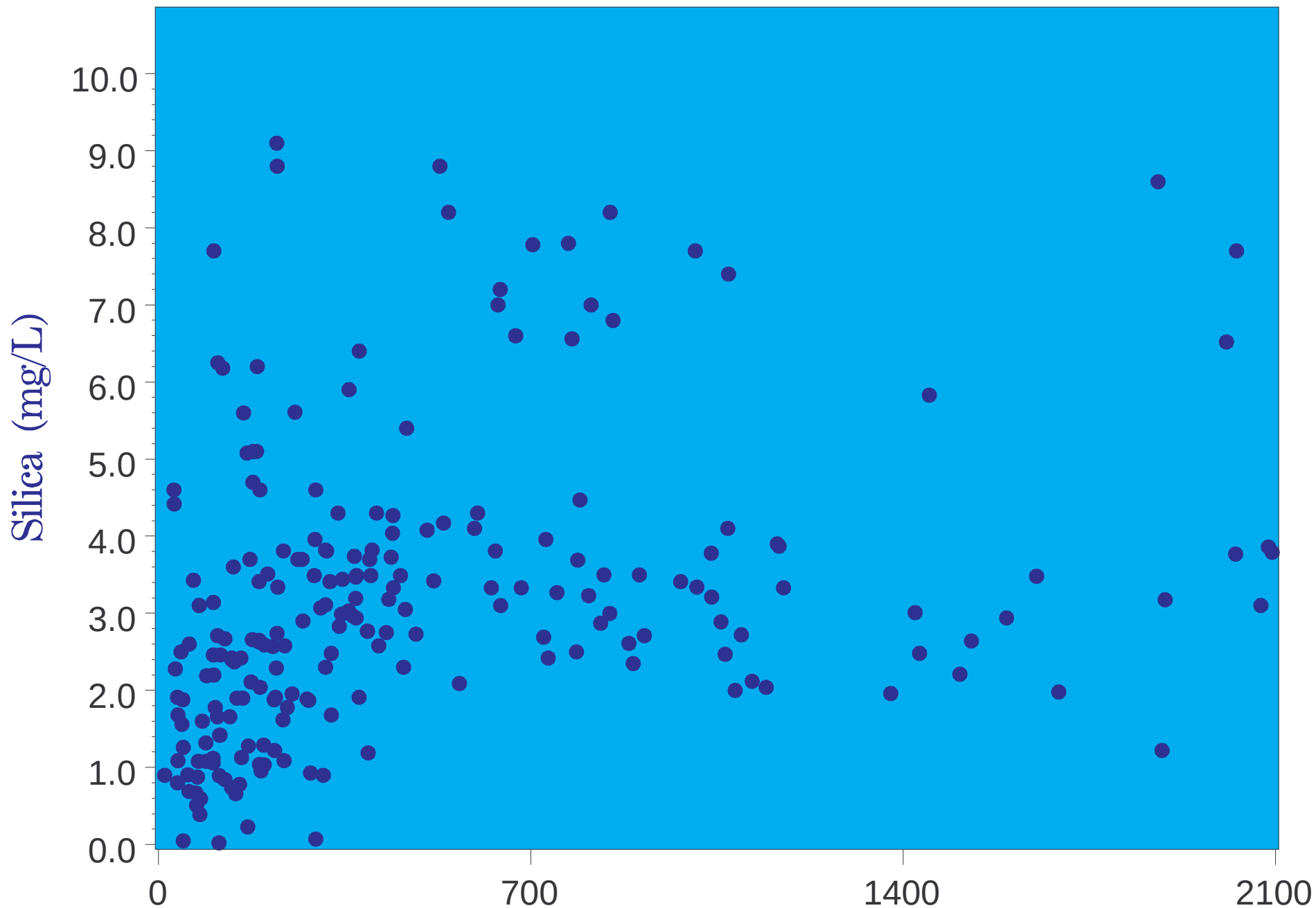


Figure 4.5.383 Surface silica at river kilometer 23.6 versus flow

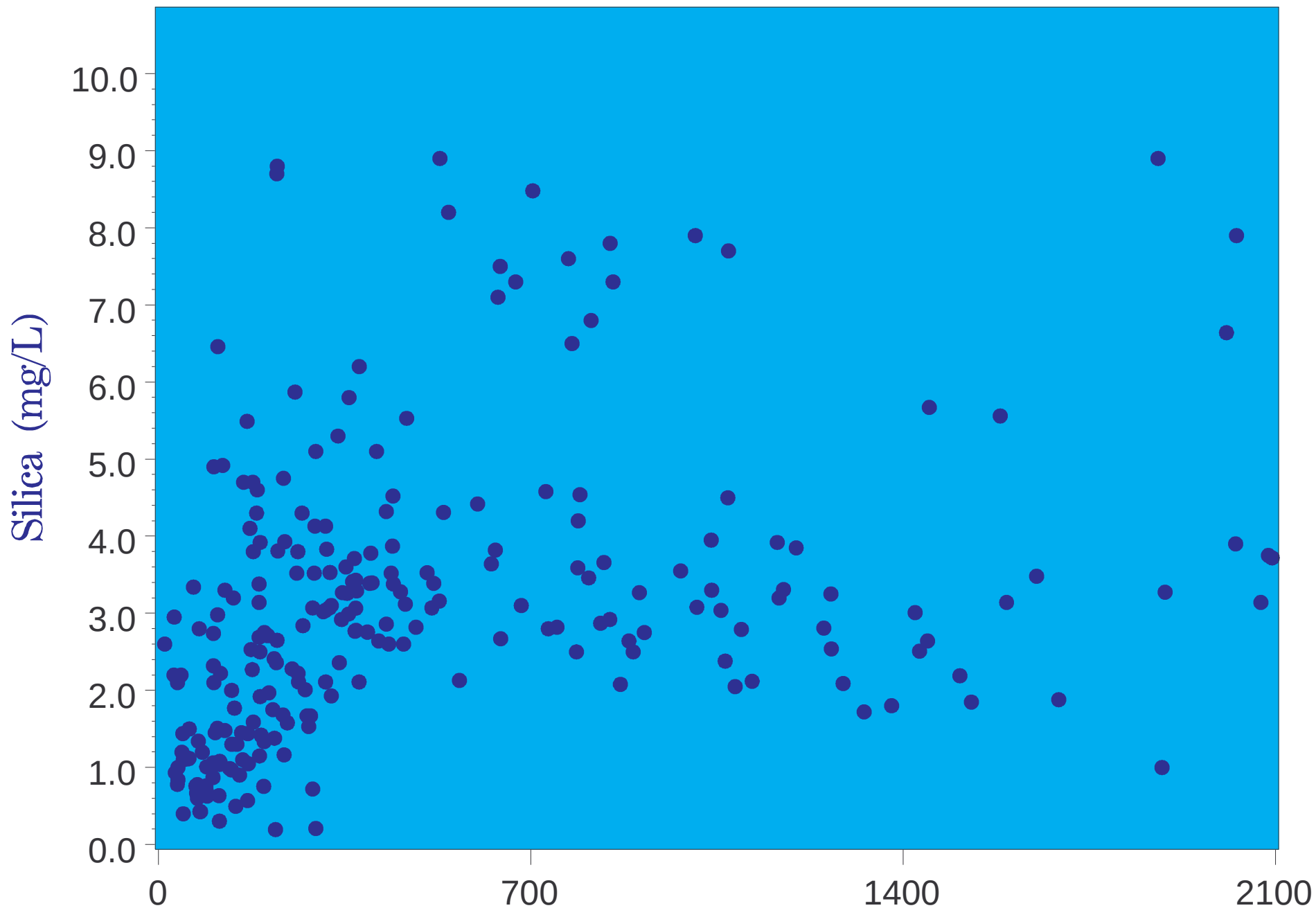


Figure 4.5.384 Surface silica at river kilometer 30.4 versus flow

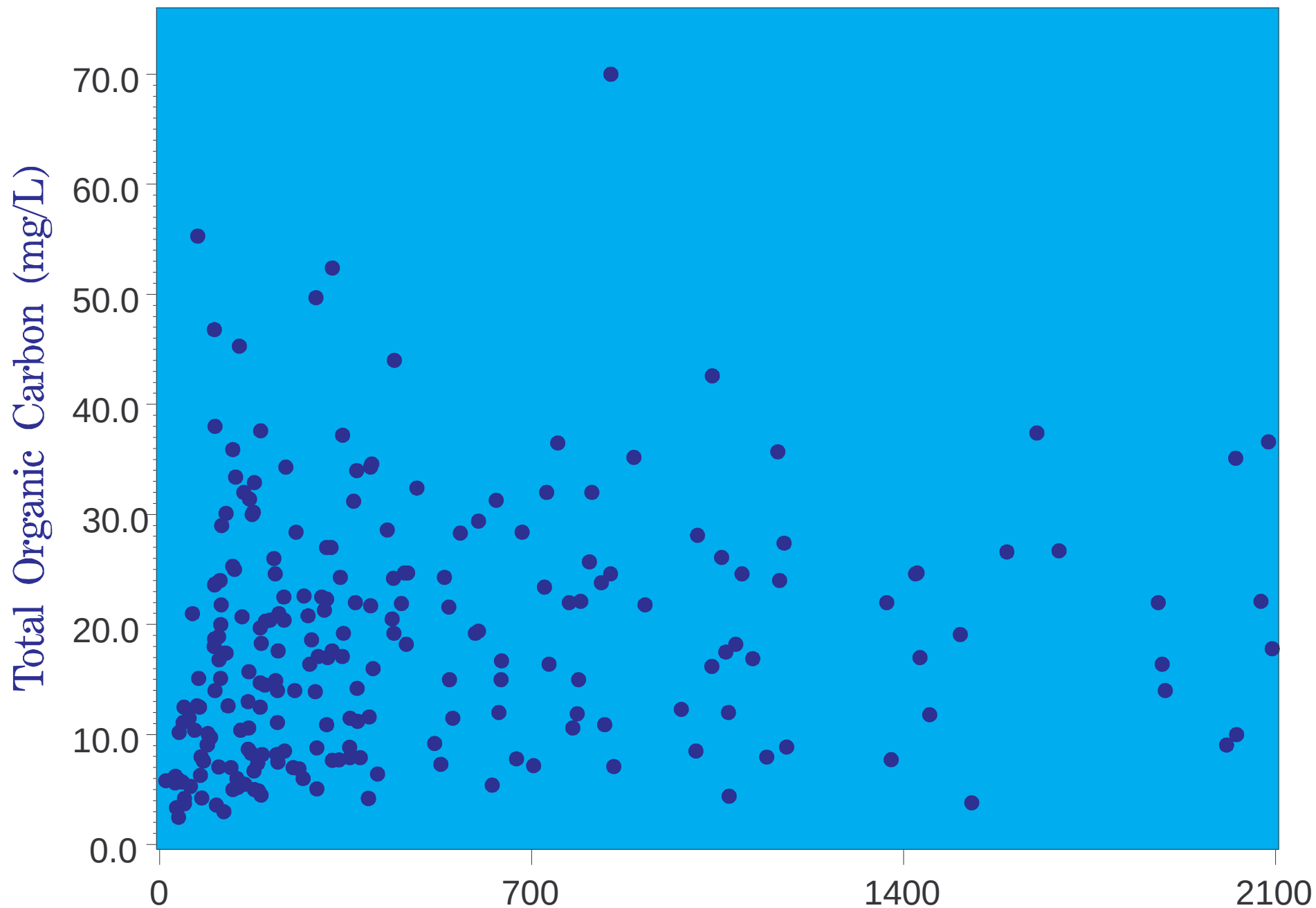


Figure 4.5.385 Surface total organic carbon at river kilometer -2.4 versus flow



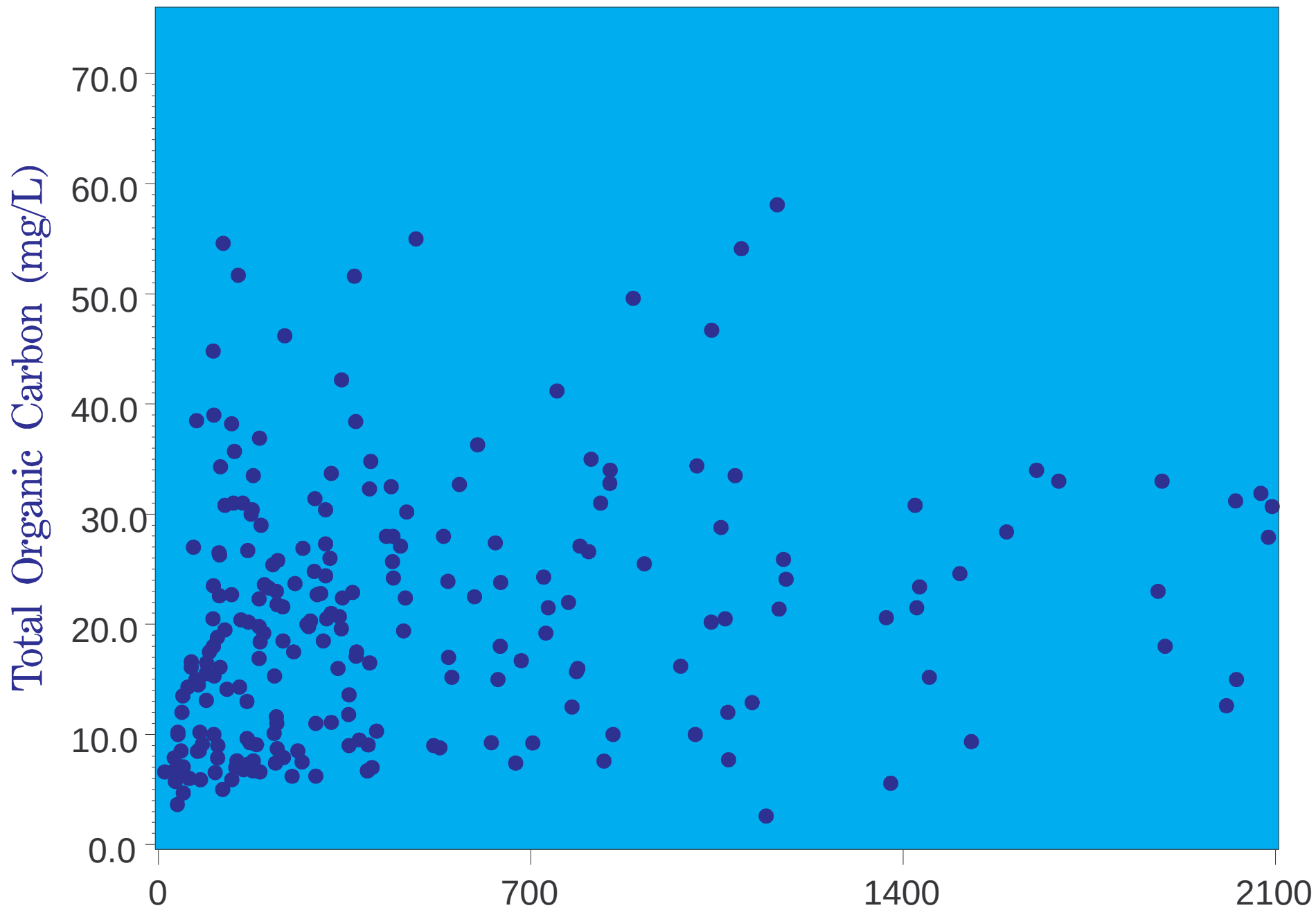


Figure 4.5.386 Surface total organic carbon at river kilometer 6.6 versus flow

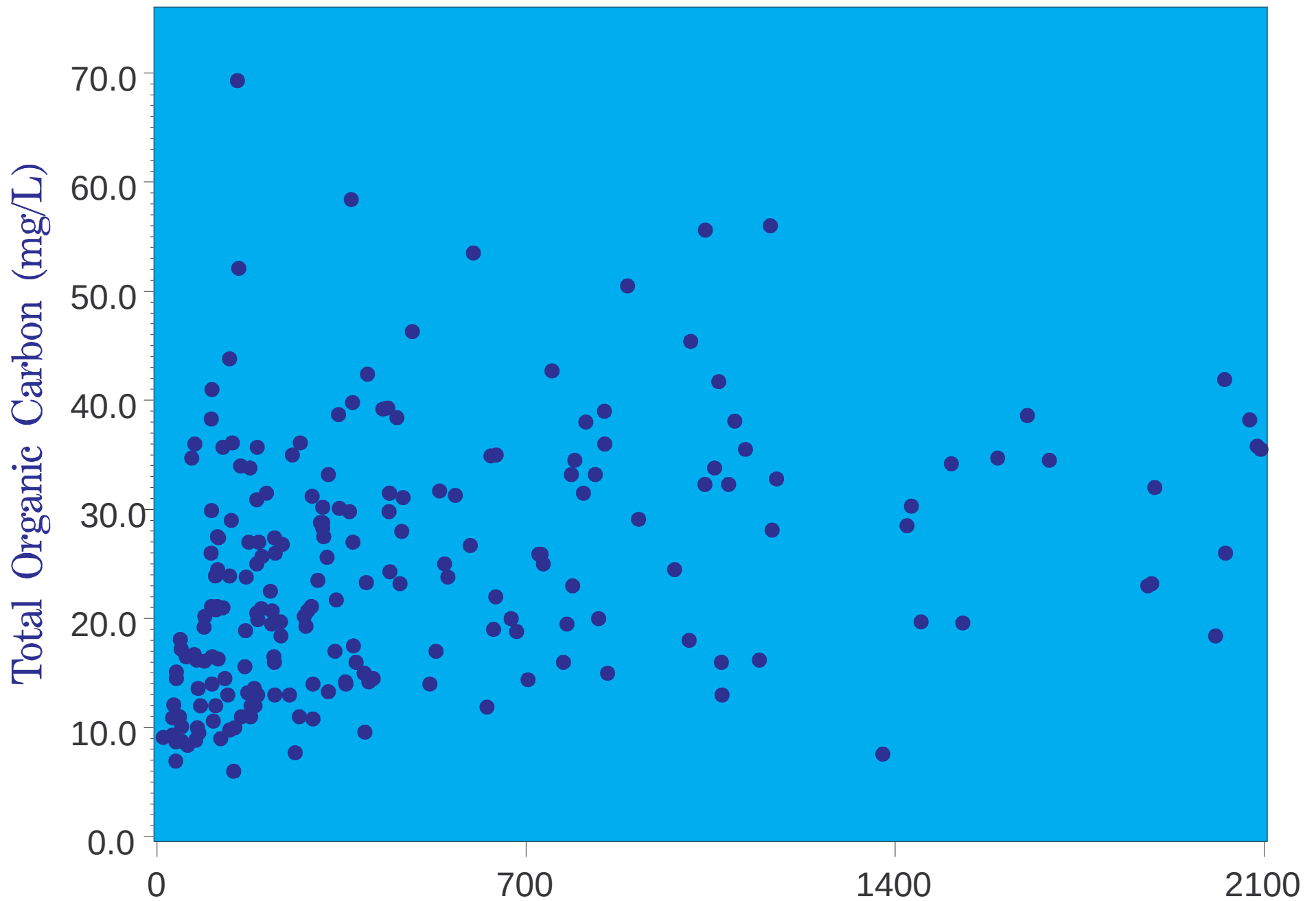


Figure 4.5.387 Surface total organic carbon at river kilometer 15.5 versus flow

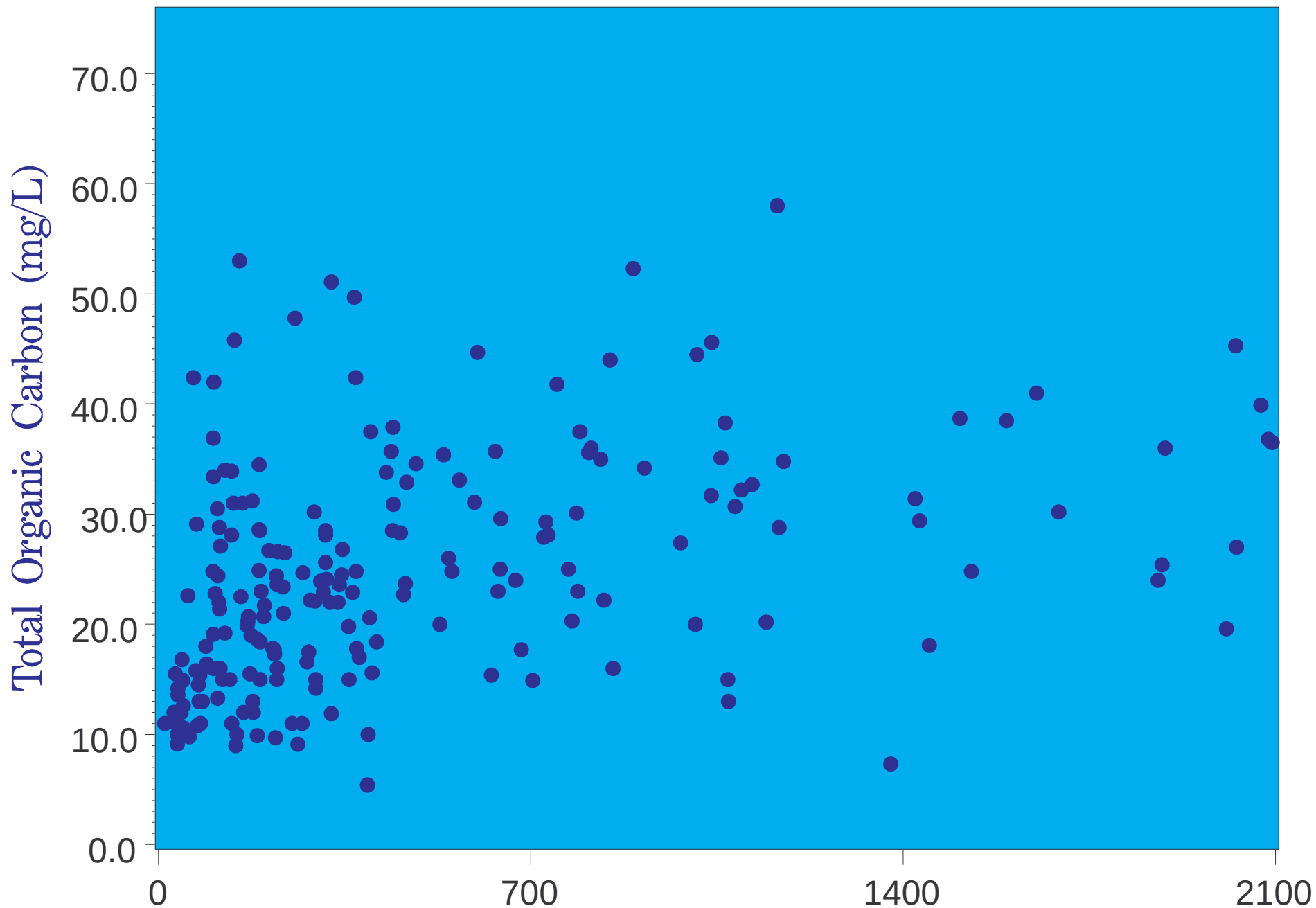


Figure 4.5.388 Surface total organic carbon at river kilometer 23.6 versus flow

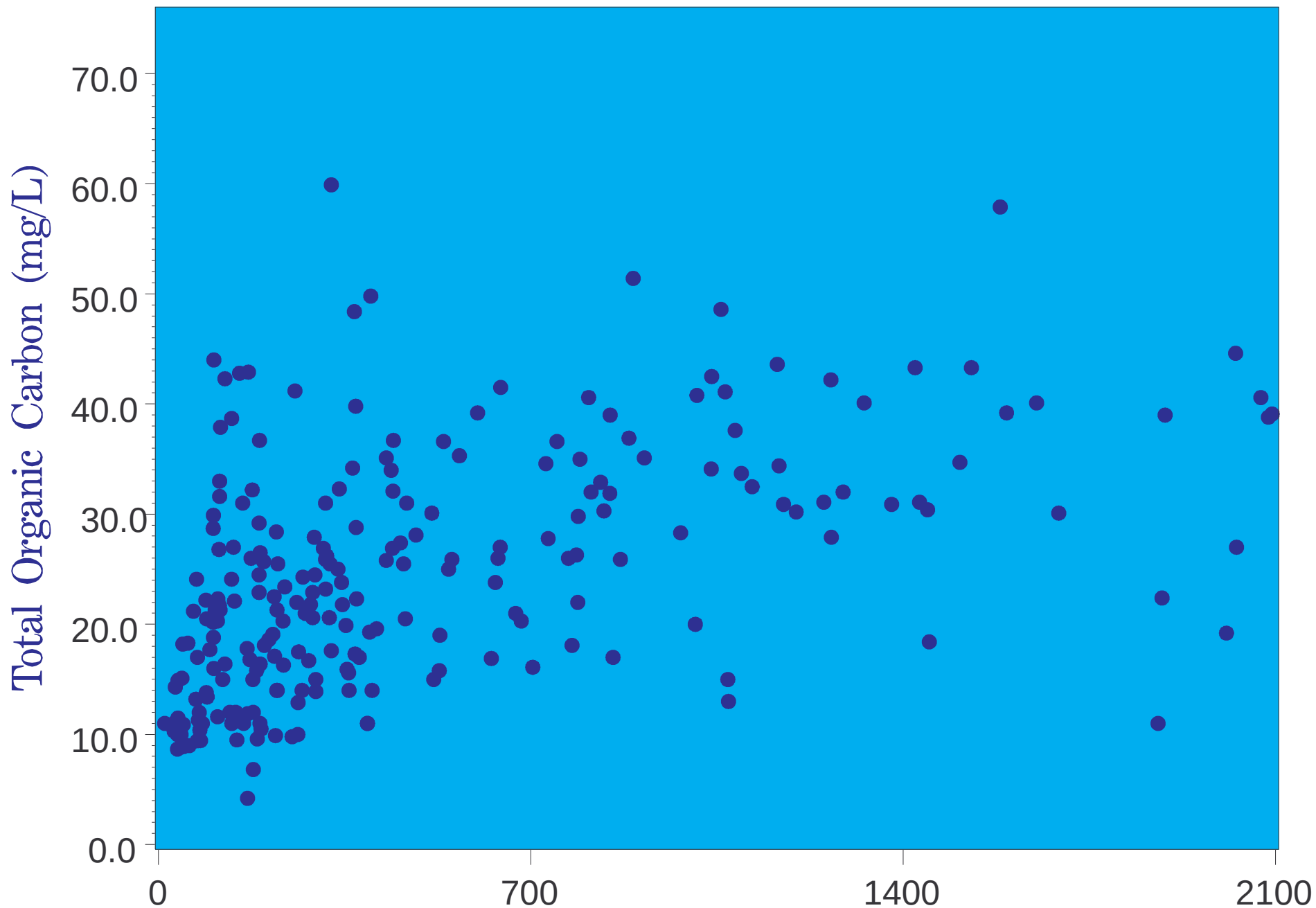


Figure 4.5.389 Surface total organic carbon at river kilometer 30.4 versus flow

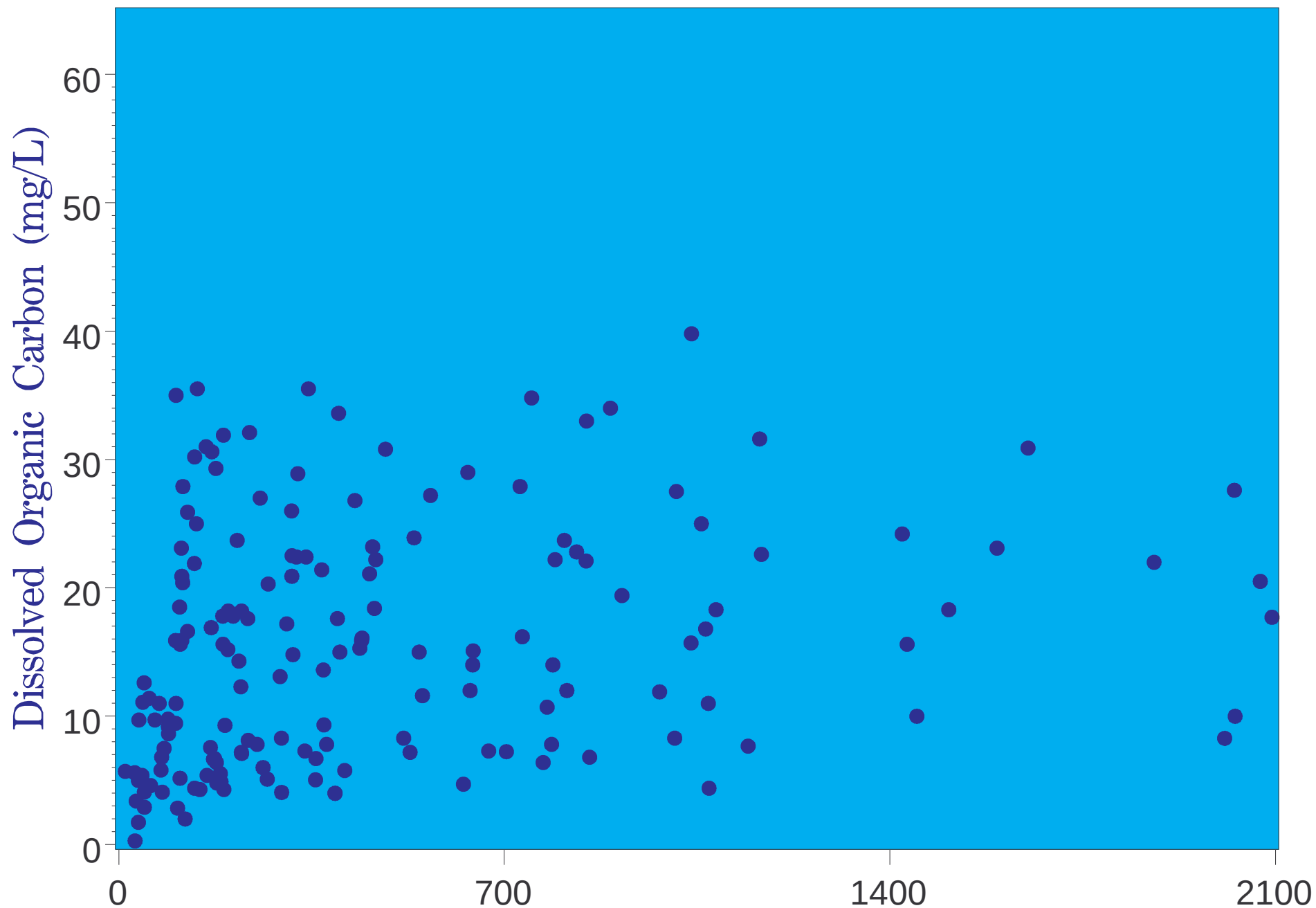


Figure 4.5.390 Surface dissolved organic carbon at river kilometer -2.4 versus flow

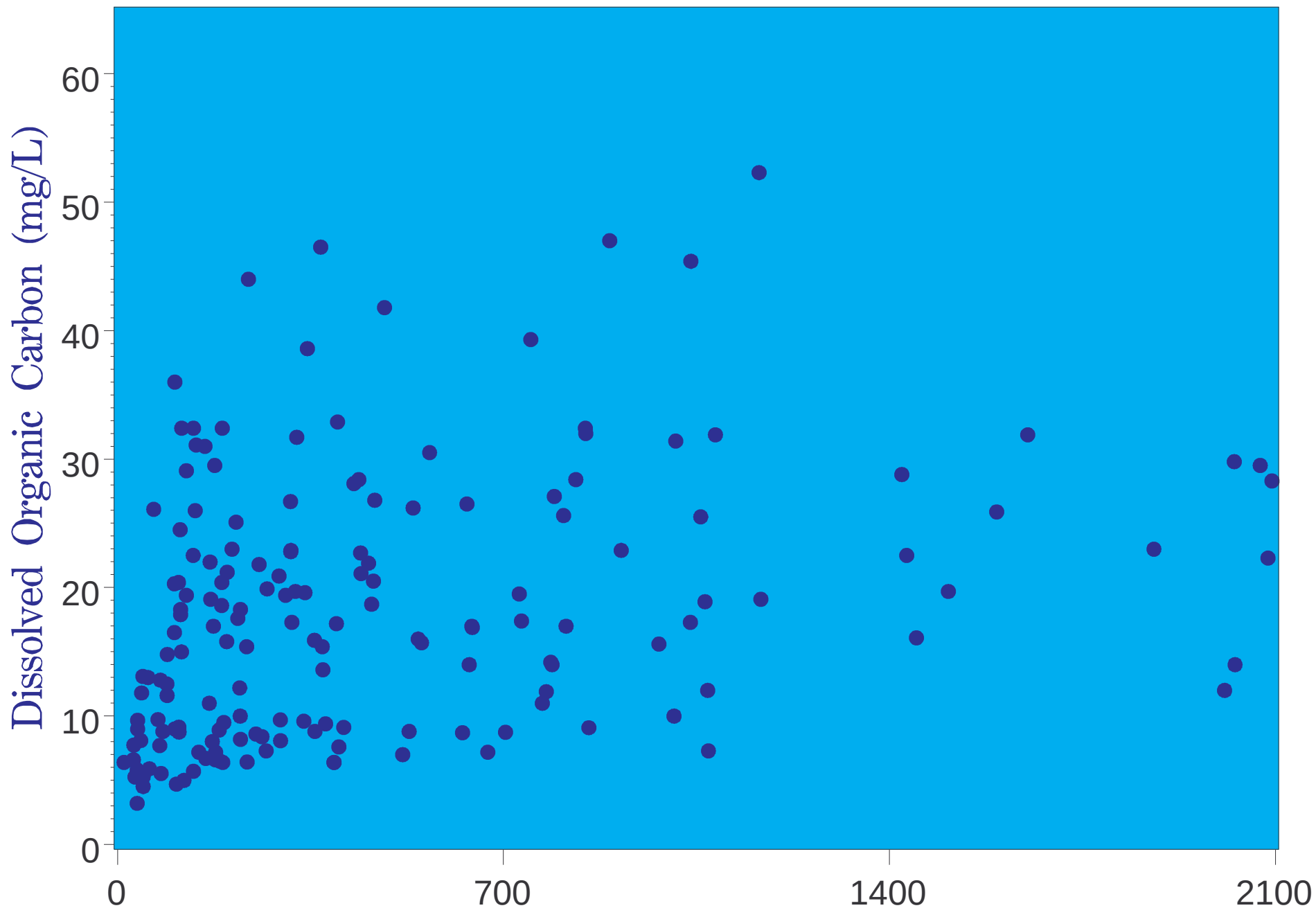


Figure 4.5.391 Surface dissolved organic carbon at river kilometer 6.6 versus flow

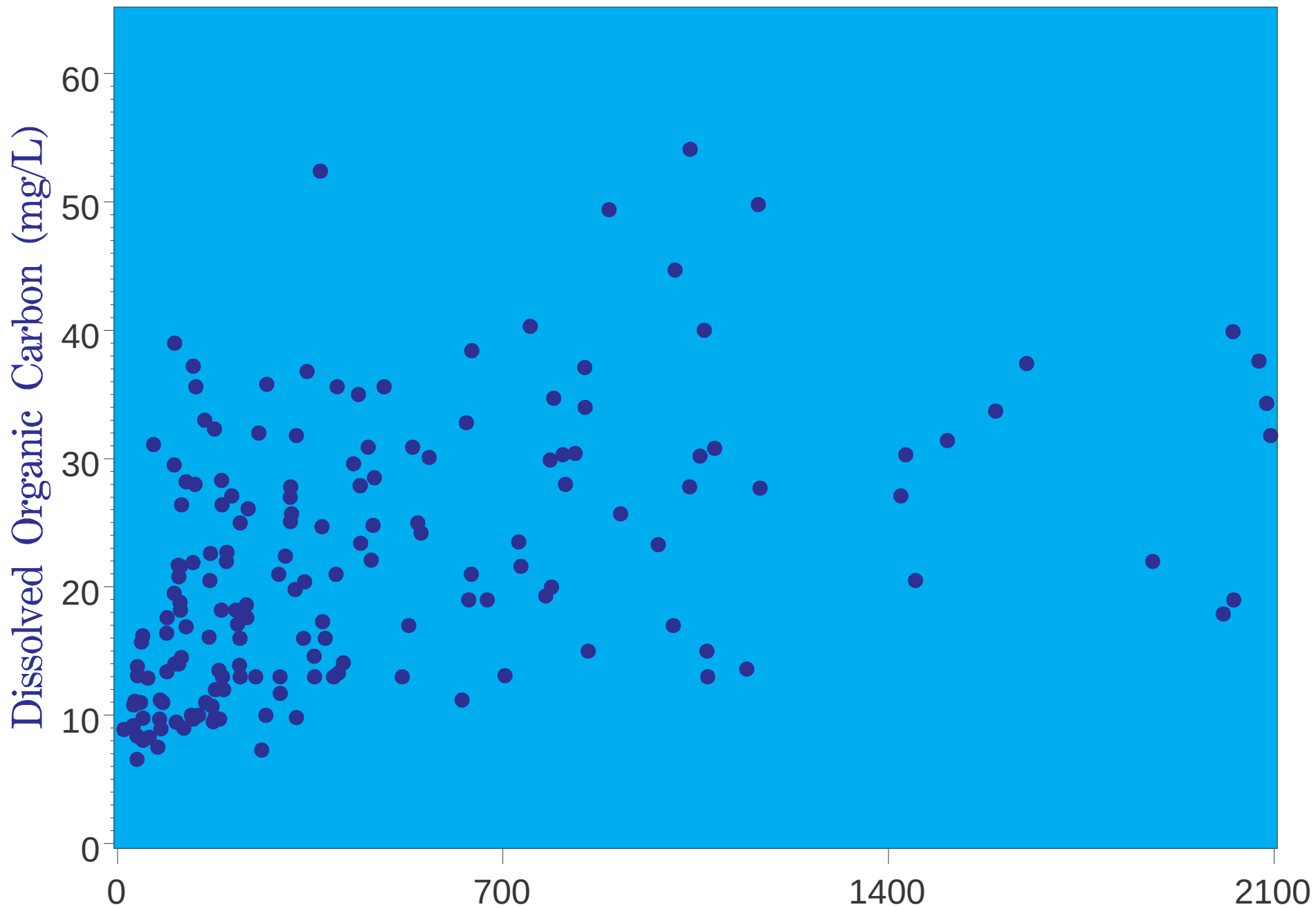


Figure 4.5.392 Surface dissolved organic carbon at river kilometer 15.5 versus flow

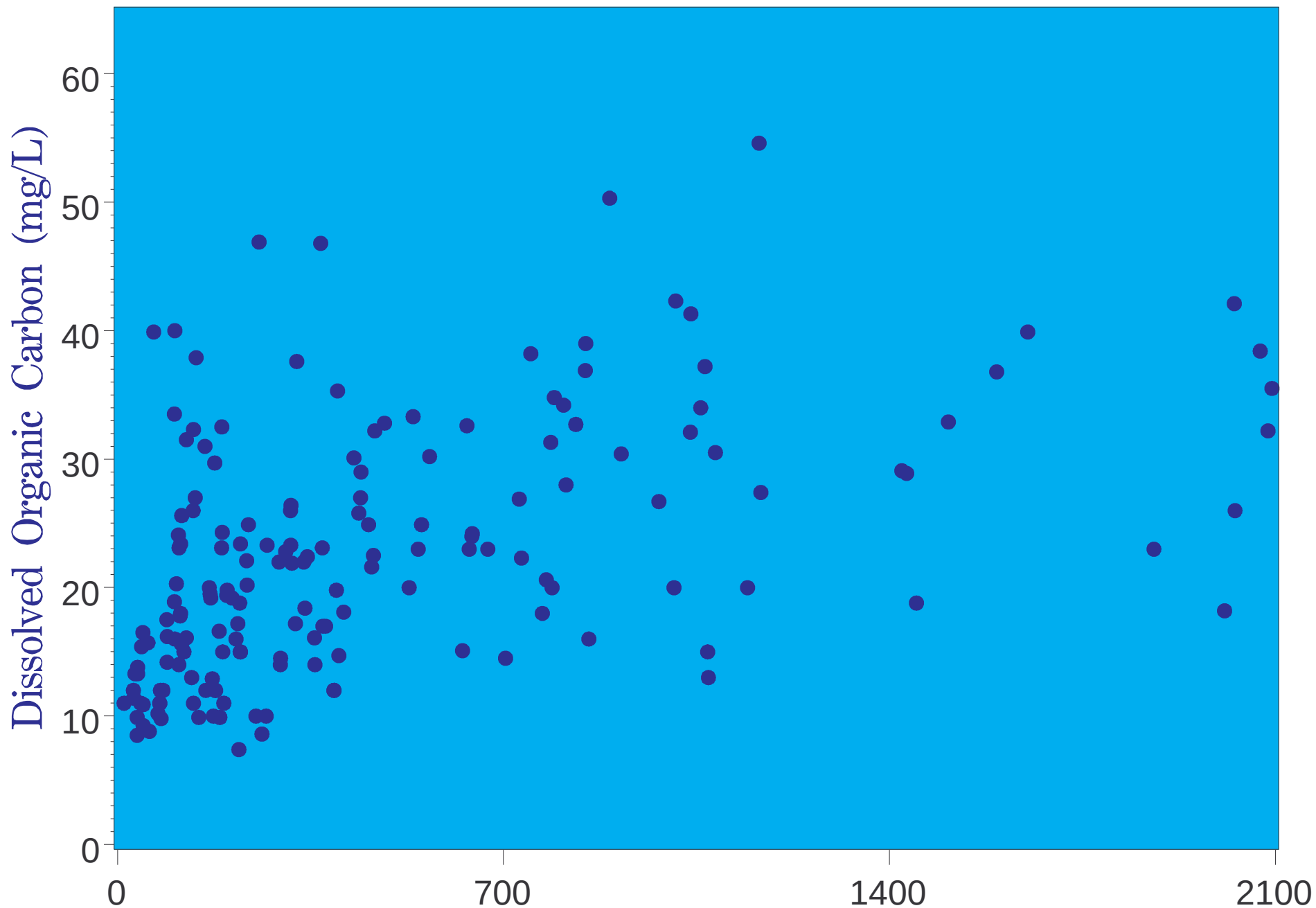


Figure 4.5.393 Surface dissolved organic carbon at river kilometer 23.6 versus flow



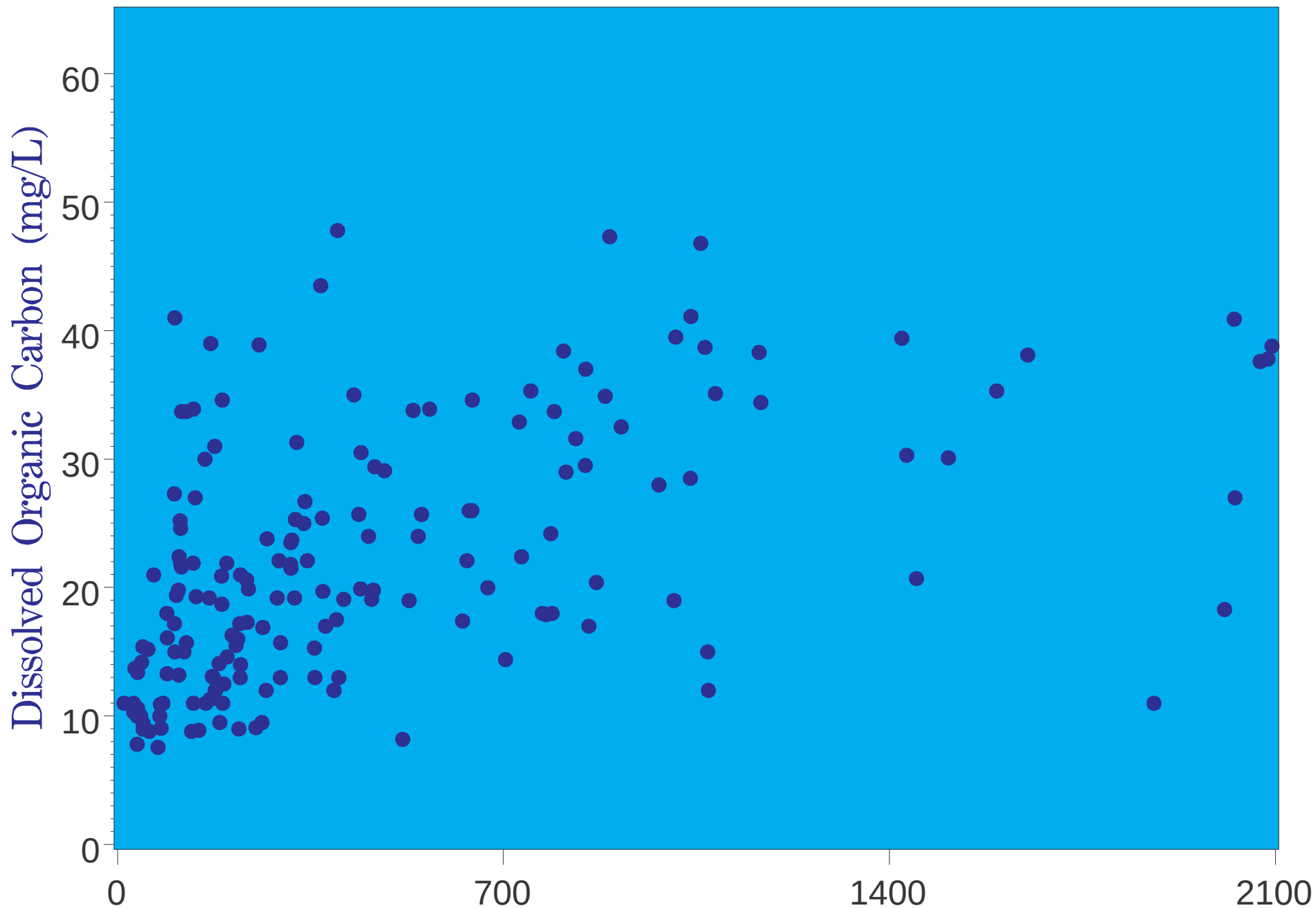


Figure 4.5.394 Surface dissolved organic carbon at river kilometer 30.4 versus flow

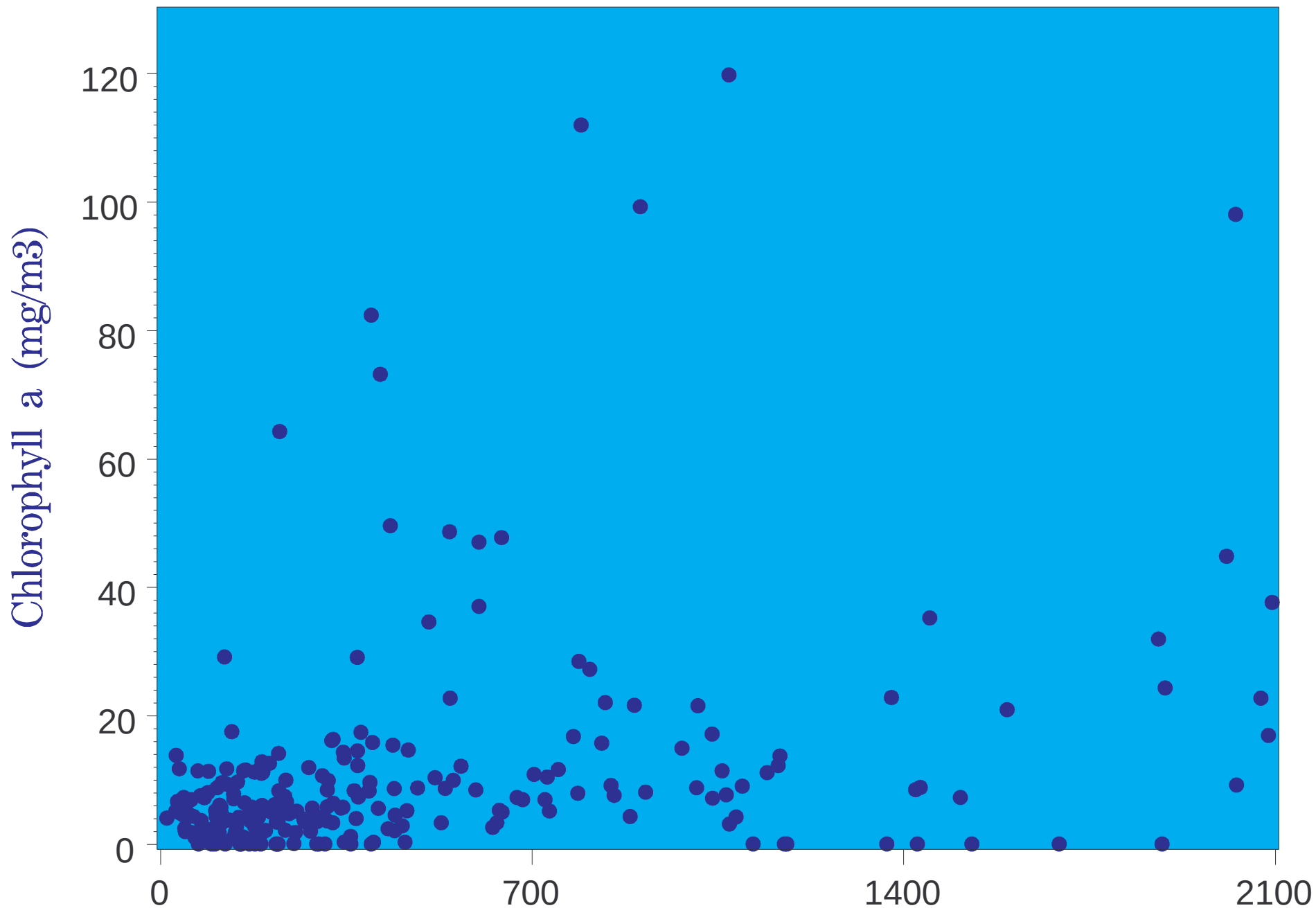


Figure 4.5.395 Surface chlorophyll a at river kilometer -2.4 versus flow

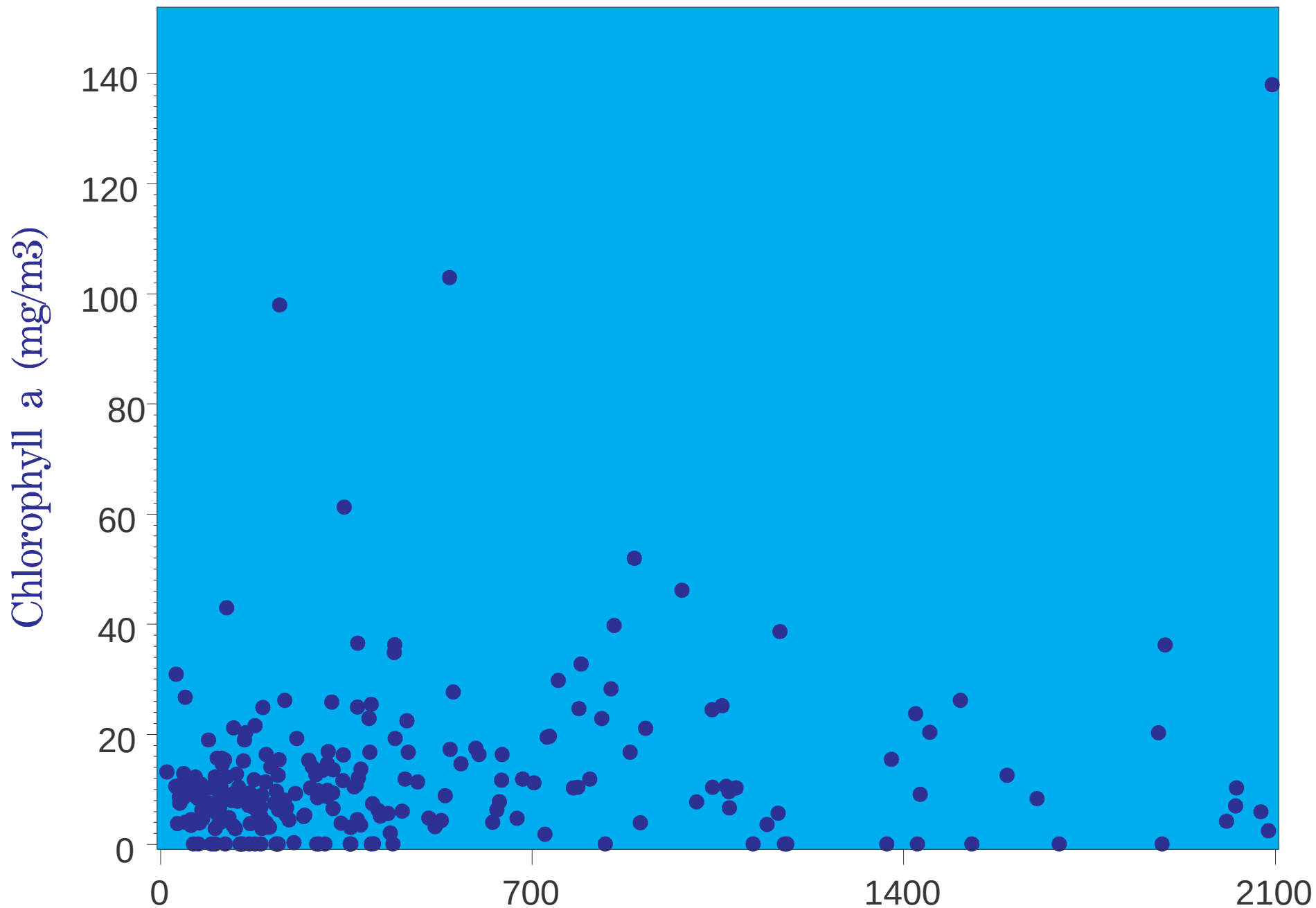


Figure 4.5.396 Surface chlorophyll a at river kilometer 6.6 versus flow

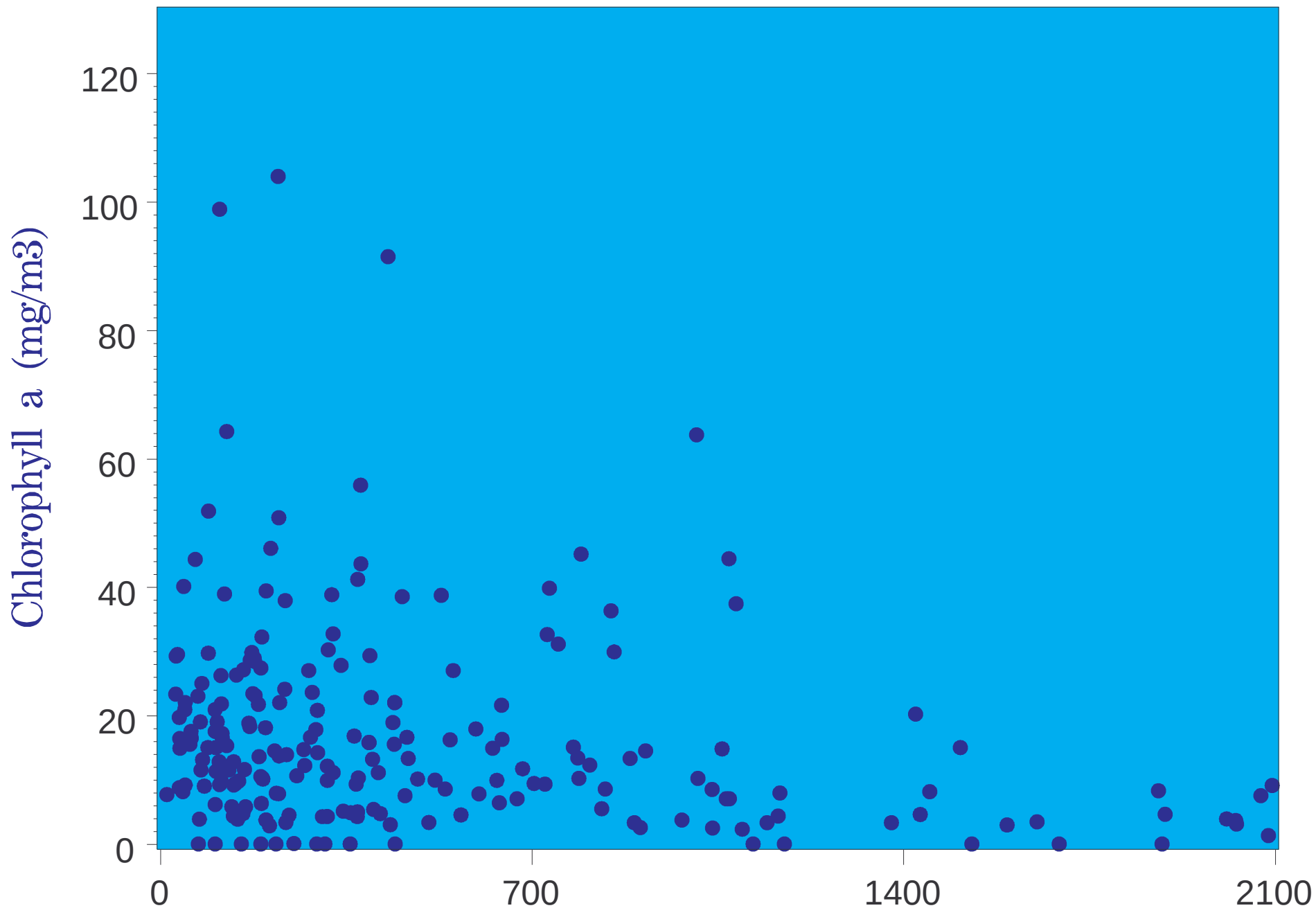


Figure 4.5.397 Surface chlorophyll a at river kilometer 15.5 versus flow

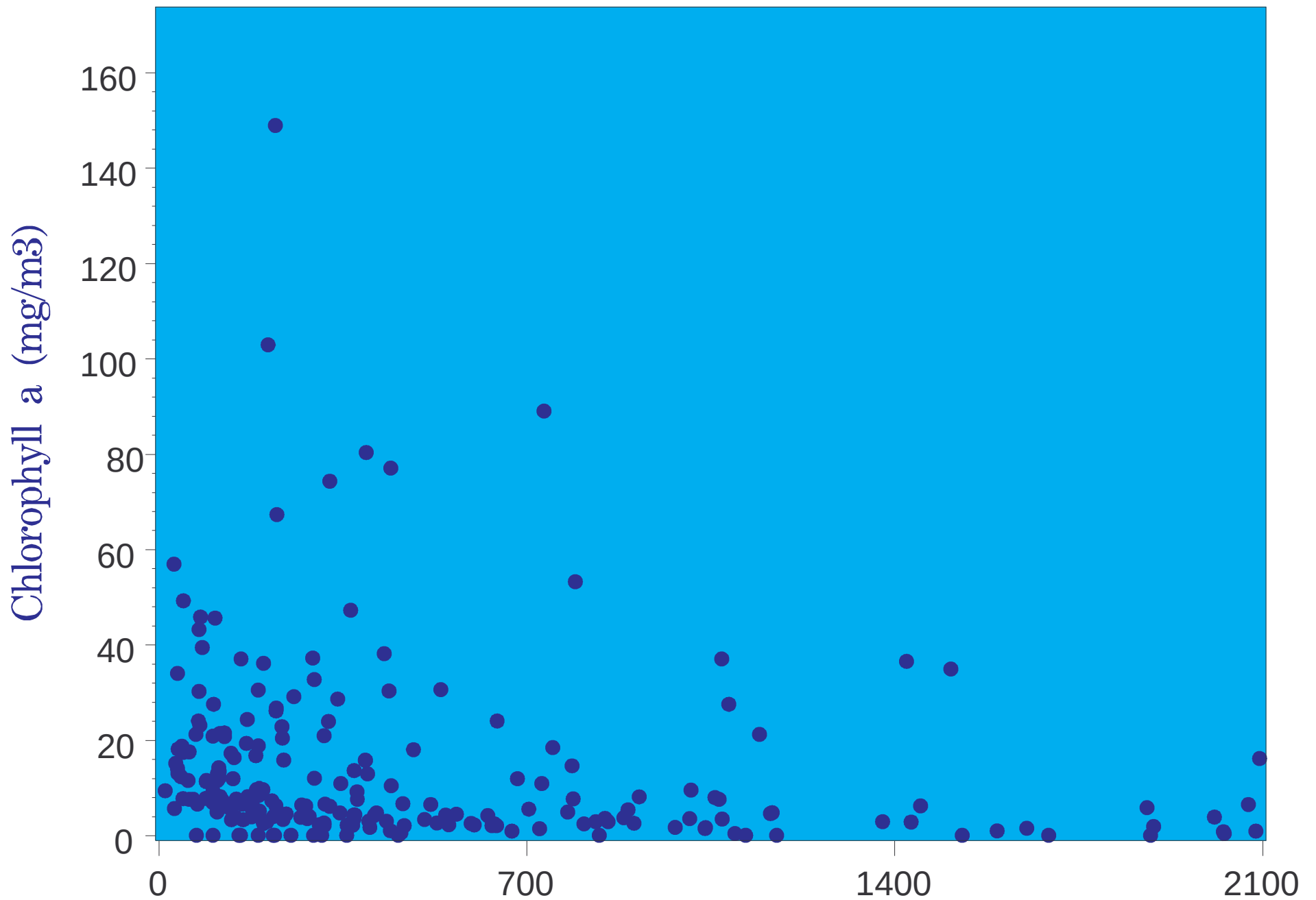


Figure 4.5.398 Surface chlorophyll a at river kilometer 23.6 versus flow

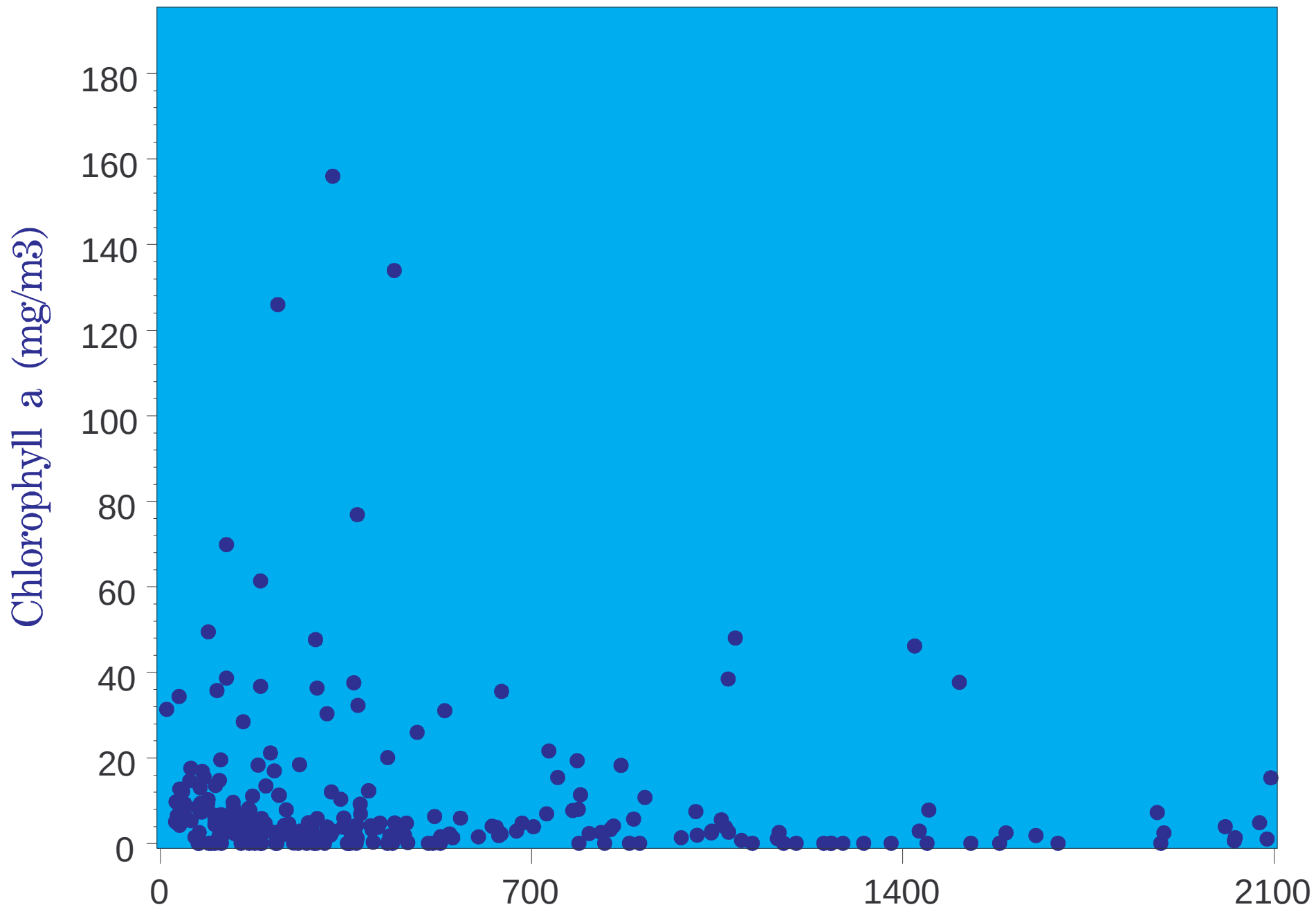
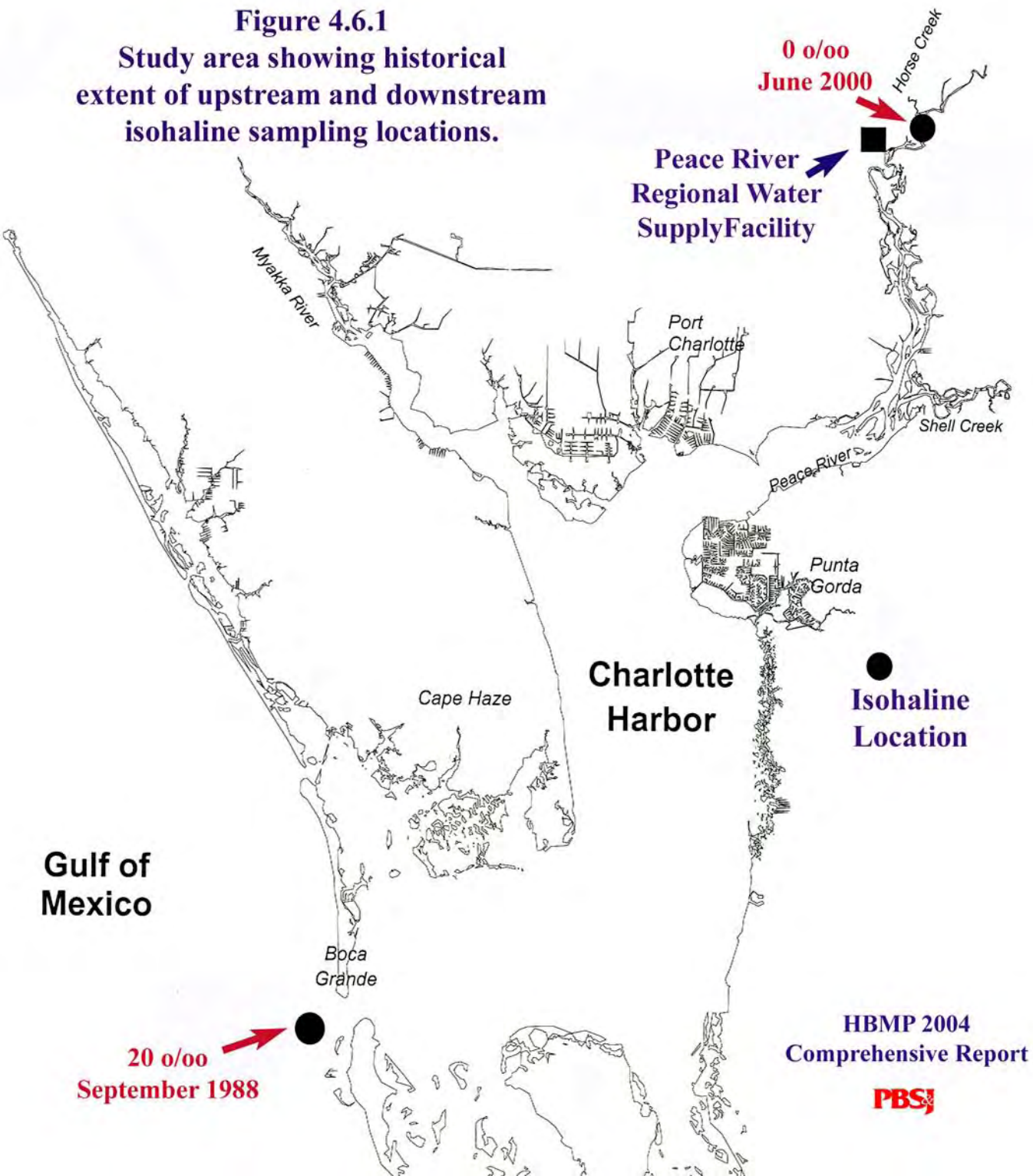


Figure 4.5.399 Surface chlorophyll a at river kilometer 30.4 versus flow

**Figure 4.6.1**

**Study area showing historical  
extent of upstream and downstream  
isohaline sampling locations.**



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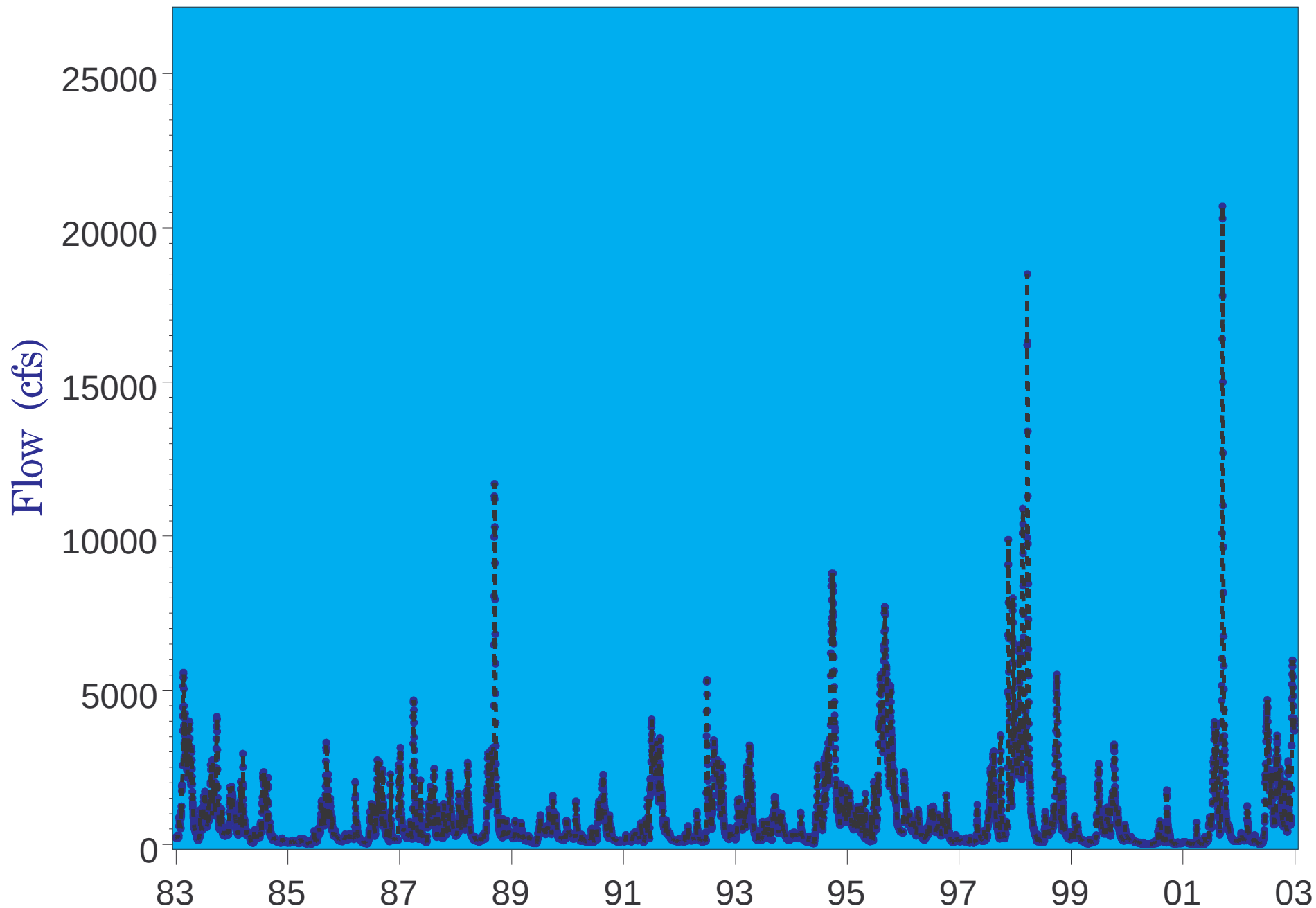


Figure 4.6.2 Daily Peace River at Arcadia gaged flow



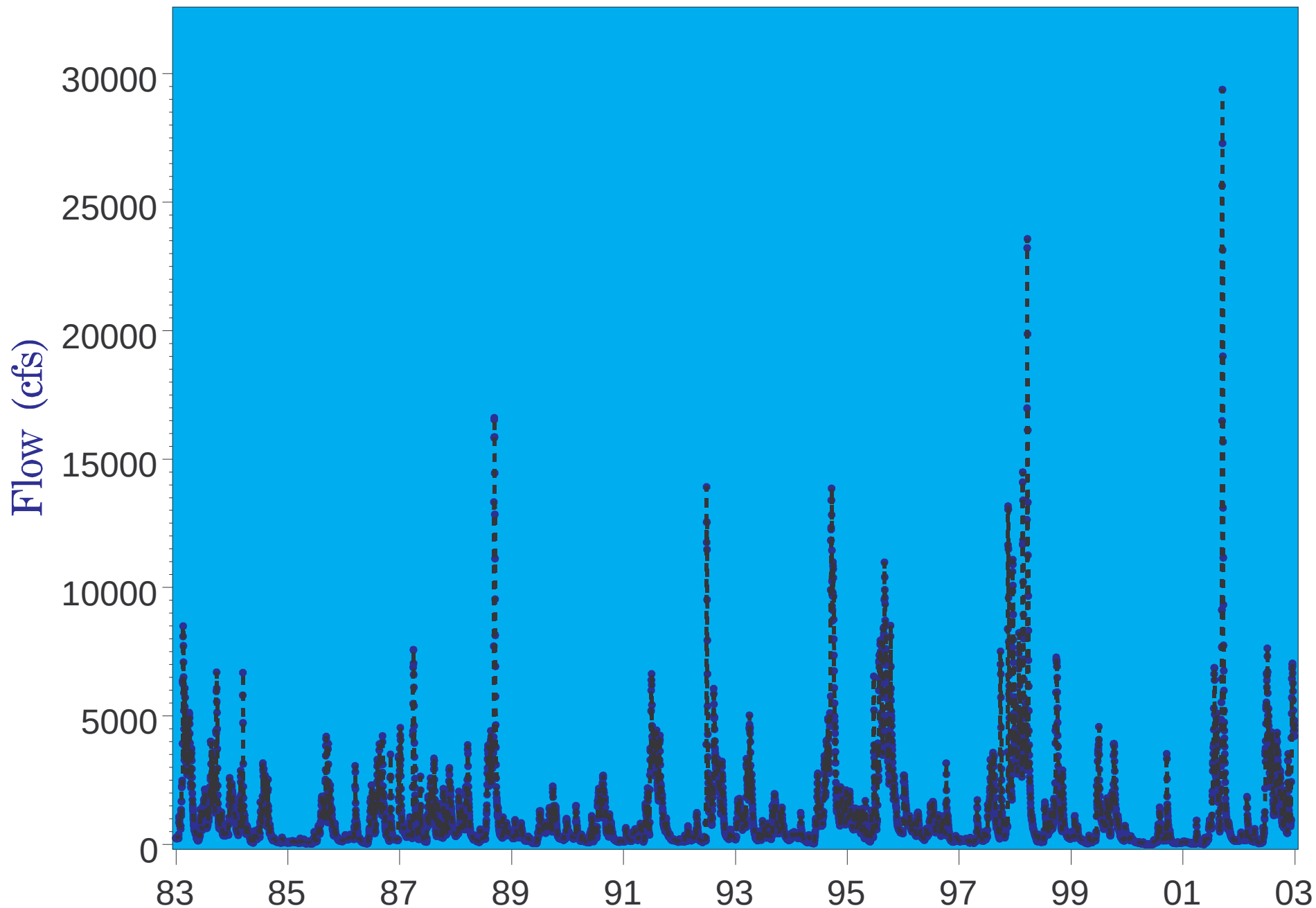


Figure 4.6.3 Daily Peace River at Arcadia + Horse & Joshua Creeks gaged flows

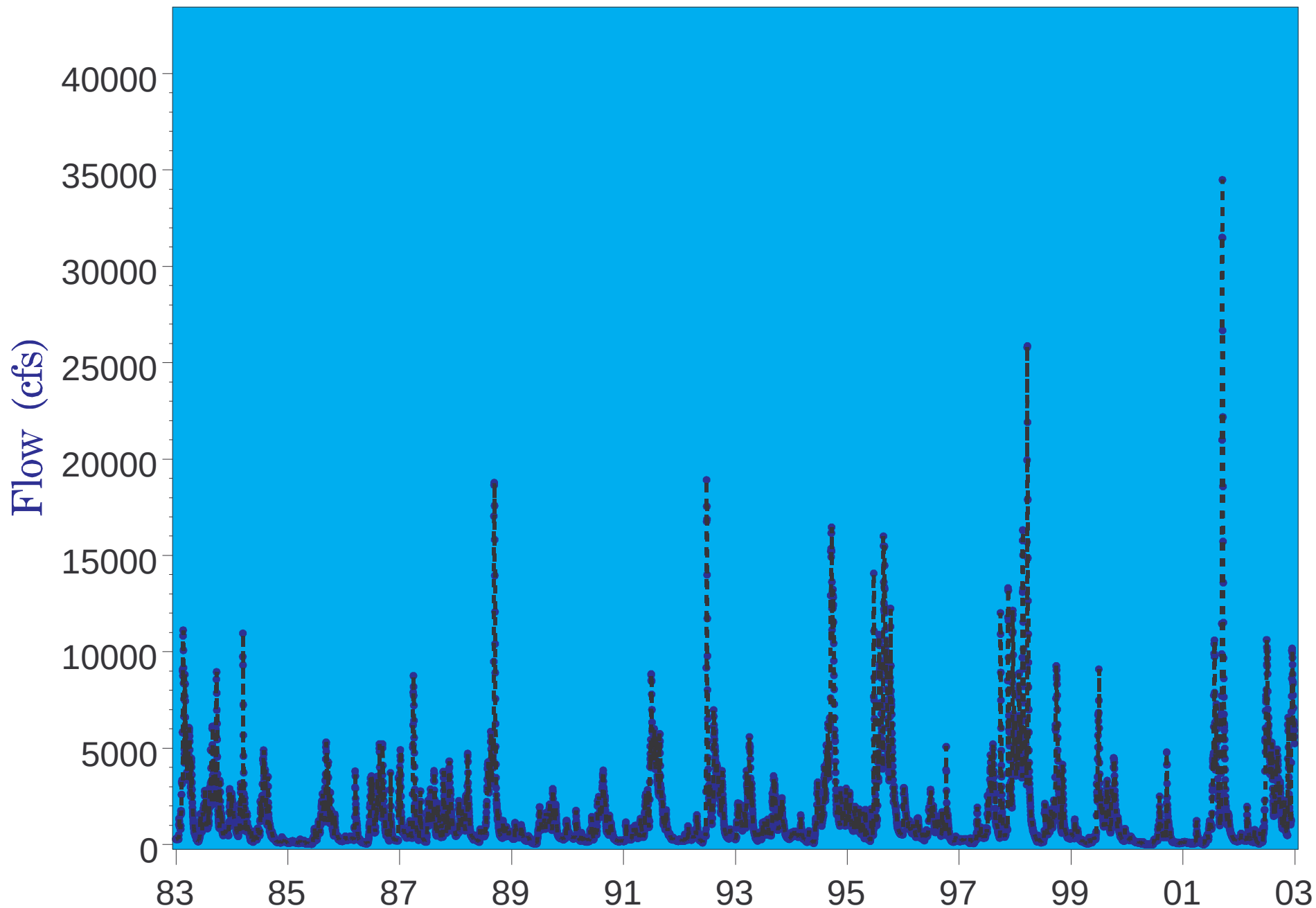


Figure 4.6.4 Daily Peace River at Arcadia + Horse + Joshua & Shell Creeks gaged flows

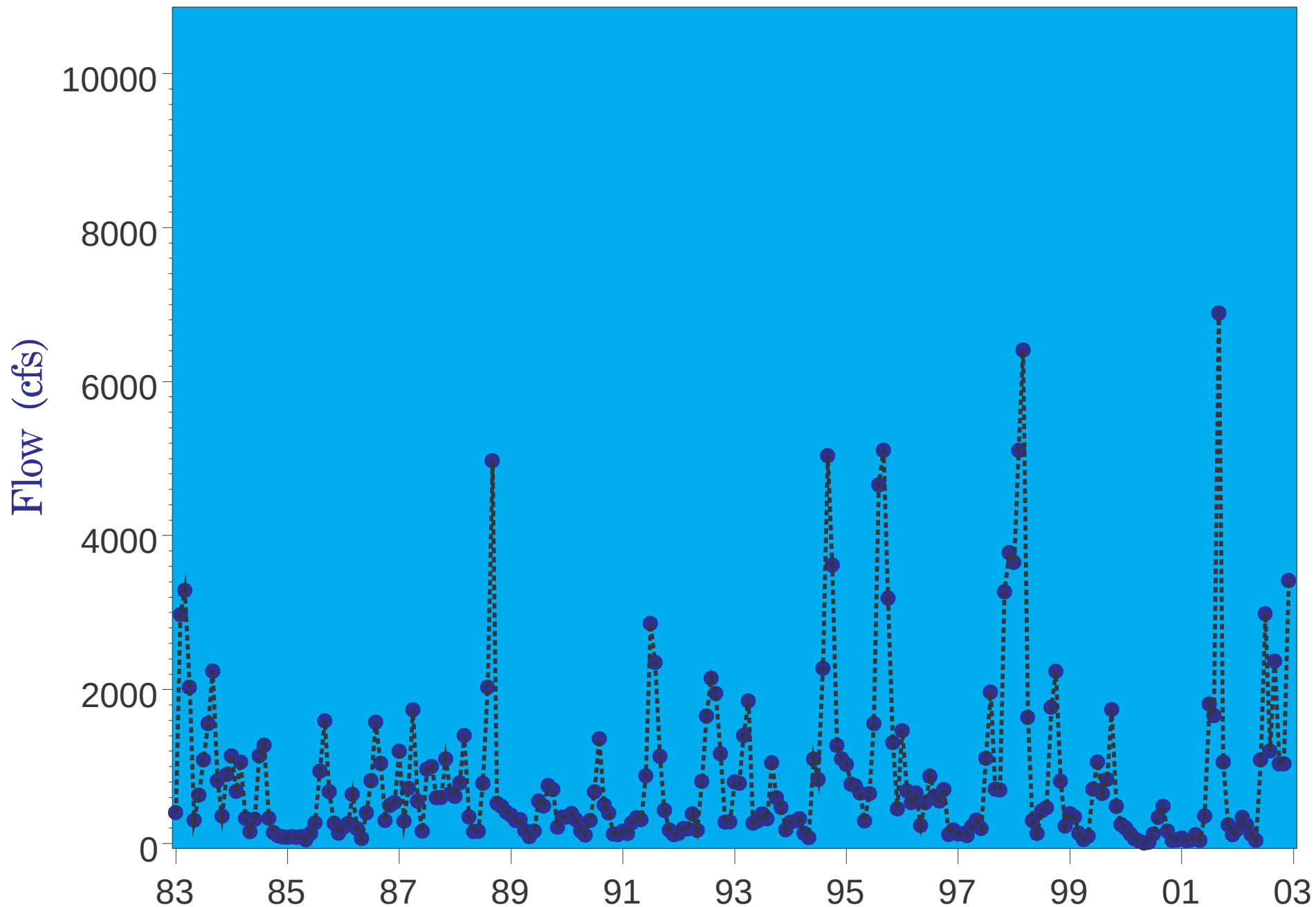


Figure 4.6.5 Mean monthly Peace River at Arcadia gaged flow

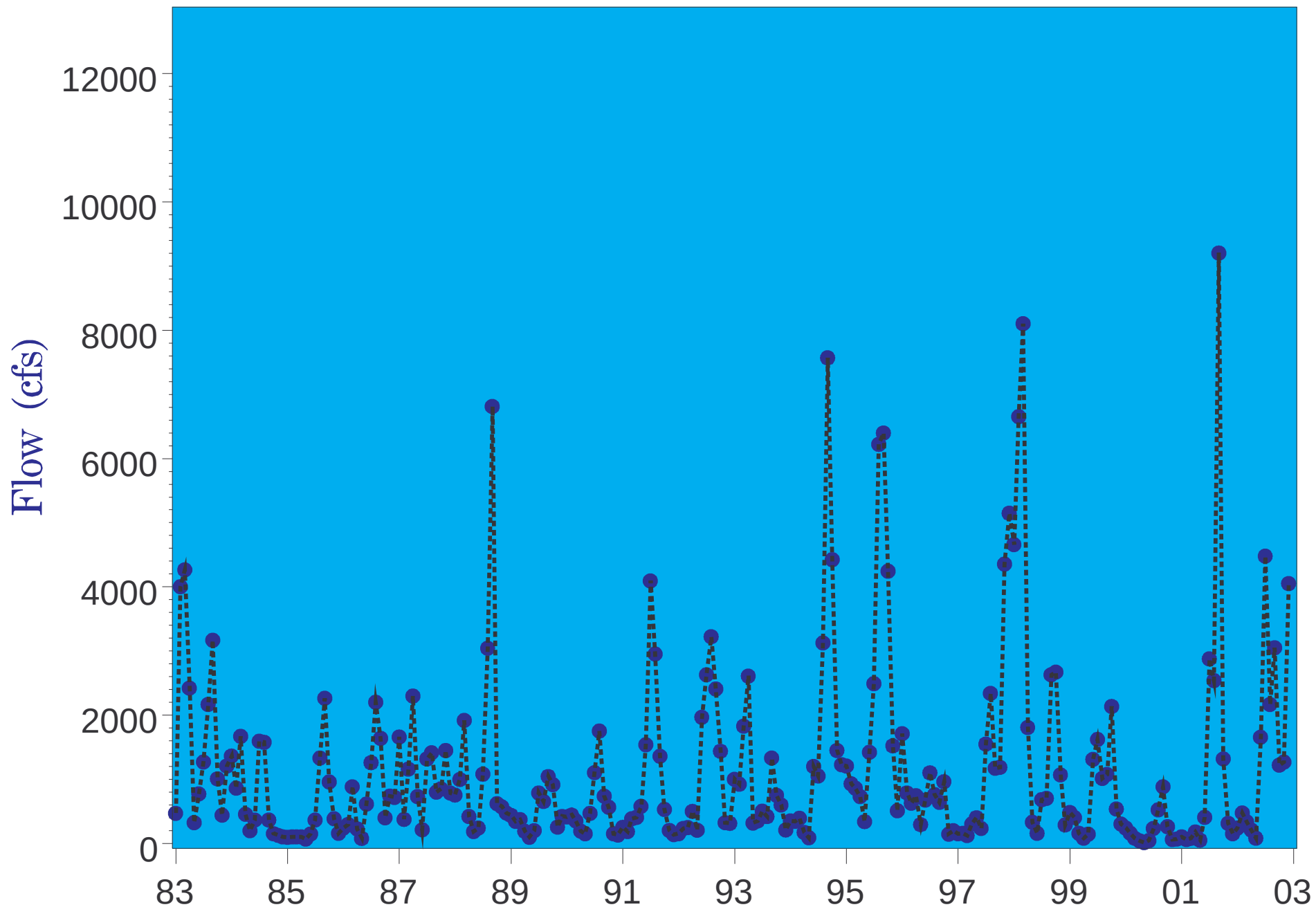


Figure 4.6.6 Mean monthly Peace River at Arcadia + Horse & Joshua Creeks gaged flows

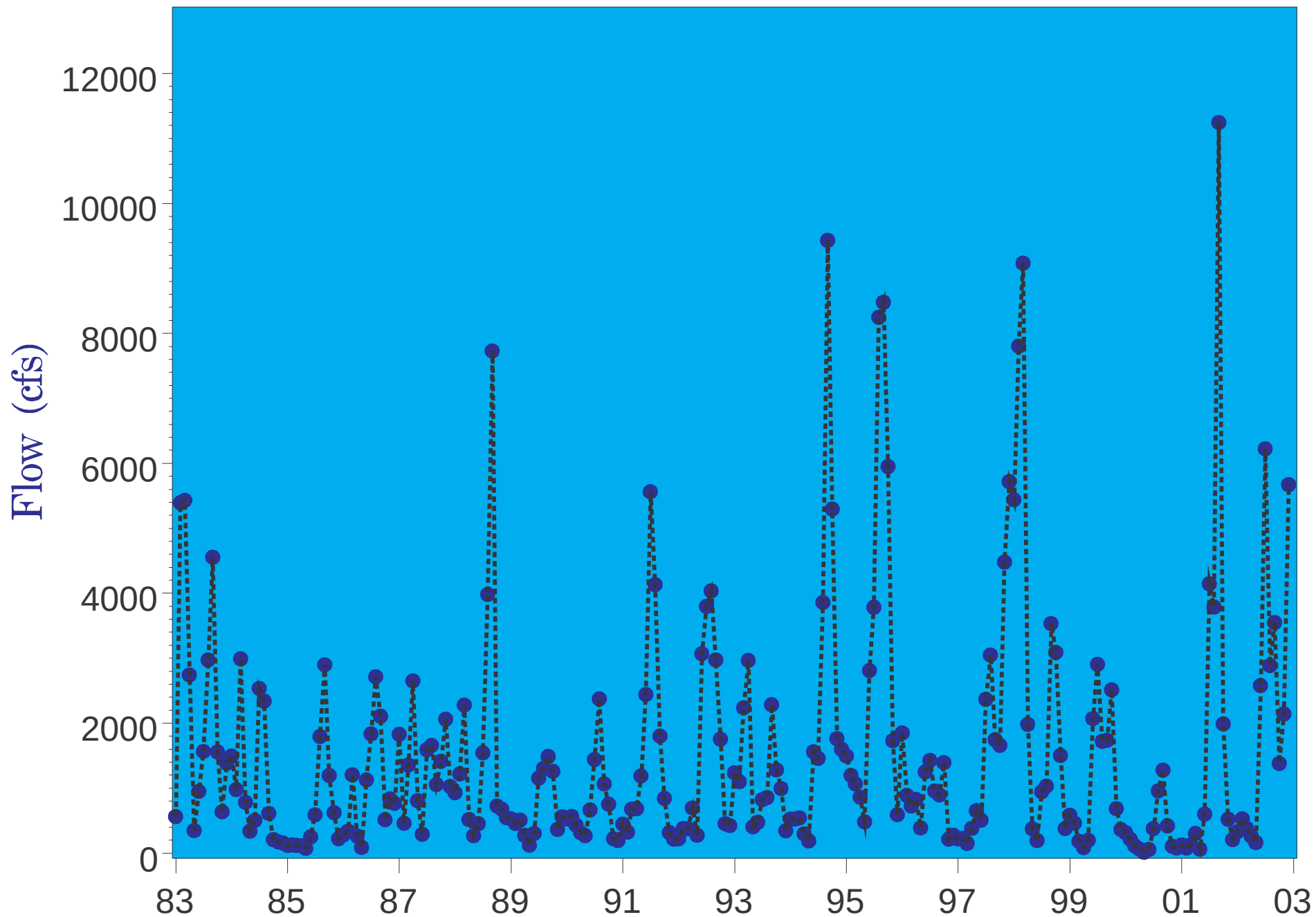


Figure 4.6.7 Mean monthly Peace River at Arcadia + Horse + Joshua & Shell Creeks gaged flows

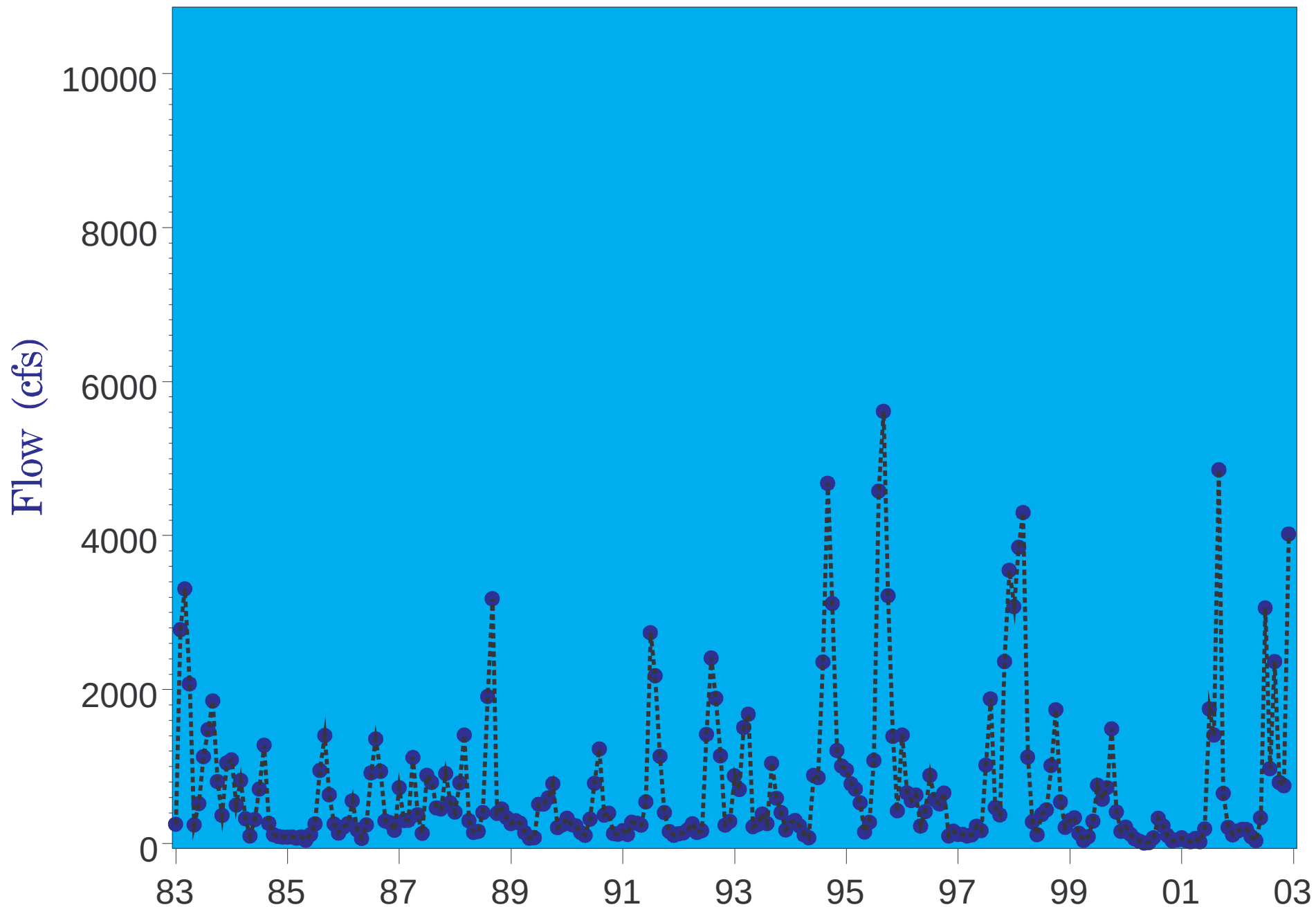


Figure 4.6.8 Median monthly Peace River at Arcadia gaged flow

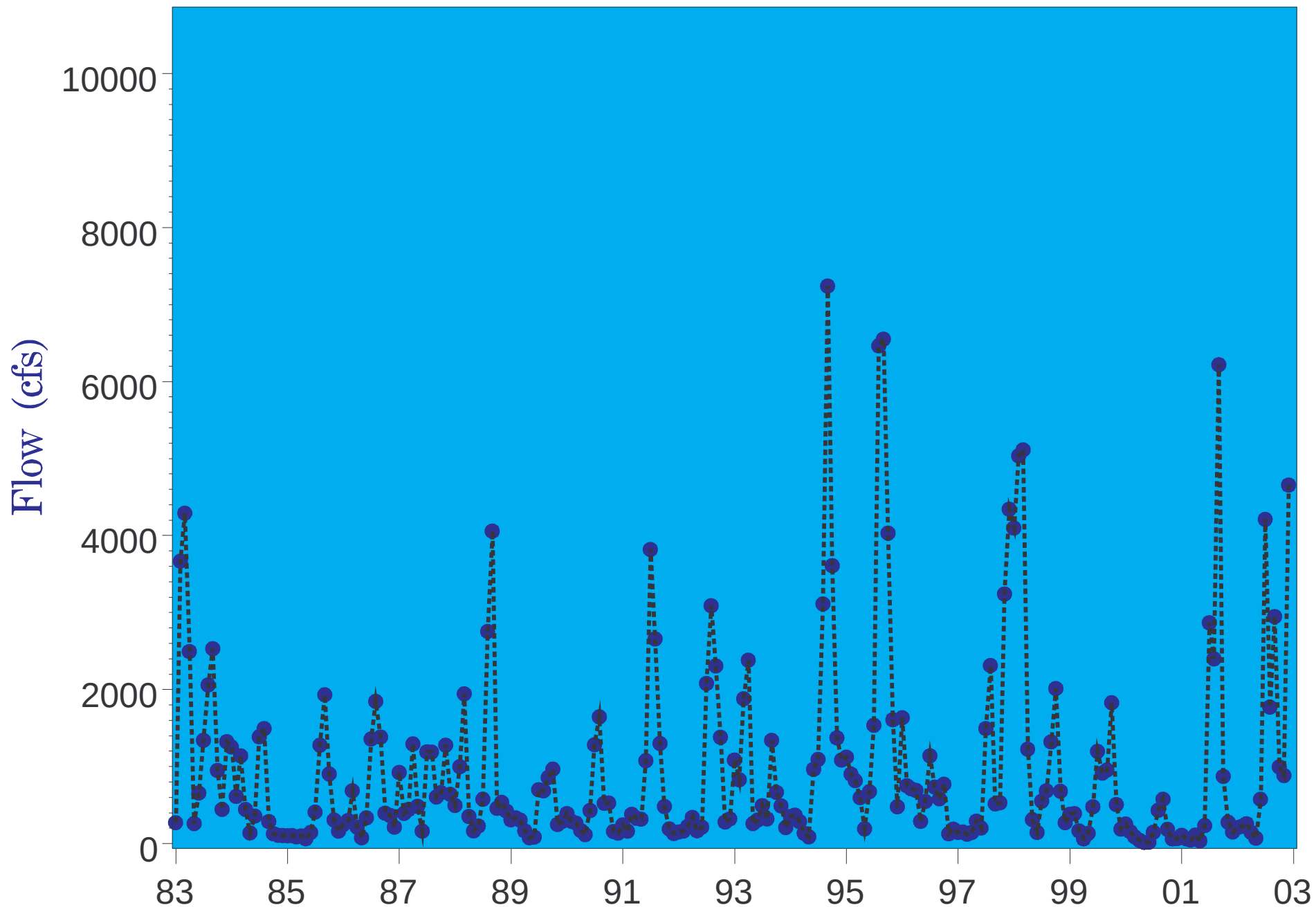


Figure 4.6.9 Median monthly Peace River at Arcadia + Horse & Joshua Creeks gaged flows

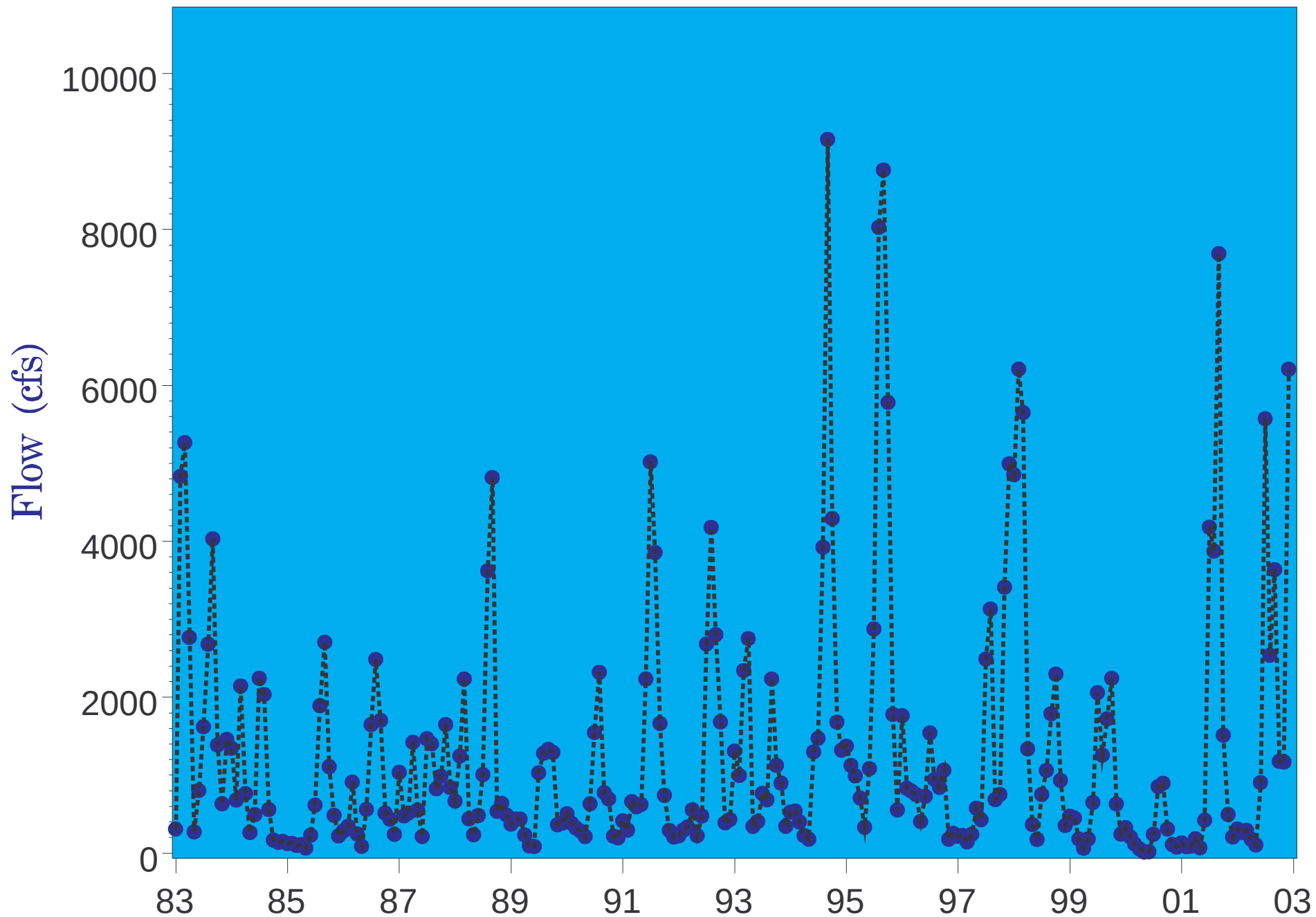


Figure 4.6.10 Median monthly Peace River at Arcadia + Horse + Joshua & Shell Creeks gaged flows



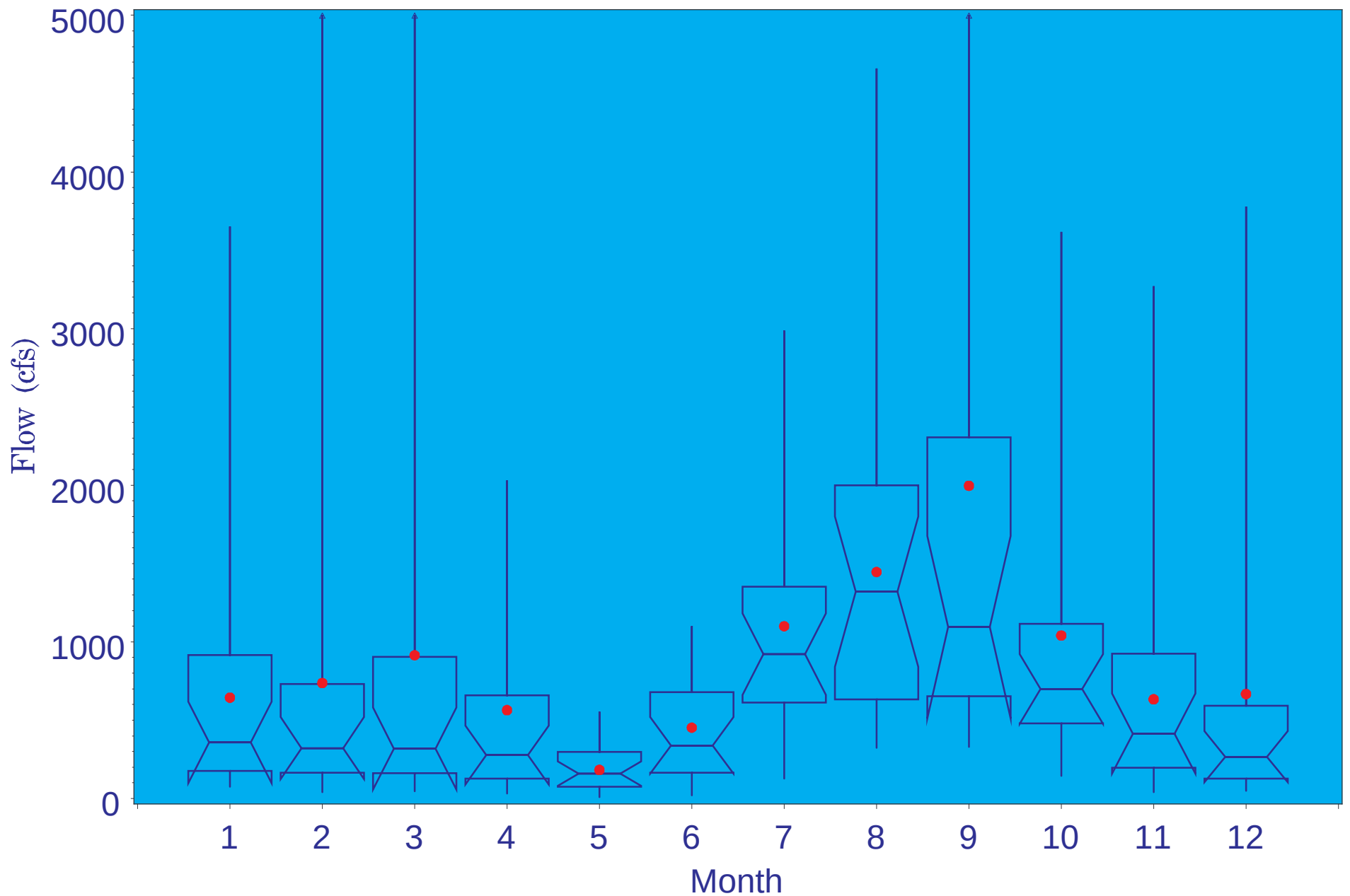


Figure 4.6.11 Mean monthly boxplots of Arcadia gaged flow (1983-2002)

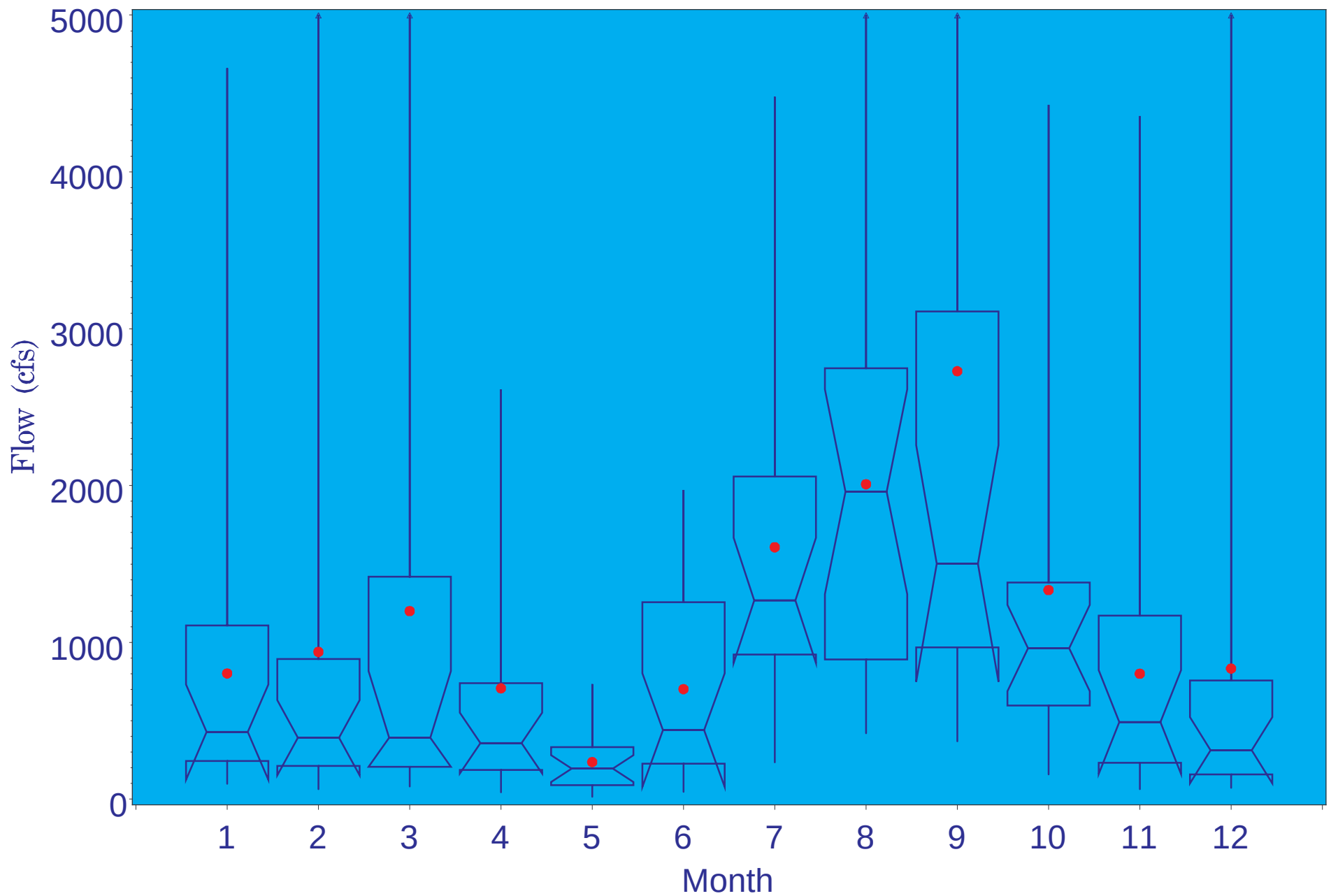


Figure 4.6.12 Mean monthly boxplots of Arcadia + Horse & Joshua Creeks gaged flow (1983-2002)

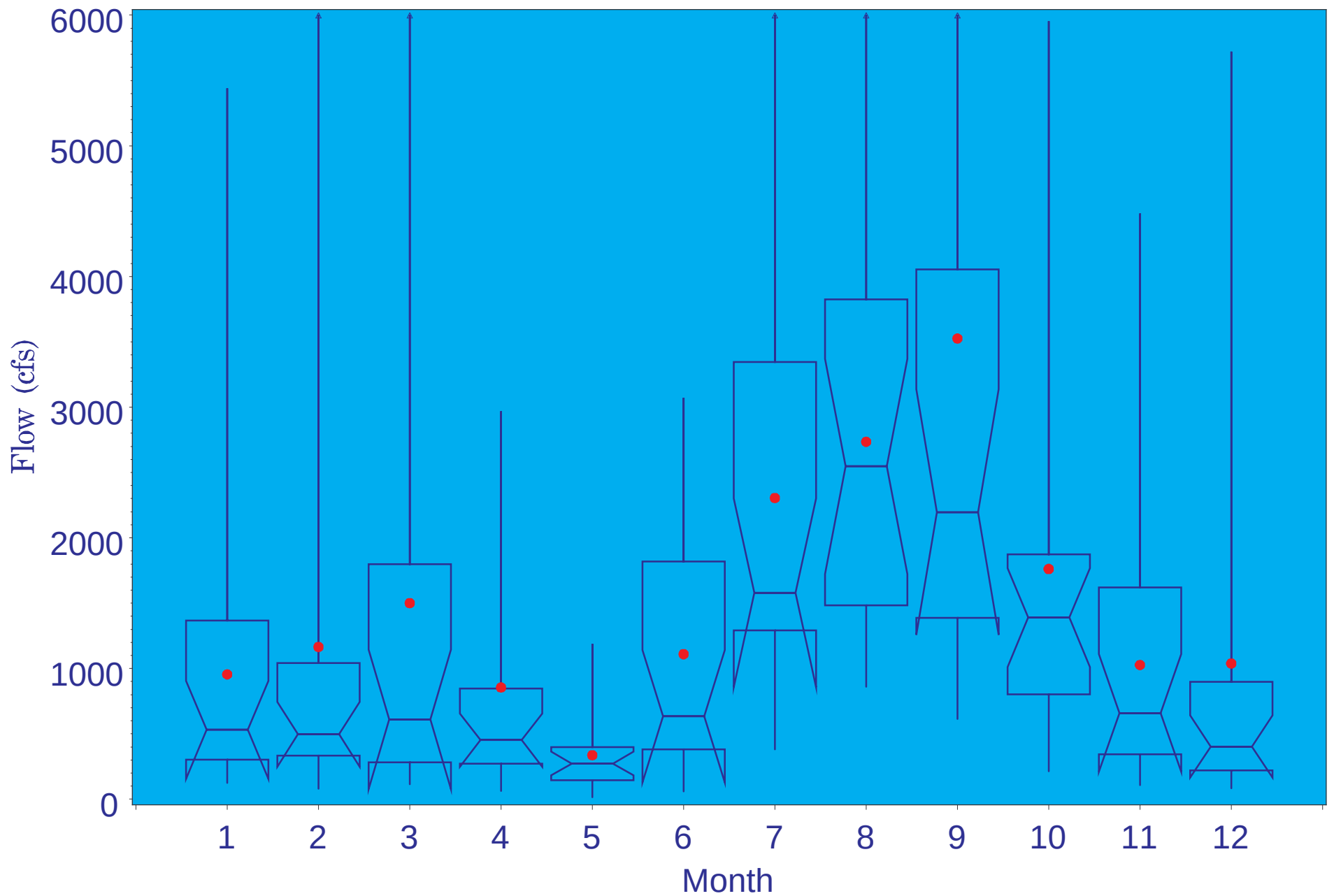


Figure 4.6.13 Mean monthly boxplots of Arcadia + Horse, Joshua & Shell Creeks gaged flow (1983-2002)

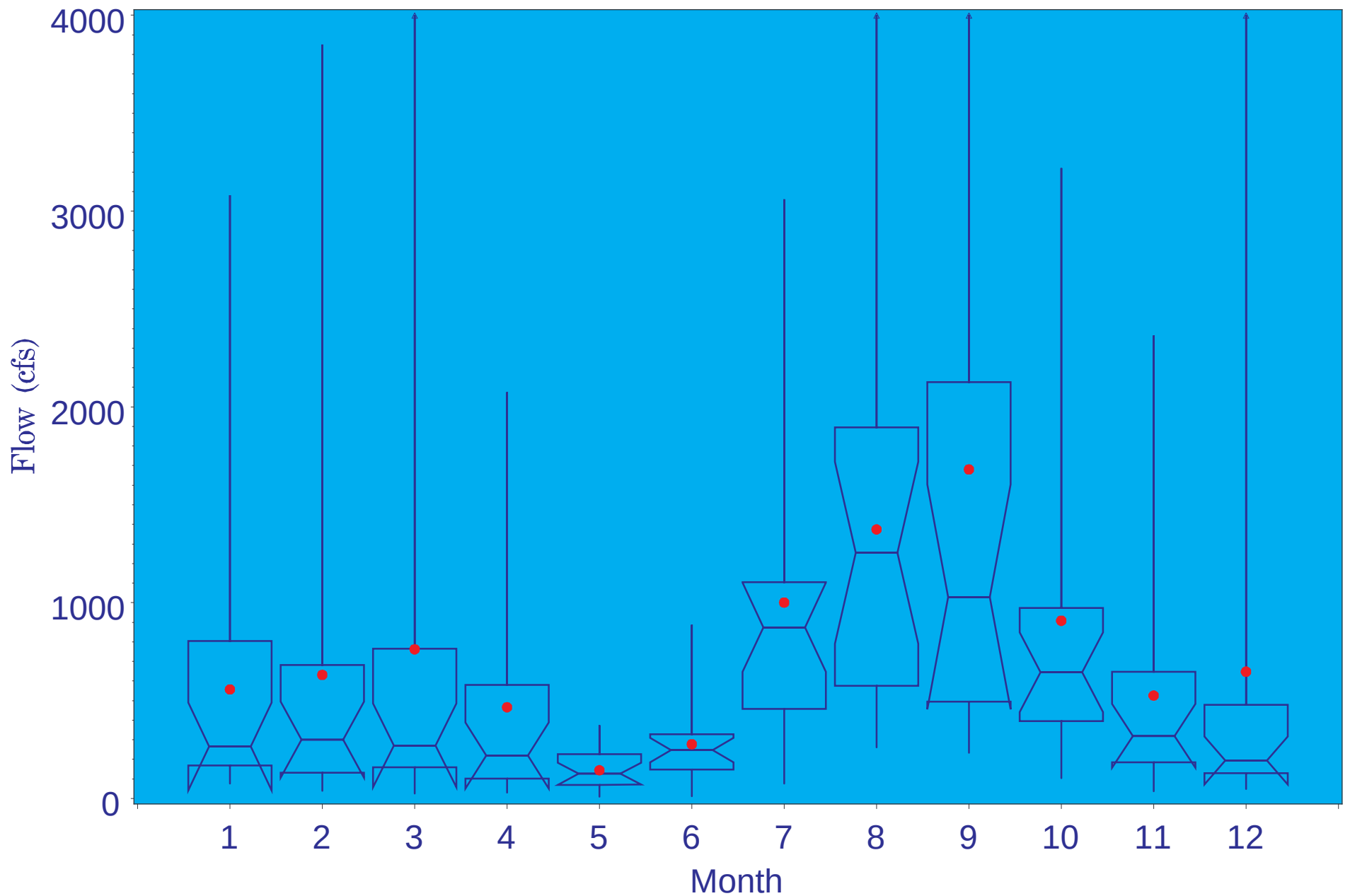


Figure 4.6.14 Median monthly boxplots of Arcadia gaged flow (1983-2002)

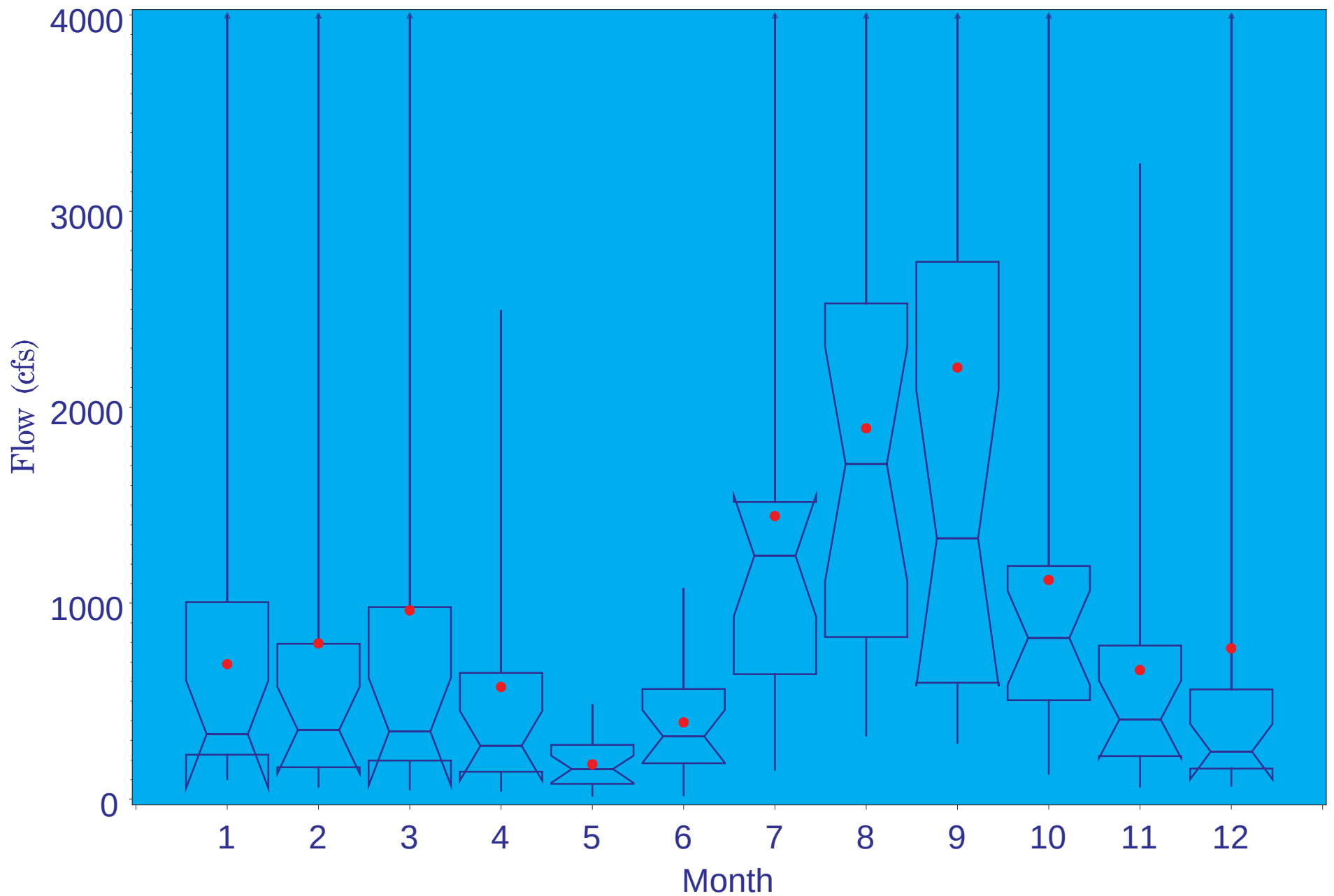


Figure 4.6.15 Median monthly boxplots of Arcadia + Horse & Joshua Creeks gaged flow (1983-2002)

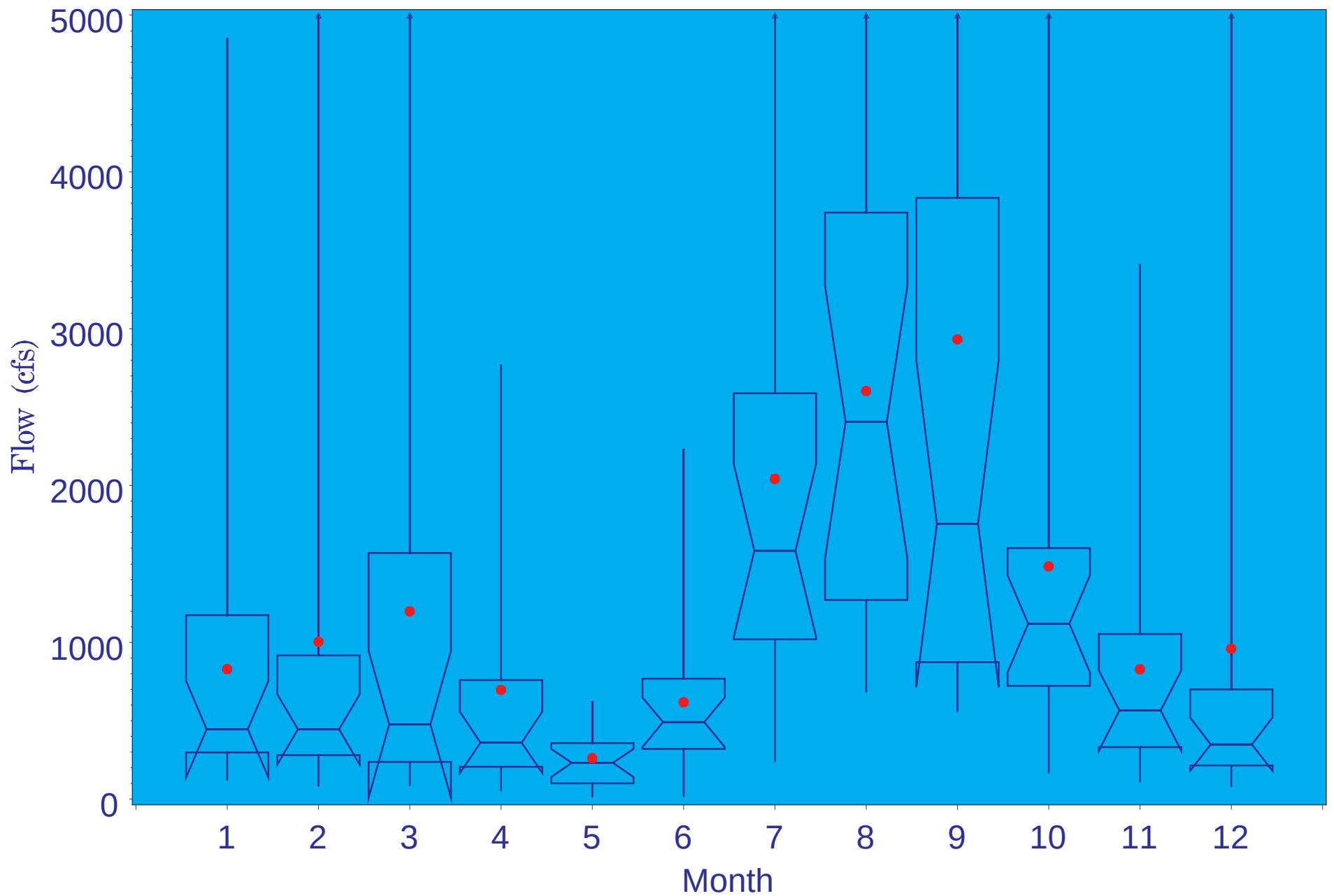


Figure 4.6.16 Median monthly boxplots of Arcadia + Horse, Joshua & Shell Creeks gaged flow (1983-2002)

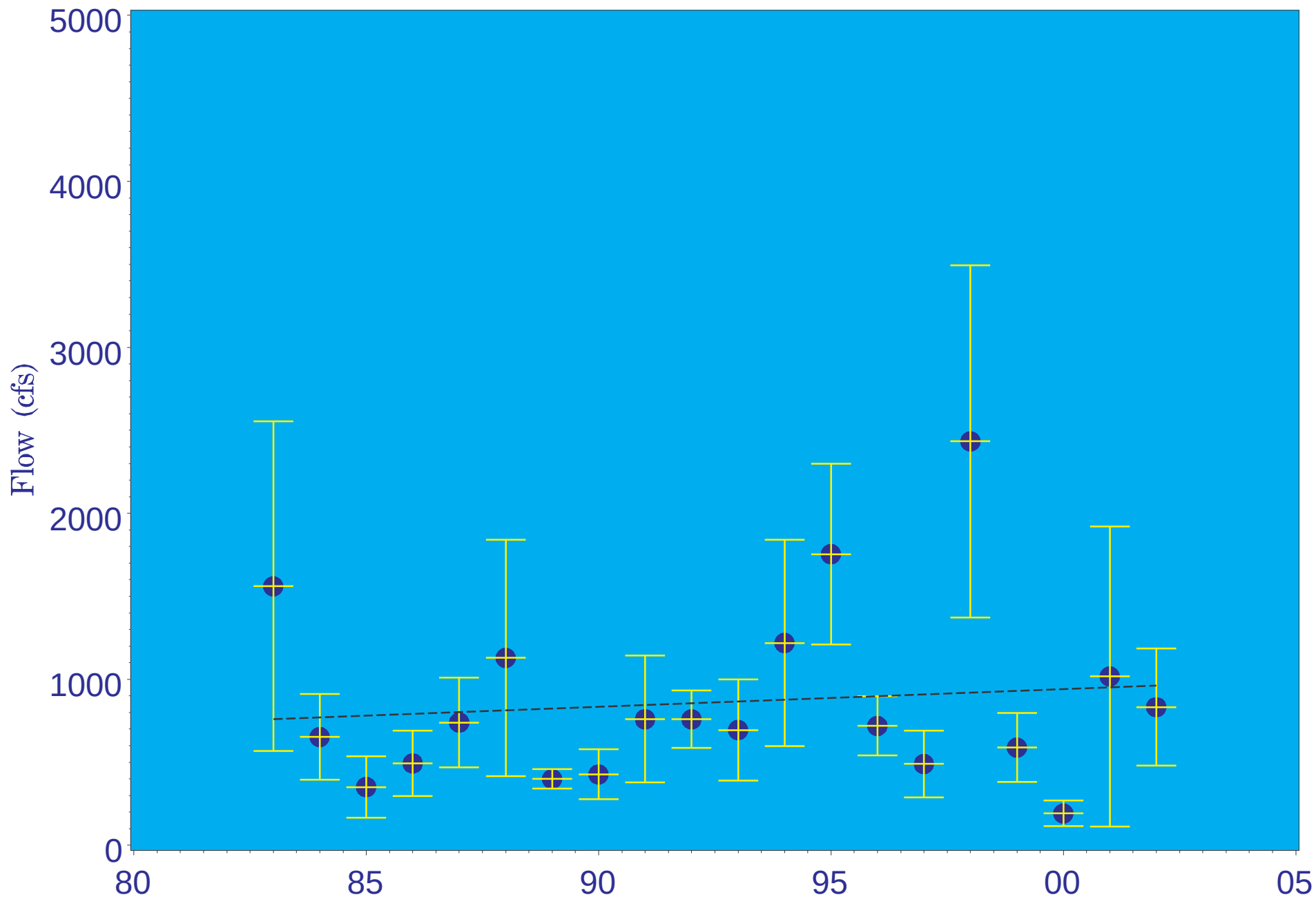


Figure 4.6.17 Annual monthly mean Peace River at Arcadia gaged flow

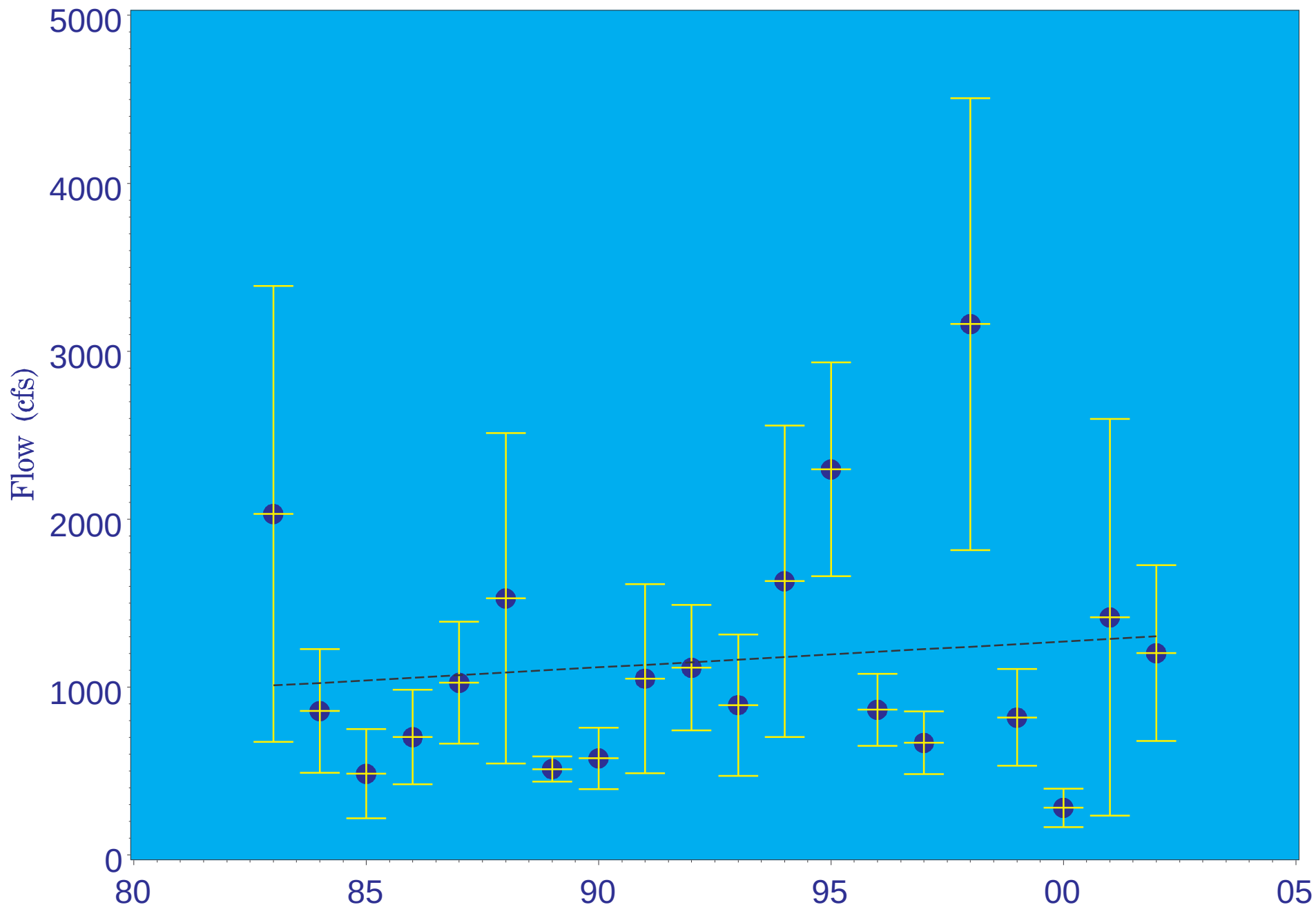


Figure 4.6.18 Annual monthly mean Peace River at Arcadia + Horse & Joshua Creeks gaged flows



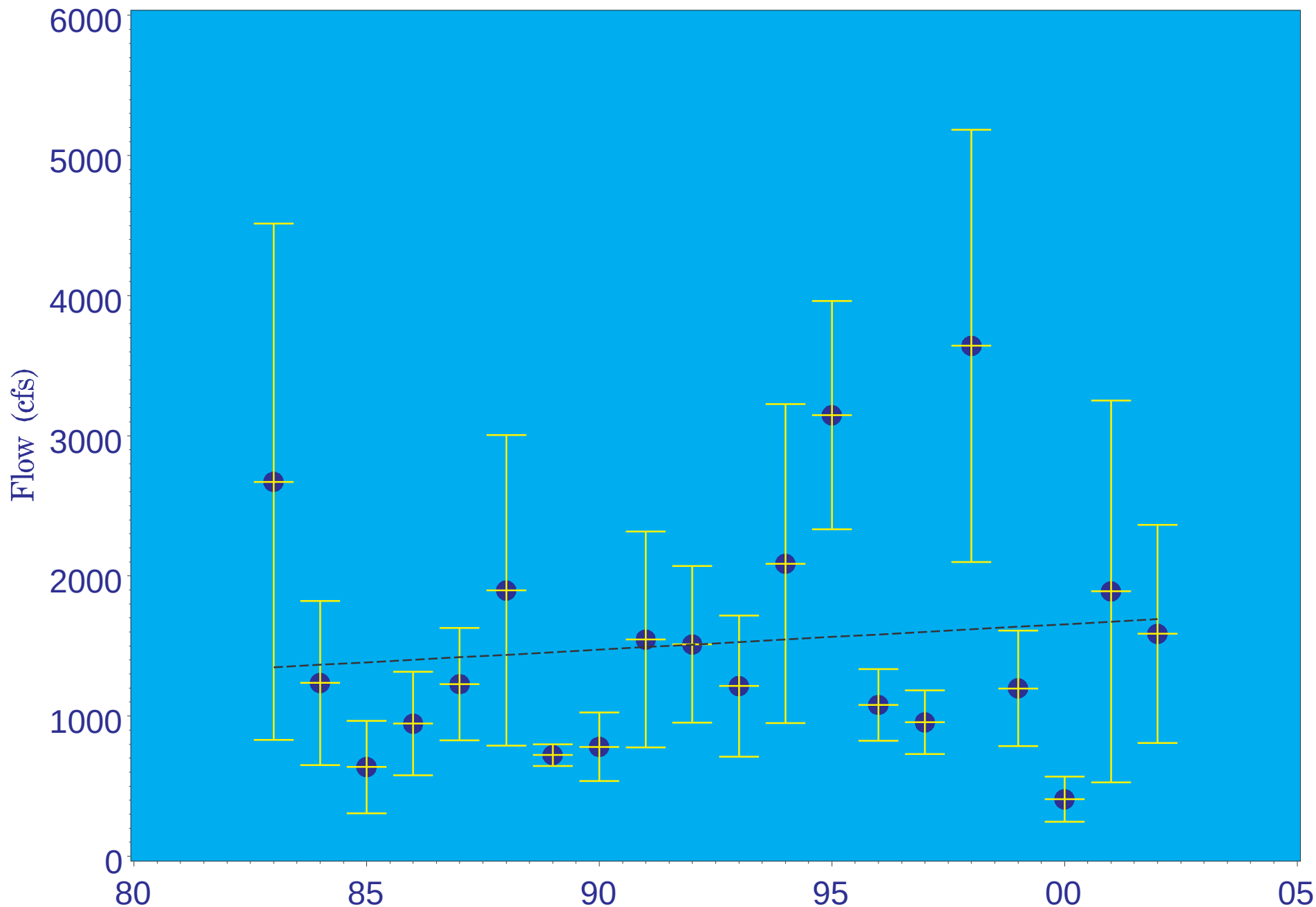


Figure 4.6.19 Annual monthly mean Peace River at Arcadia + Horse + Joshua & Shell Creeks gaged flows

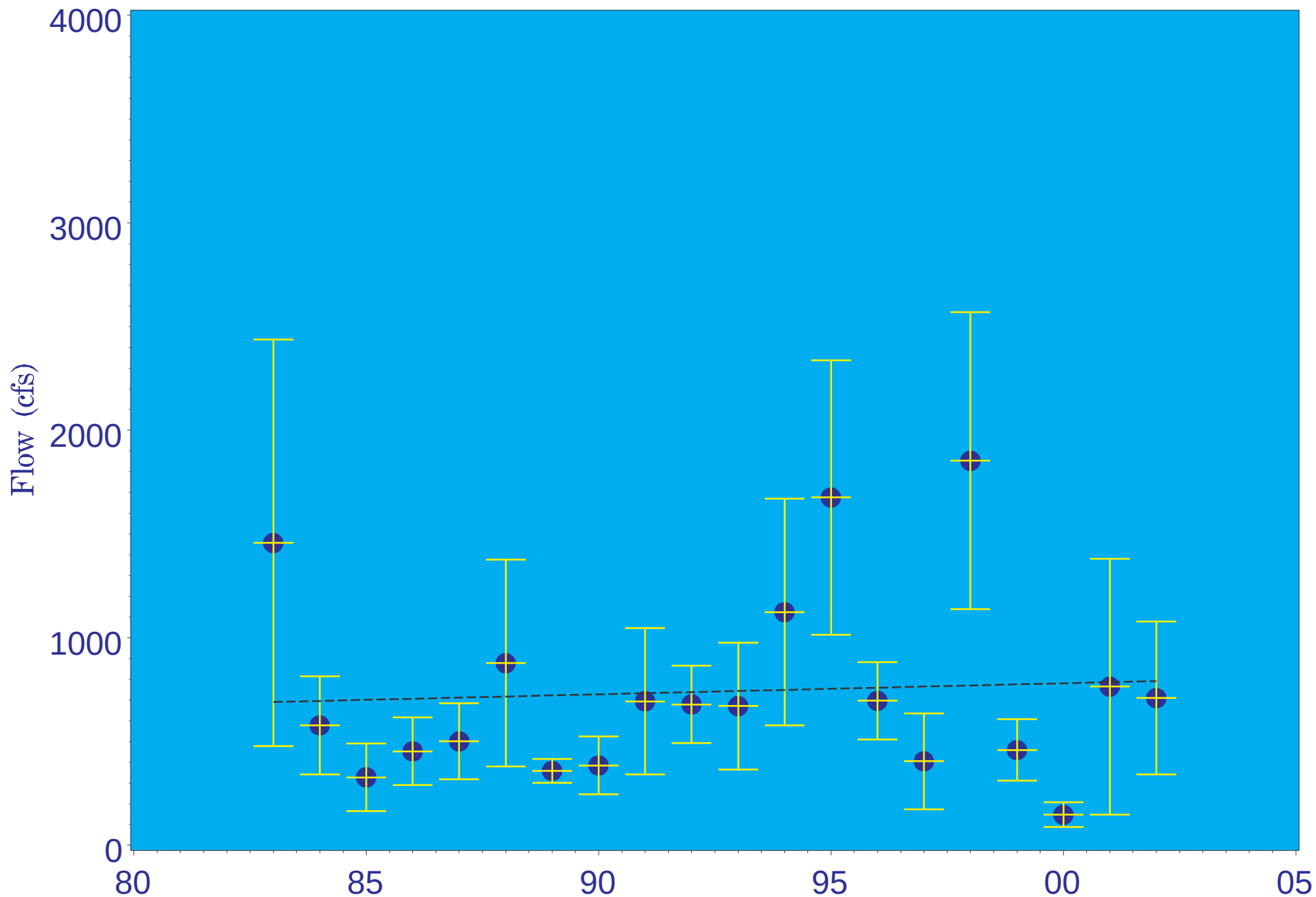


Figure 4.6.20 Annual monthly median Peace River at Arcadia gaged flow

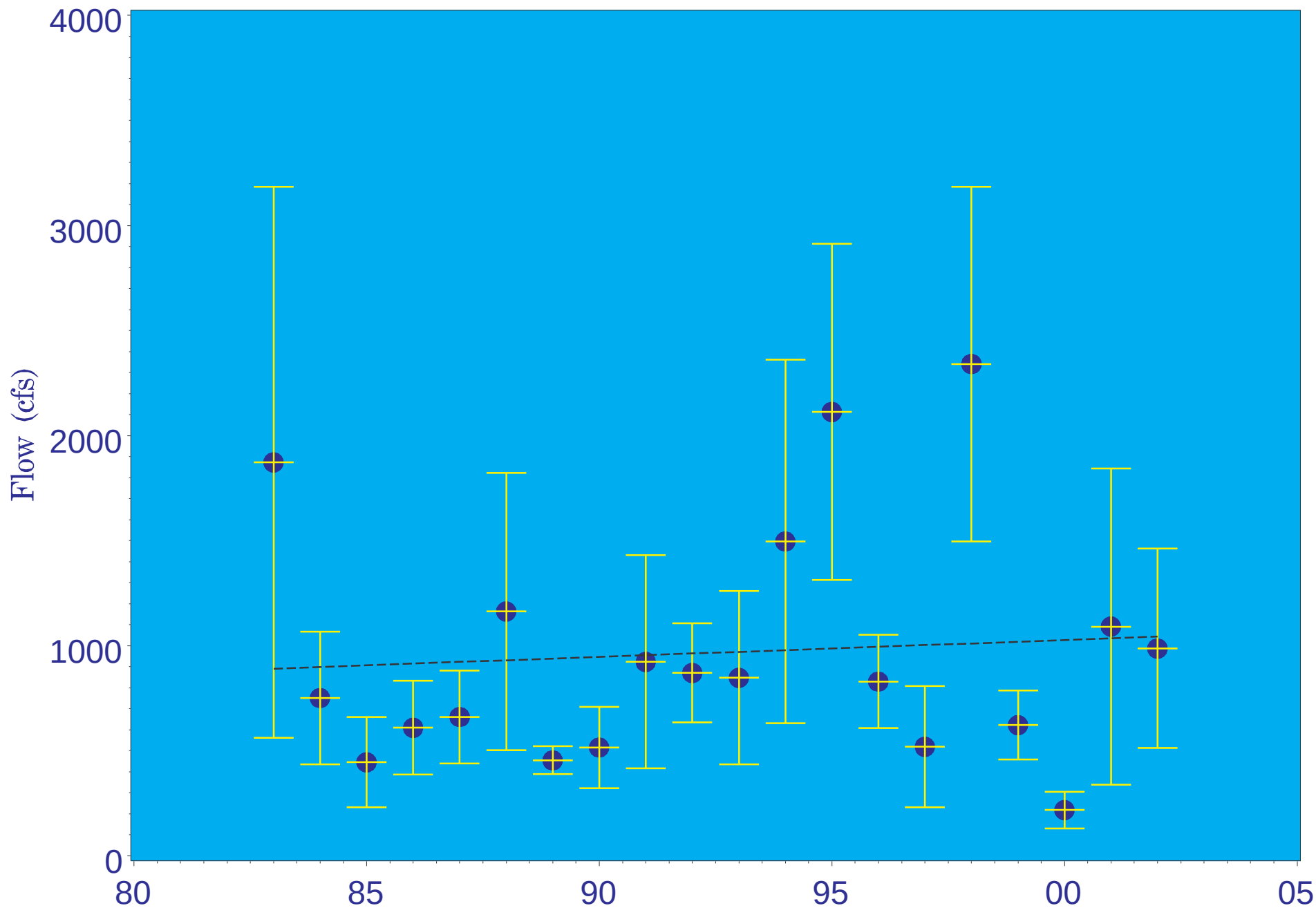


Figure 4.6.21 Annual monthly median Peace River at Arcadia + Horse & Joshua Creeks gaged flows

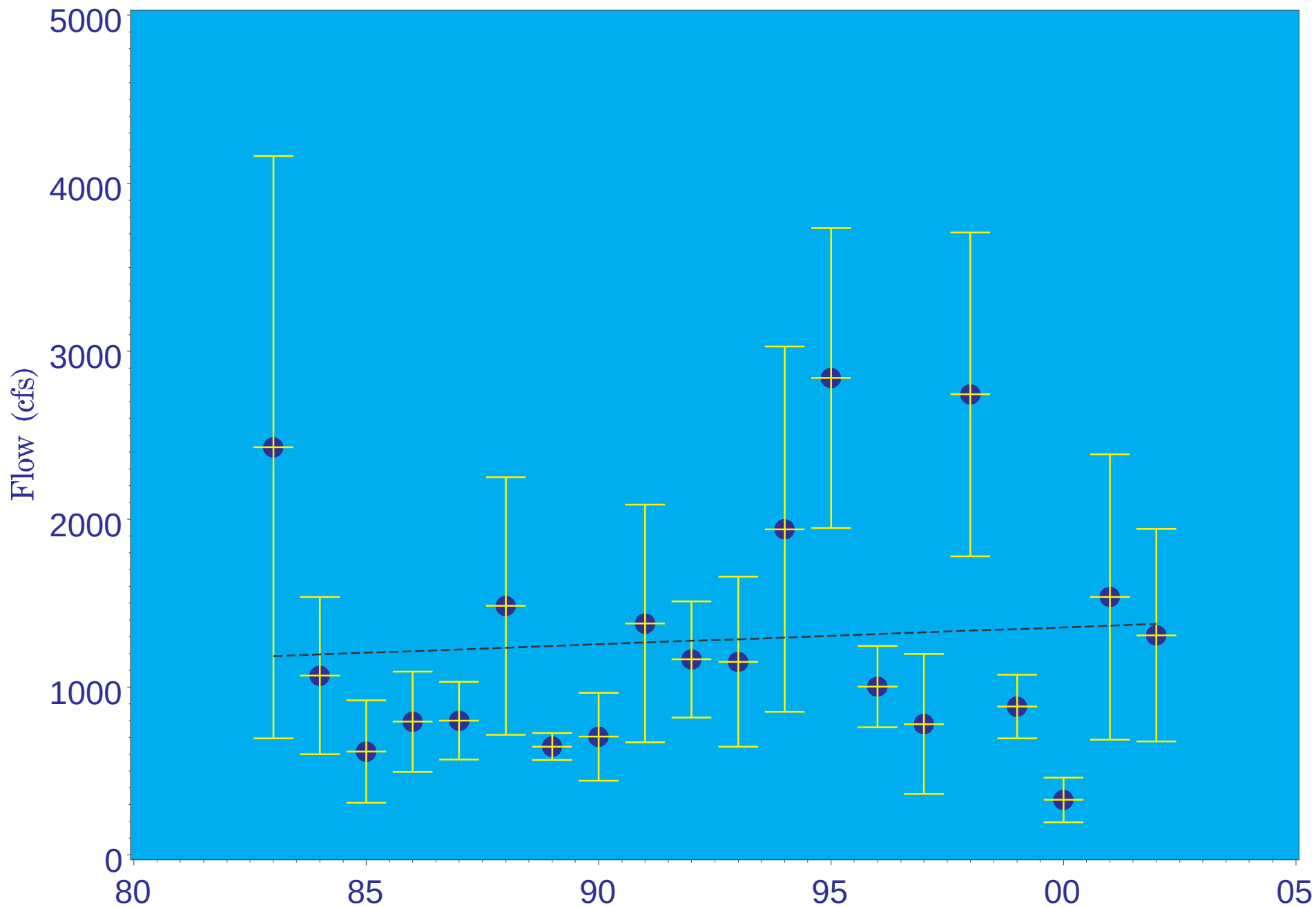


Figure 4.6.22 Annual monthly median Peace River at Arcadia + Horse + Joshua & Shell Creeks gaged flows

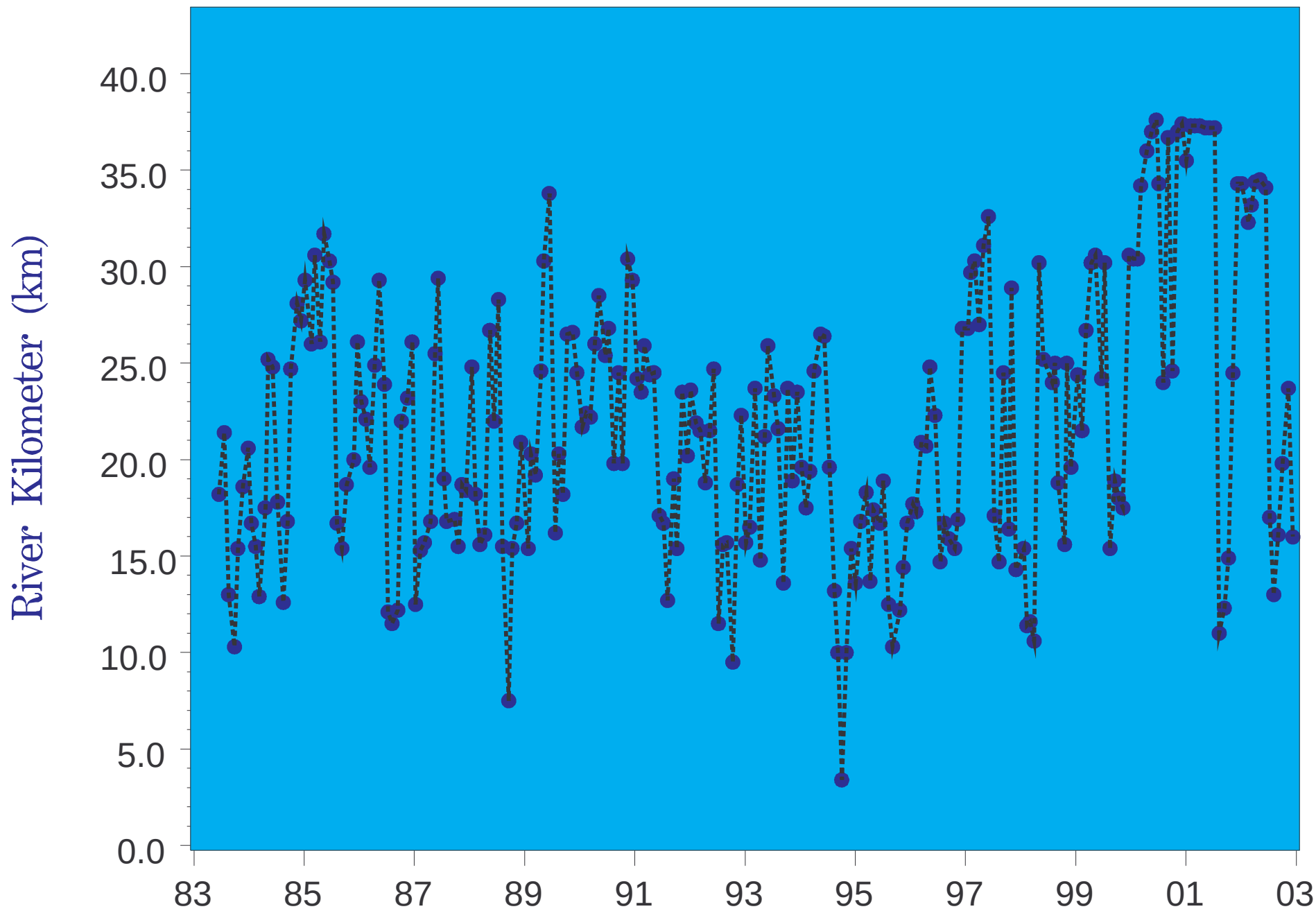


Figure 4.6.23a Monthly river kilometer location of the 0 o/oo isohaline (1983-2002)

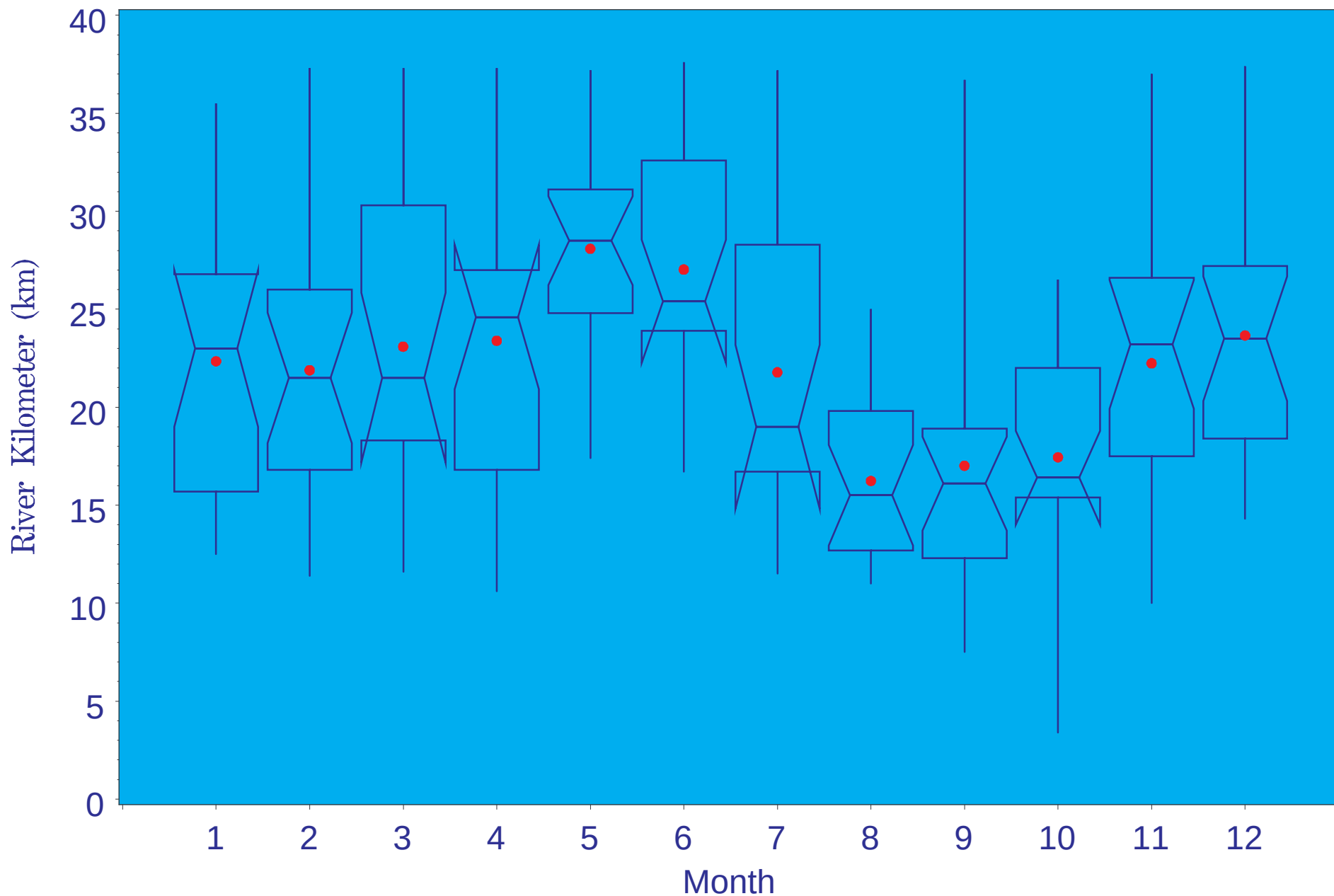


Figure 4.6.23b Mean monthly boxplots of location of 0 ppt isohaline (1984-2002)

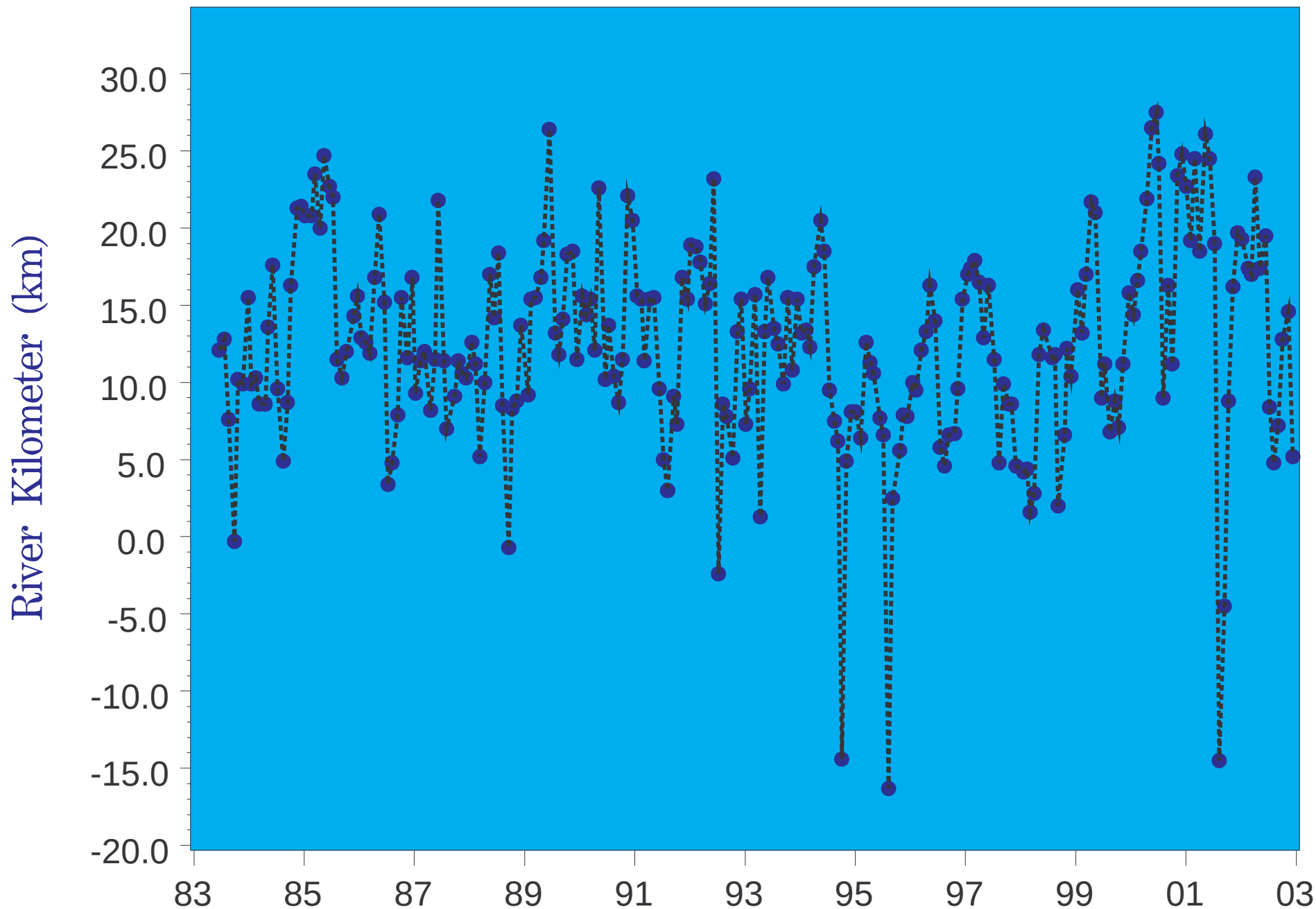


Figure 4.6.24a Monthly river kilometer location of the 6 o/oo isohaline (1983-2002)

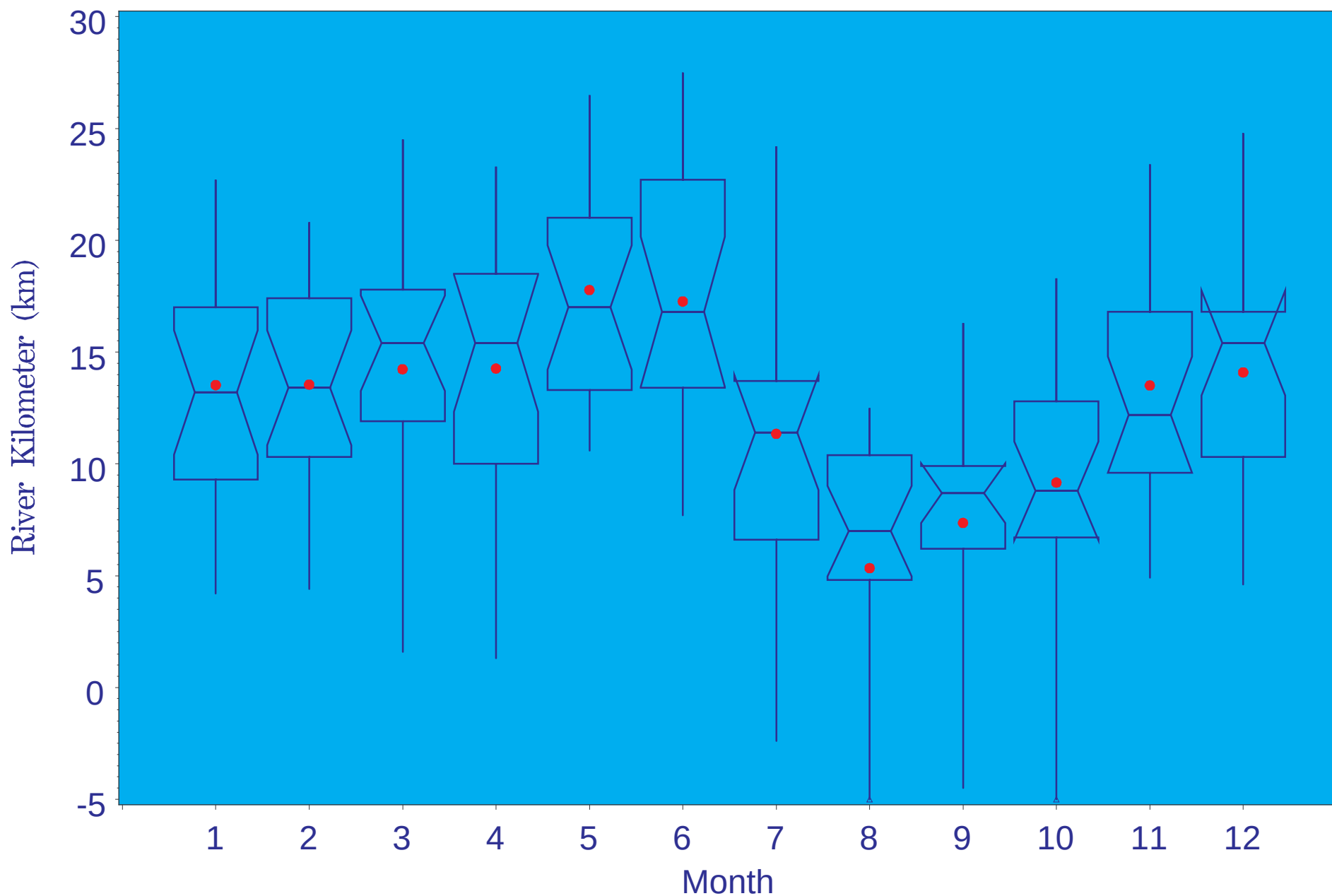


Figure 4.6.24b Mean monthly boxplots of location of 6 ppt isohaline (1984-2002)



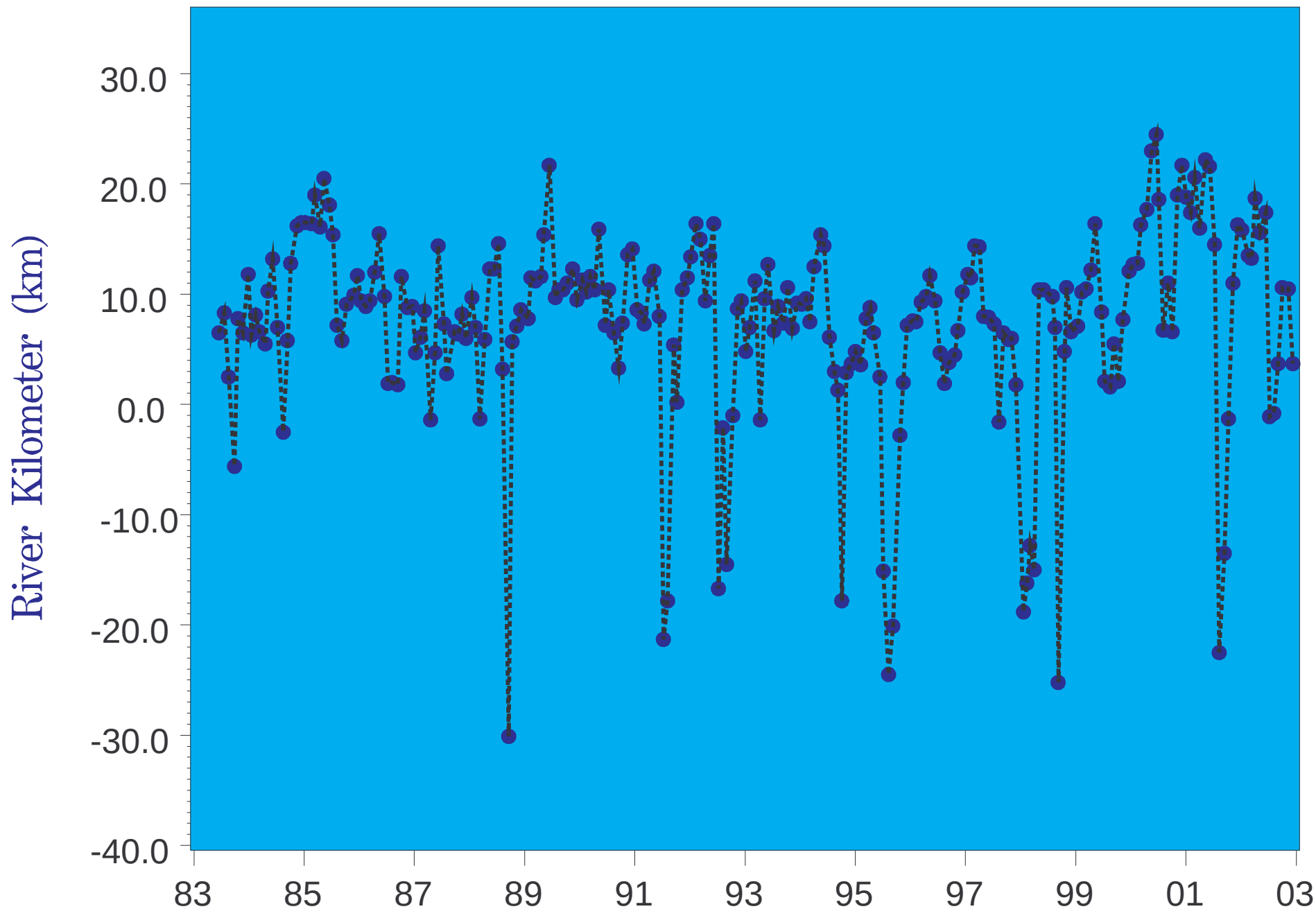


Figure 4.6.25a Monthly river kilometer location of the 12 o/oo isohaline (1983-2002)

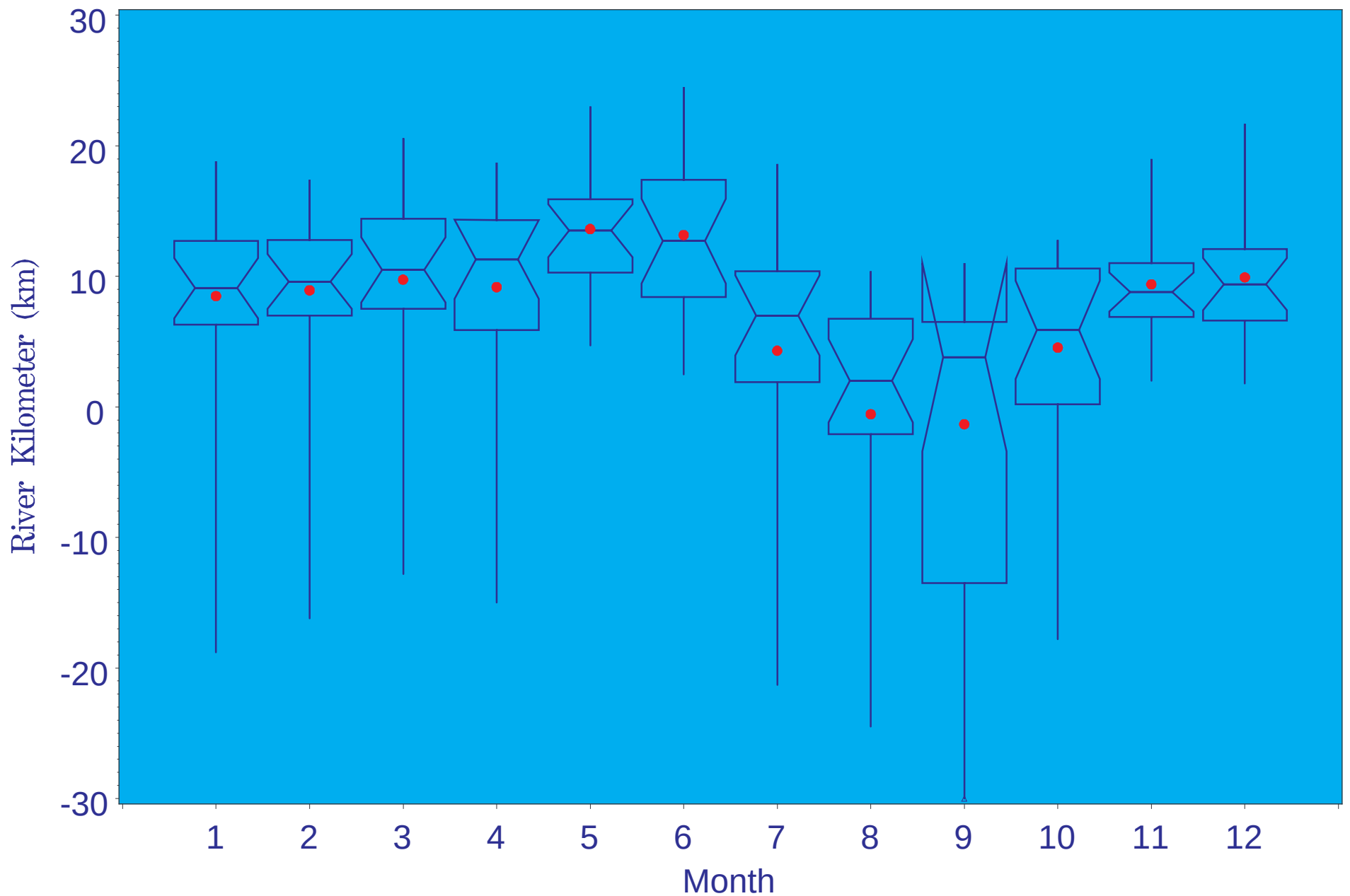


Figure 4.6.25b Mean monthly boxplots of location of 12 ppt isohaline (1984-2002)

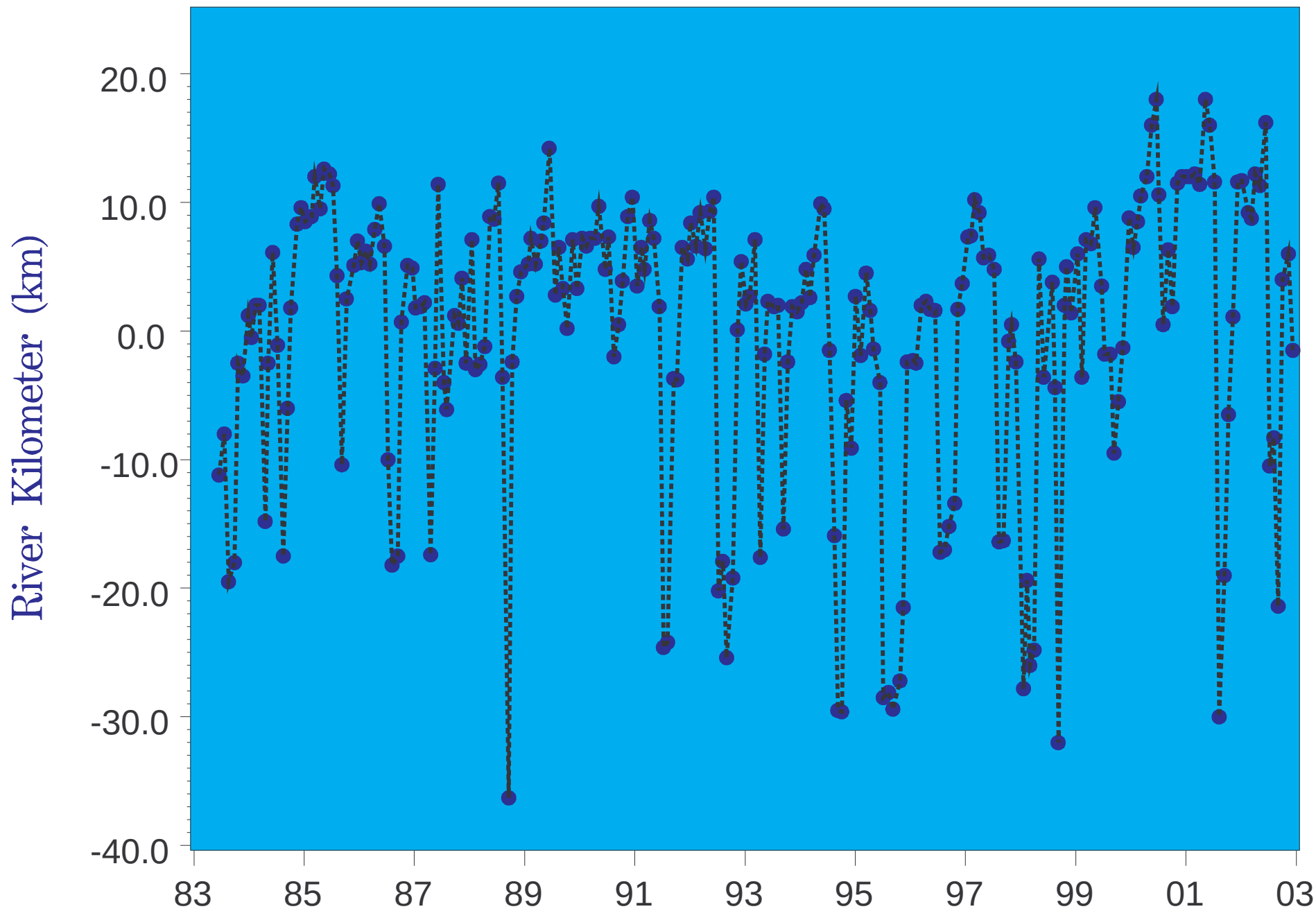


Figure 4.6.26a Monthly river kilometer location of the 20 o/oo isohaline (1983-2002)

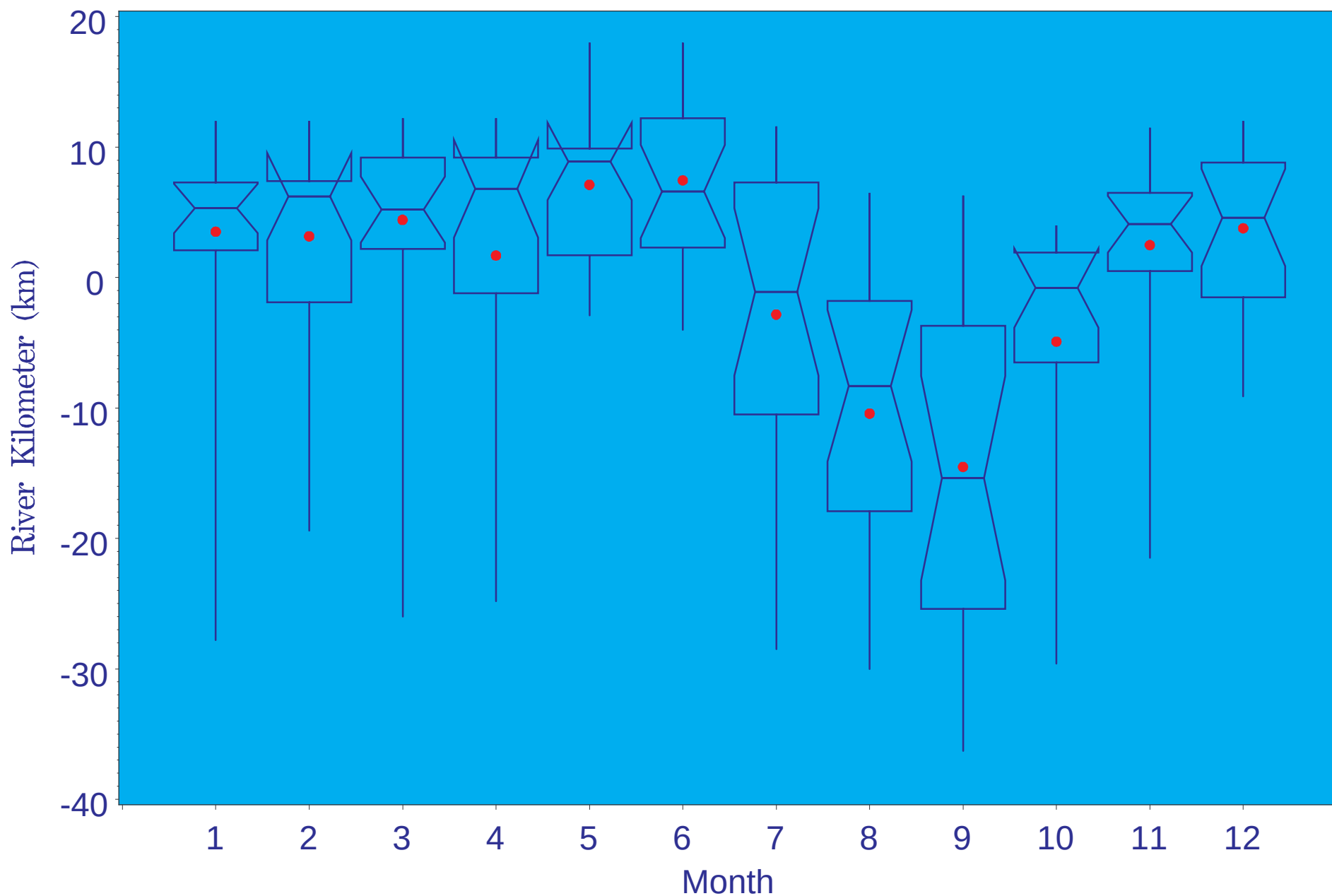


Figure 4.6.26b Mean monthly boxplots of location of 20 ppt isohaline (1984-2002)

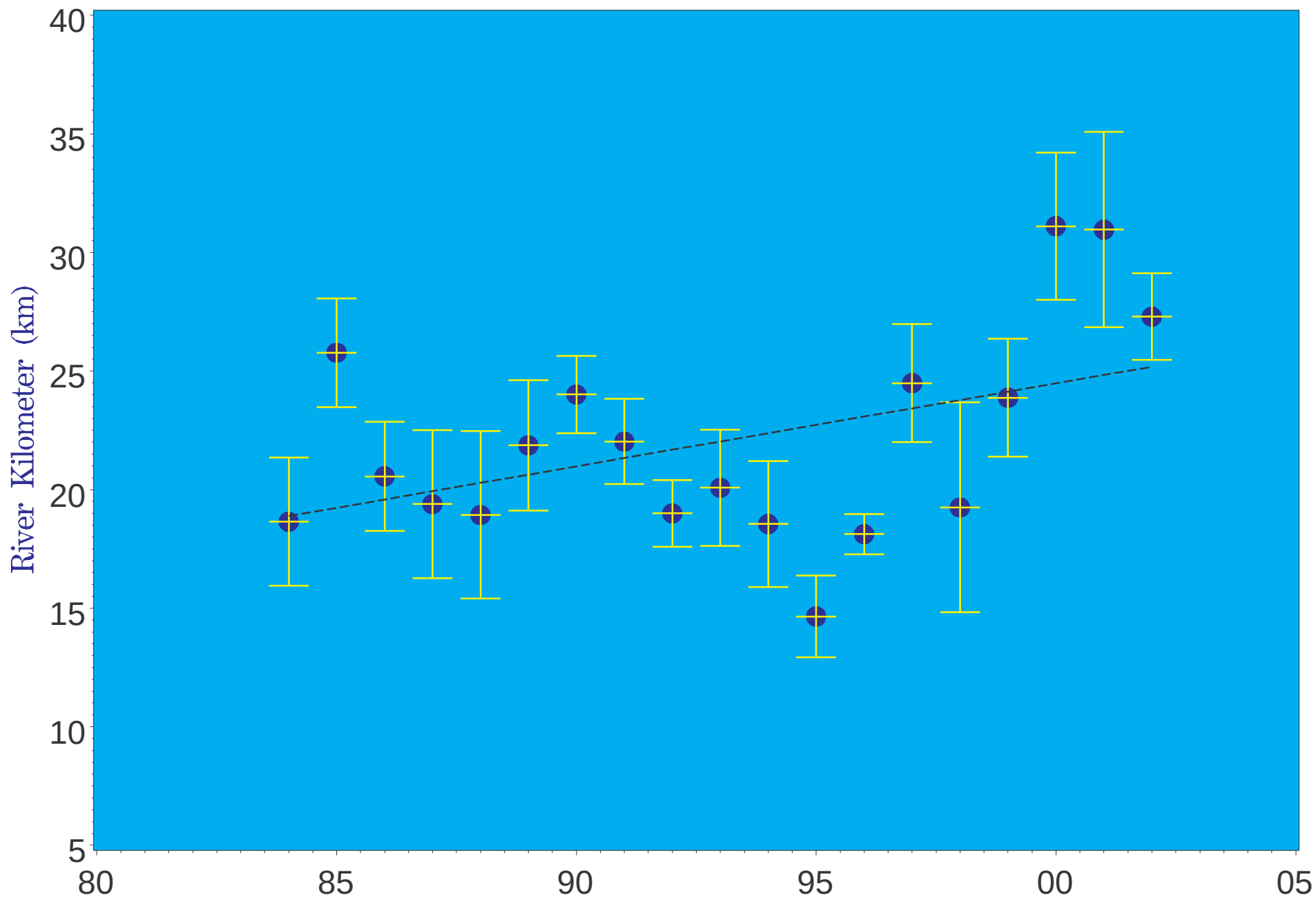


Figure 4.6.27 Annual monthly river kilometer location of the 0 o/oo isohaline (1984-2002)

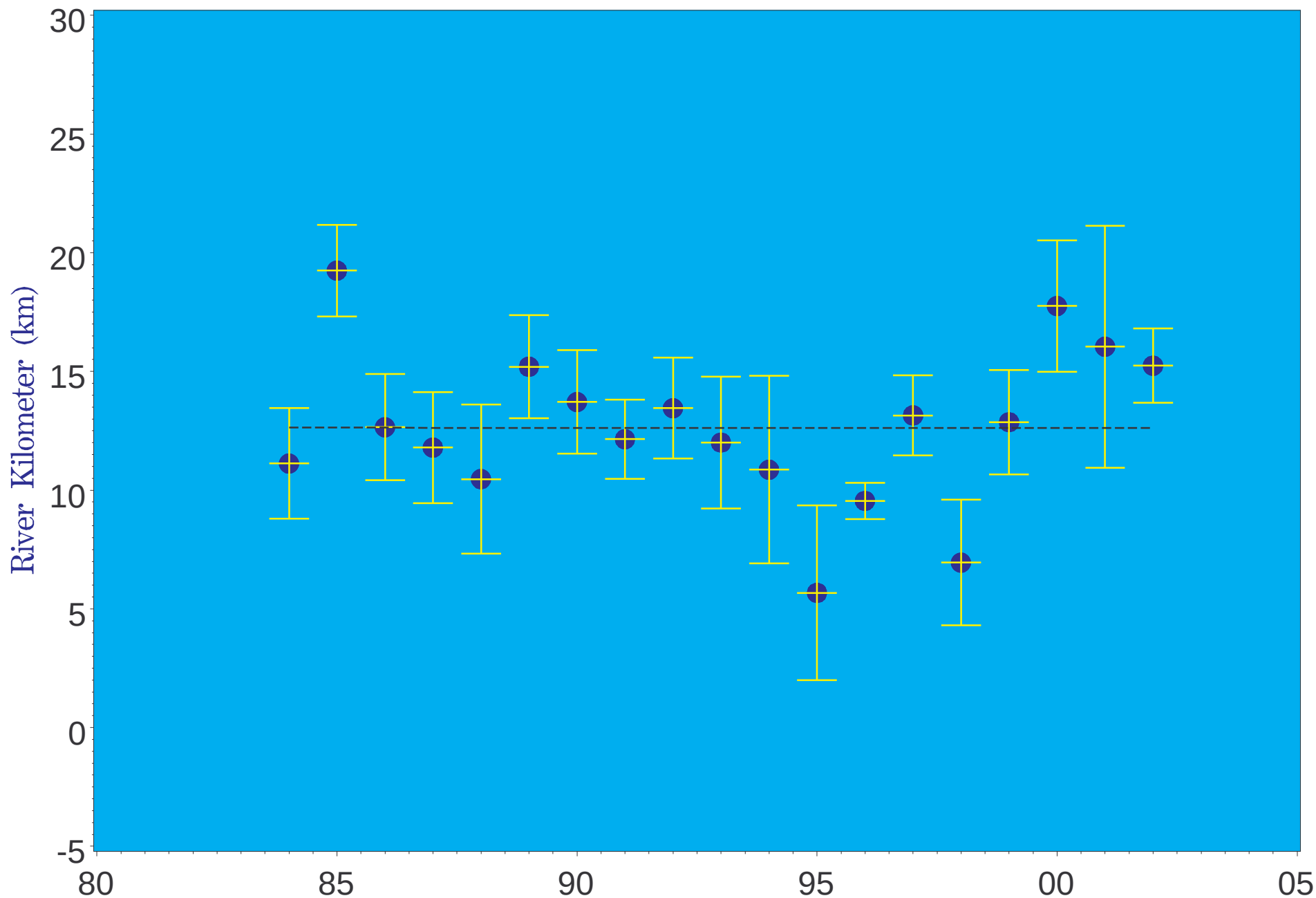


Figure 4.6.28 Annual monthly river kilometer location of the 6 o/oo isohaline (1984-2002)

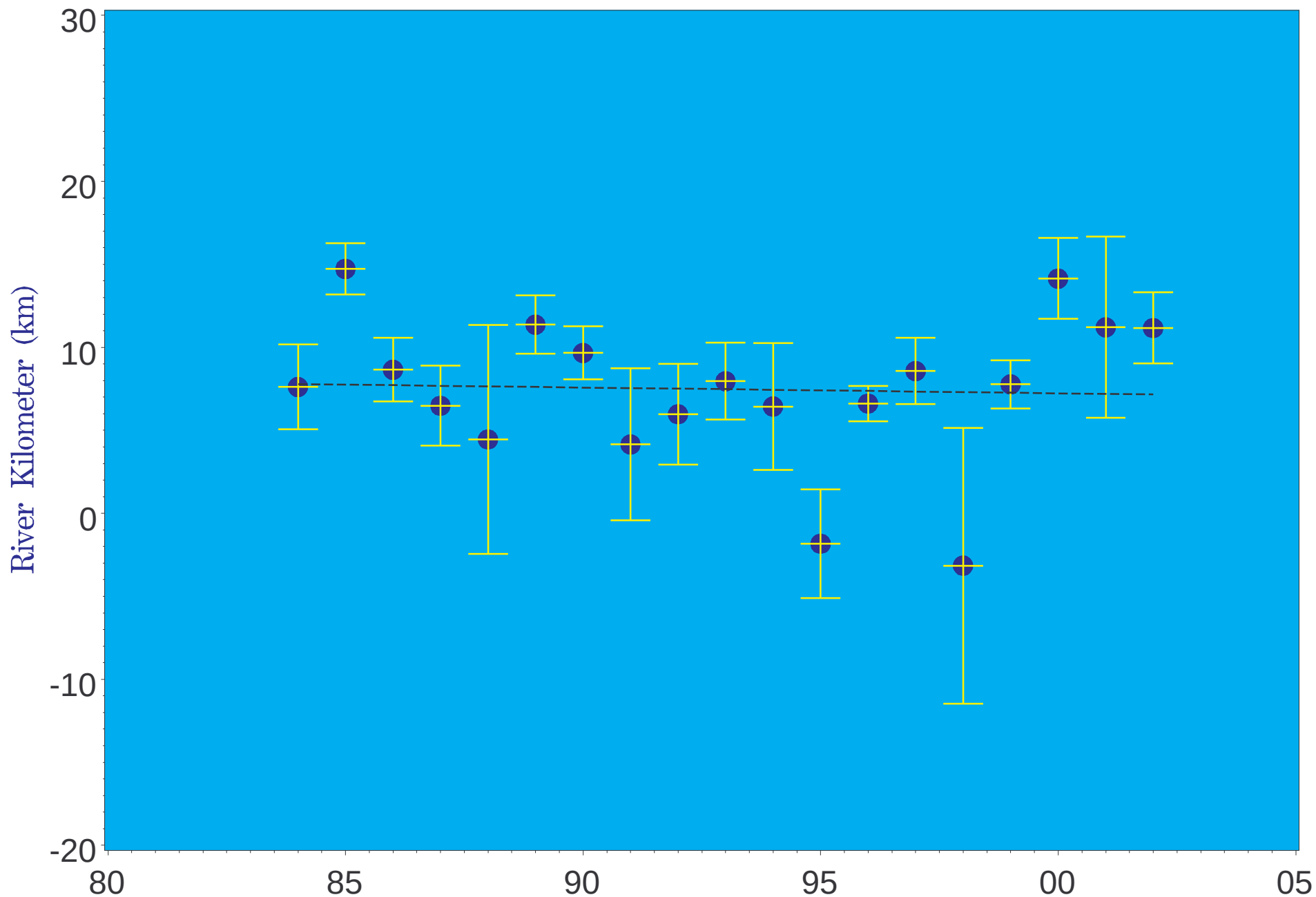


Figure 4.6.29 Annual monthly river kilometer location of the 12 o/oo isohaline (1984-2002)

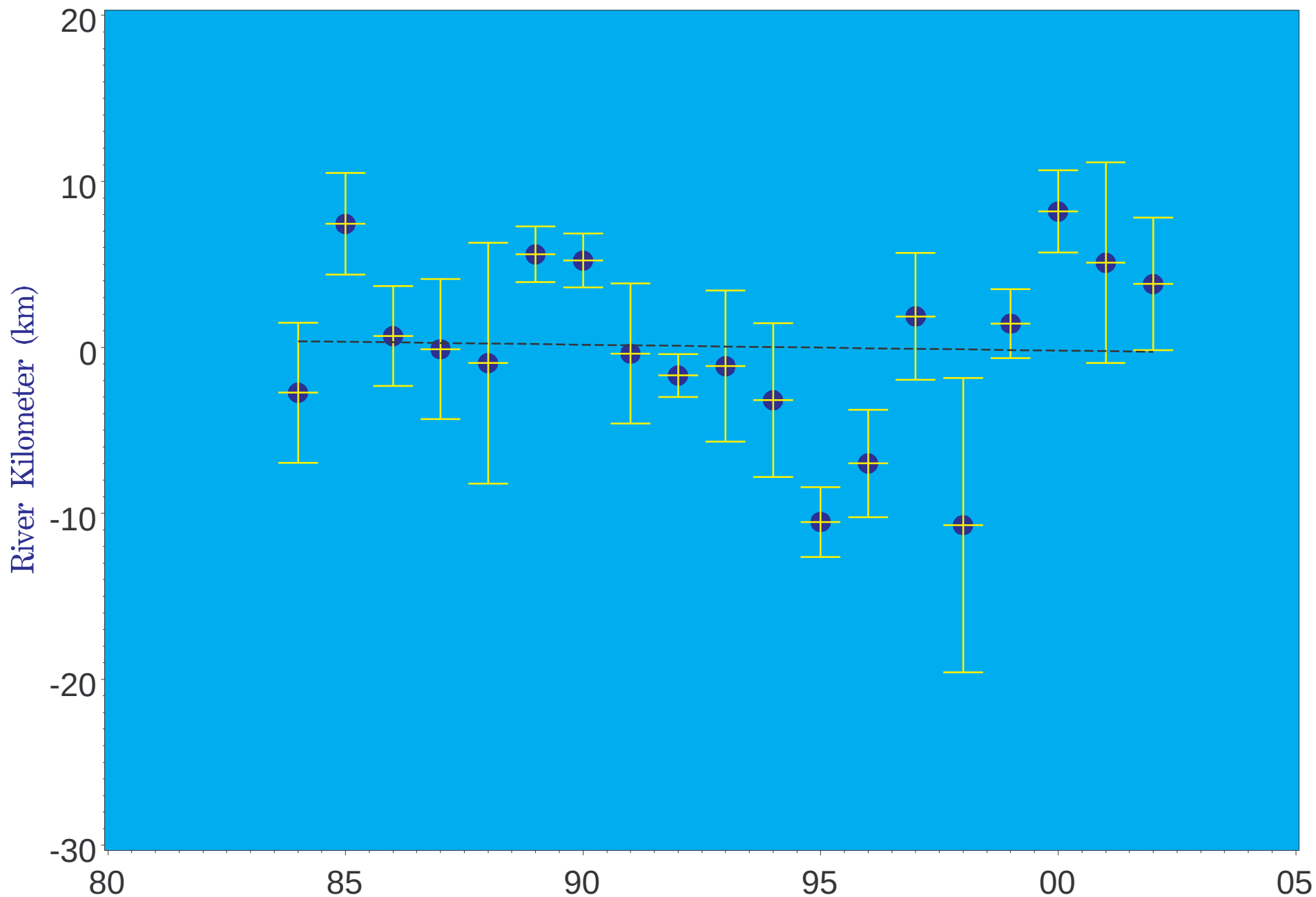


Figure 4.6.30 Annual monthly river kilometer location of the 20 o/oo isohaline (1984-2002)



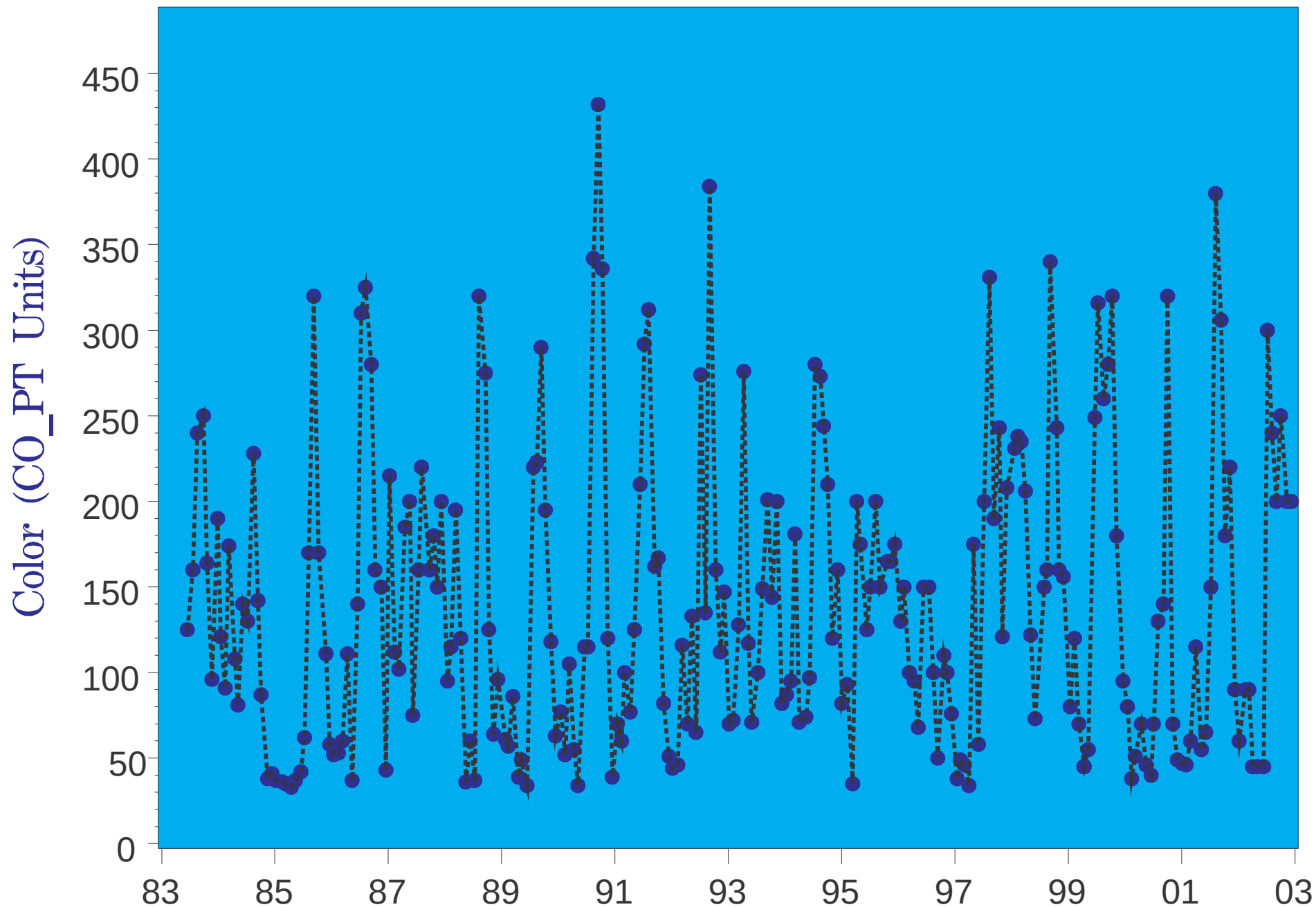


Figure 4.6.31 Monthly surface color at 0 o/oo isohaline (1983-2002)

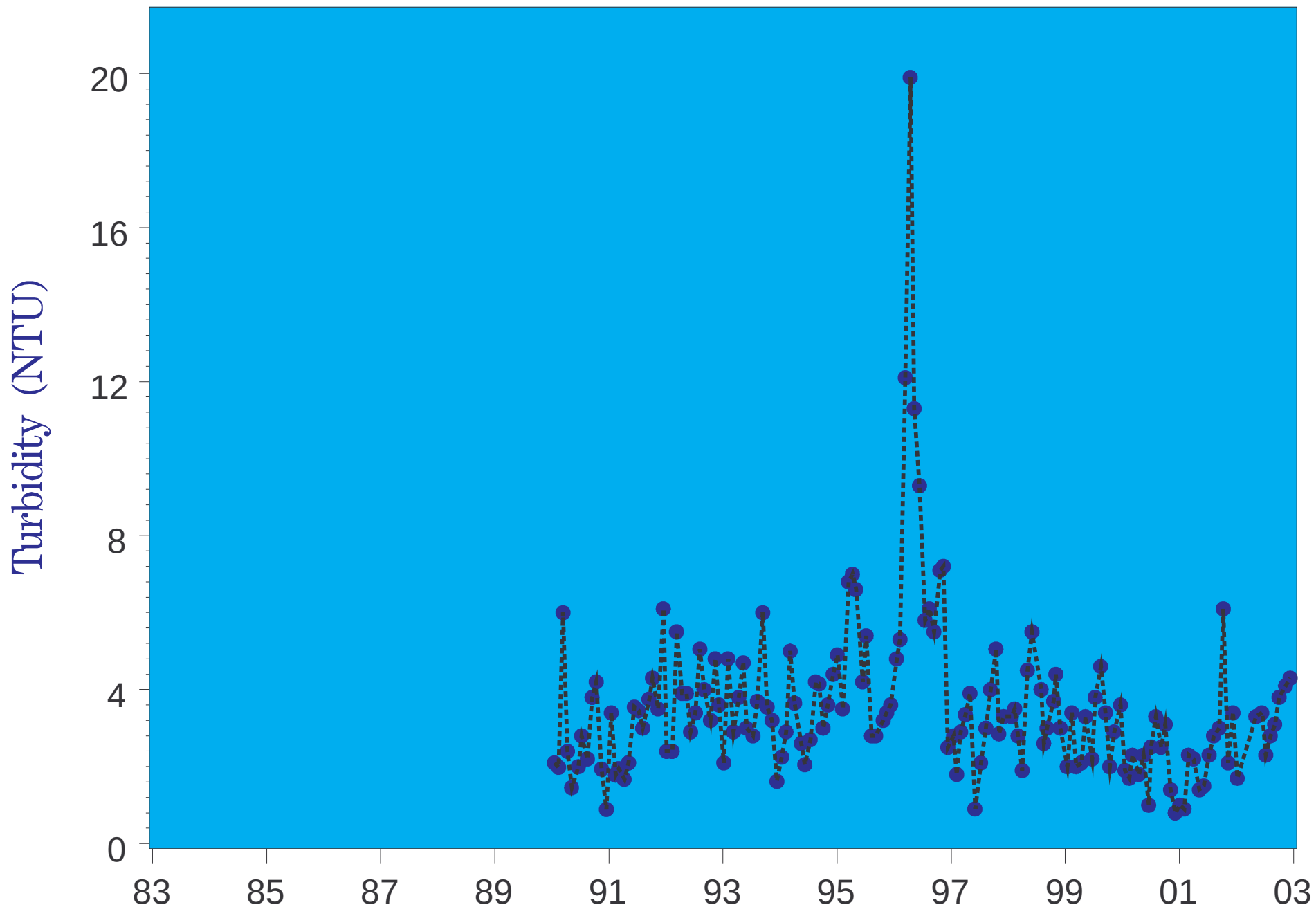


Figure 4.6.32 Monthly surface turbidity at 0 o/oo isohaline (1983-2002)

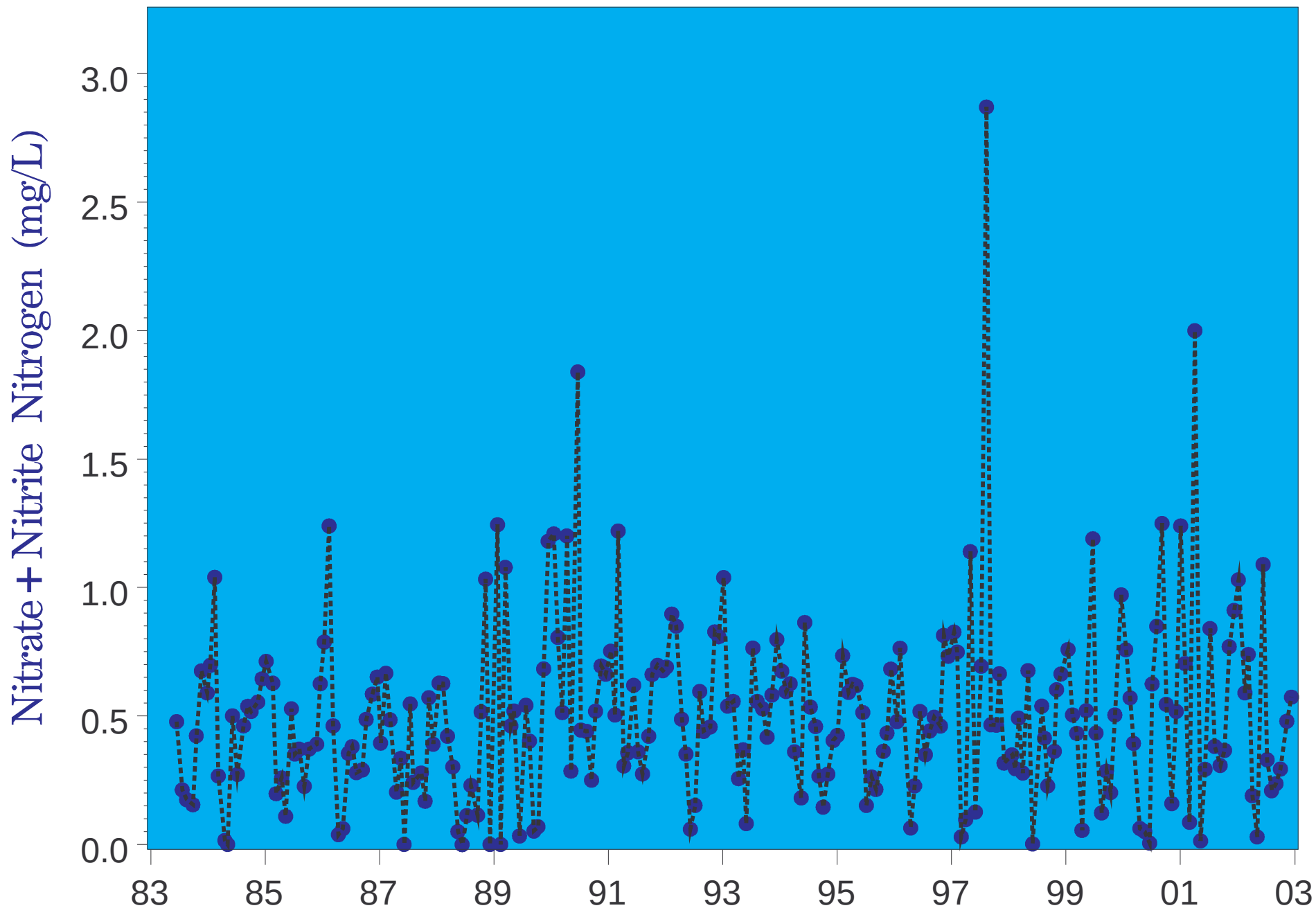


Figure 4.6.33 Monthly surface nitrate/nitrite nitrogen at 0 o/oo isohaline (1983-2002)

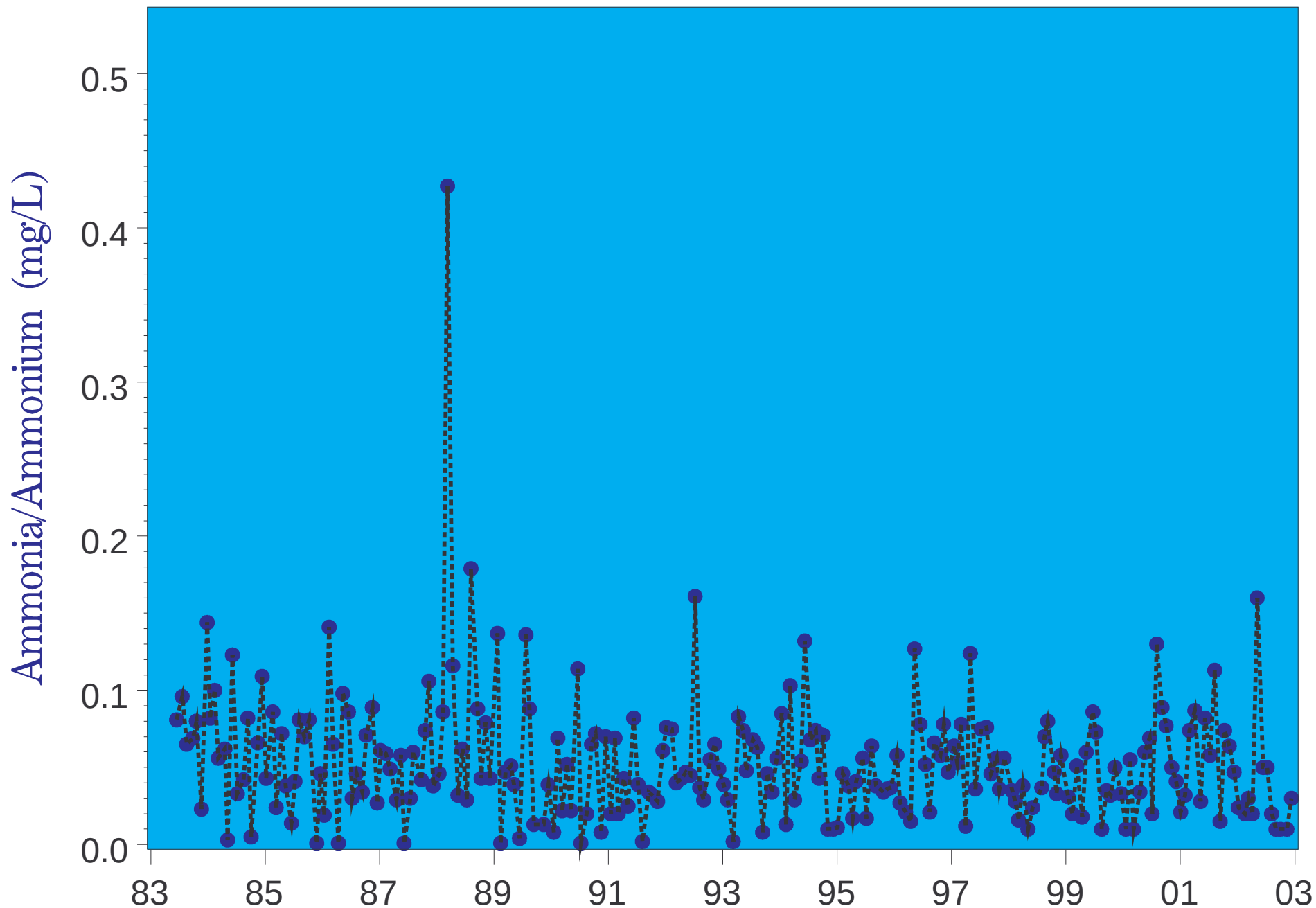


Figure 4.6.34 Monthly surface Ammonia/Ammonium at 0 o/oo isohaline (1983-2002)

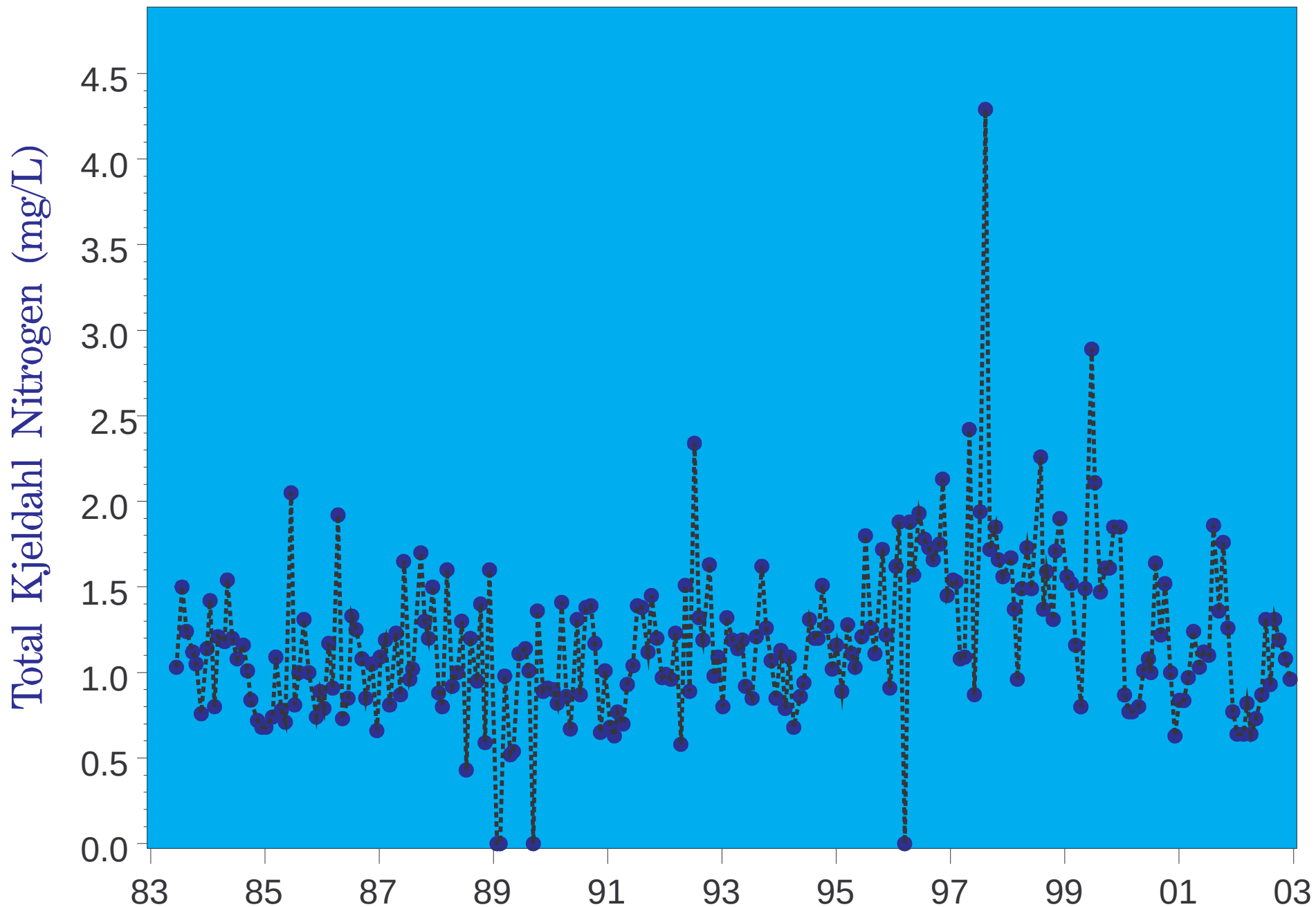


Figure 4.6.35 Monthly surface total Kjeldahl nitrogen at 0 o/oo isohaline (1983-2002)

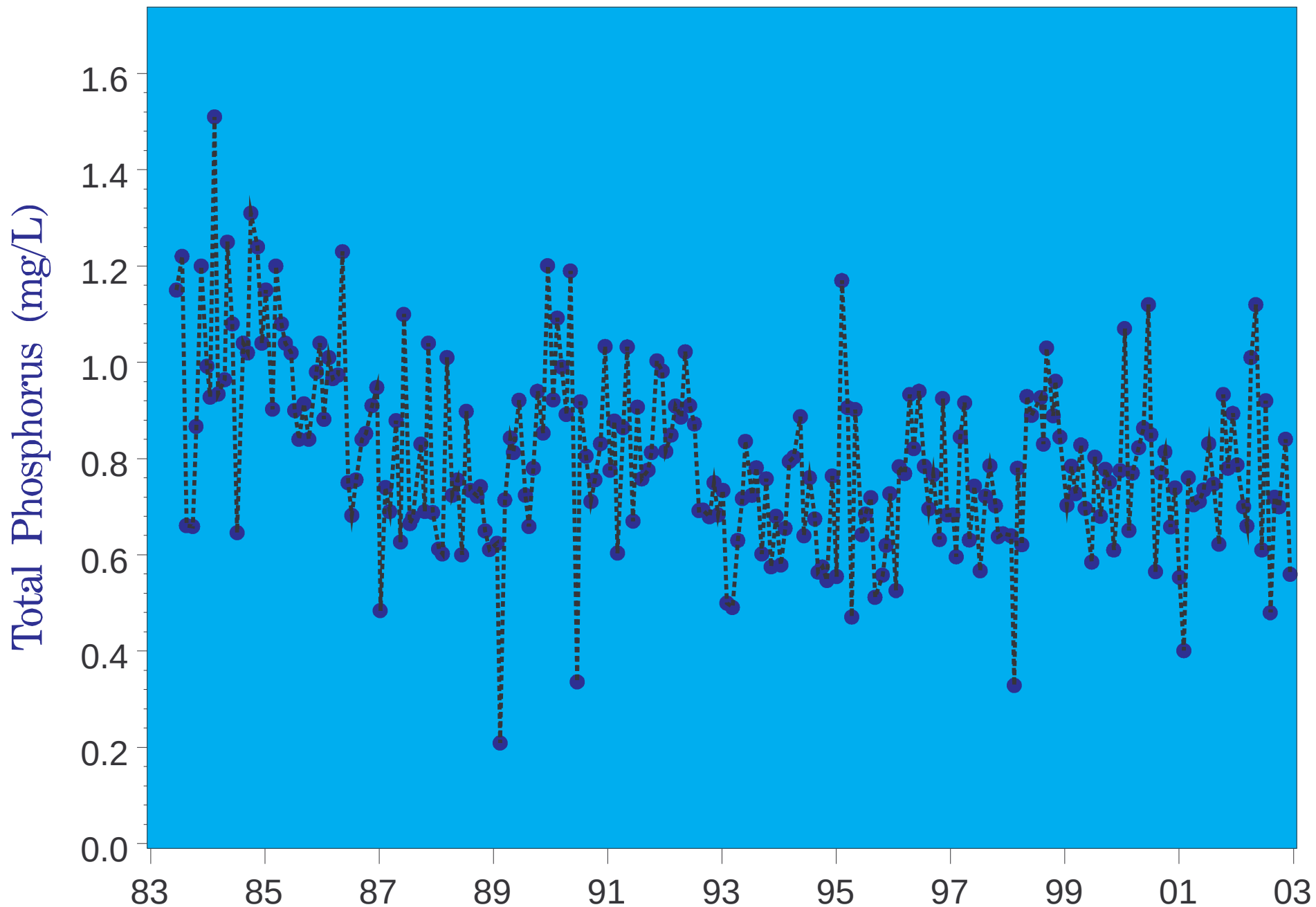


Figure 4.6.36 Monthly surface total phosphorus at 0 o/oo isohaline (1983-2002)

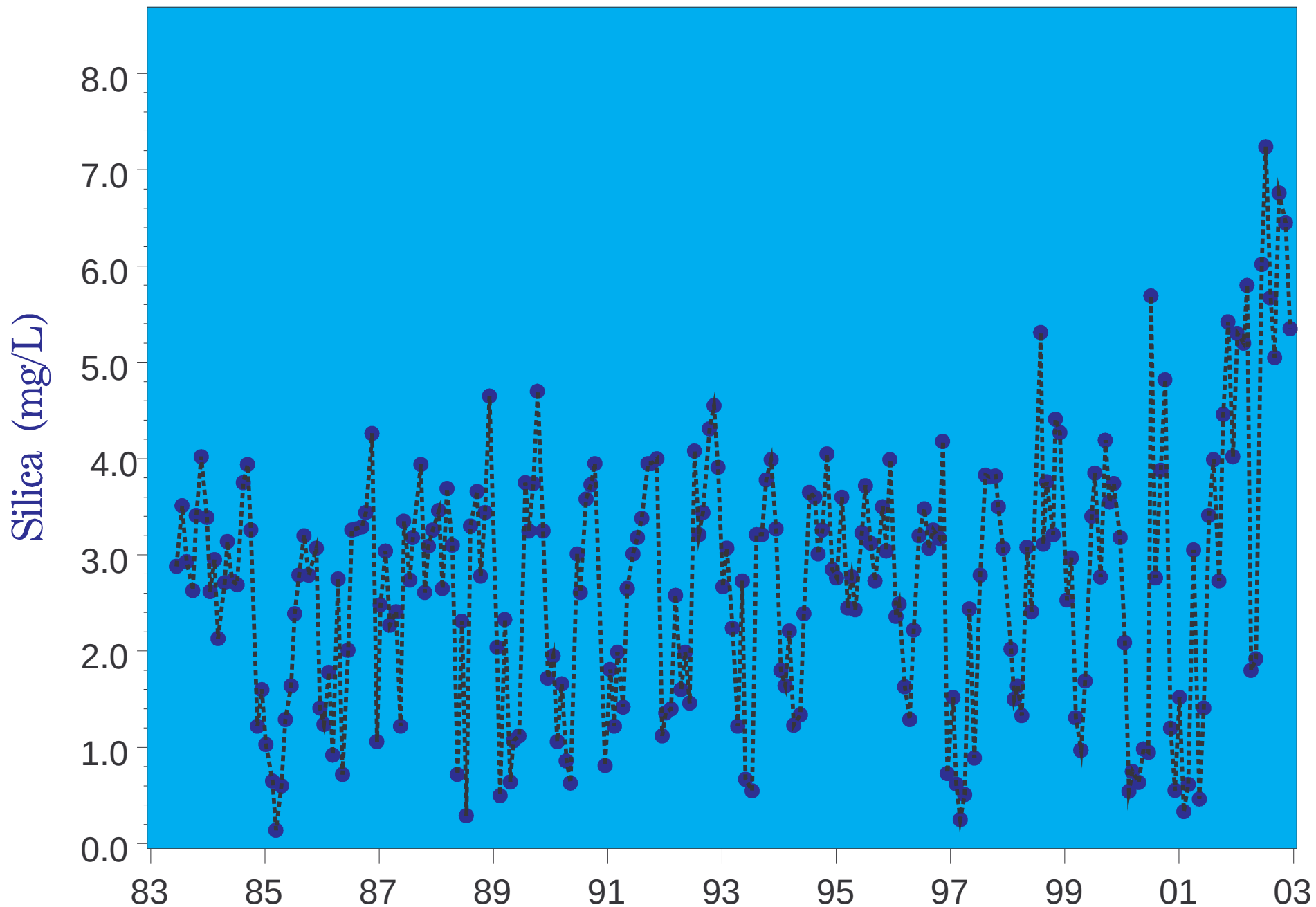


Figure 4.6.37 Monthly surface silica at 0 o/oo isohaline (1983-2002)

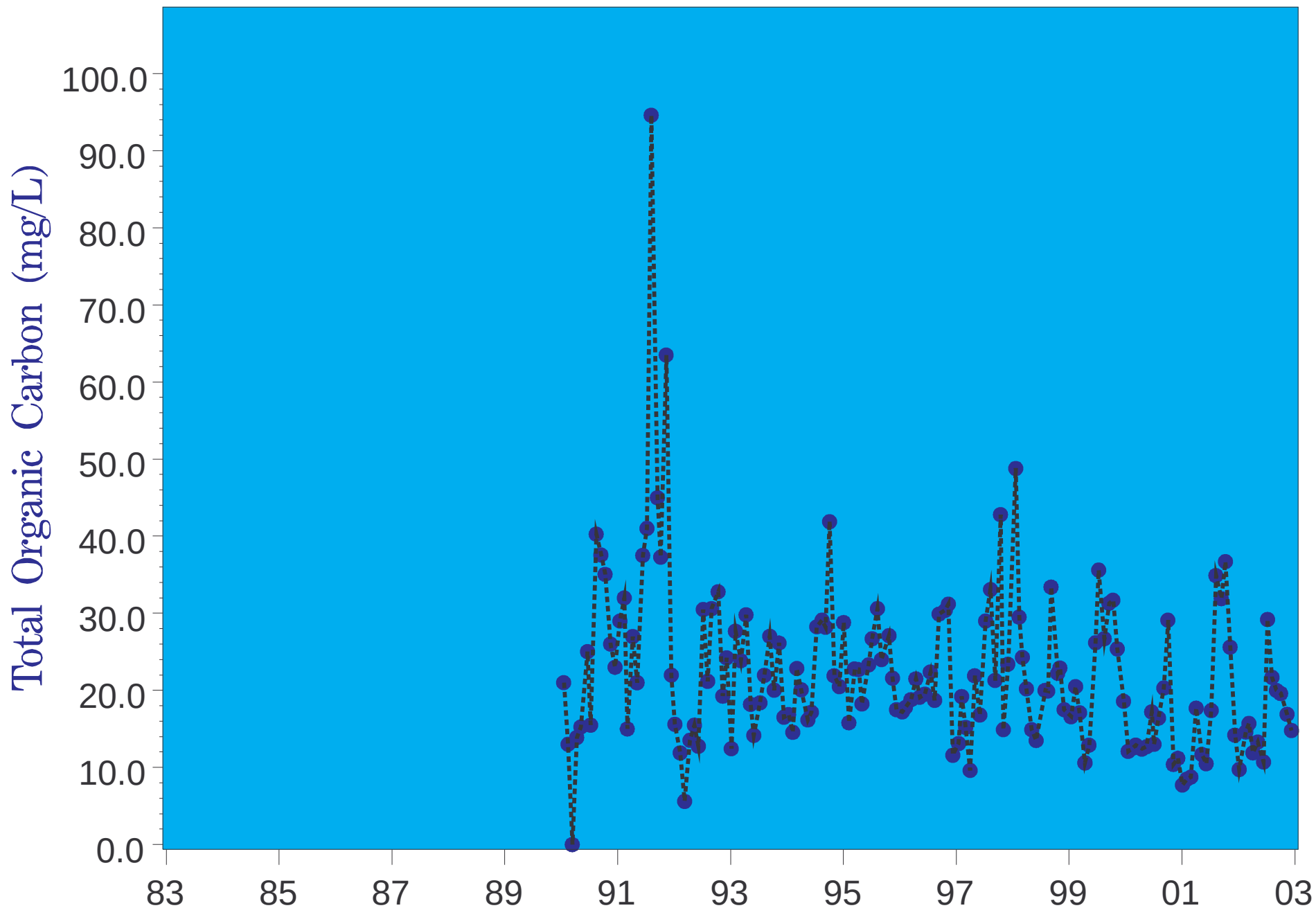


Figure 4.6.38 Monthly surface total organic carbon at 0 o/oo isohaline (1983-2002)



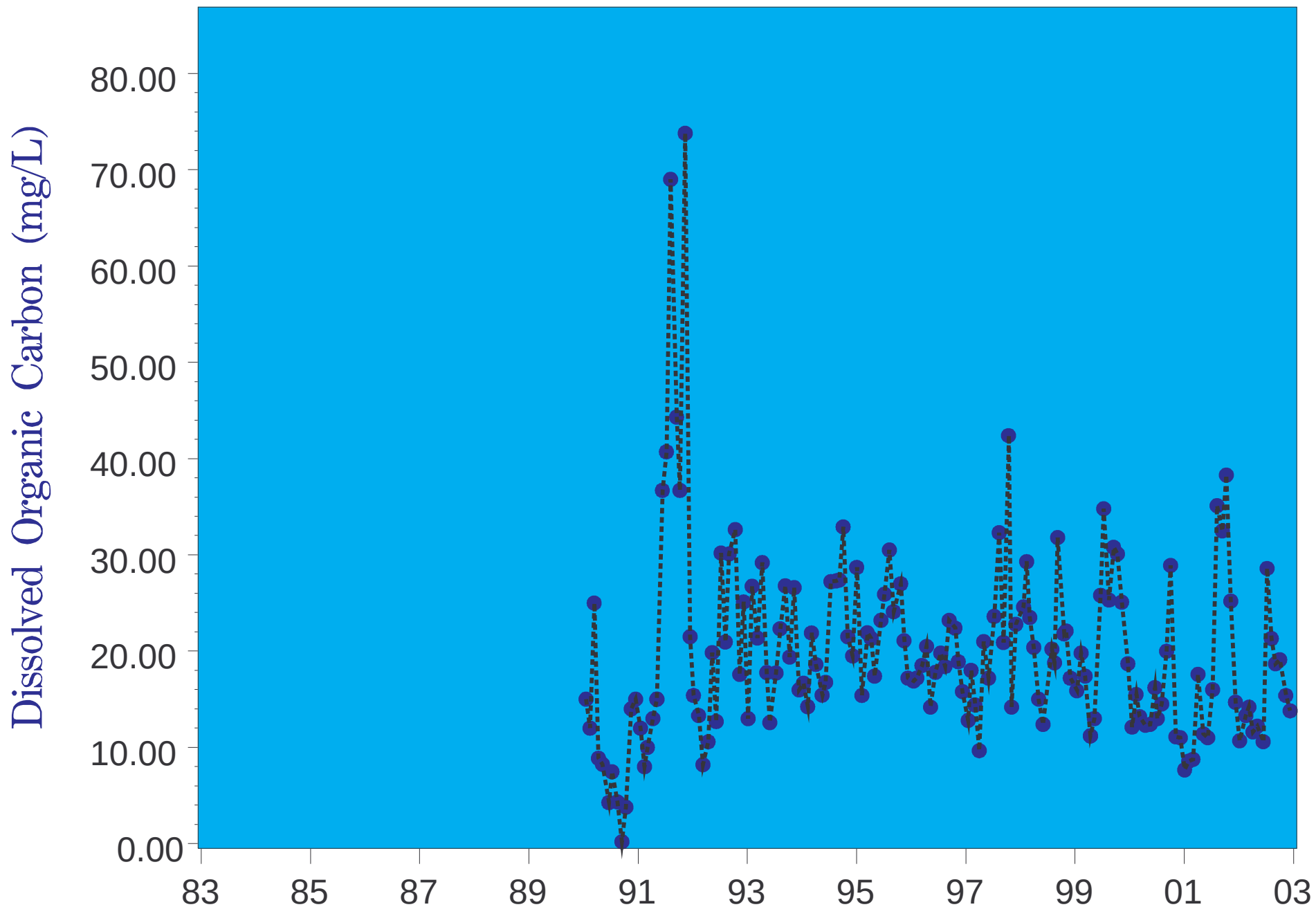


Figure 4.6.39 Monthly surface dissolved organic carbon at 0 o/oo isohaline (1983-2002)

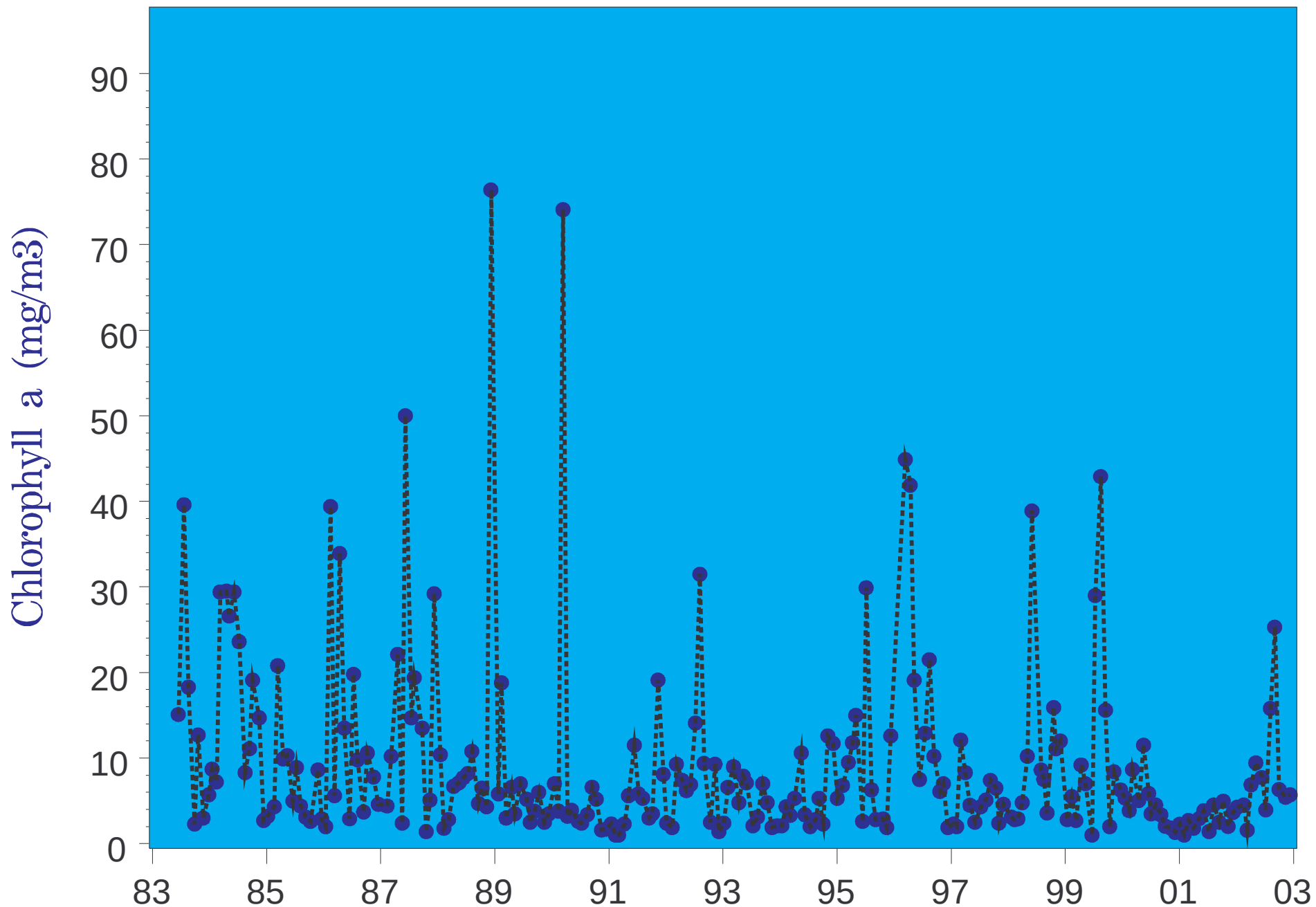


Figure 4.6.40 Monthly surface chlorophyll a at 0 o/oo isohaline (1983-2002)

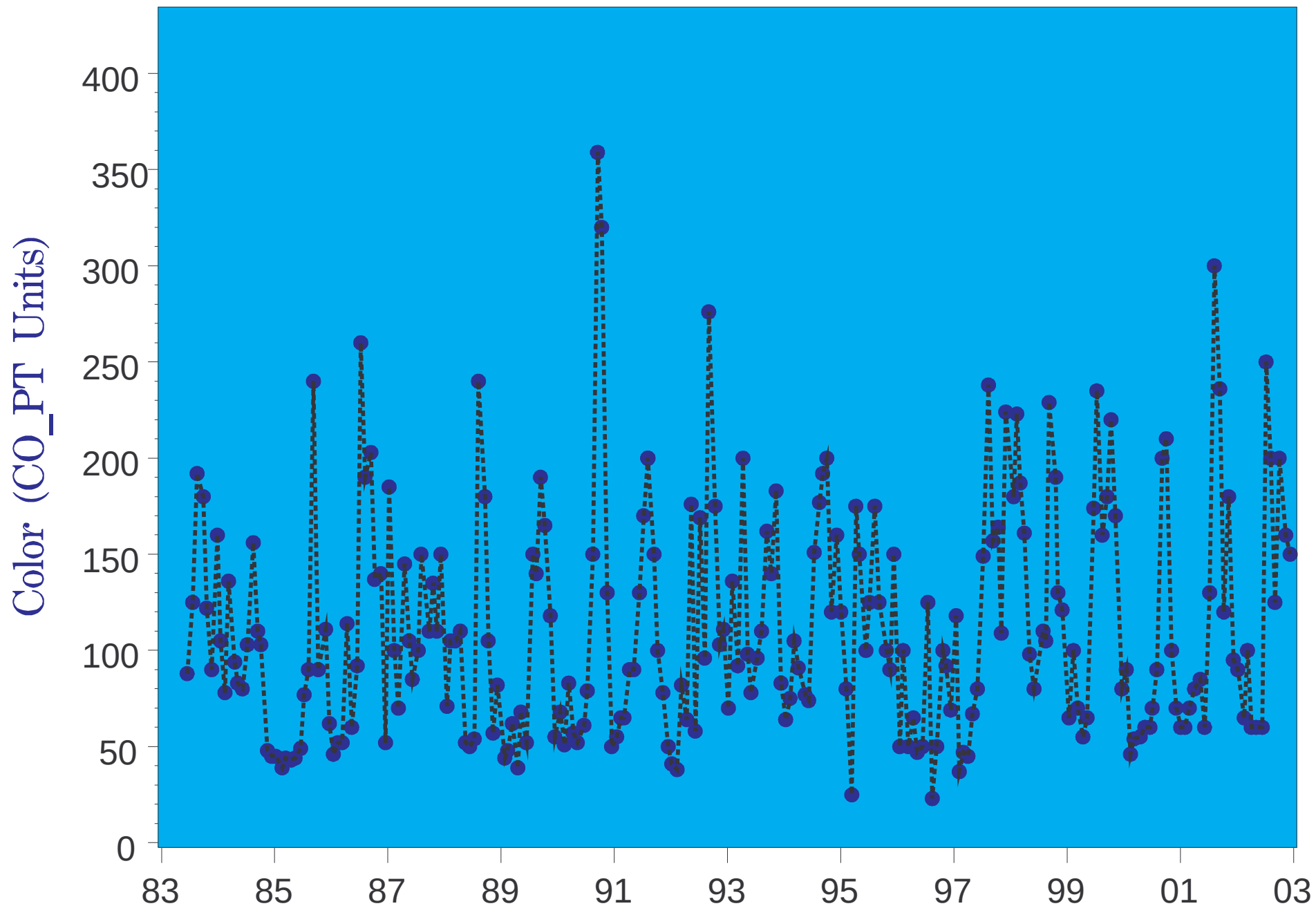


Figure 4.6.41 Monthly surface color at 6  $\sigma_t$  isohaline (1983-2002)

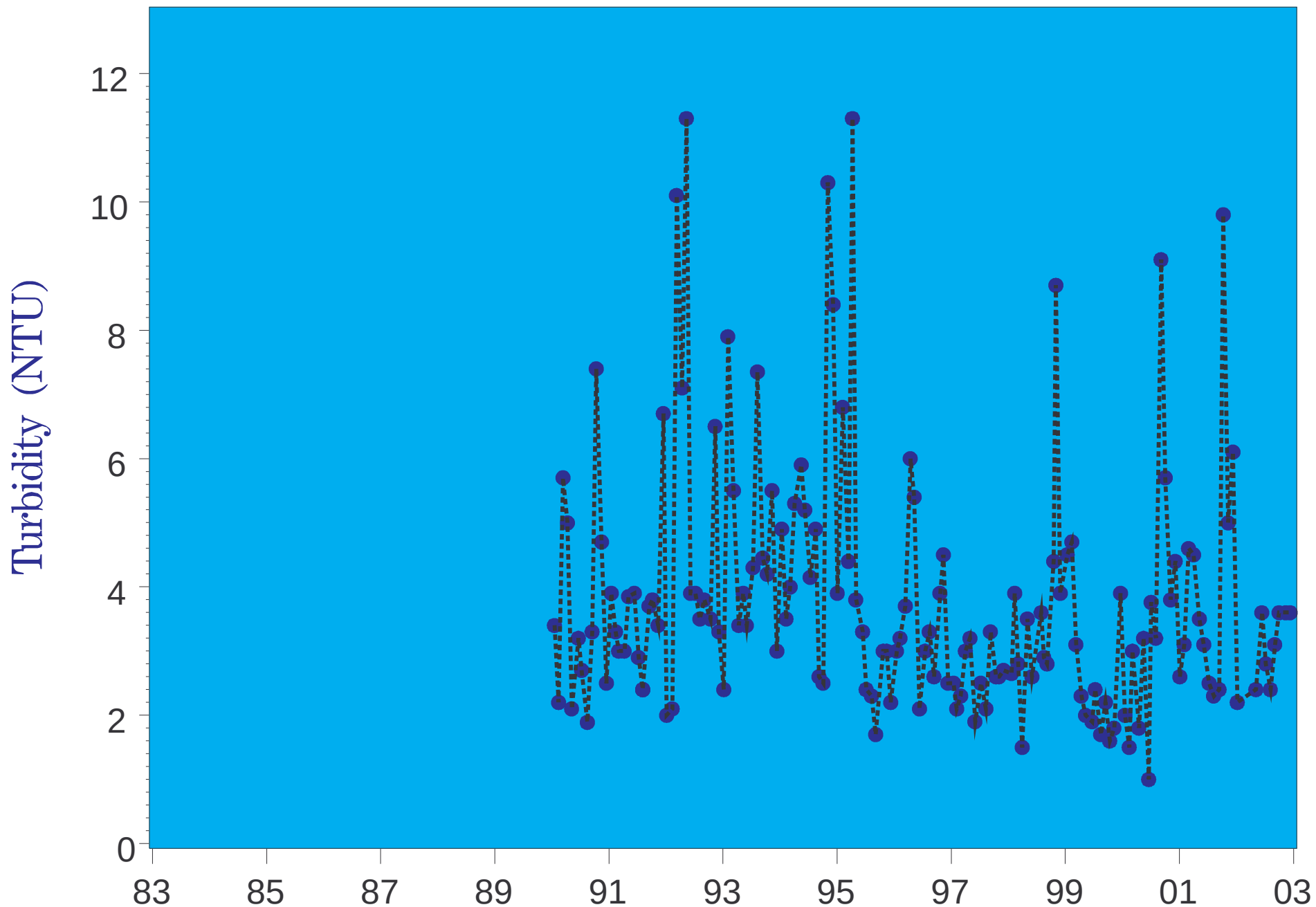


Figure 4.6.42 Monthly surface turbidity at 6 o/oo isohaline (1983-2002)

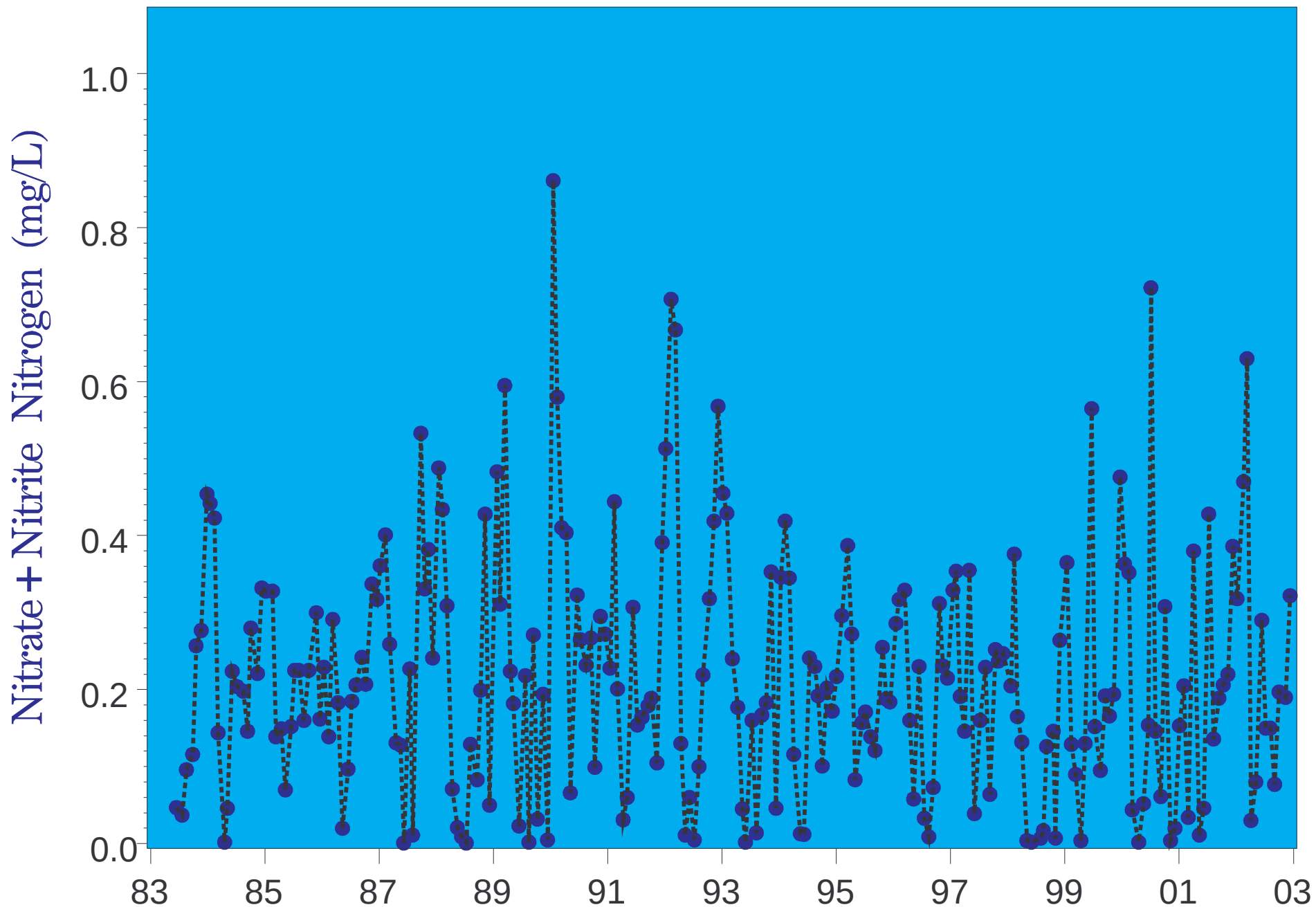


Figure 4.6.43 Monthly surface nitrate/nitrite nitrogen at 6 o/oo isohaline (1983-2002)

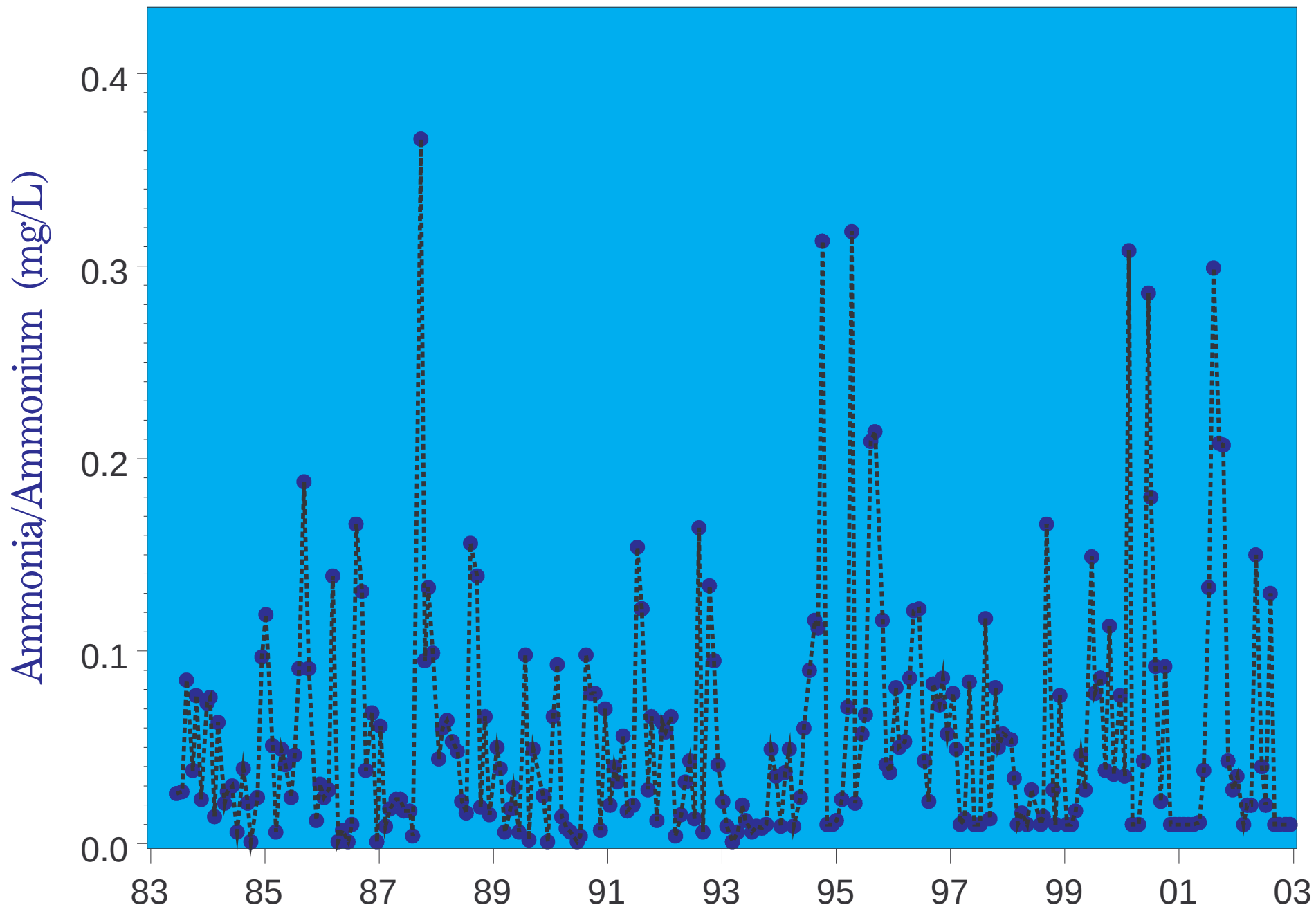


Figure 4.6.44 Monthly surface Ammonia/Ammonium at 6 o/oo isohaline (1983-2002)

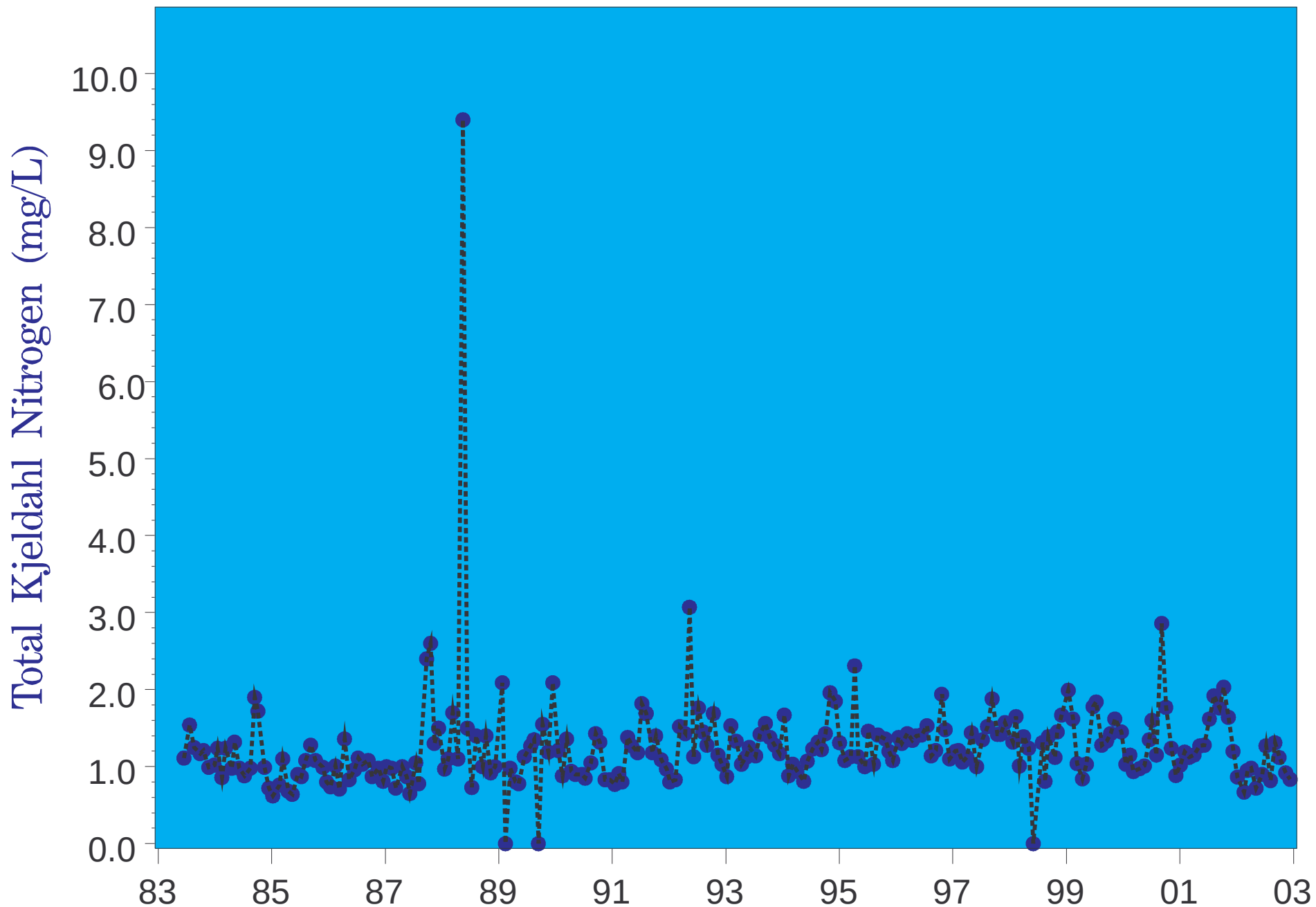


Figure 4.6.45 Monthly surface total Kjeldahl nitrogen at 6 o/oo isohaline (1983-2002)

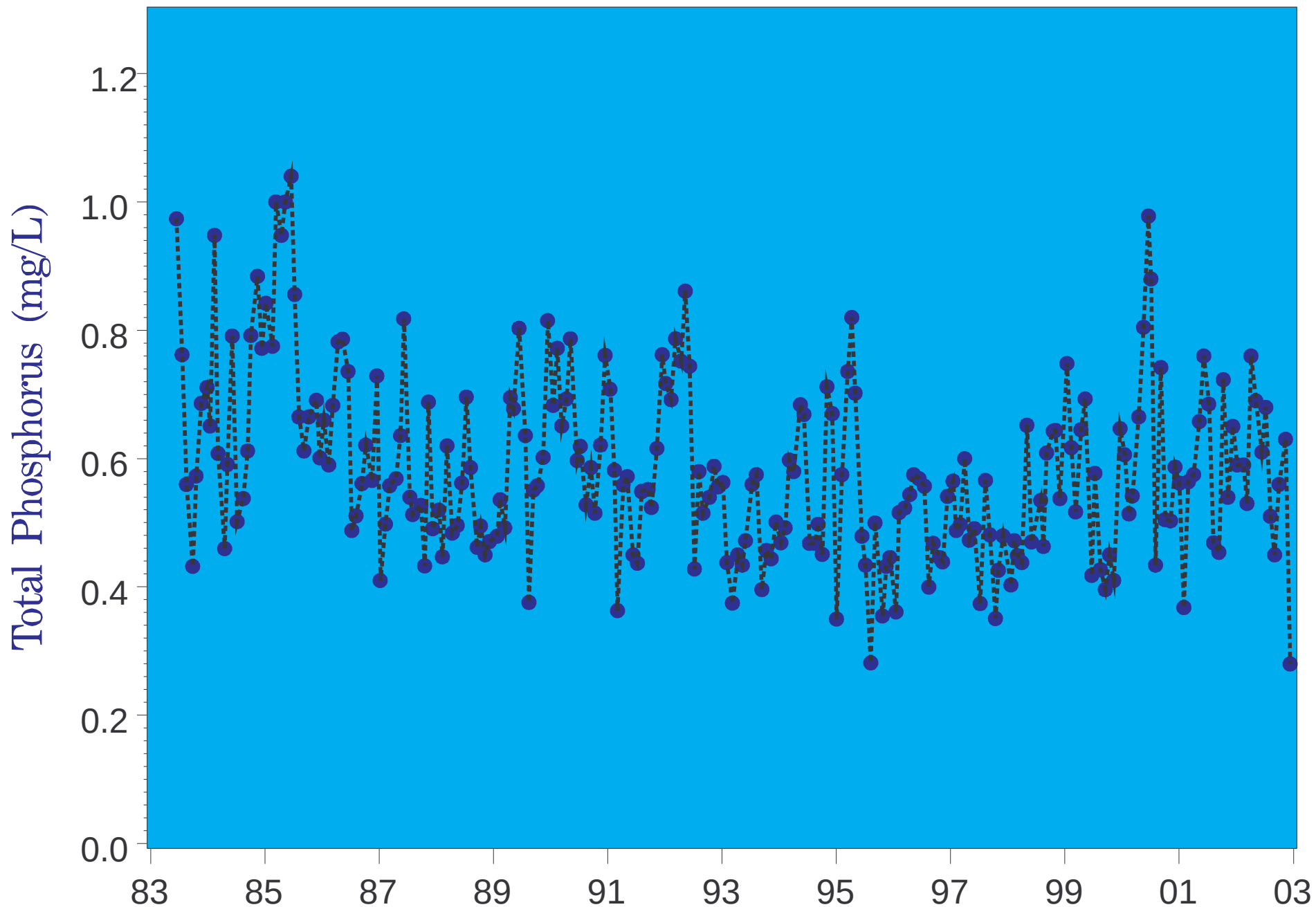


Figure 4.6.46 Monthly surface total phosphorus at 6 o/oo isohaline (1983-2002)



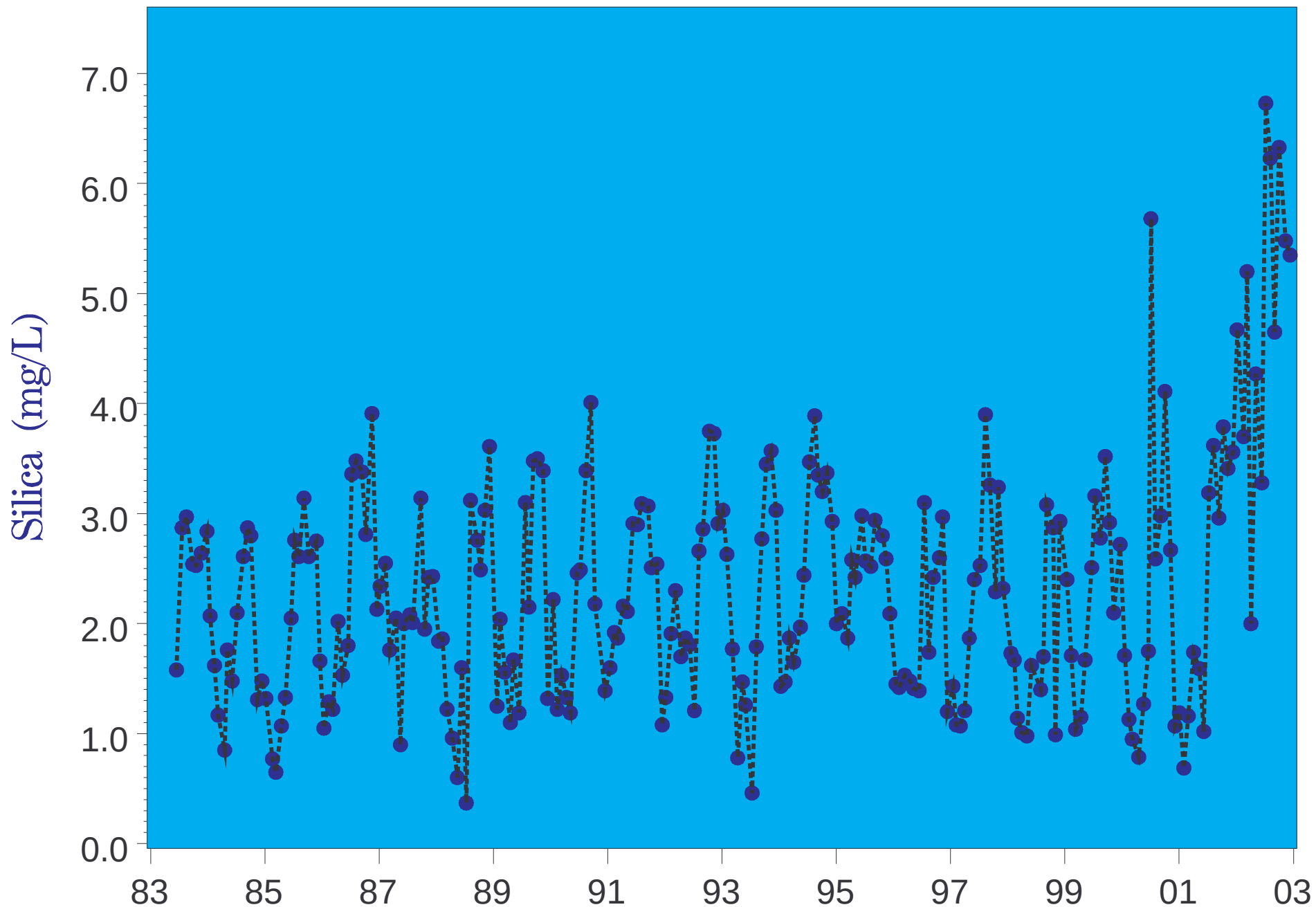


Figure 4.6.47 Monthly surface silica at 6 o/oo isohaline (1983-2002)

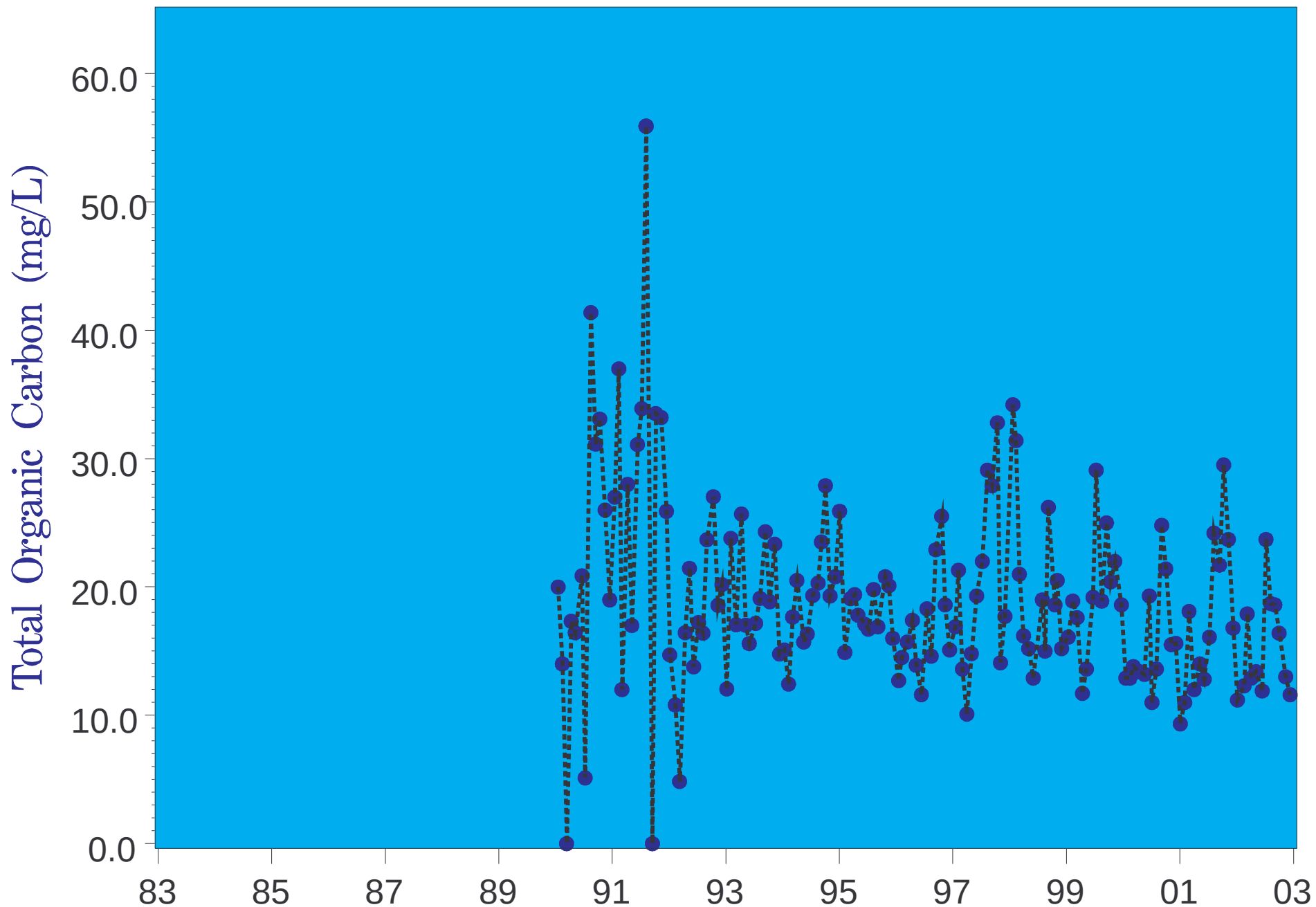


Figure 4.6.48 Monthly surface total organic carbon at 6 o/oo isohaline (1983-2002)

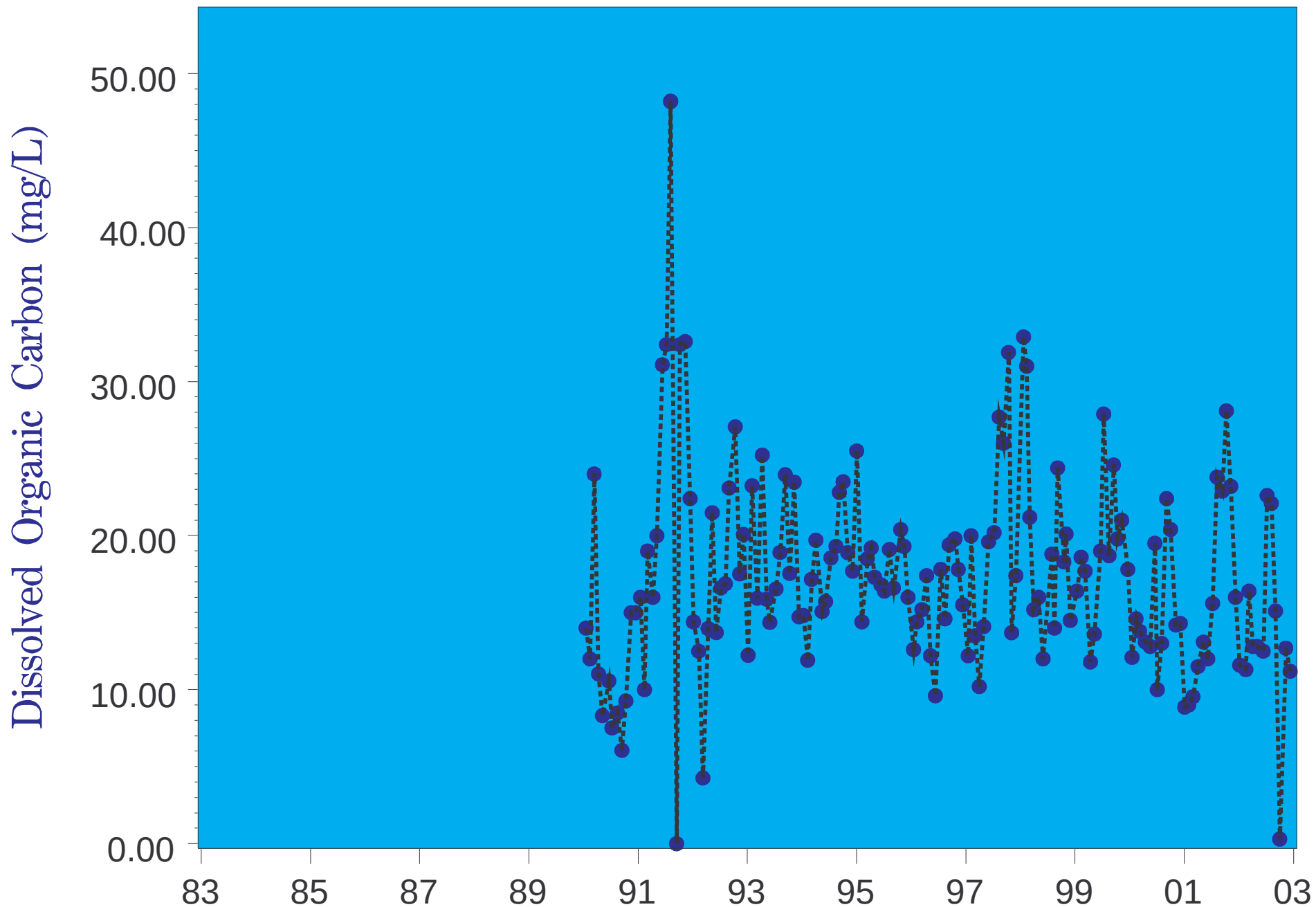


Figure 4.6.49 Monthly surface dissolved organic carbon at 6 o/oo isohaline (1983-2002)

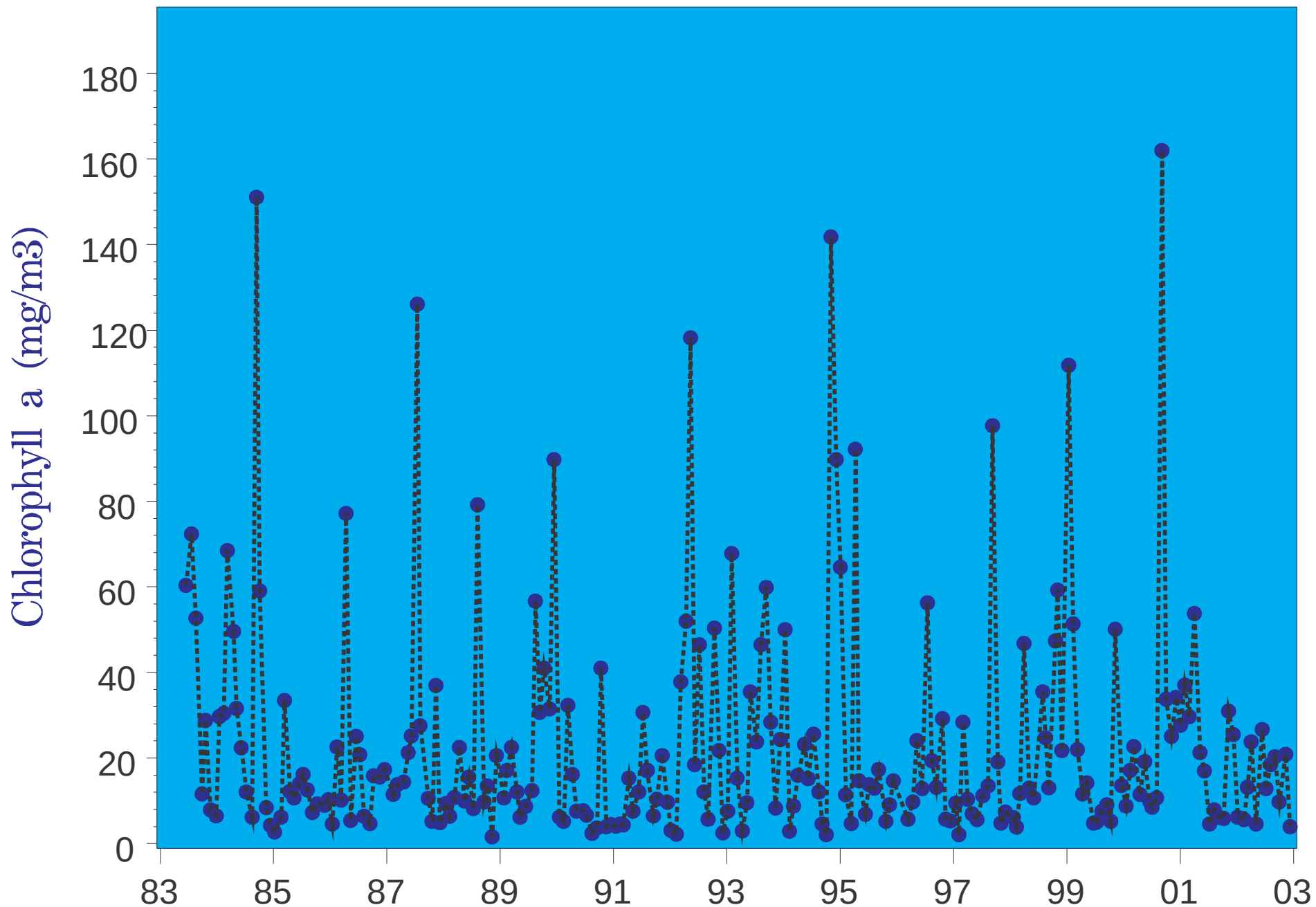


Figure 4.6.50 Monthly surface chlorophyll a at 6 o/oo isohaline (1983-2002)

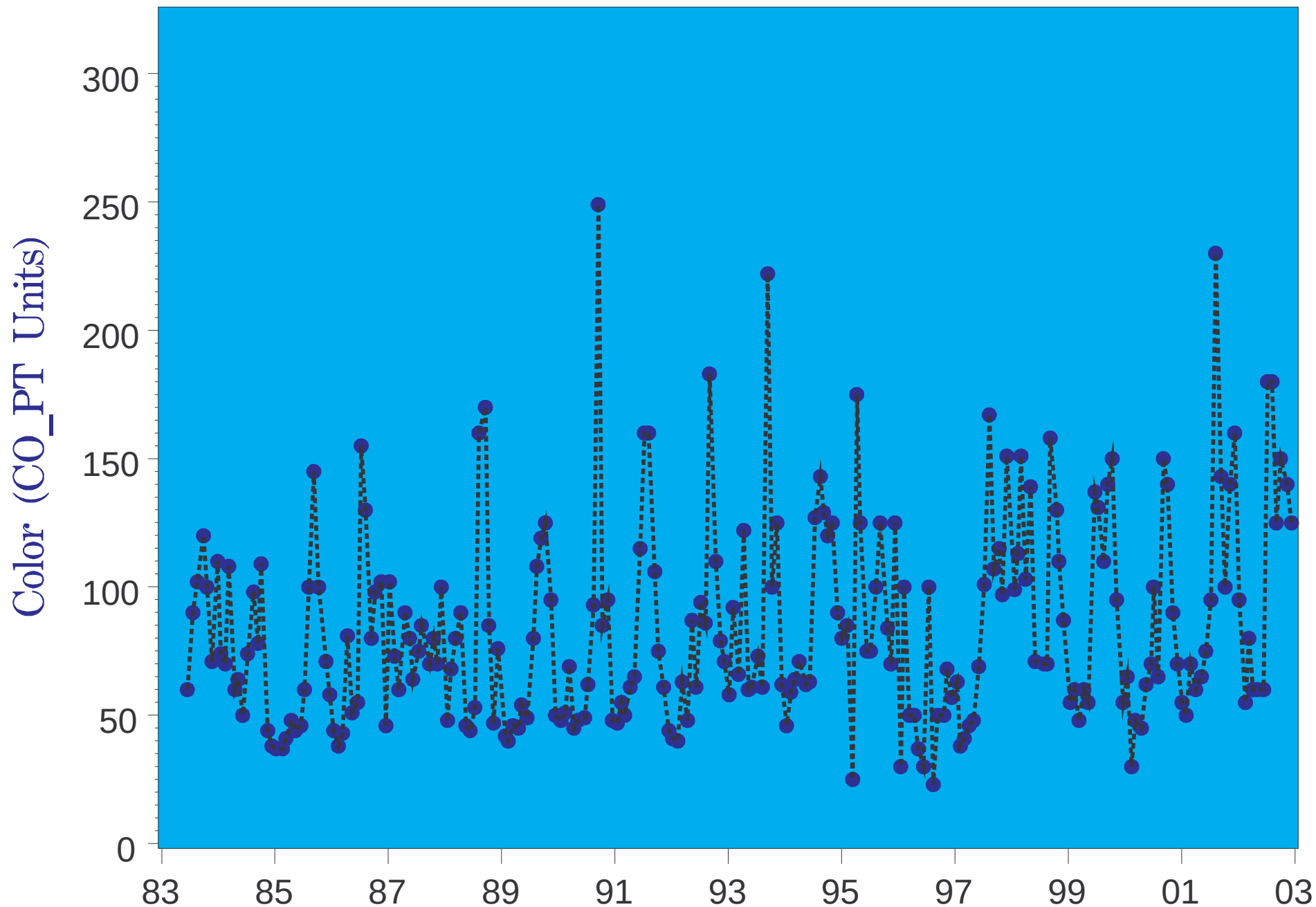


Figure 4.6.51 Monthly surface color at 12 o/oo isohaline (1983-2002)

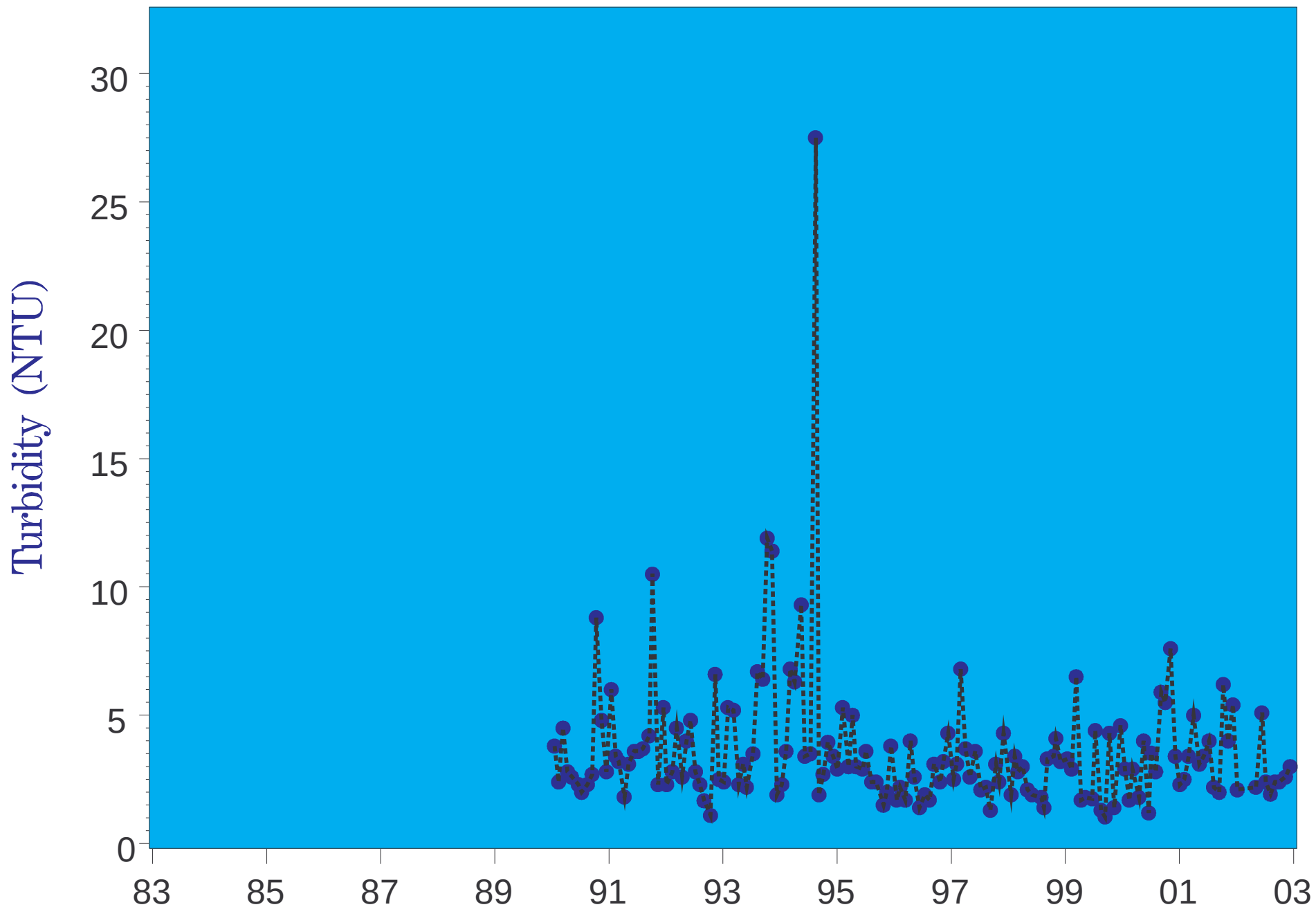


Figure 4.6.52 Monthly surface turbidity at 12 o/oo isohaline (1983-2002)

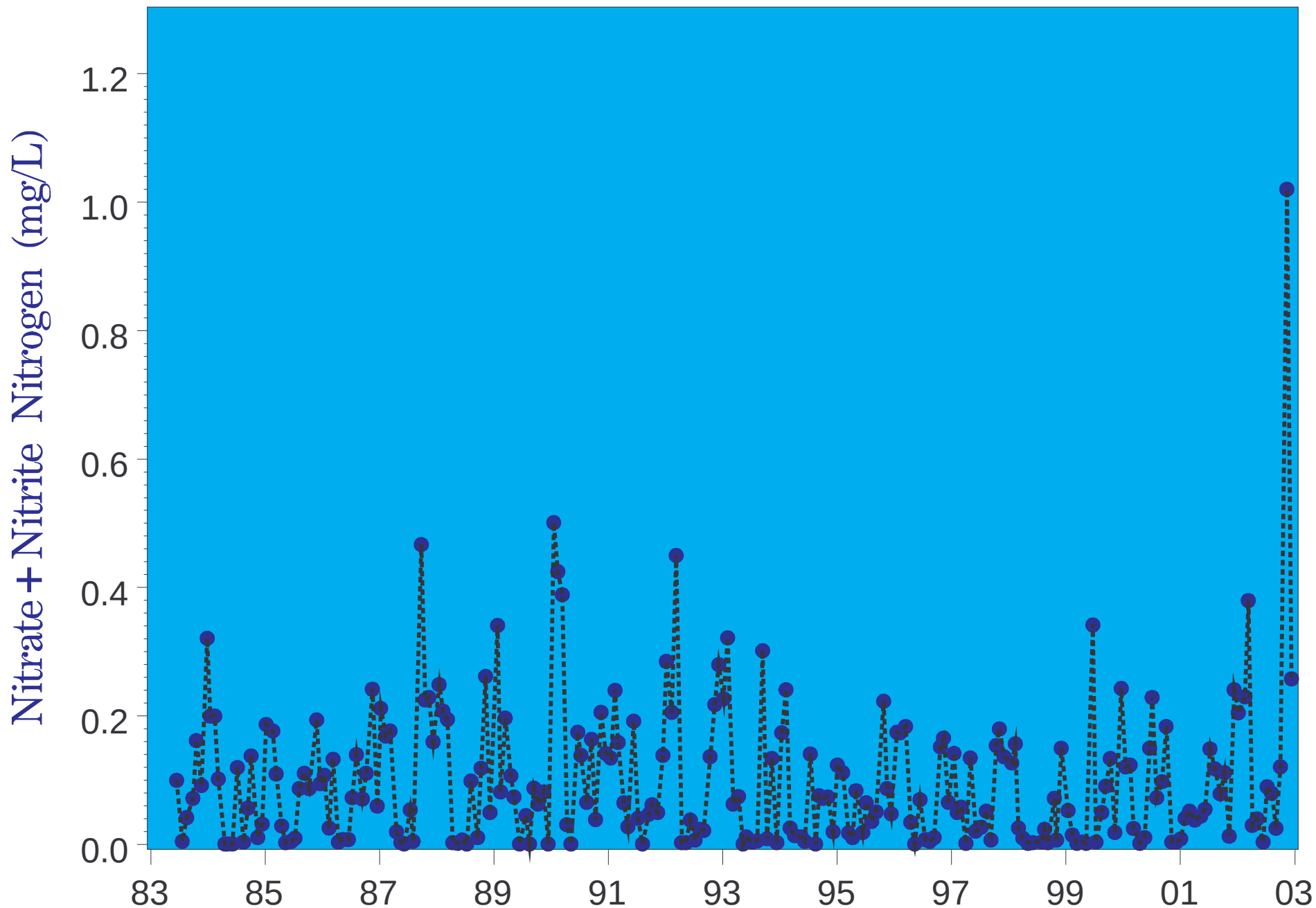


Figure 4.6.53 Monthly surface nitrate/nitrite nitrogen at 12 o/oo isohaline (1983-2002)

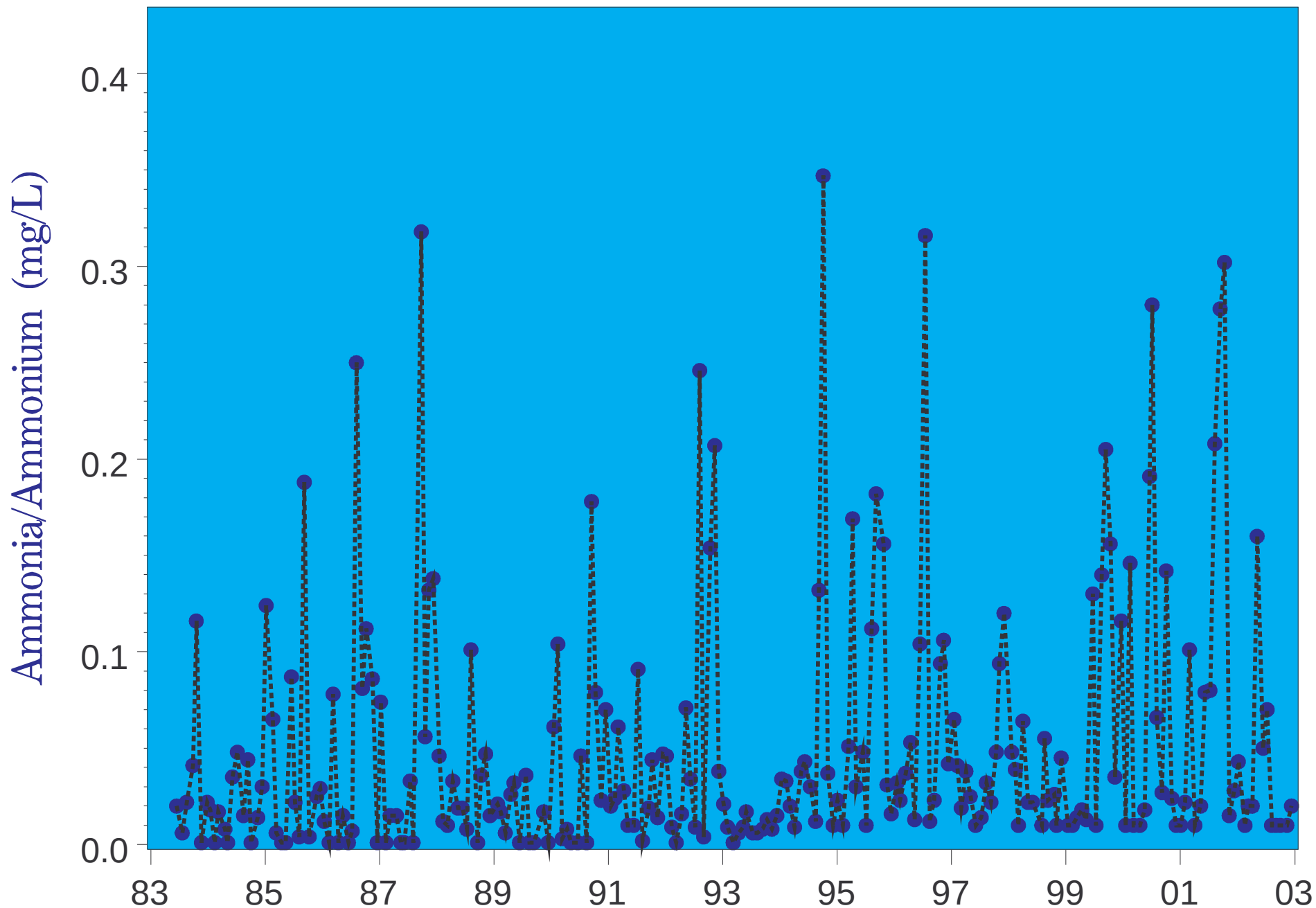


Figure 4.6.54 Monthly surface Ammonia/Ammonium at 12 o/oo isohaline (1983-2002)



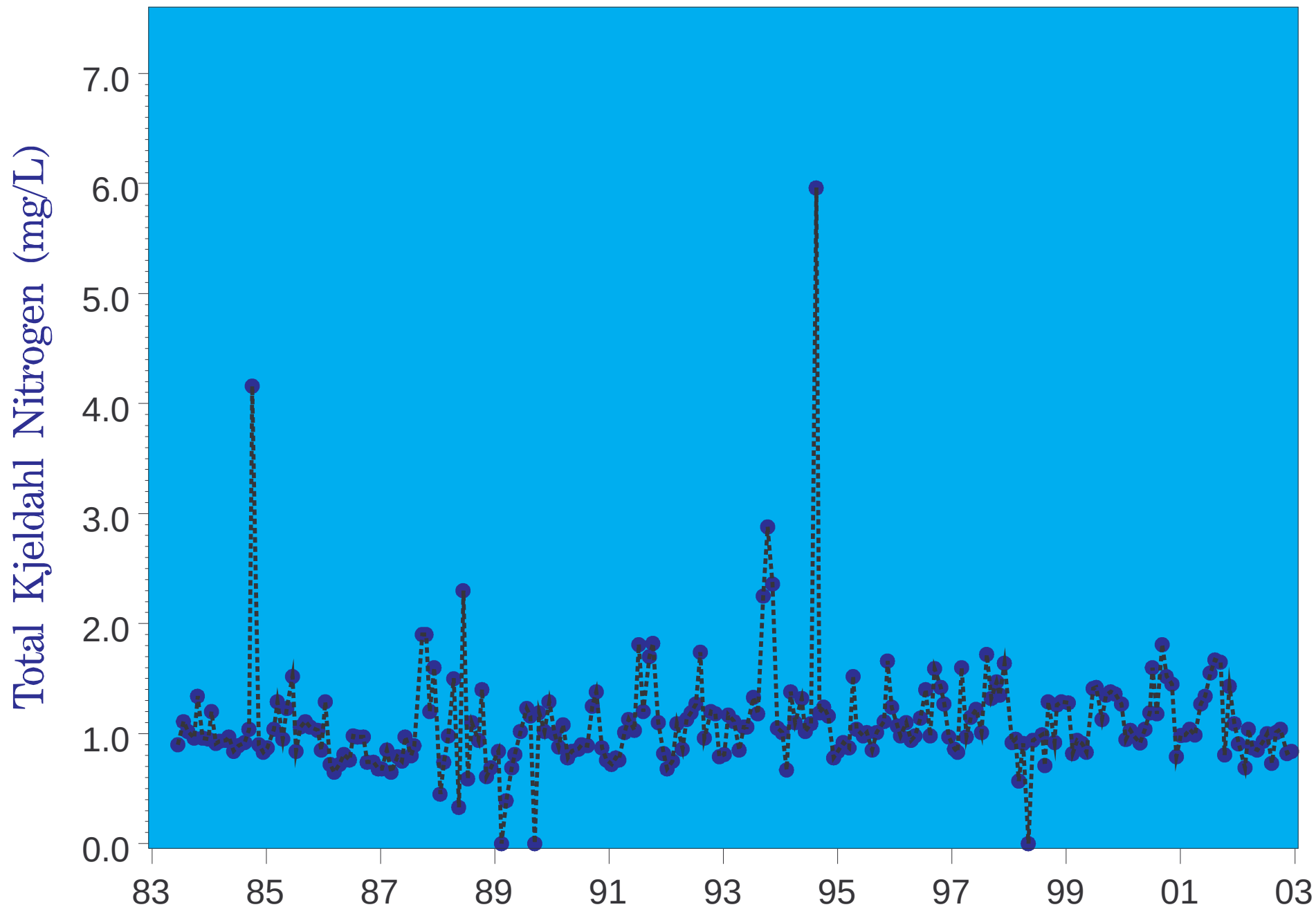


Figure 4.6.55 Monthly surface total Kjeldahl nitrogen at 12 o/oo isohaline (1983-2002)

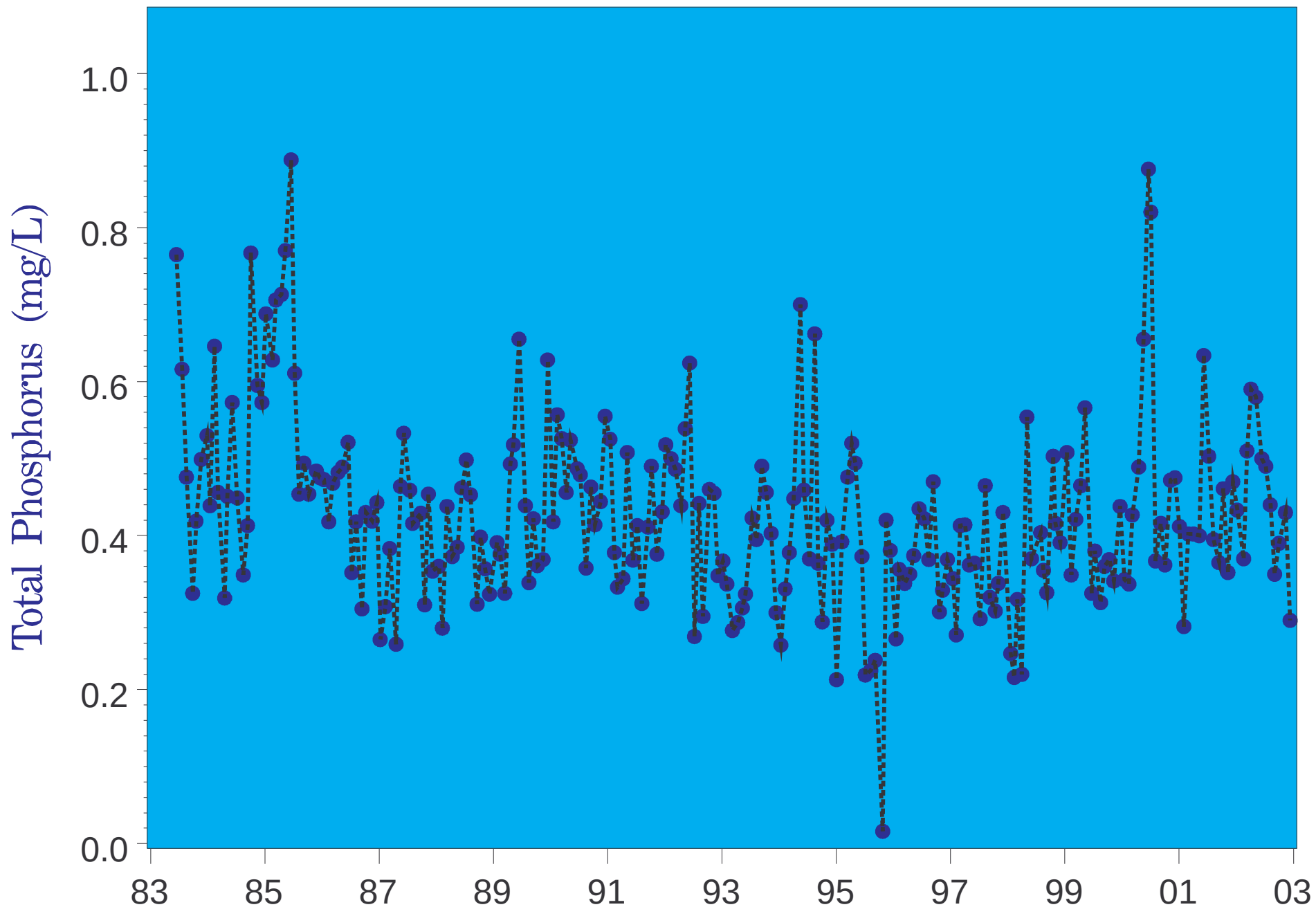


Figure 4.6.56 Monthly surface total phosphorus at 12 o/oo isohaline (1983-2002)

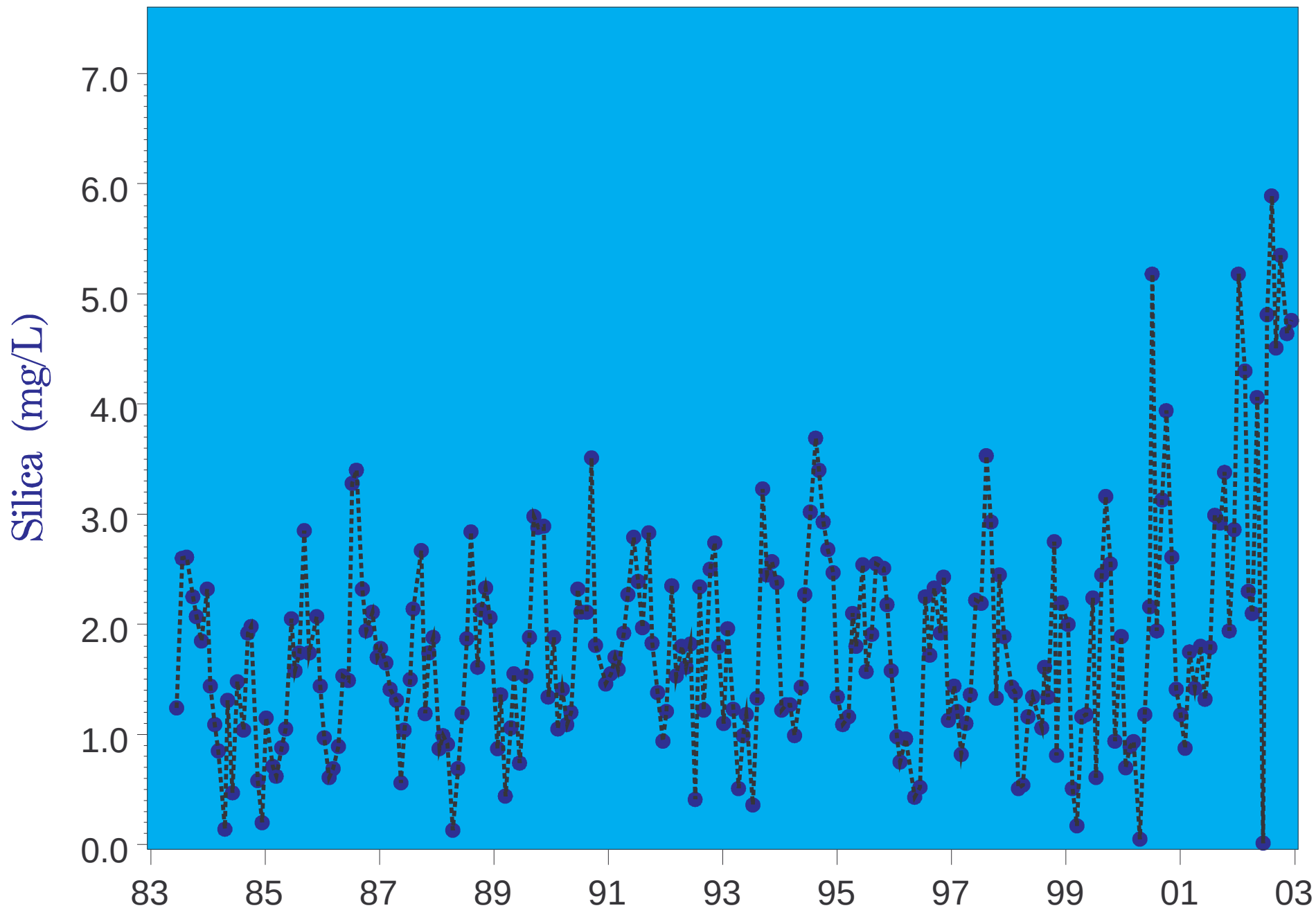


Figure 4.6.57 Monthly surface silica at 12 o/oo isohaline (1983-2002)

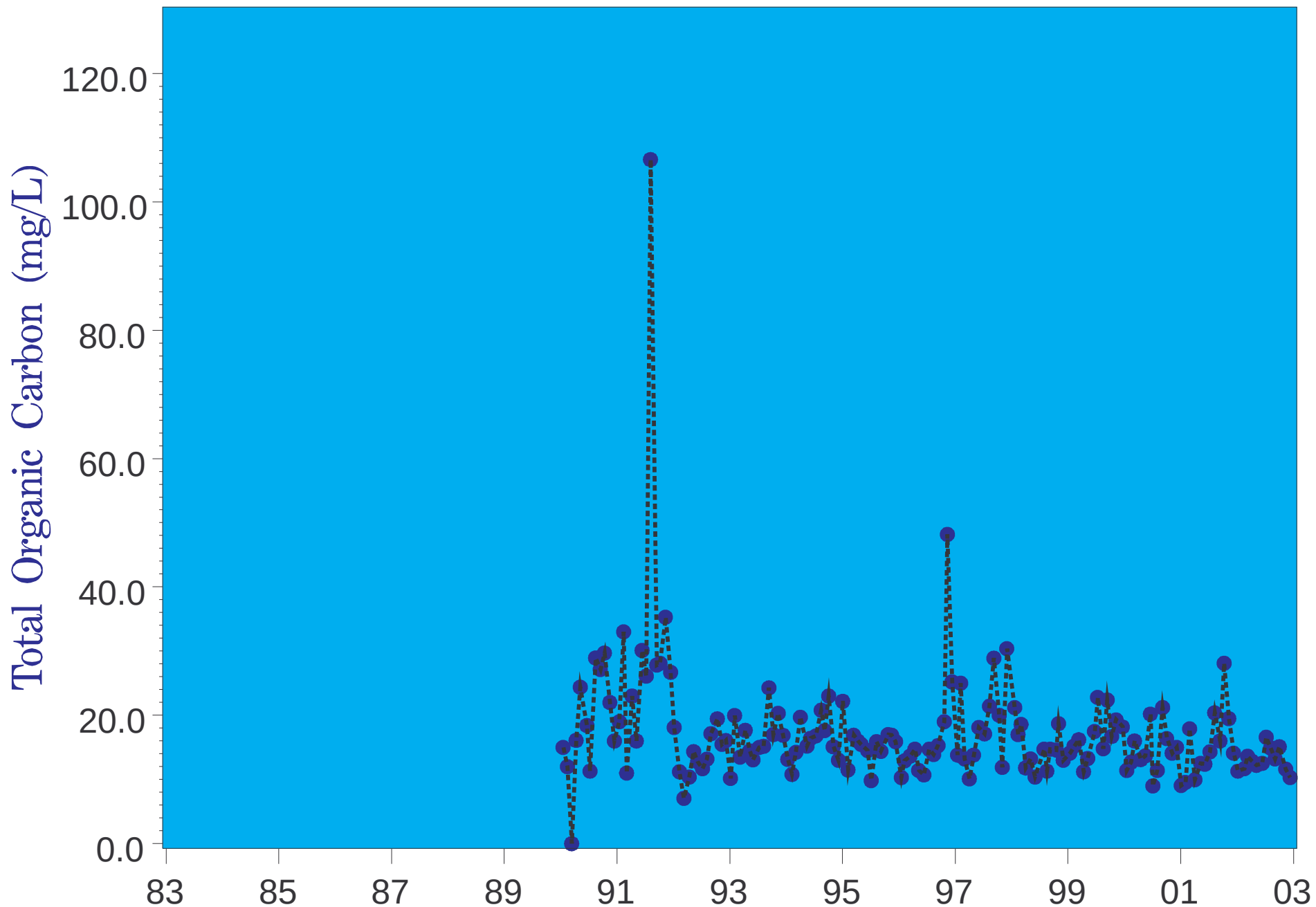


Figure 4.6.58 Monthly surface total organic carbon at 12 o/oo isohaline (1983-2002)

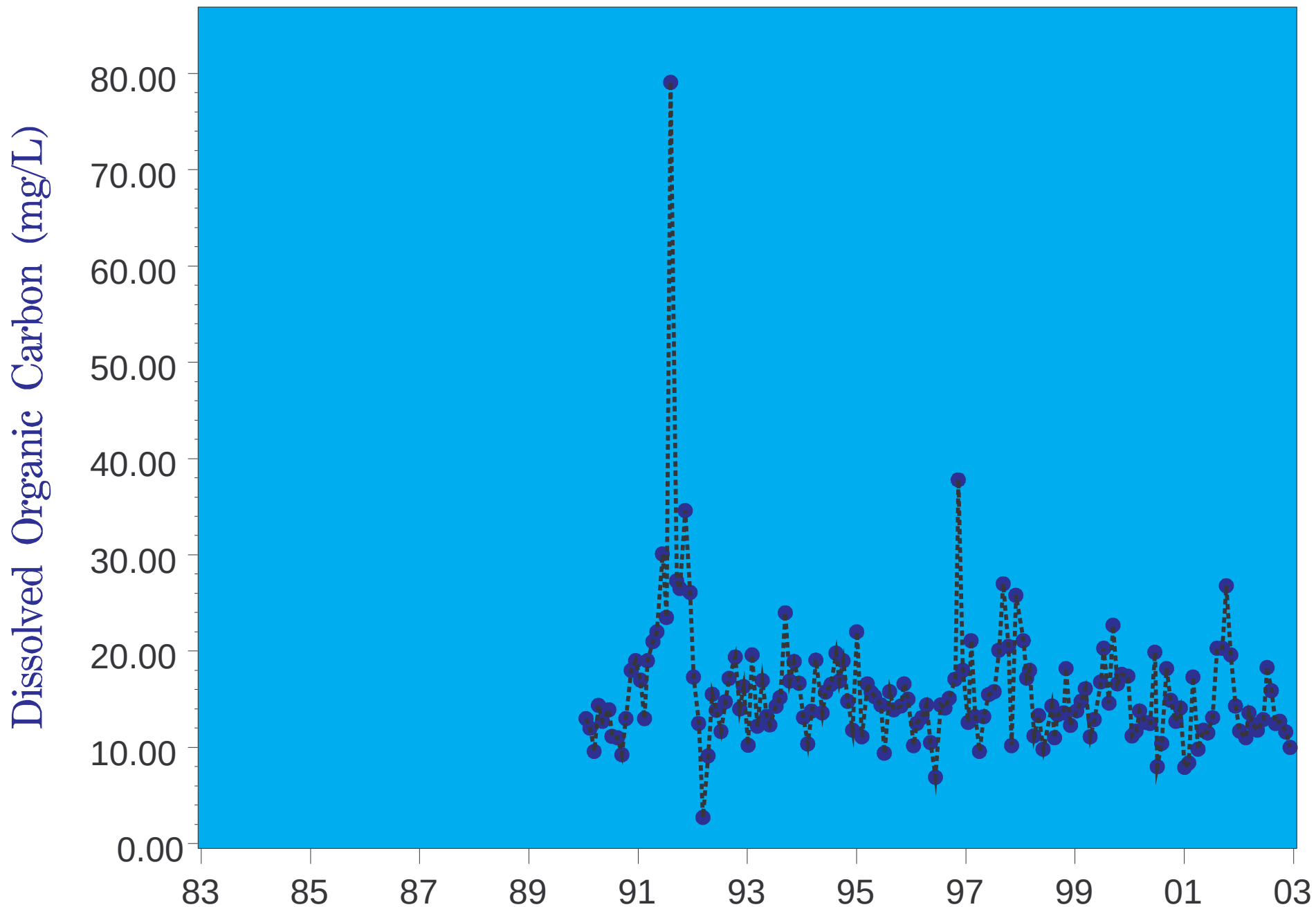


Figure 4.6.59 Monthly surface dissolved organic carbon at 12 o/oo isohaline (1983-2002)

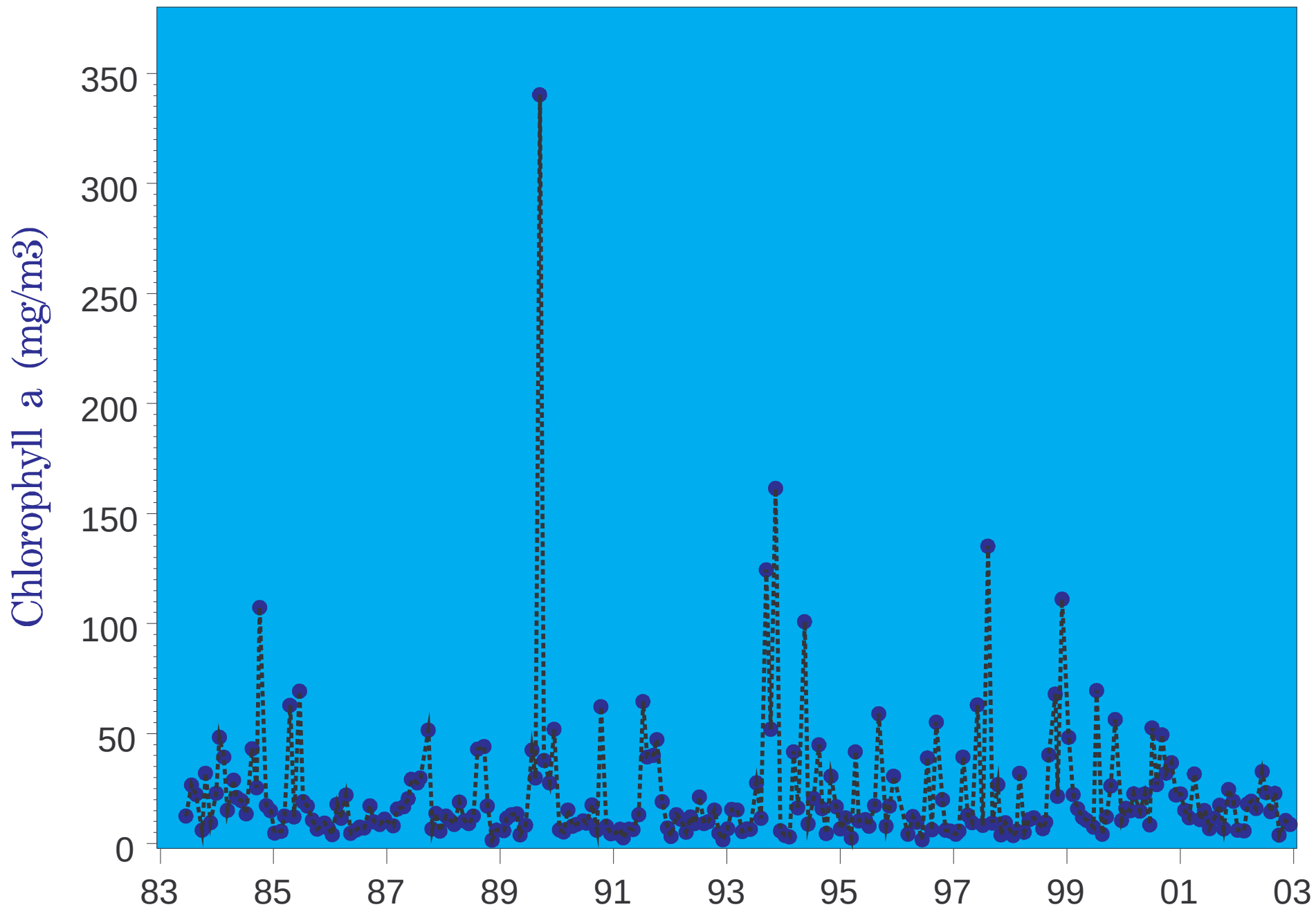


Figure 4.6.60 Monthly surface chlorophyll a at 12 o/oo isohaline (1983-2002)

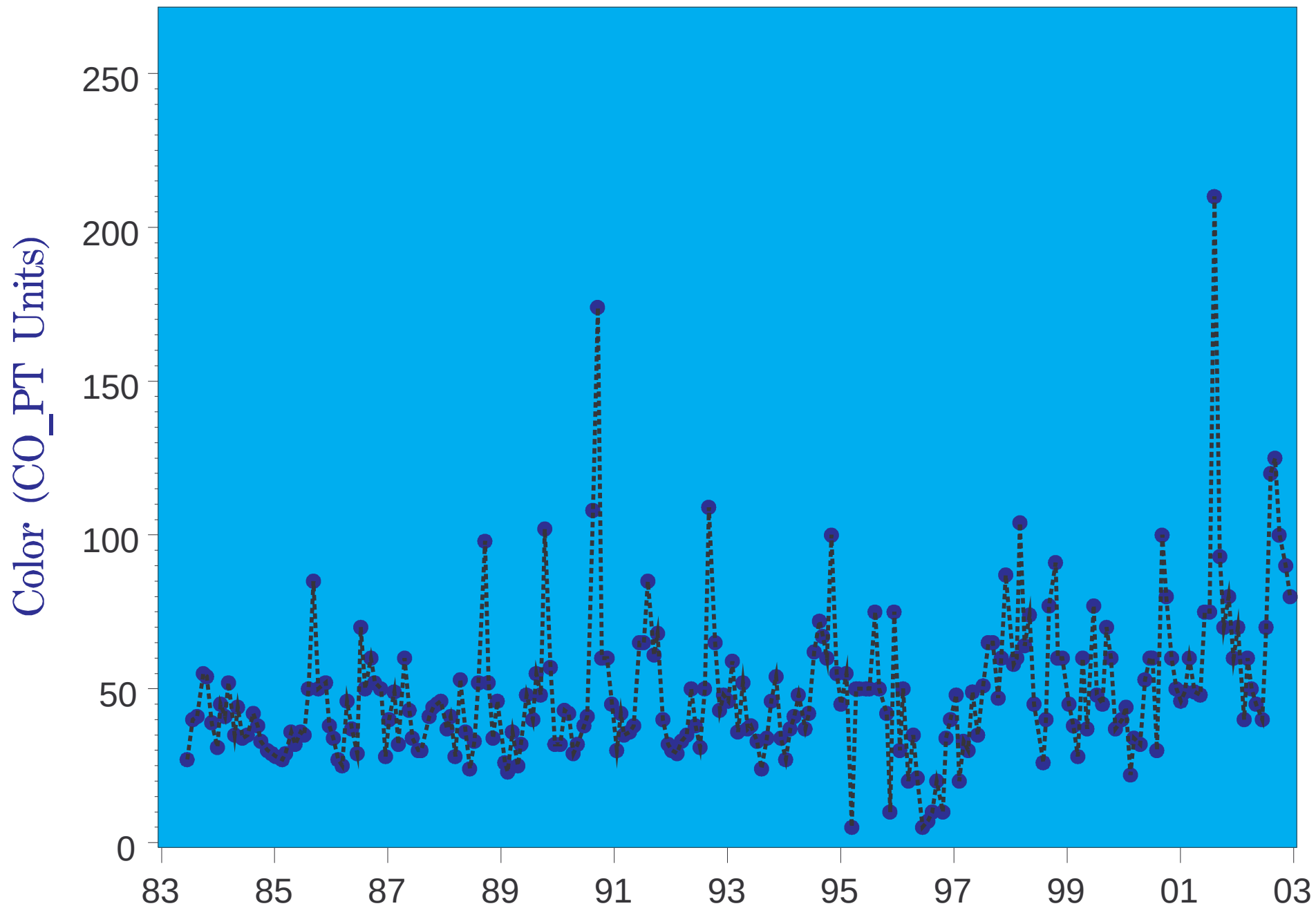


Figure 4.6.61 Monthly surface color at 20 o/oo isohaline (1983-2002)

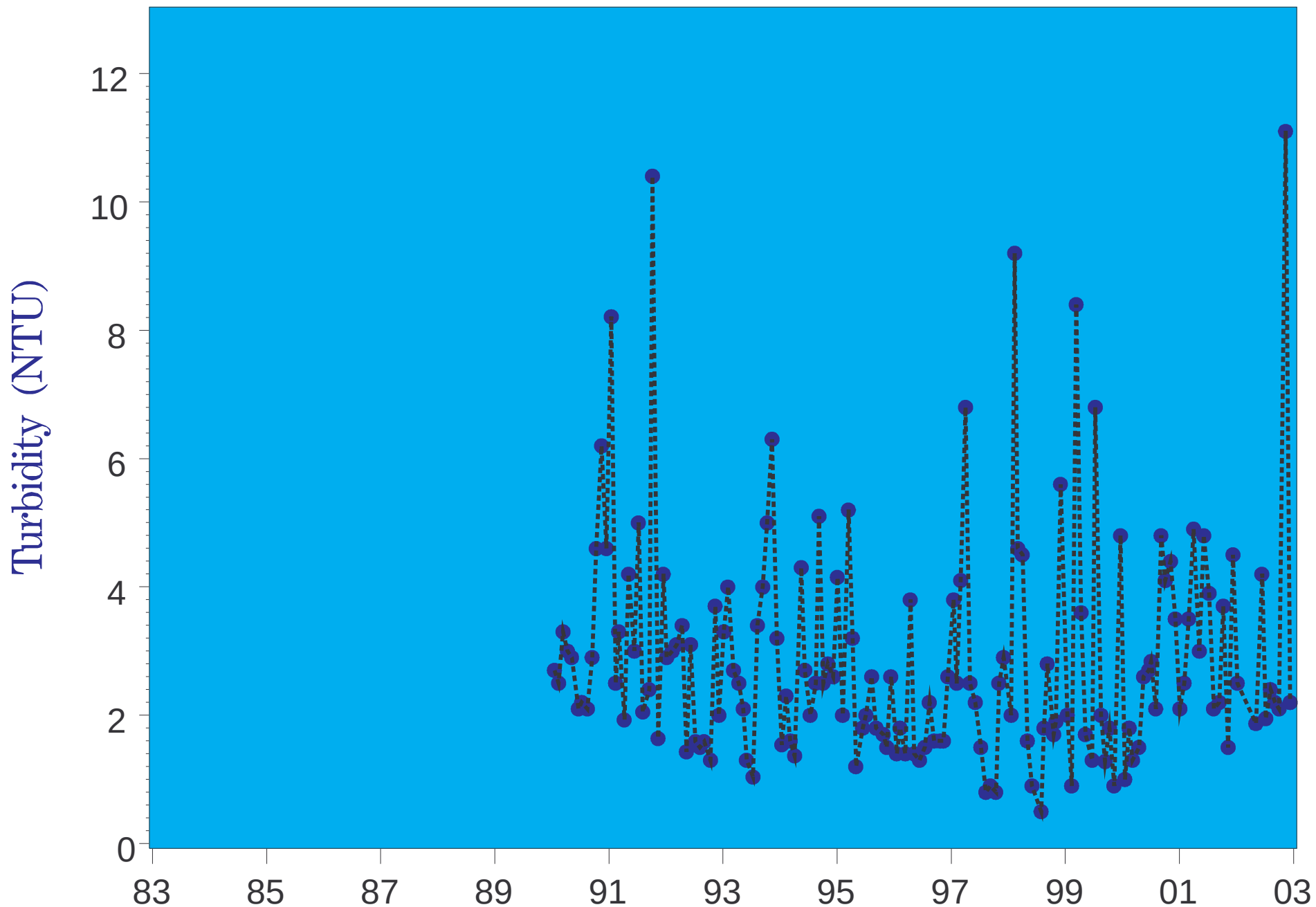


Figure 4.6.62 Monthly surface turbidity at 20 o/oo isohaline (1983-2002)



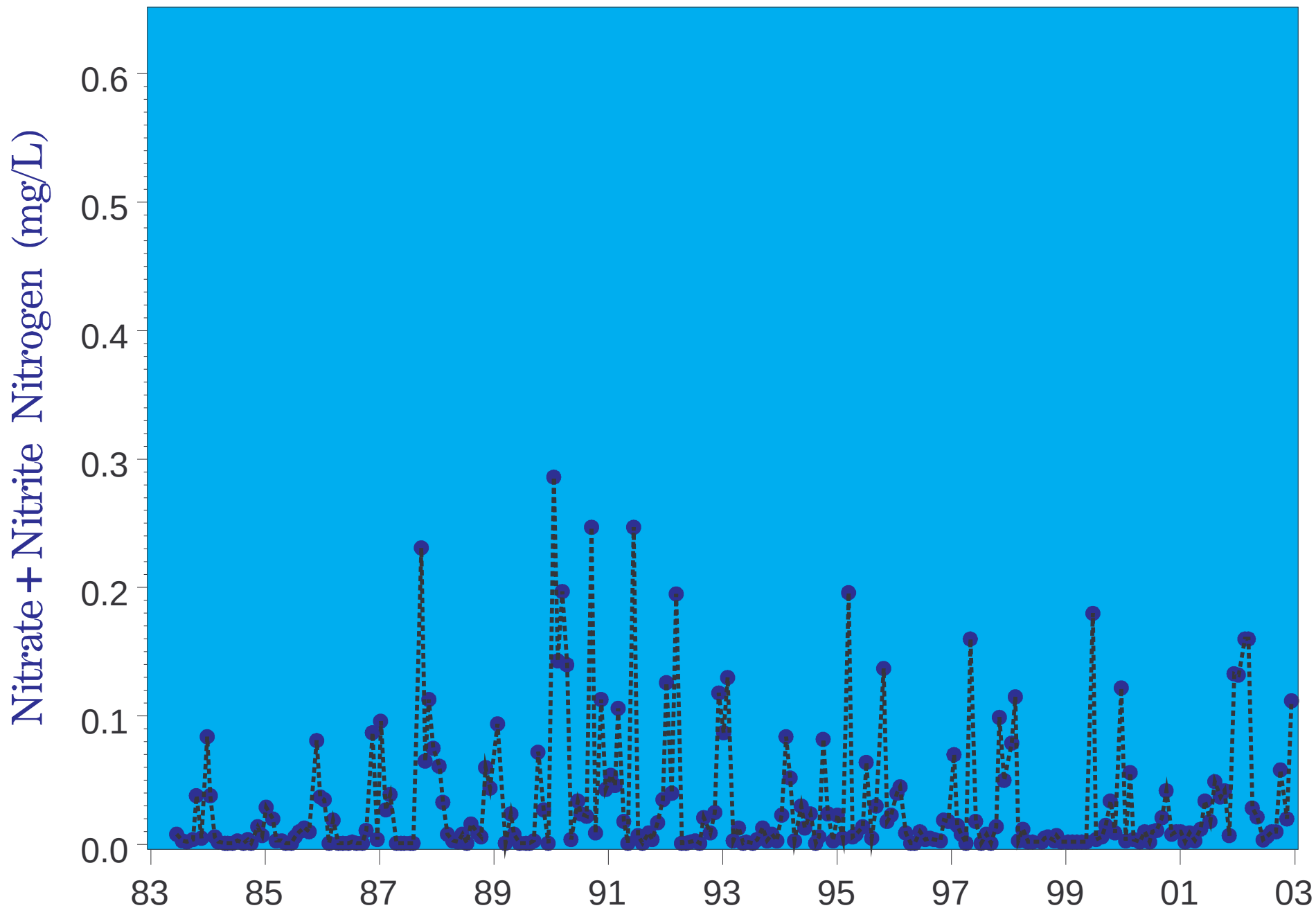


Figure 4.6.63 Monthly surface nitrate/nitrite nitrogen at 20 o/oo isohaline (1983-2002)

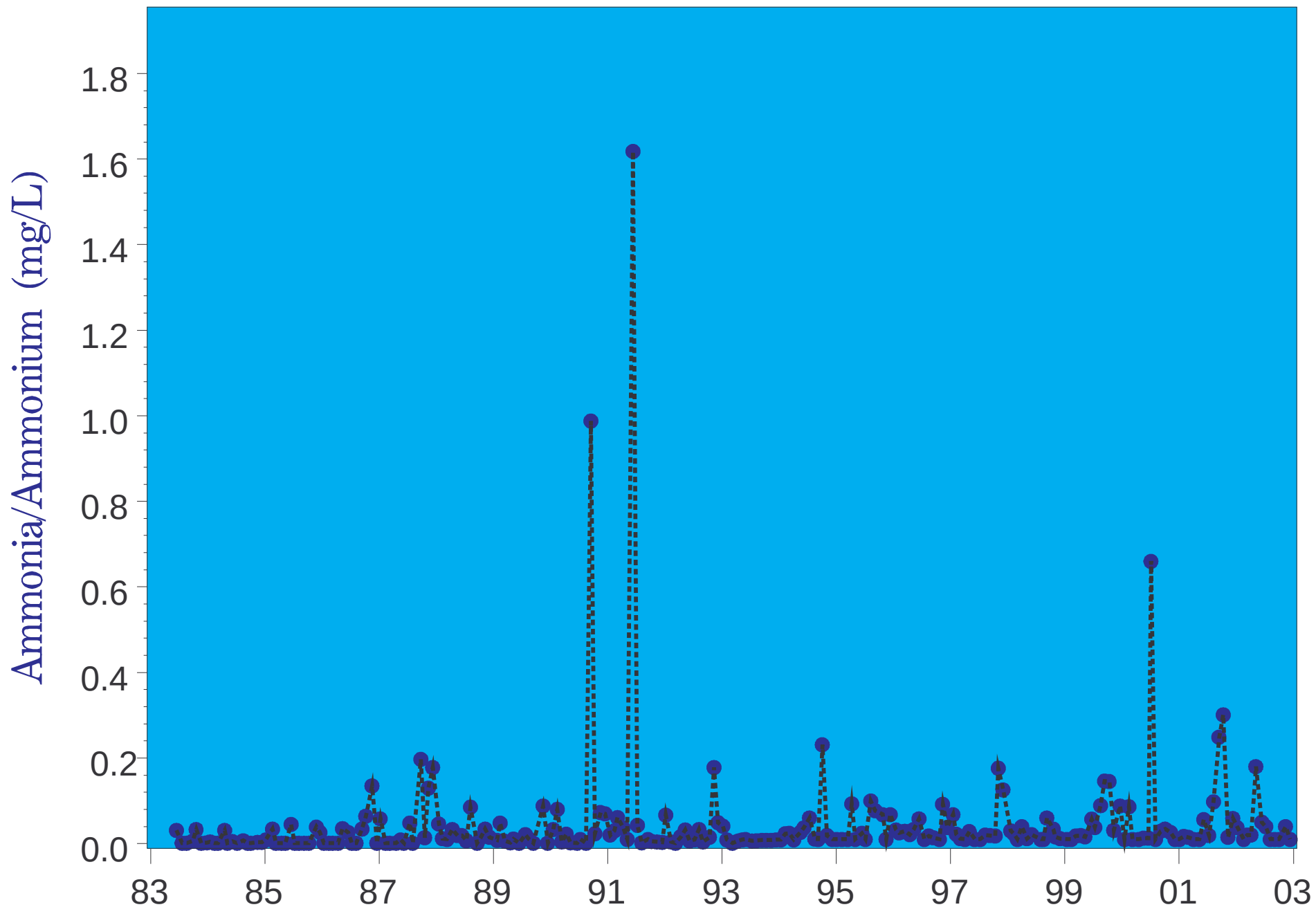


Figure 4.6.64 Monthly surface Ammonia/Ammonium at 20 o/oo isohaline (1983-2002)

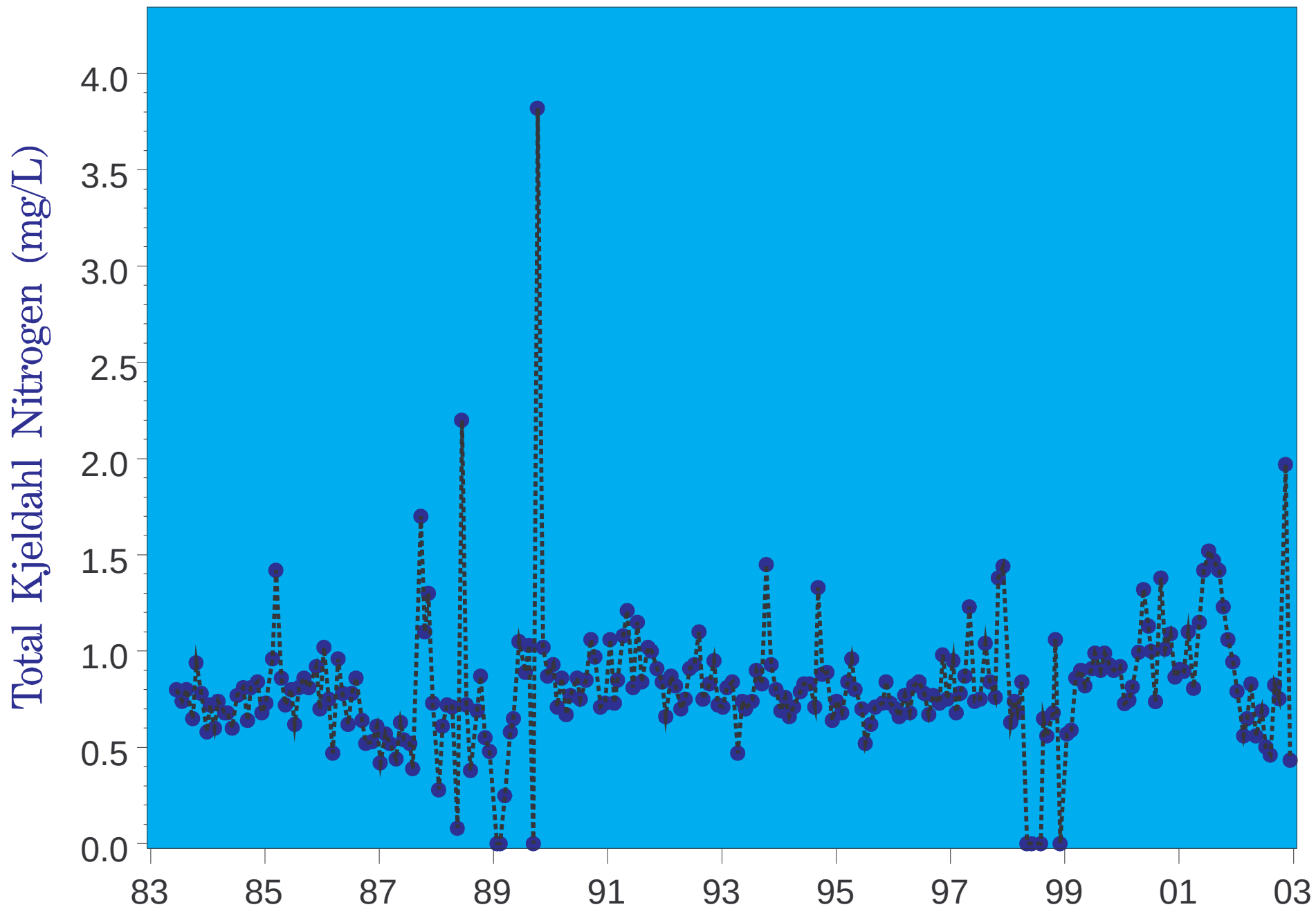


Figure 4.6.65 Monthly surface total Kjeldahl nitrogen at 20 o/oo isohaline (1983-2002)

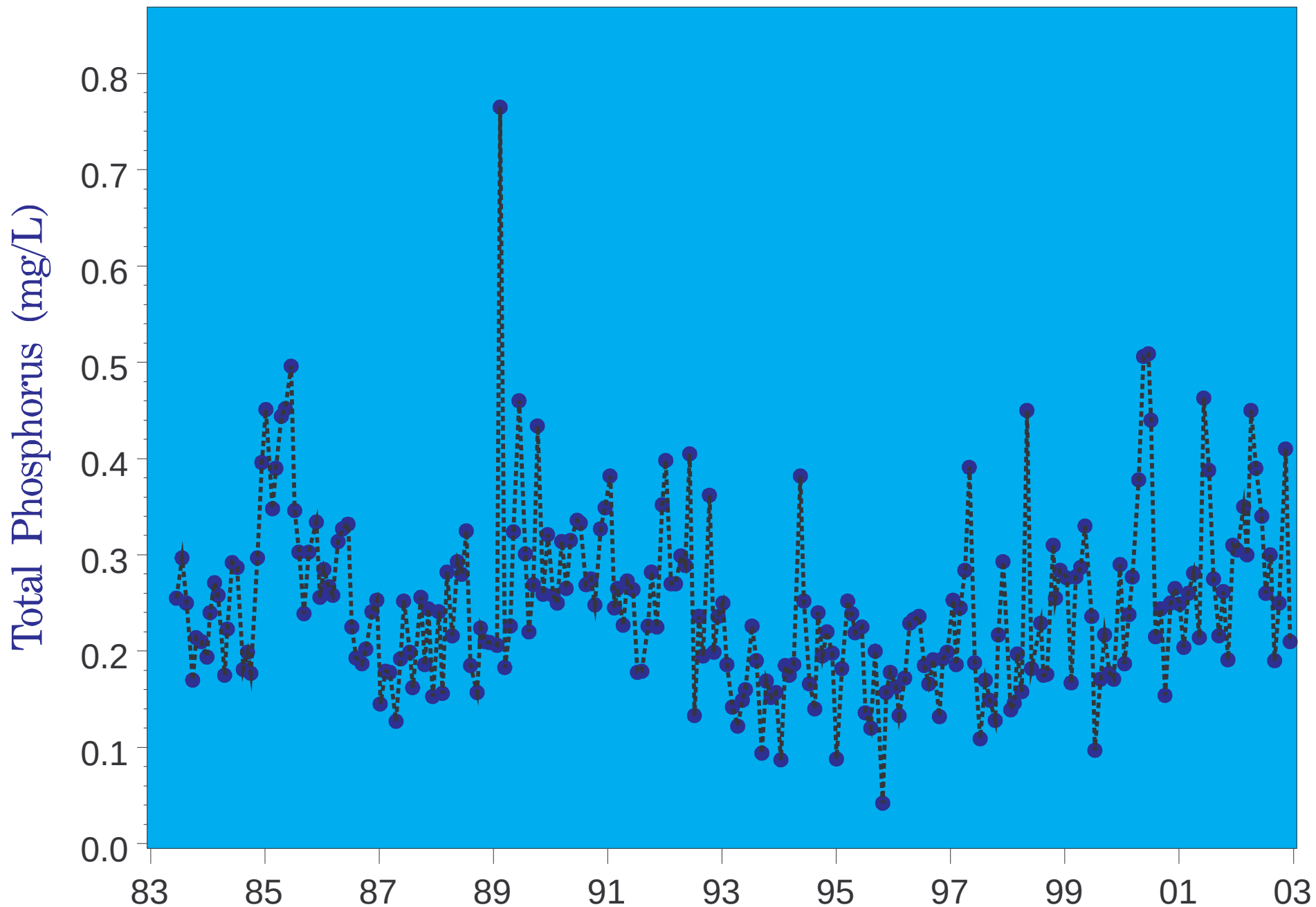


Figure 4.6.66 Monthly surface total phosphorus at 20 o/oo isohaline (1983-2002)

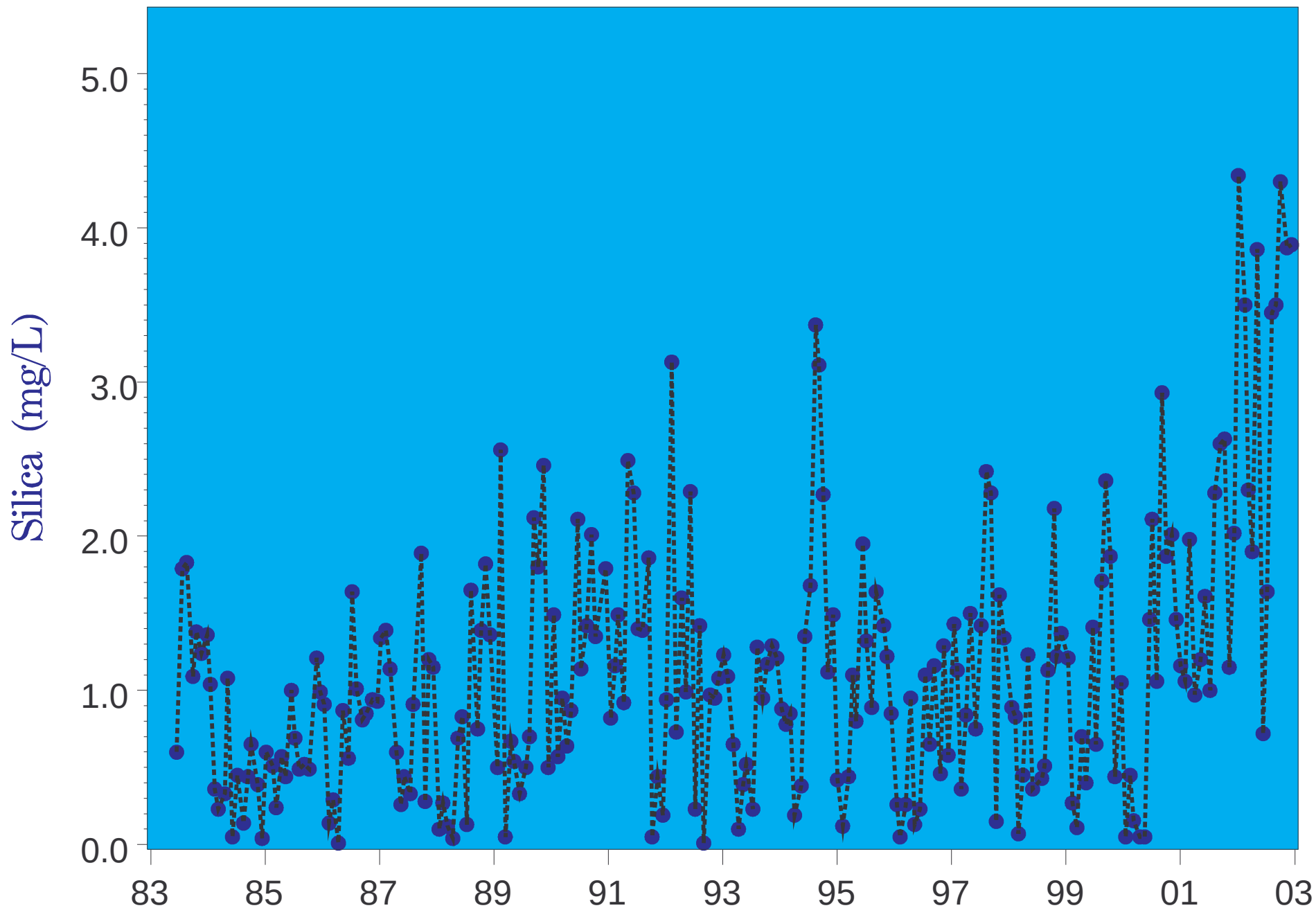


Figure 4.6.67 Monthly surface silica at 20 o/oo isohaline (1983-2002)

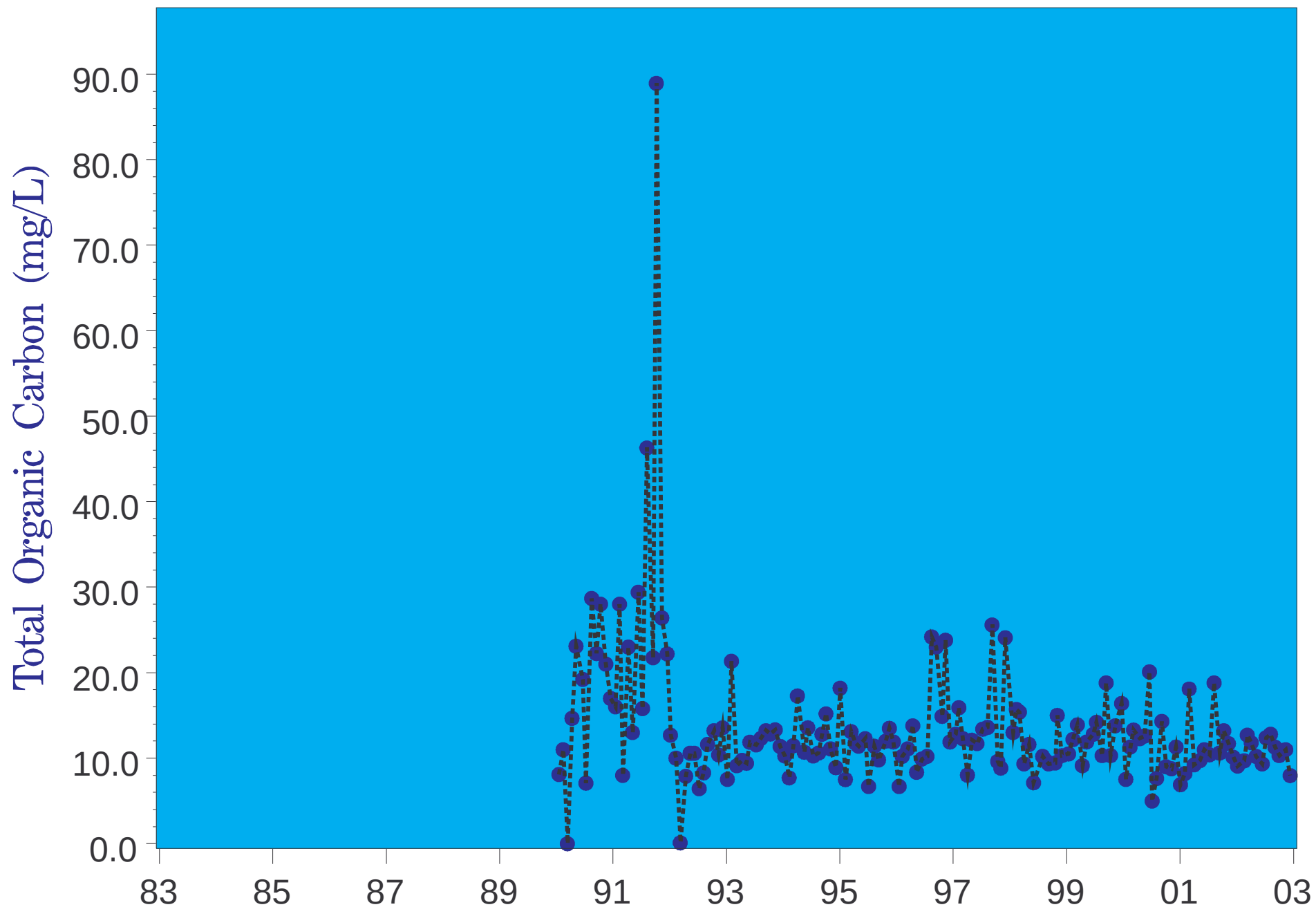


Figure 4.6.68 Monthly surface total organic carbon at 20 o/oo isohaline (1983-2002)

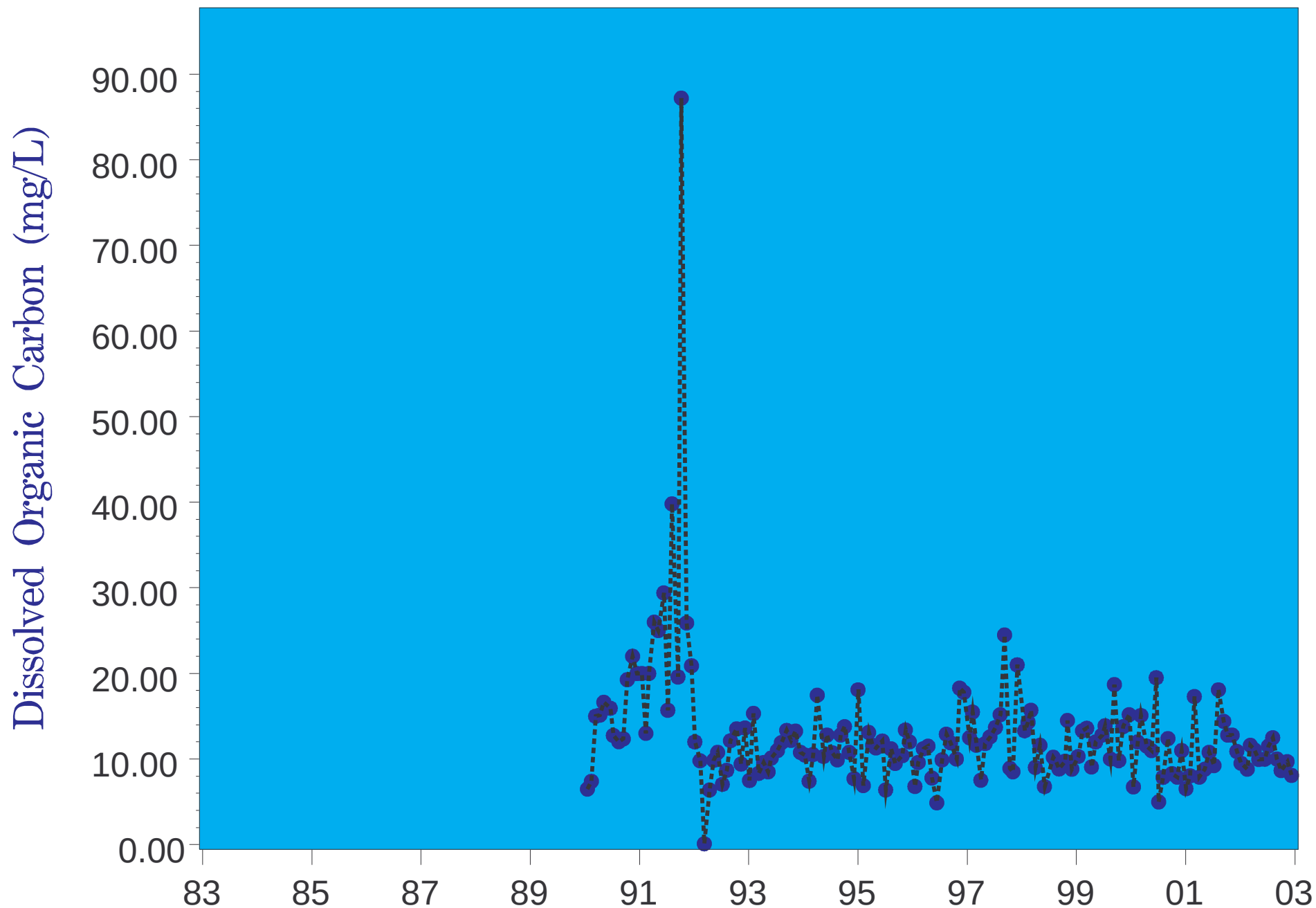


Figure 4.6.69 Monthly surface dissolved organic carbon at 20 o/oo isohaline (1983-2002)

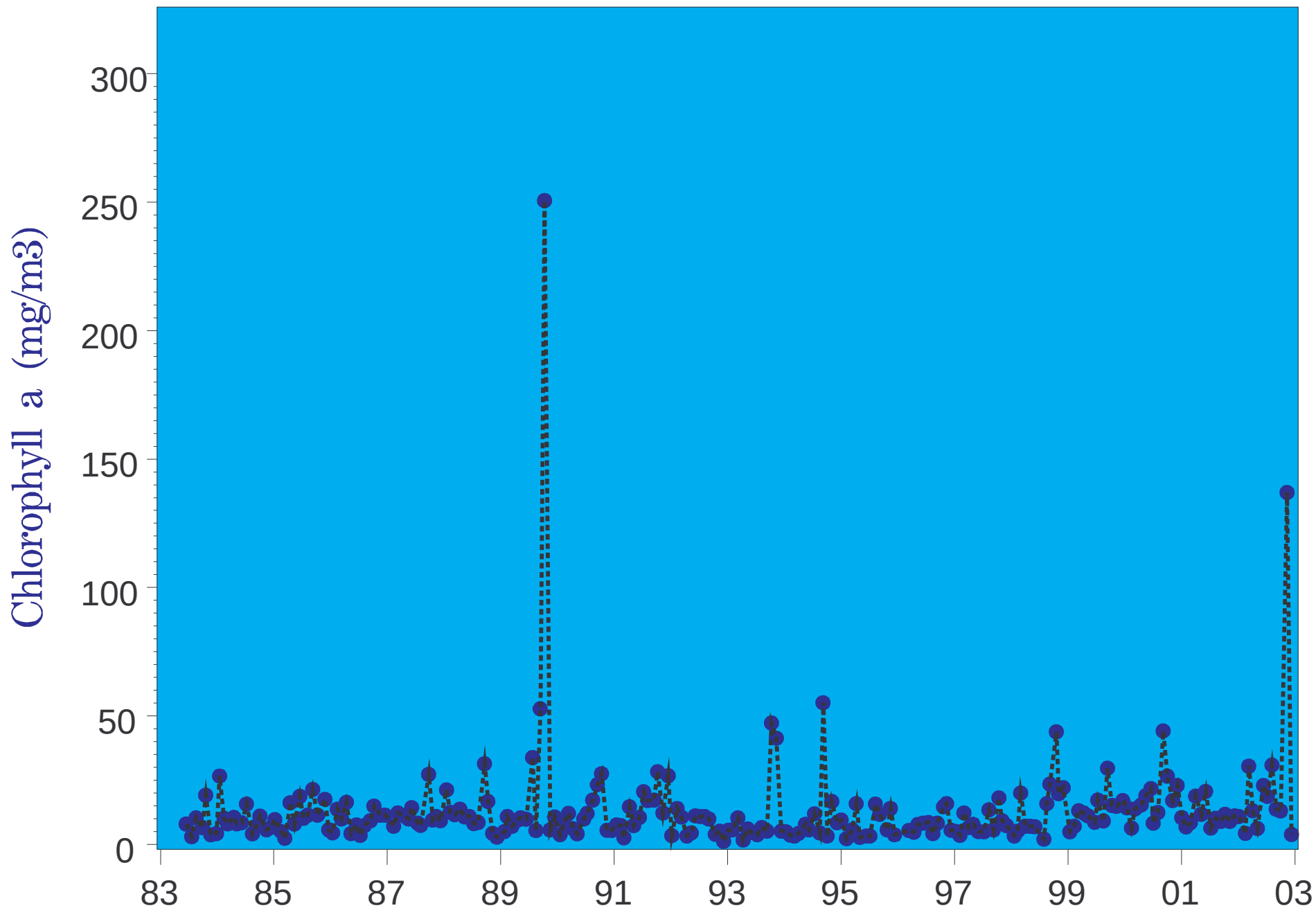


Figure 4.6.70 Monthly surface chlorophyll a at 20 o/oo isohaline (1983-2002)



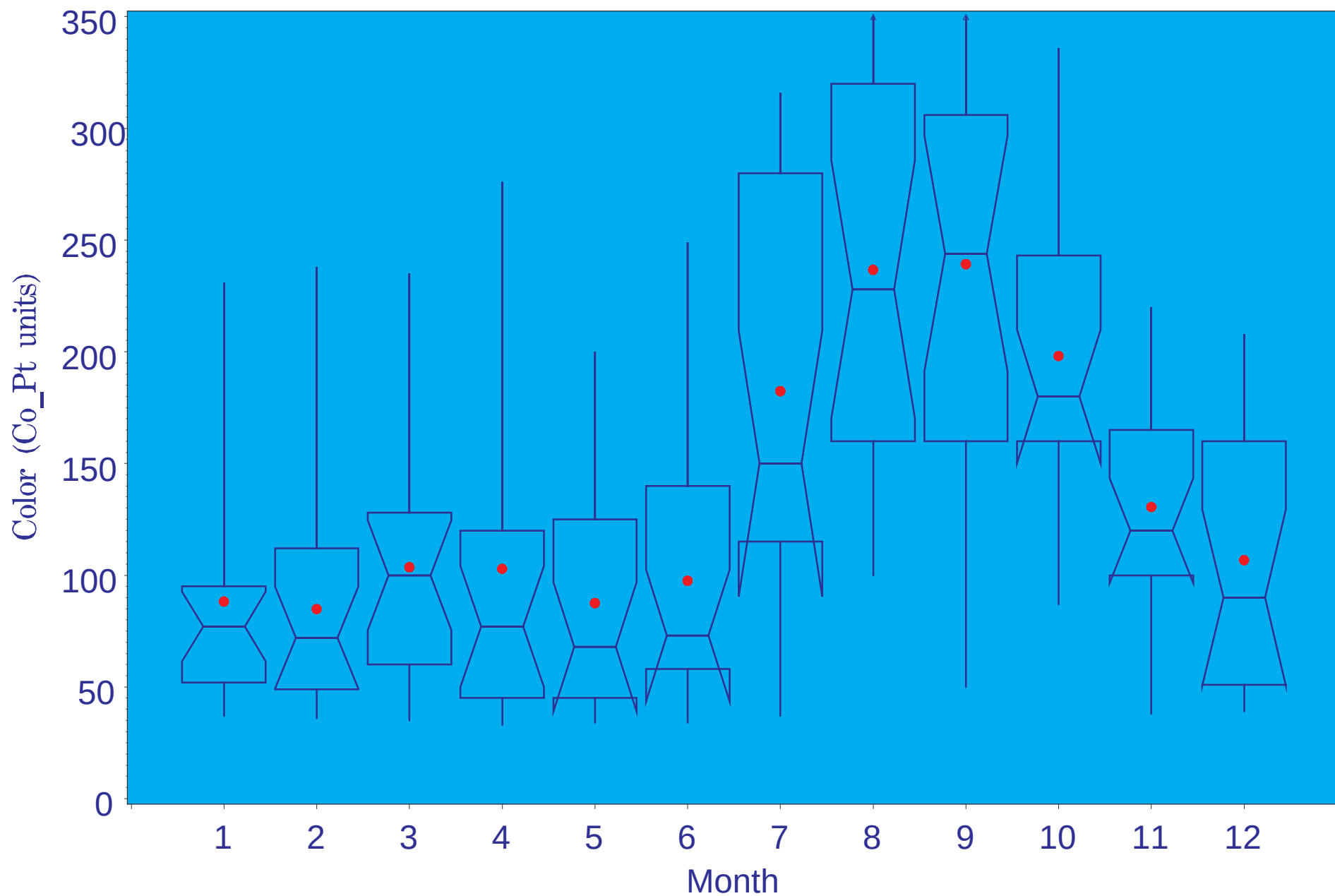


Figure 4.6.71 Mean monthly boxplots of water color - 0 ppt isohaline (1984-2002)

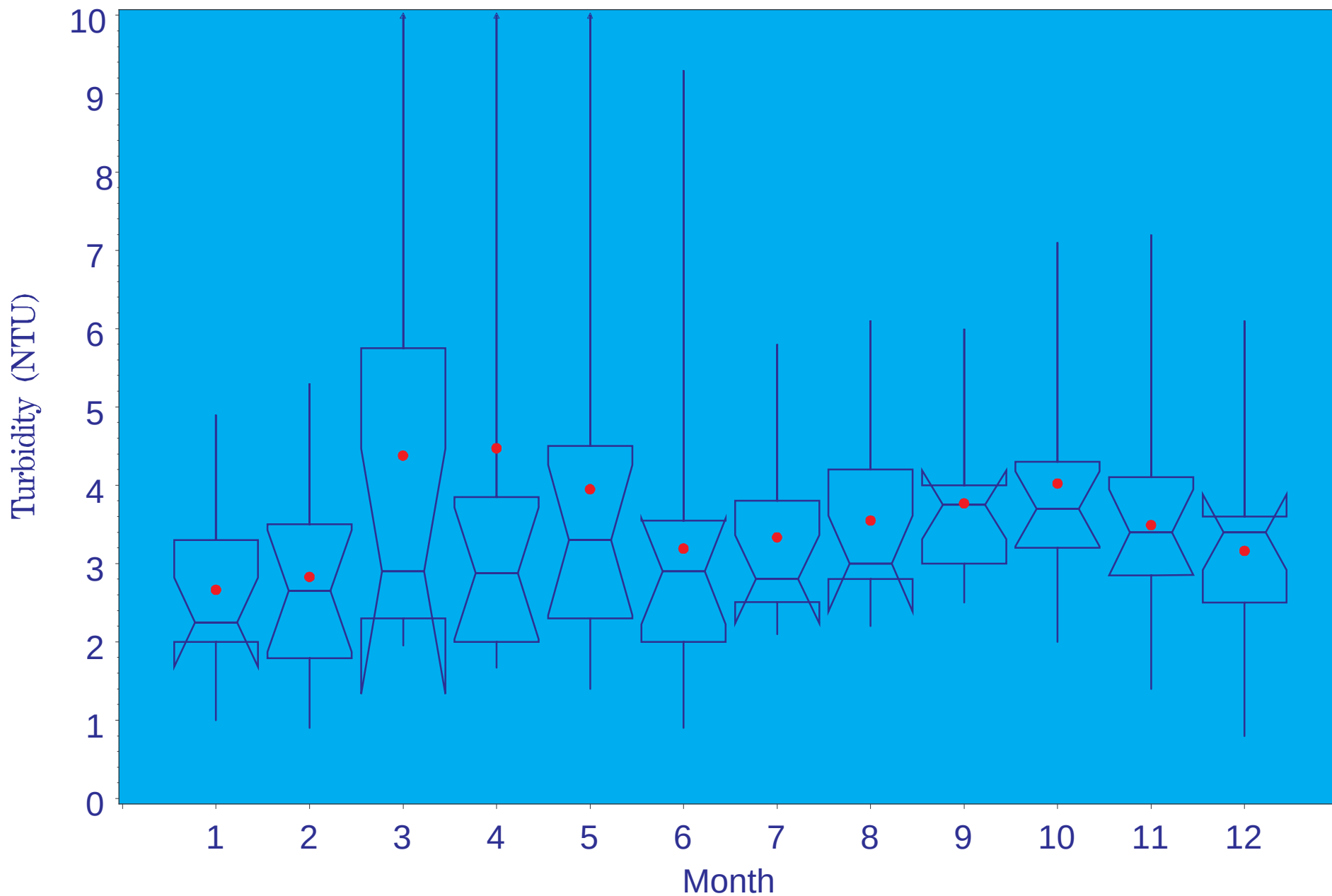


Figure 4.6.72 Mean monthly boxplots of turbidity - 0 ppt isohaline (1984-2002)

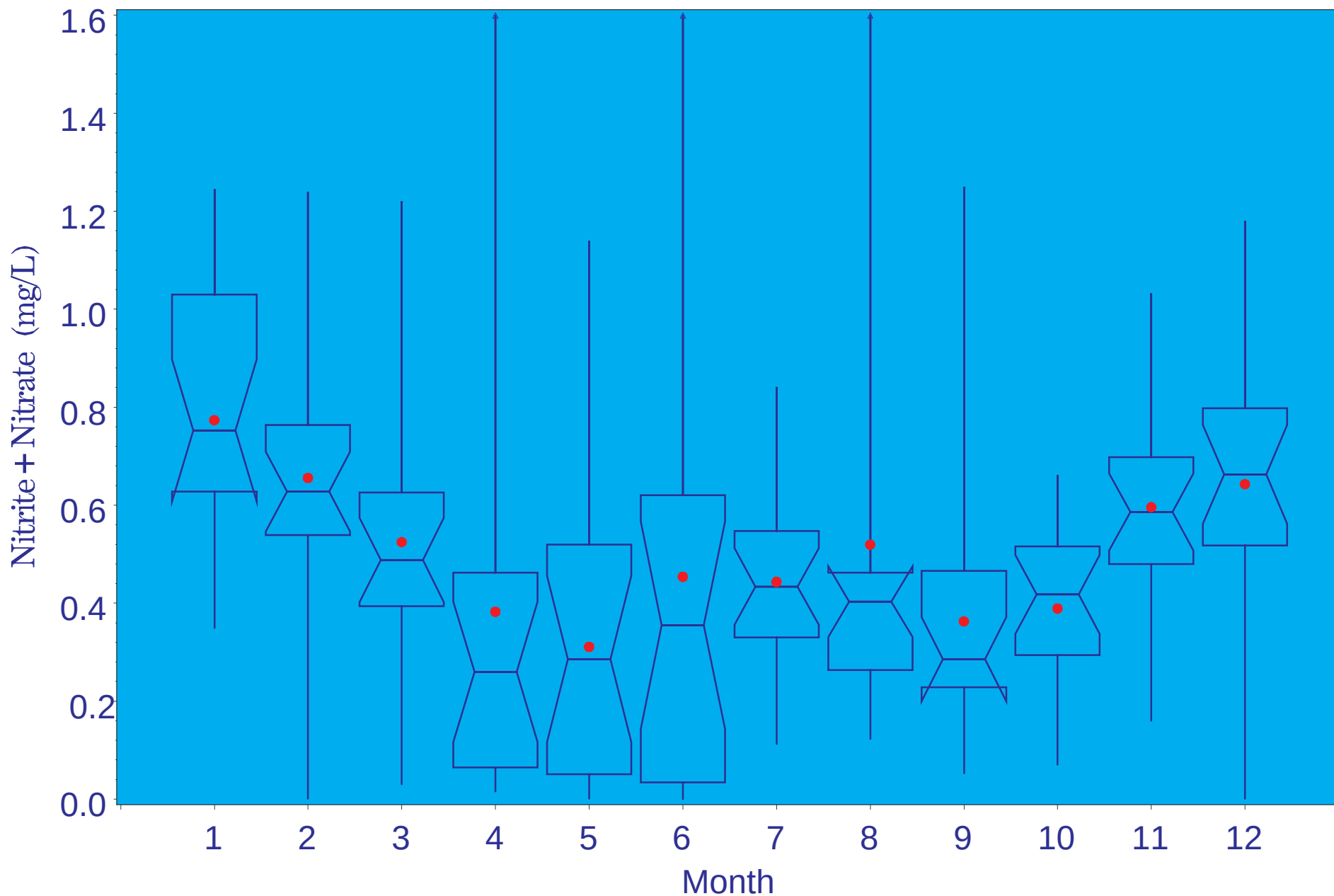


Figure 4.6.73 Mean monthly boxplots of nitrite+nitrate - 0 ppt isohaline (1984-2002)

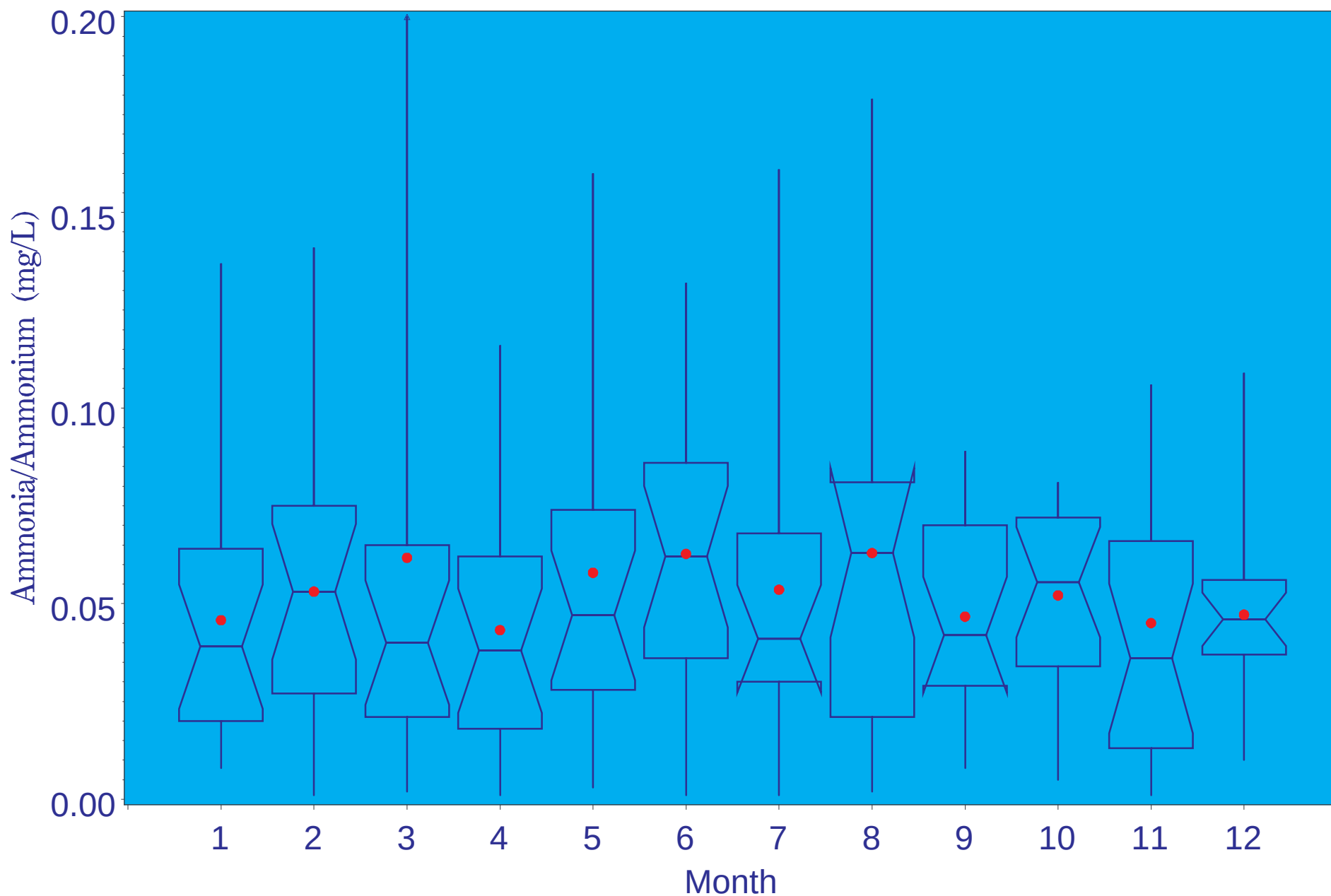


Figure 4.6.74 Mean monthly boxplots of ammonia/ammonium - 0 ppt isohaline (1984-2002)

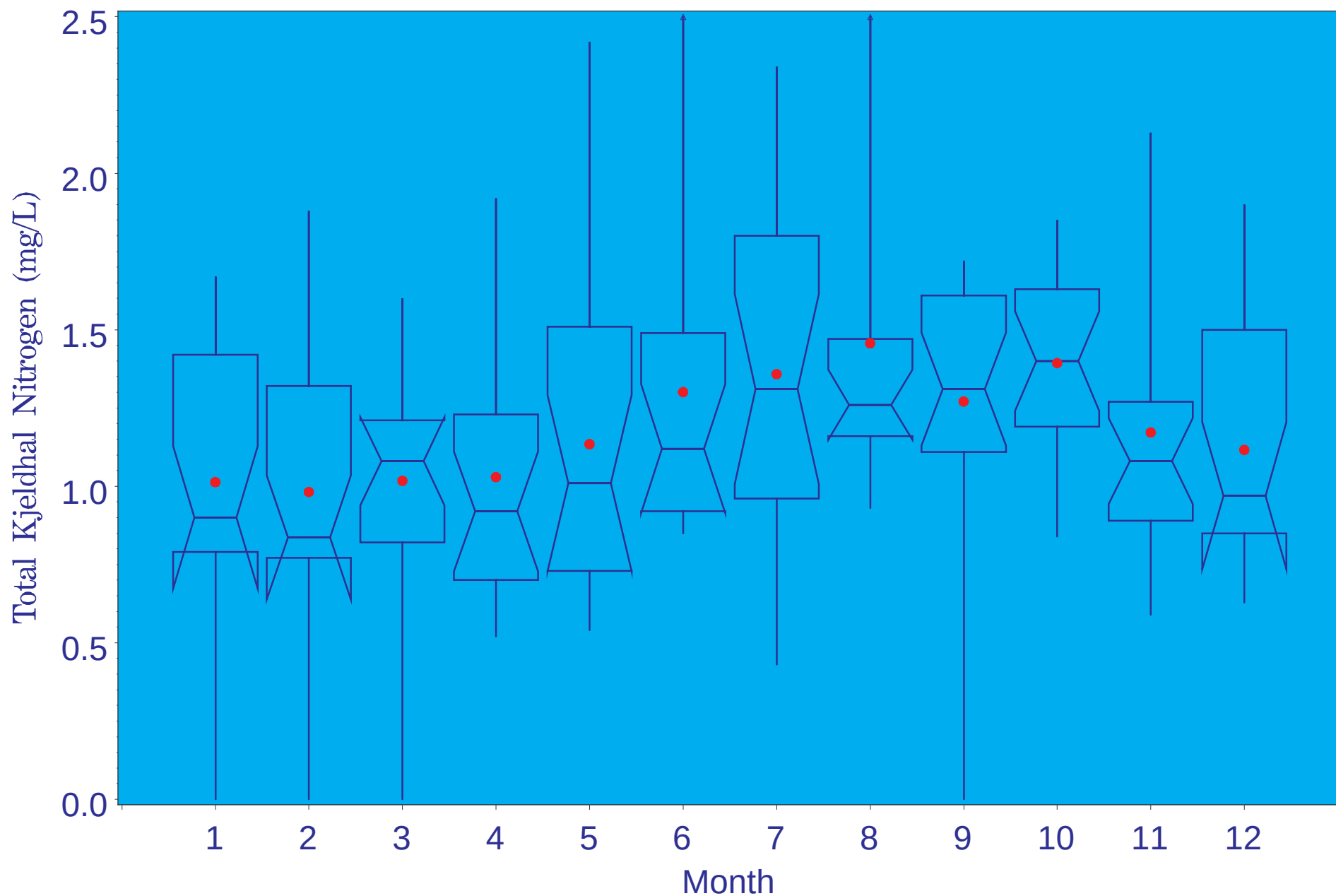


Figure 4.6.75 Mean monthly boxplots of total Kjeldhal nitrogen - 0 ppt isohaline (1984-2002)

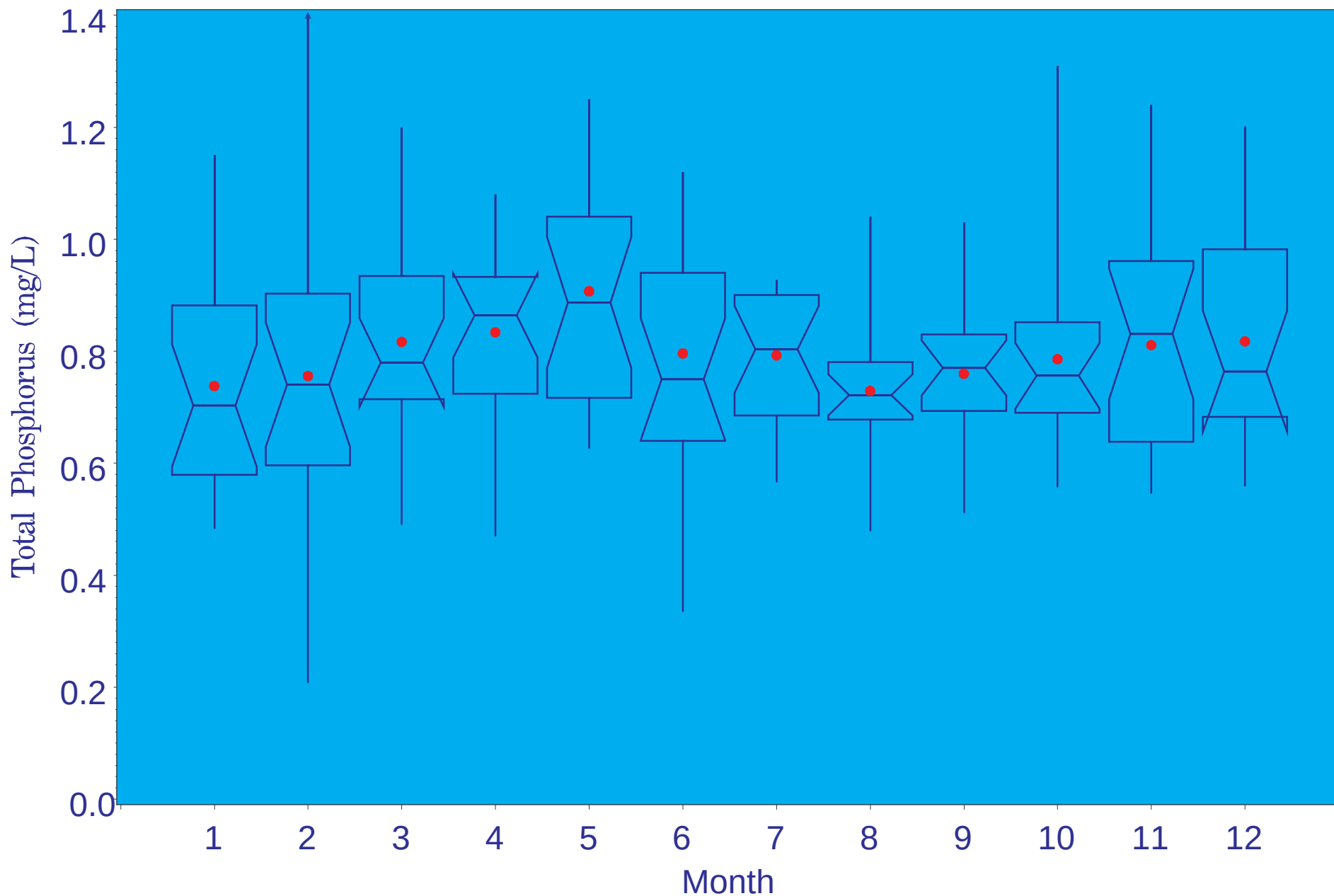


Figure 4.6.76 Mean monthly boxplots of total phosphorus - 0 ppt isohaline (1984-2002)

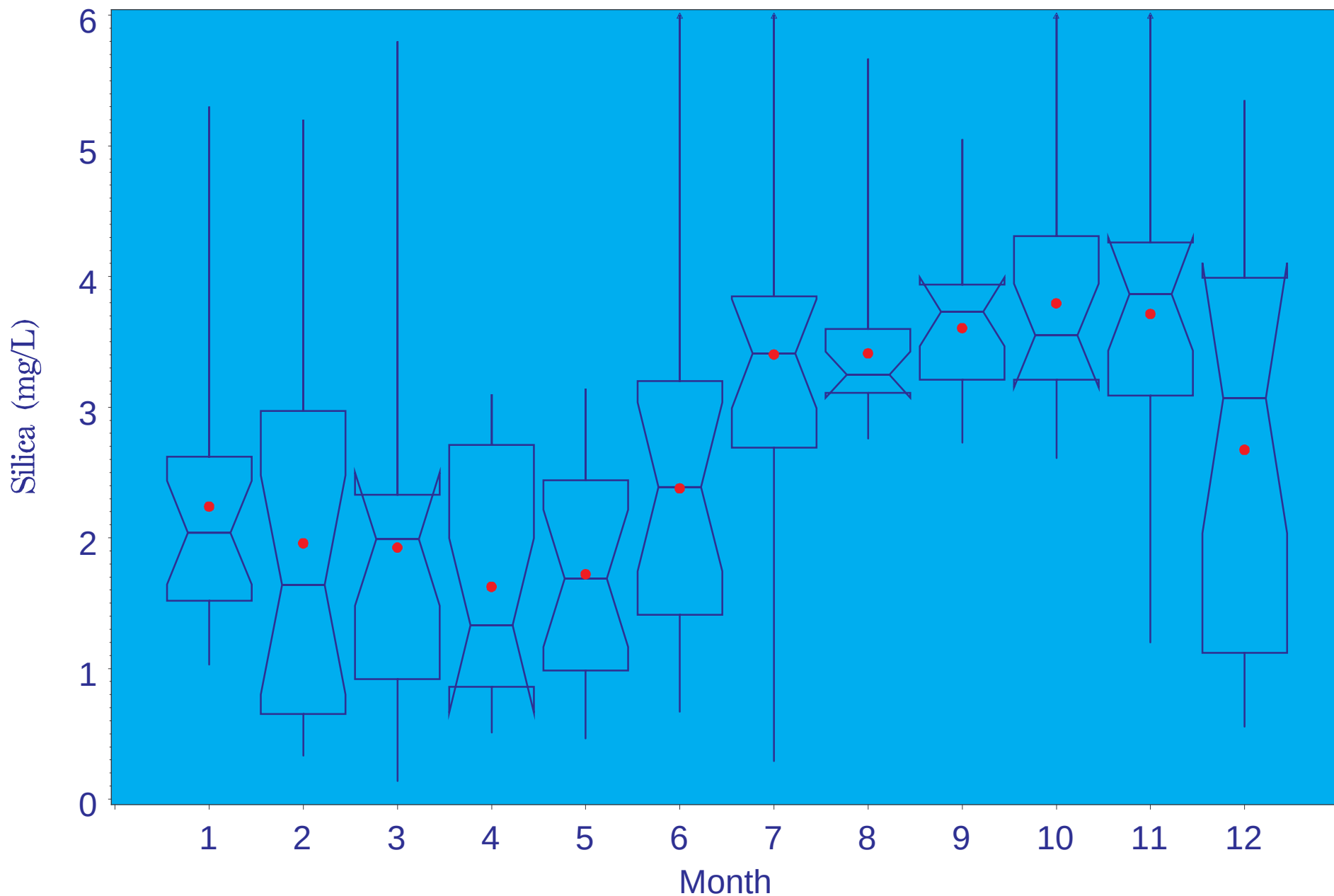


Figure 4.6.77 Mean monthly boxplots of silica - 0 ppt isohaline (1984-2002)

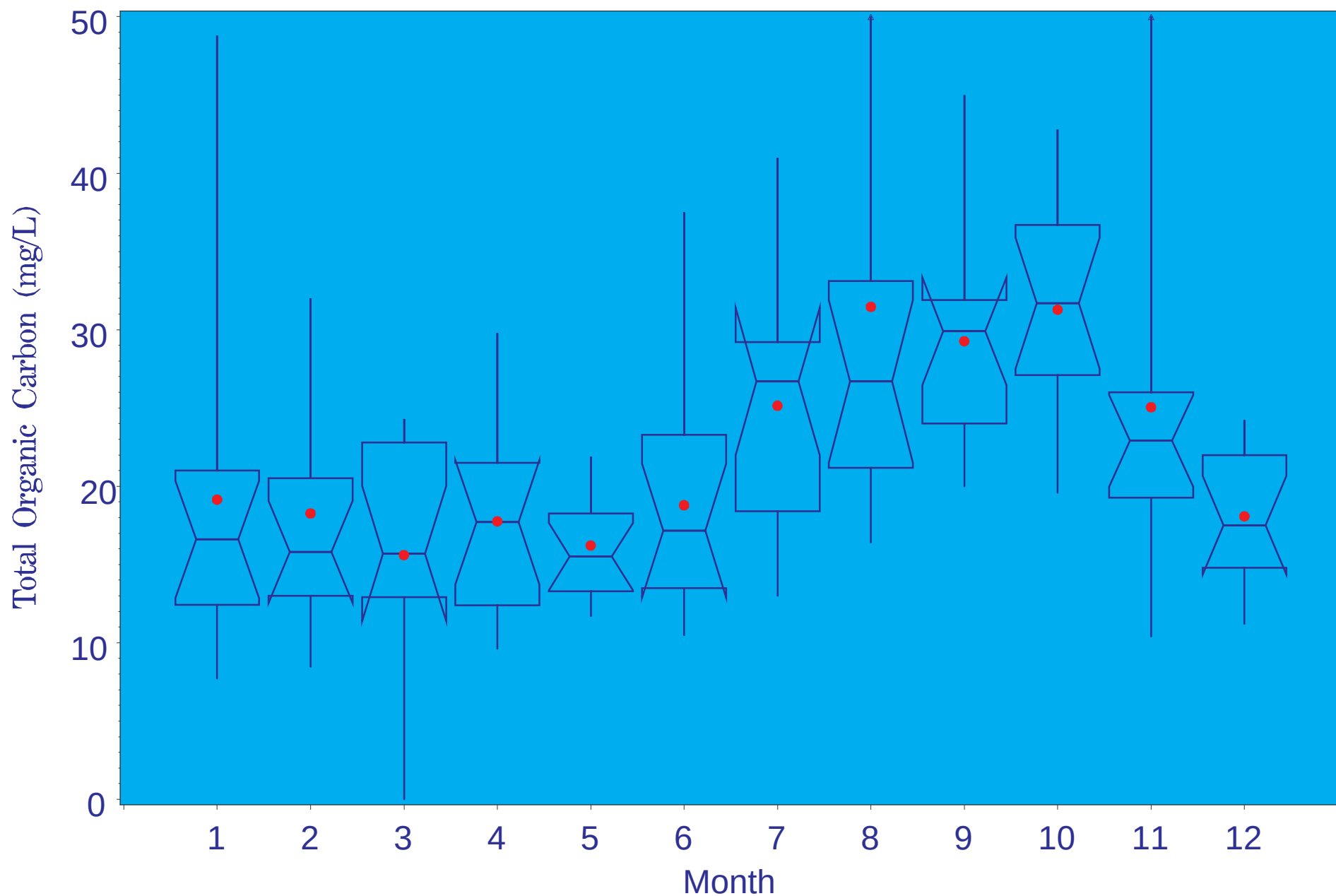


Figure 4.6.78 Mean monthly boxplots of total organic carbon - 0 ppt isohaline (1984-2002)



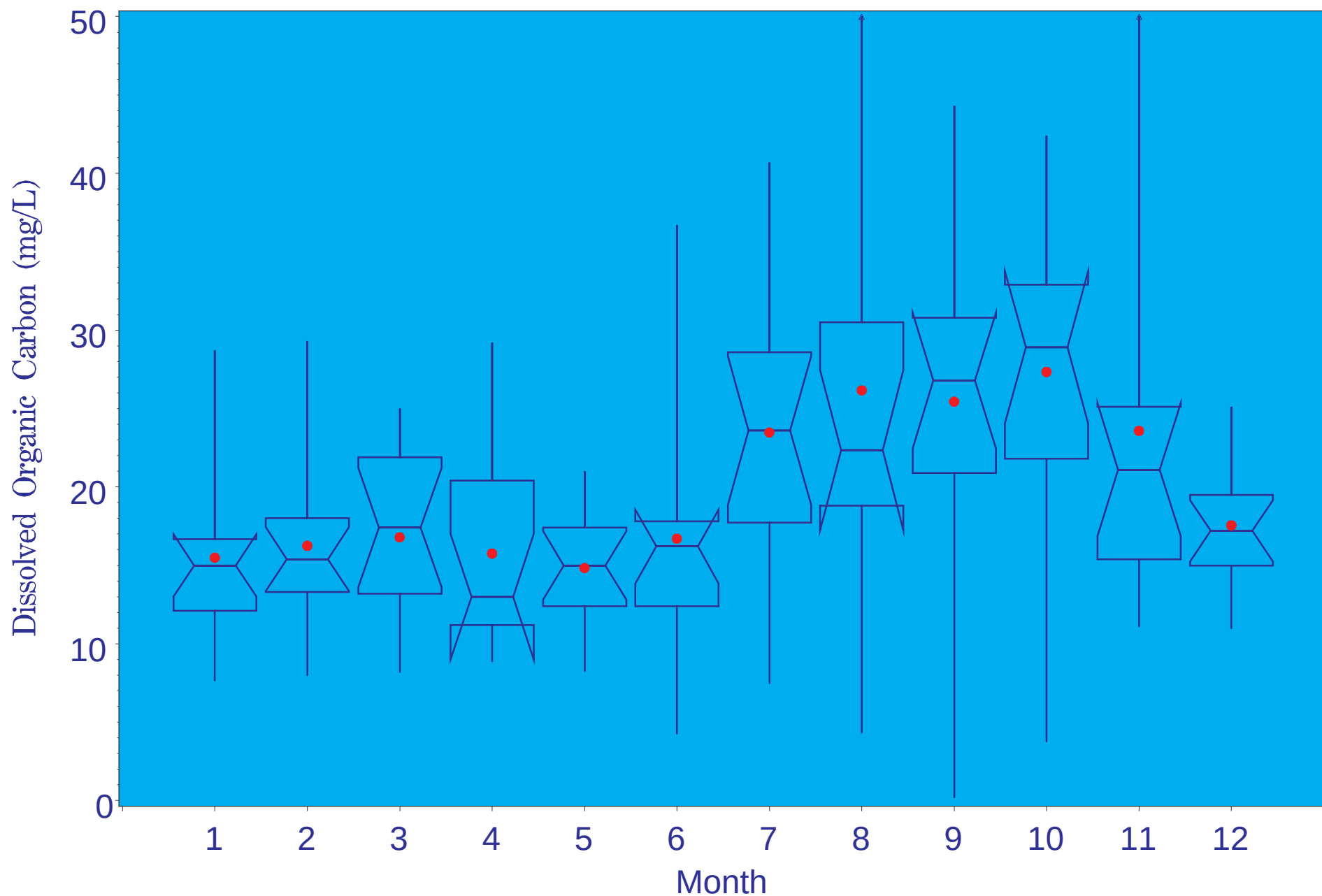


Figure 4.6.79 Mean monthly boxplots of dissolved organic carbon - 0 ppt isohaline (1984-2002)

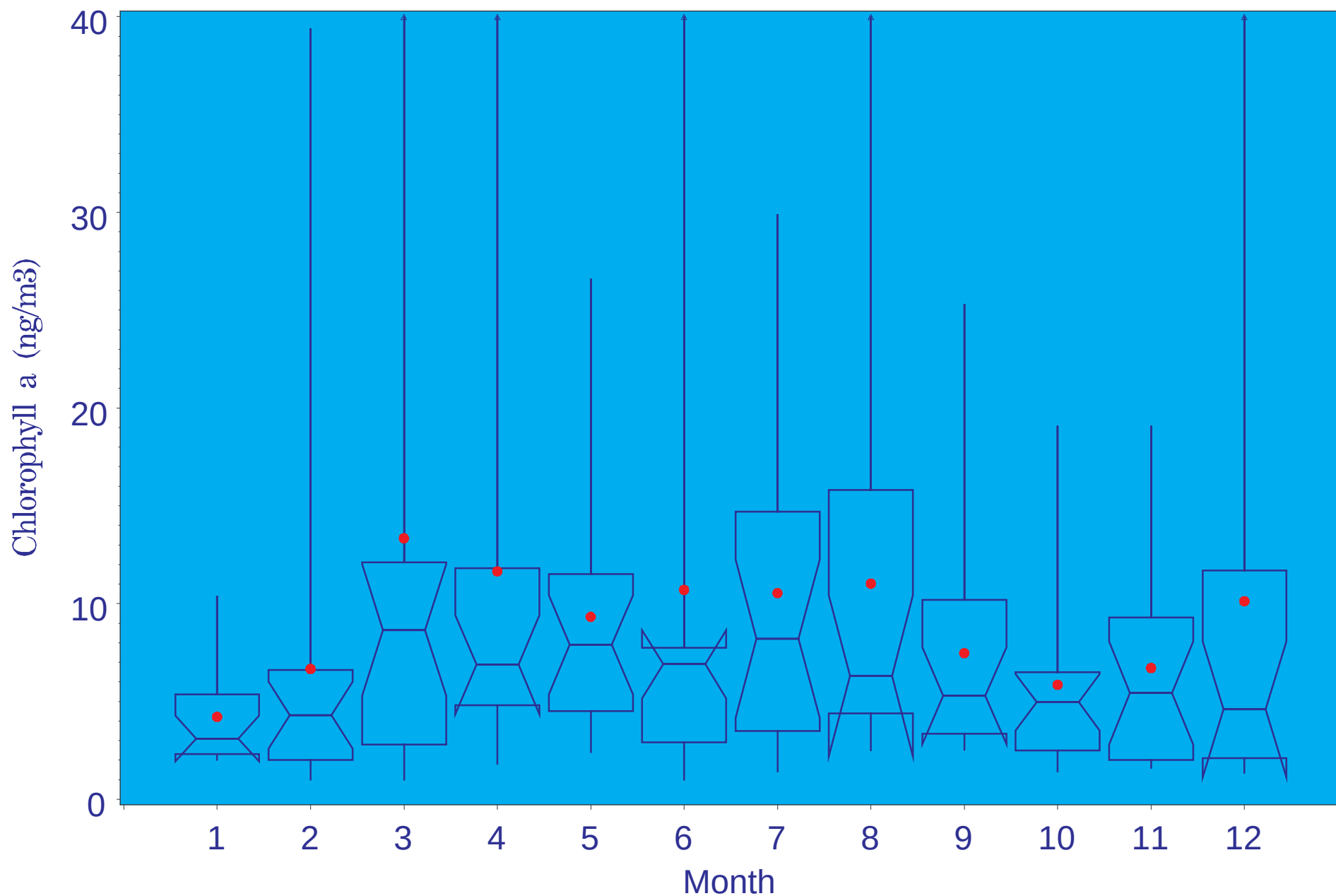


Figure 4.6.80 Mean monthly boxplots of chlorophyll a - 0 ppt isohaline (1984-2002)

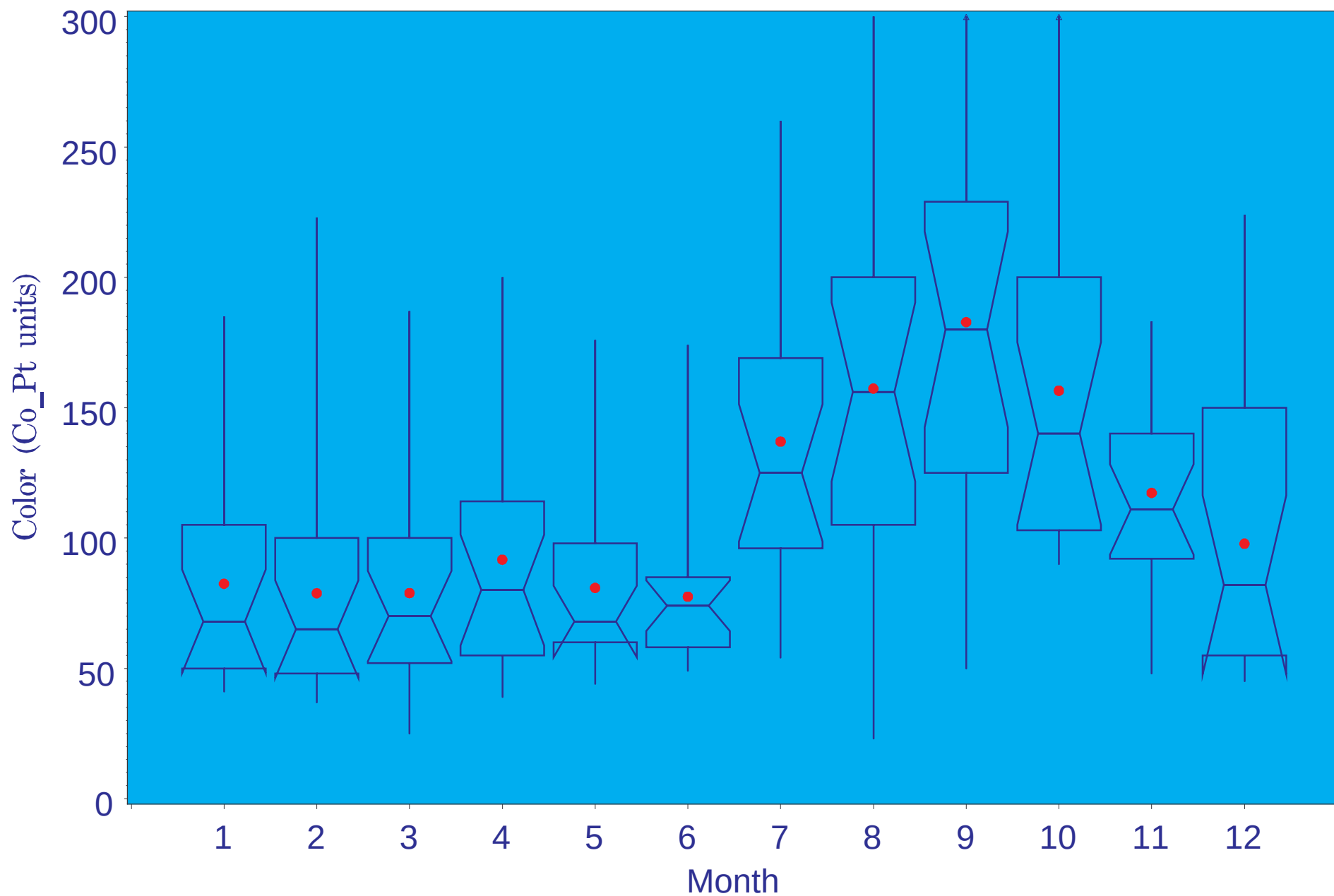


Figure 4.6.81 Mean monthly boxplots of water color - 6 ppt isohaline (1984-2002)

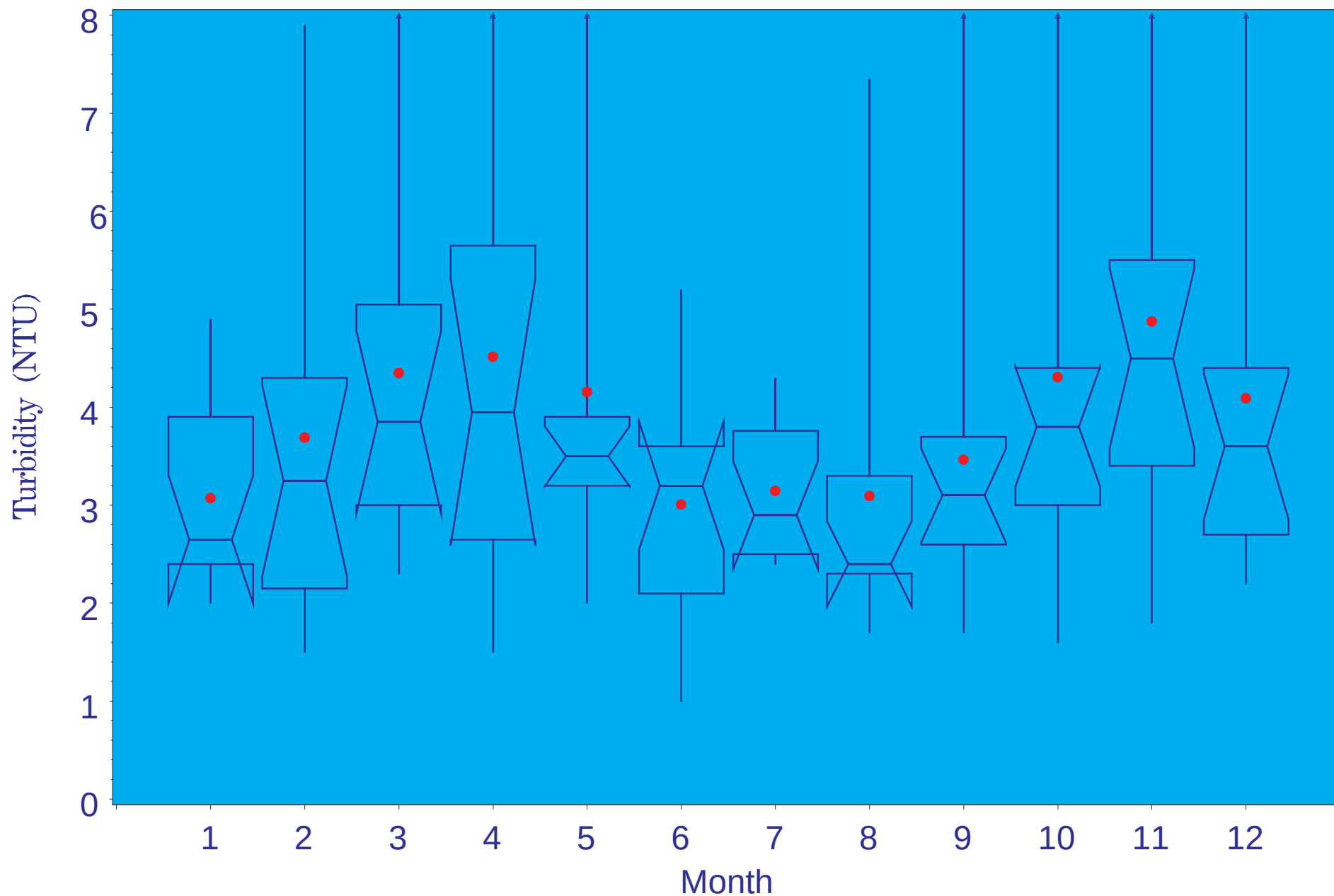


Figure 4.6.82 Mean monthly boxplots of turbidity - 6 ppt isohaline (1984-2002)

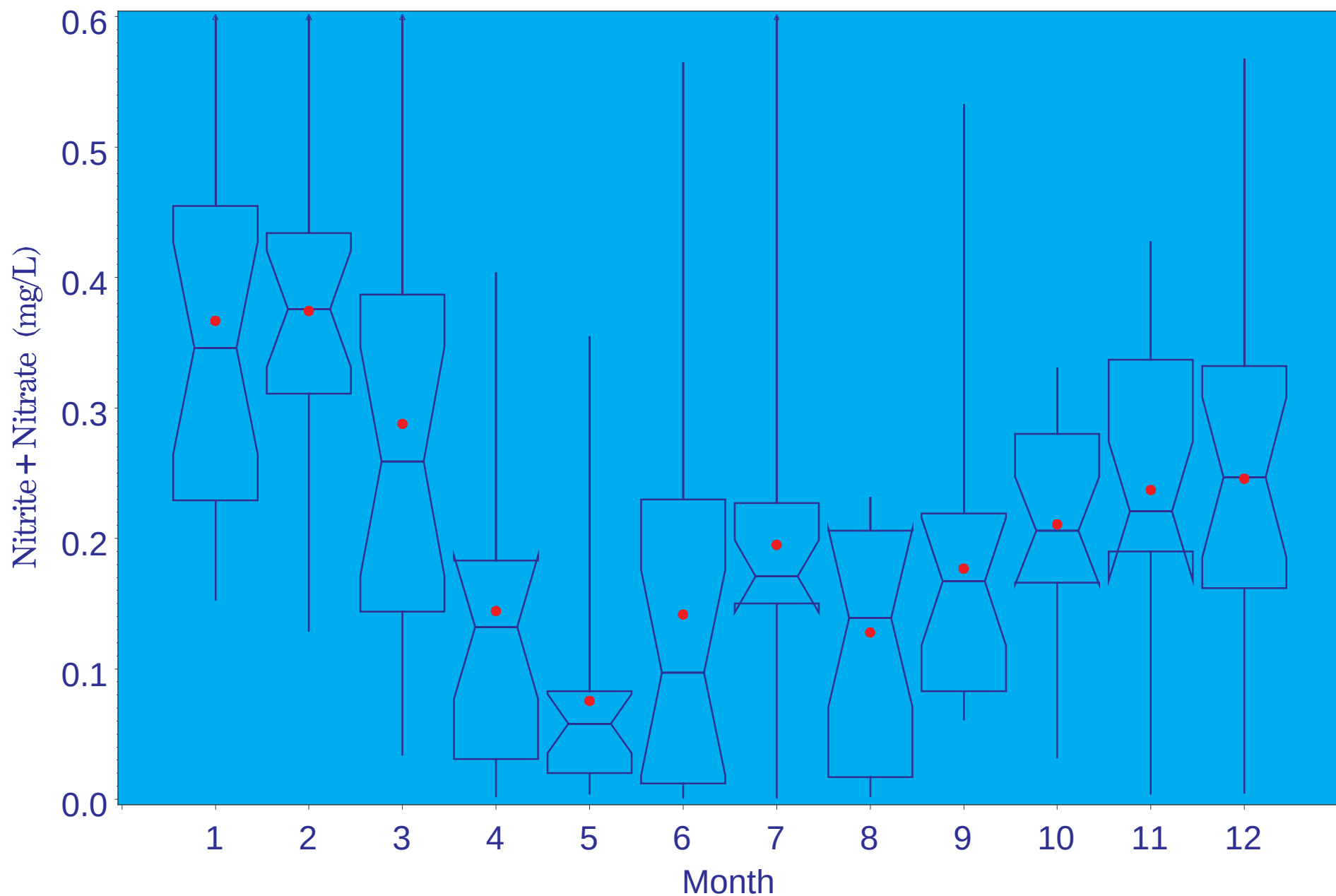


Figure 4.6.83 Mean monthly boxplots of nitrite+nitrate - 6 ppt isohaline (1984-2002)

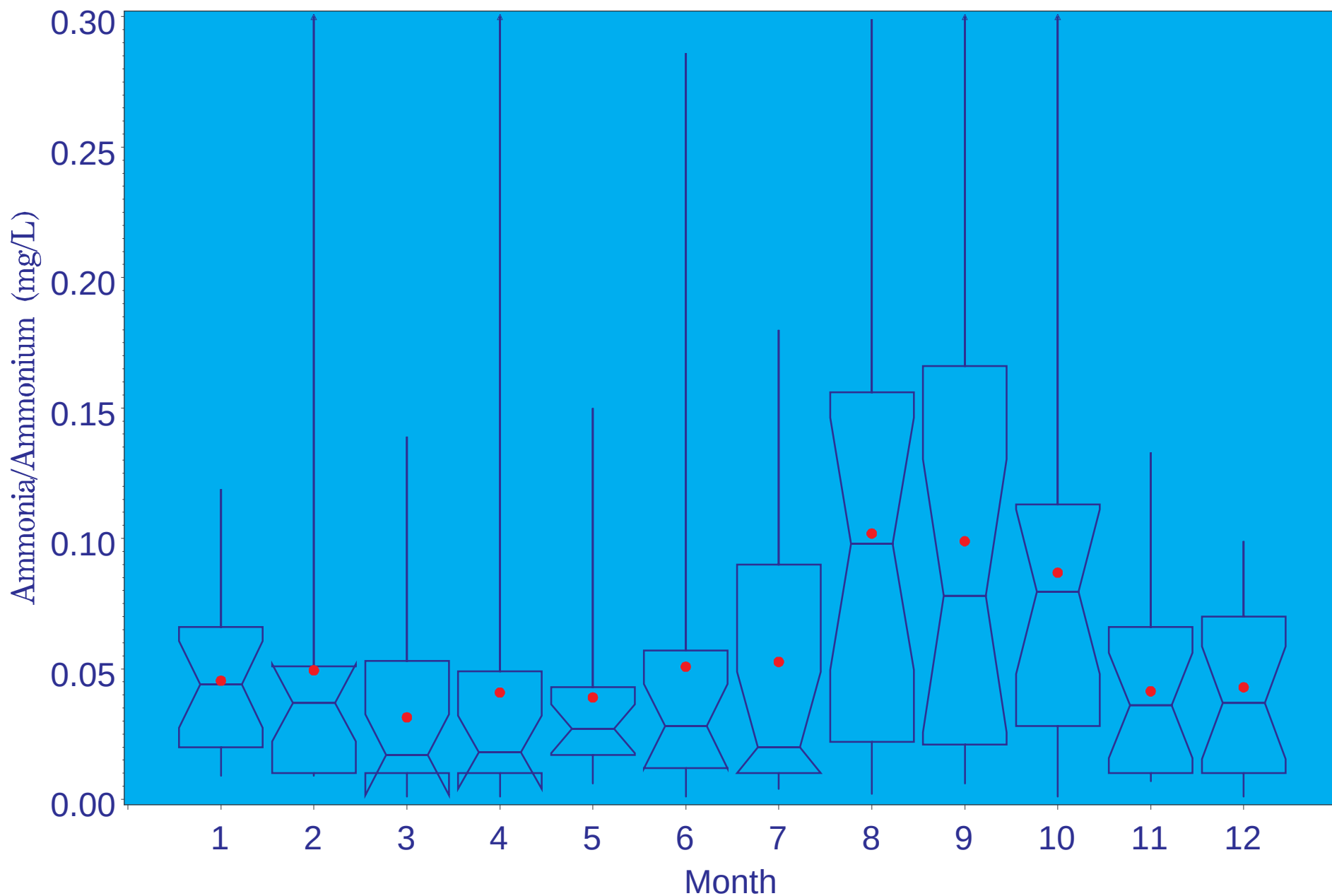


Figure 4.6.84 Mean monthly boxplots of ammonia/ammonium - 6 ppt isohaline (1984-2002)

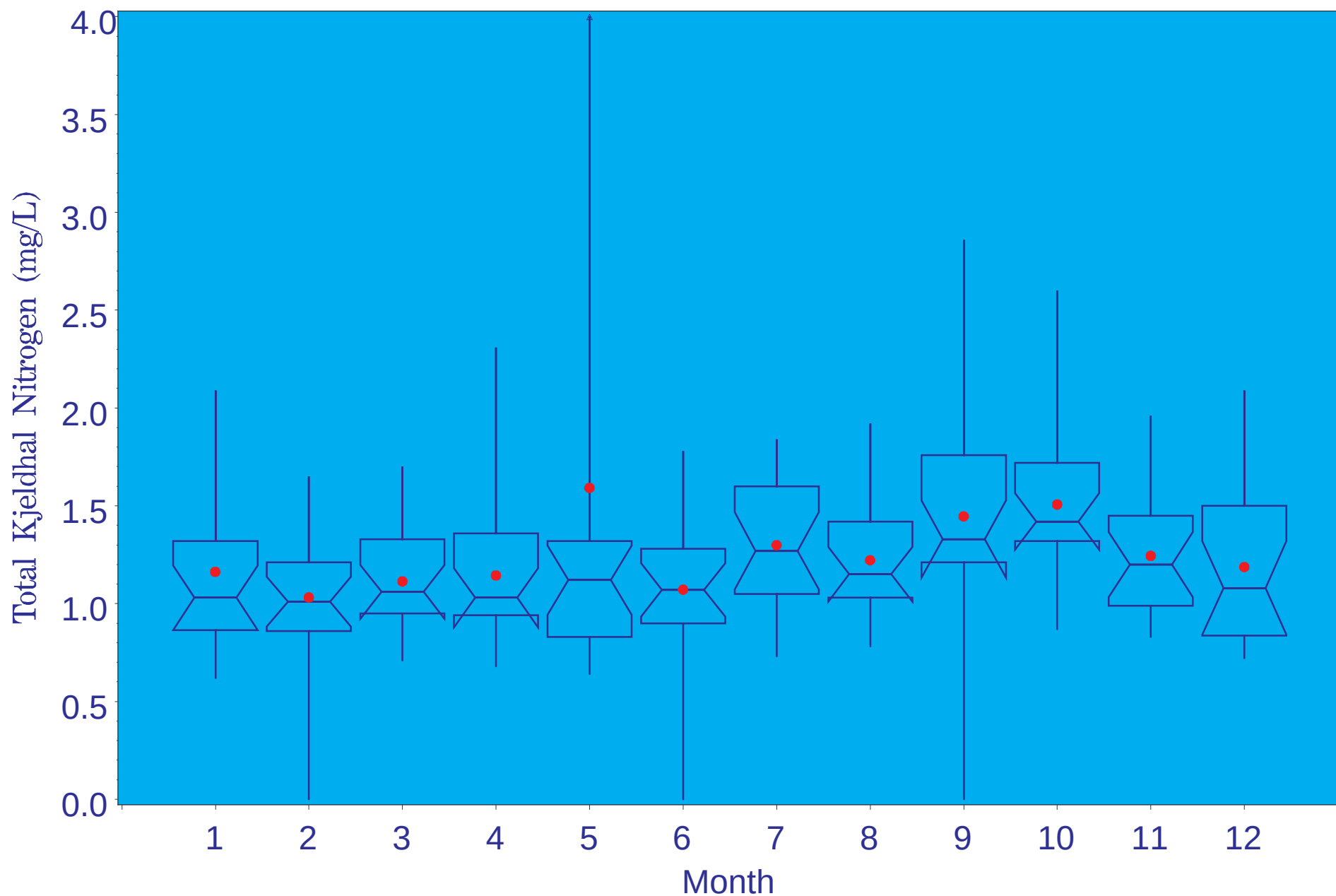


Figure 4.6.85 Mean monthly boxplots of total Kjeldhal nitrogen - 6 ppt isohaline (1984-2002)

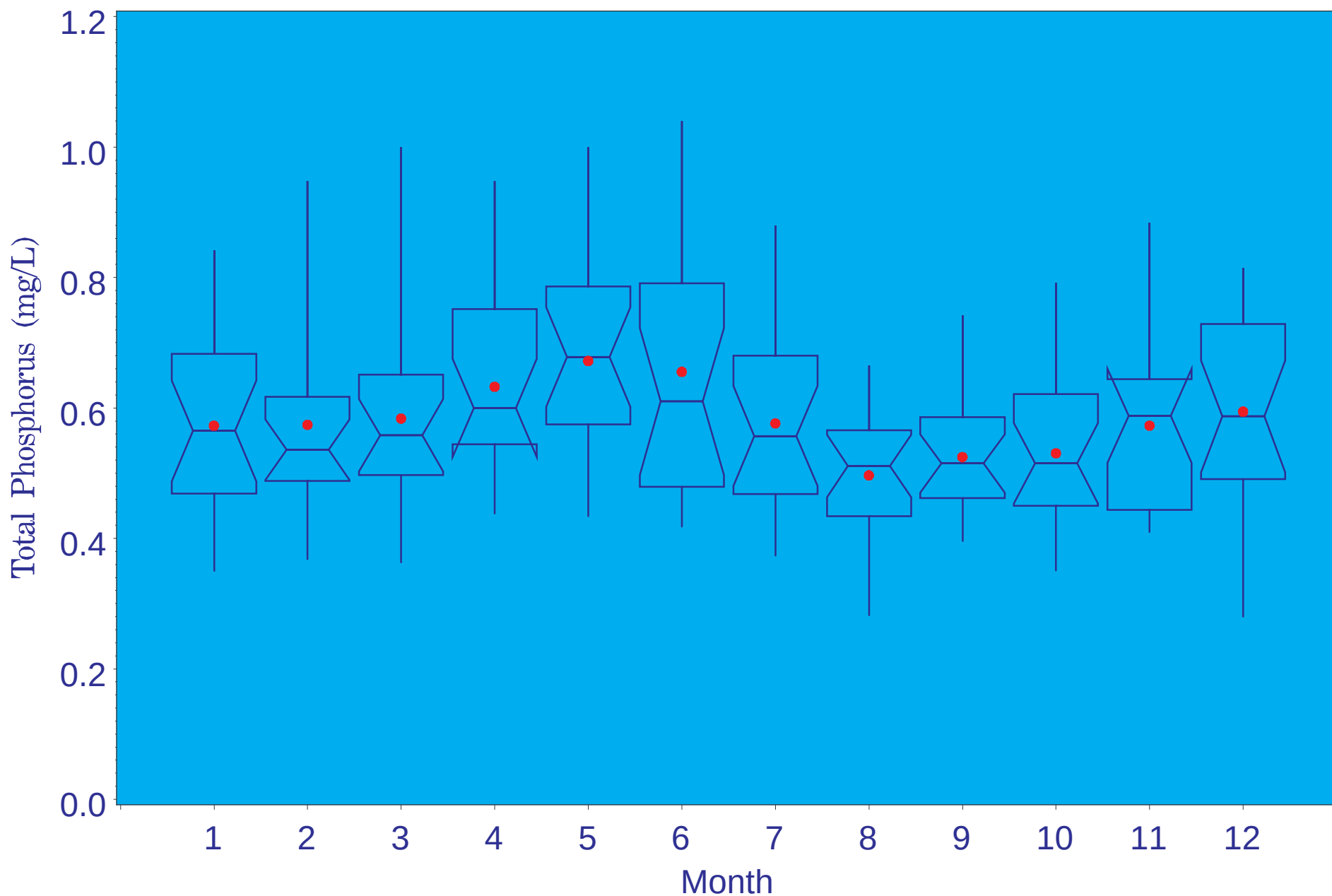


Figure 4.6.86 Mean monthly boxplots of total phosphorus - 6 ppt isohaline (1984-2002)



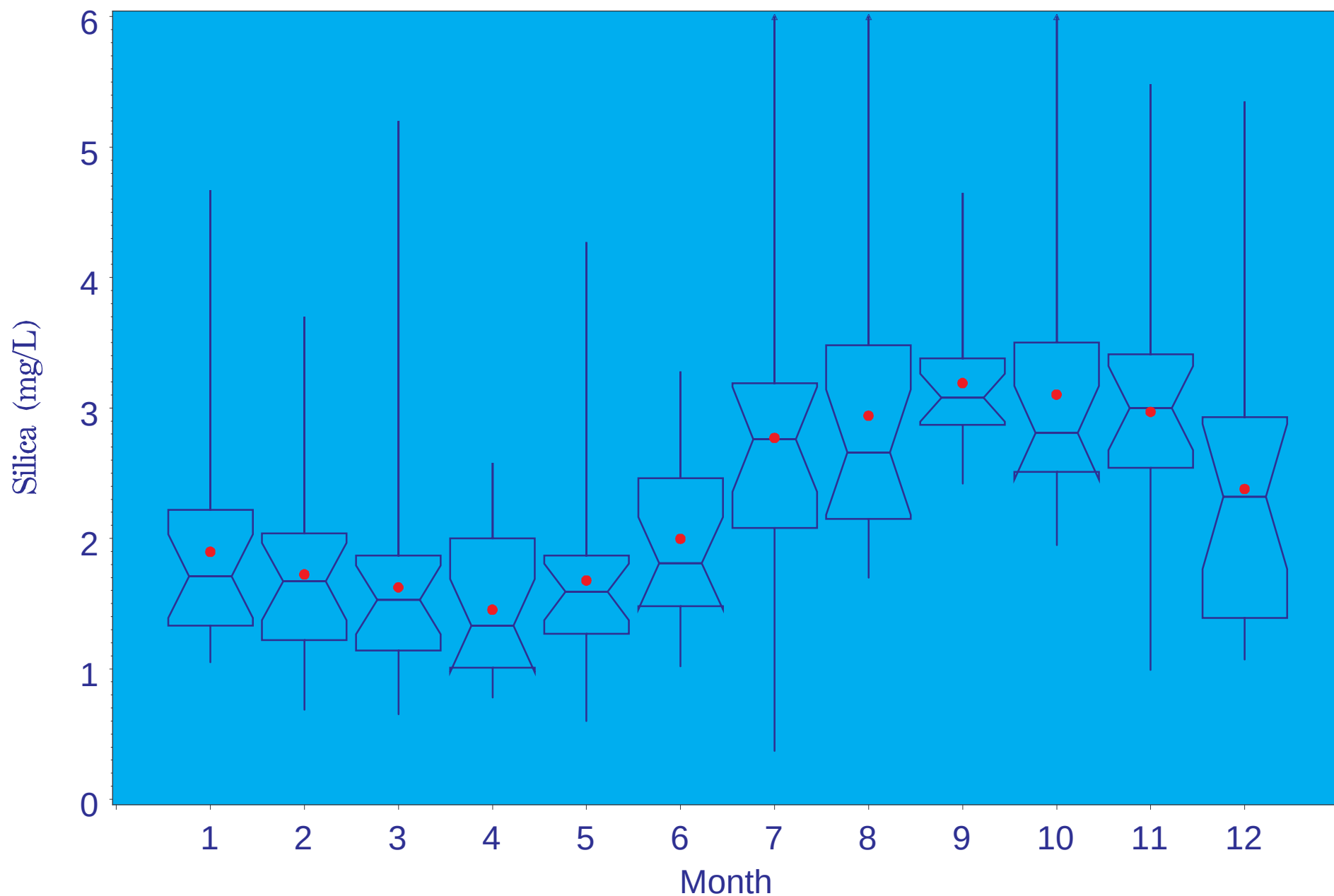


Figure 4.6.87 Mean monthly boxplots of silica - 6 ppt isohaline (1984-2002)

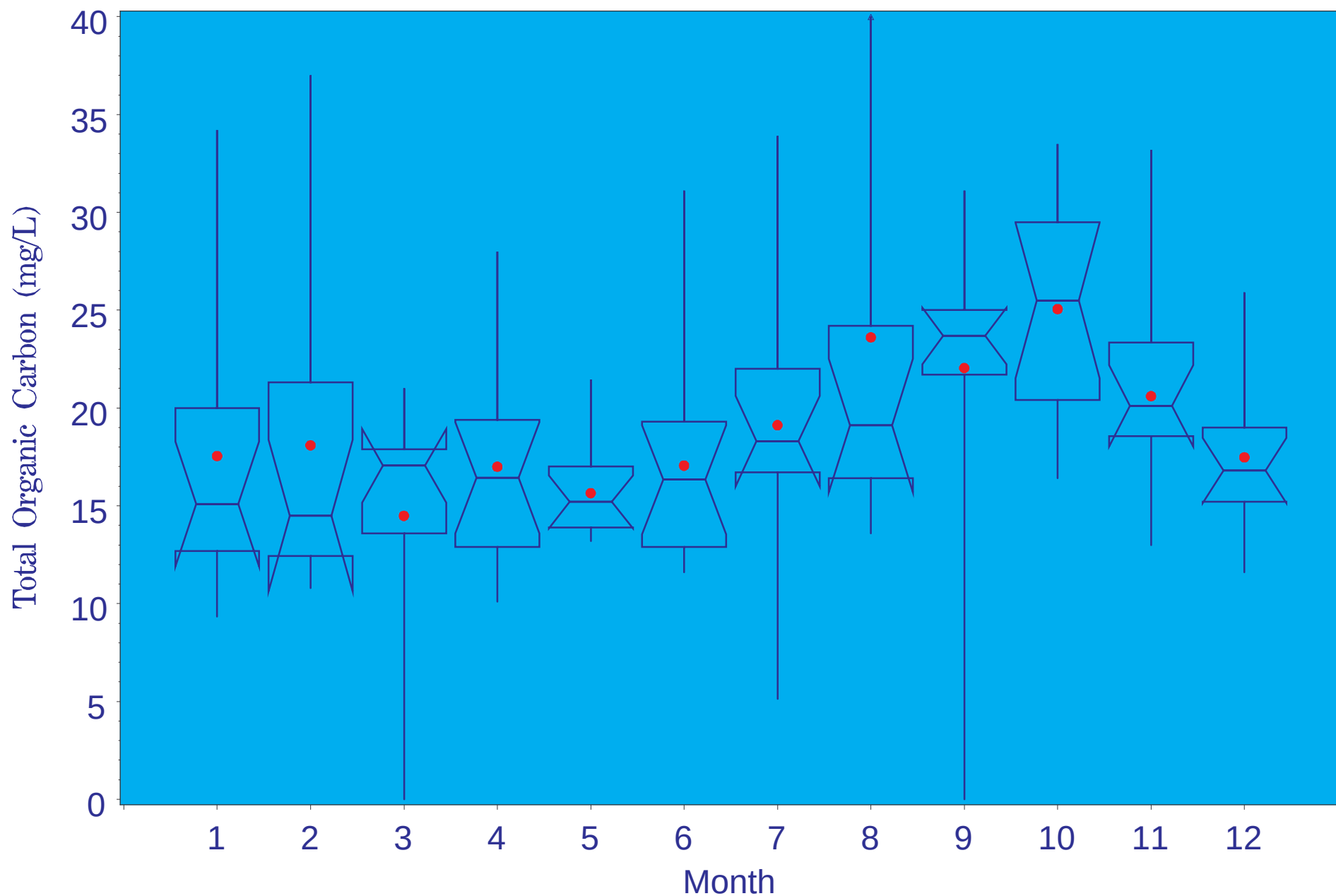


Figure 4.6.88 Mean monthly boxplots of total organic carbon - 6 ppt isohaline (1984-2002)

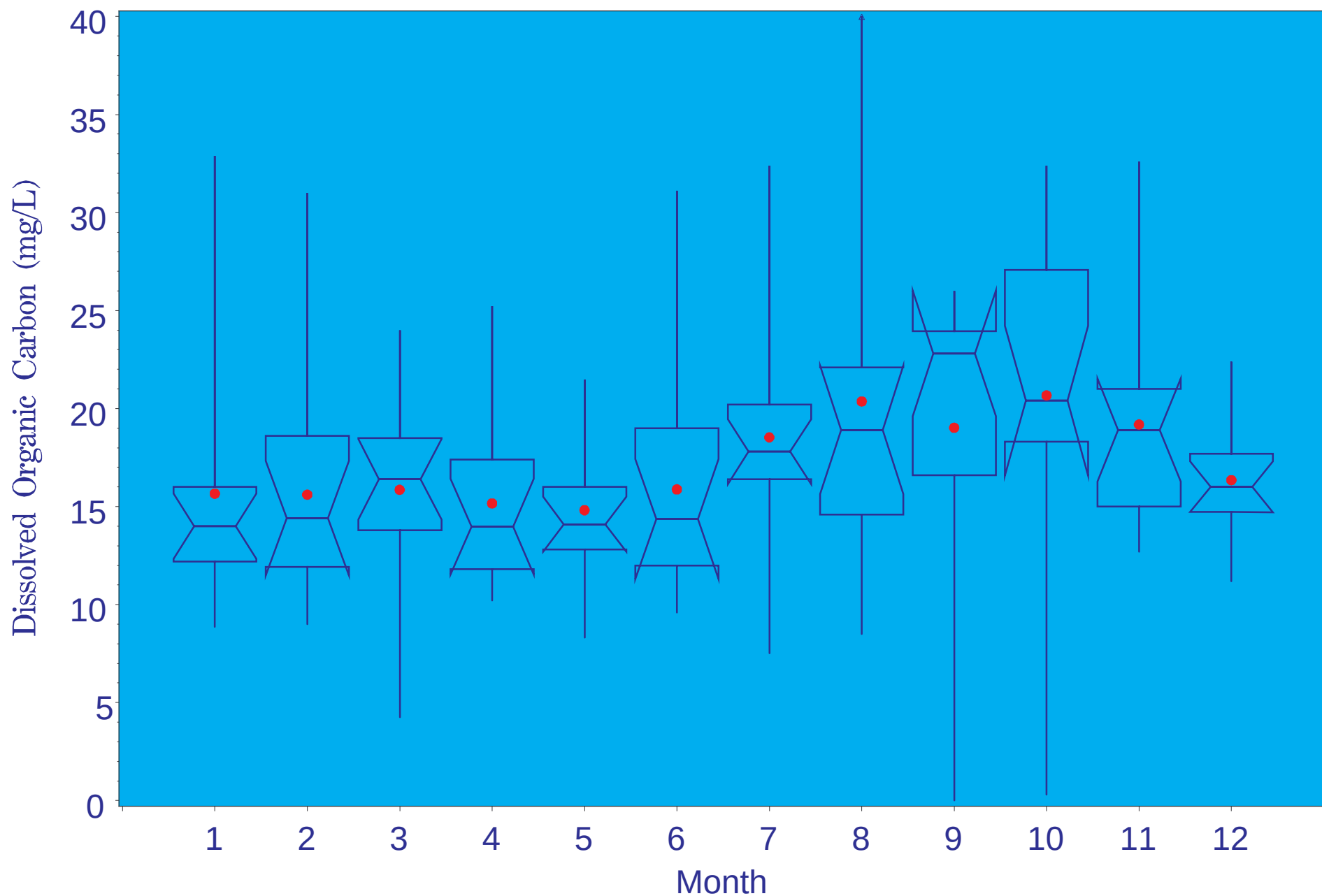


Figure 4.6.89 Mean monthly boxplots of dissolved organic carbon - 6 ppt isohaline (1984-2002)

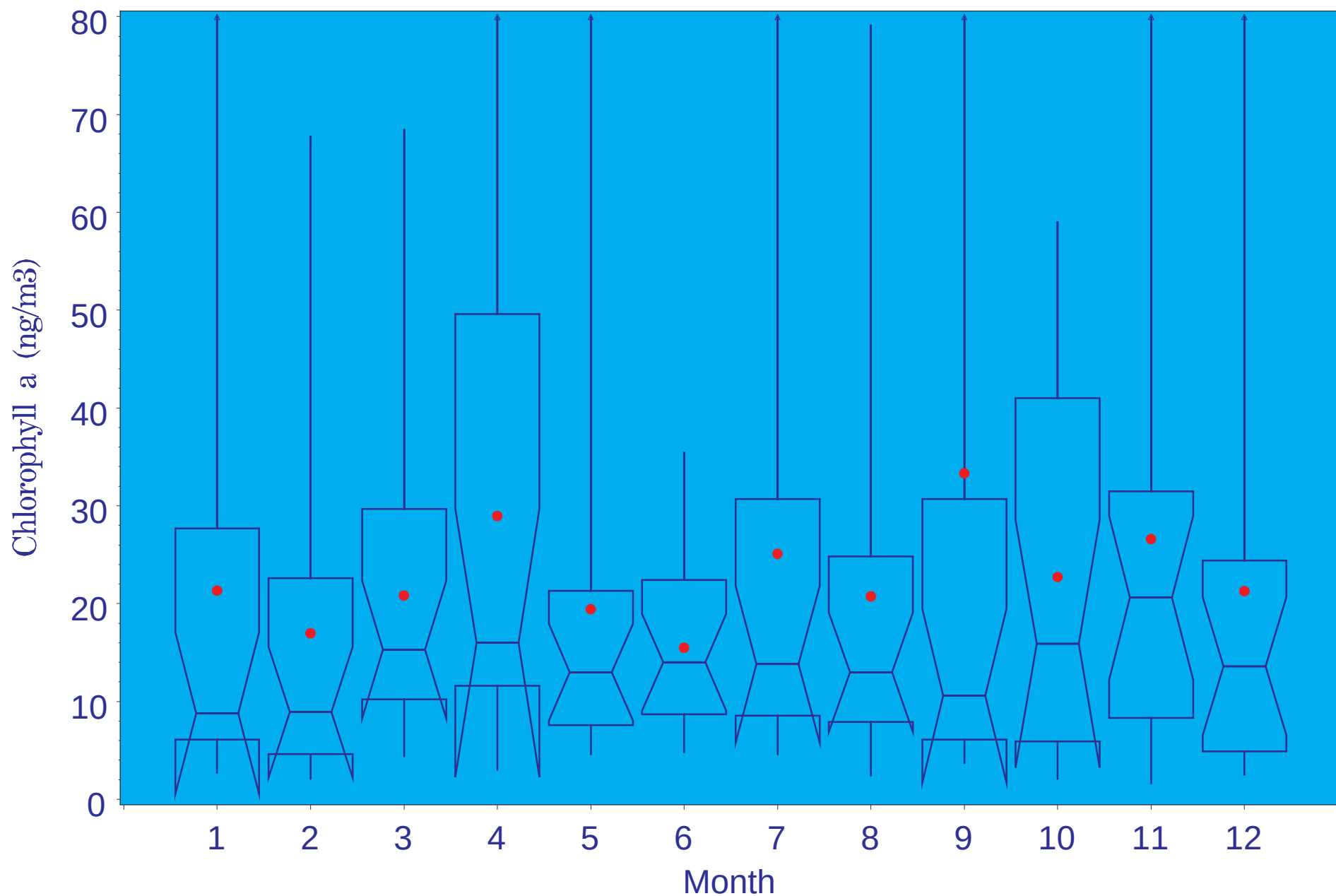


Figure 4.6.90 Mean monthly boxplots of chlorophyll a - 6 ppt isohaline (1984-2002)

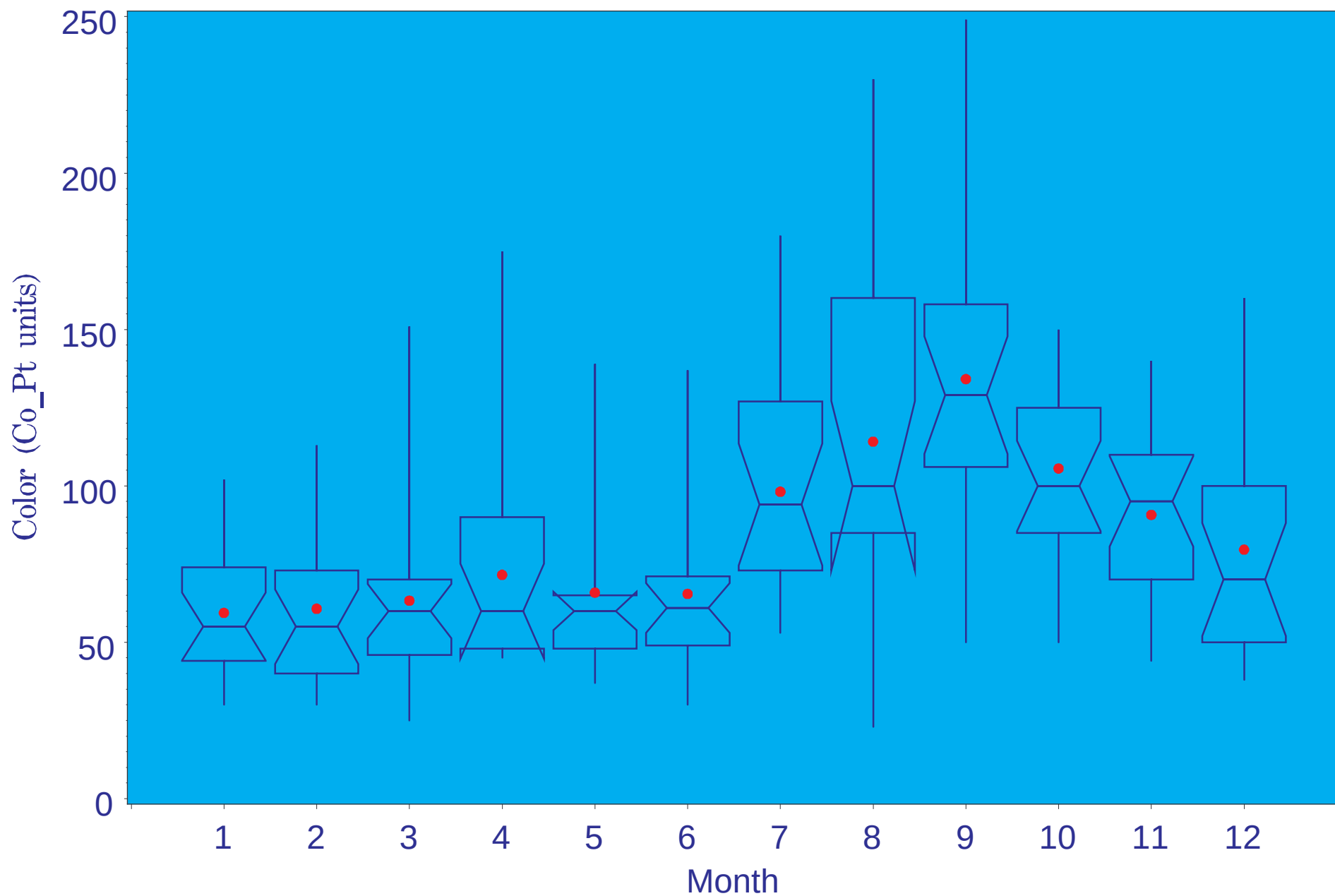


Figure 4.6.91 Mean monthly boxplots of water color - 12 ppt isohaline (1984-2002)

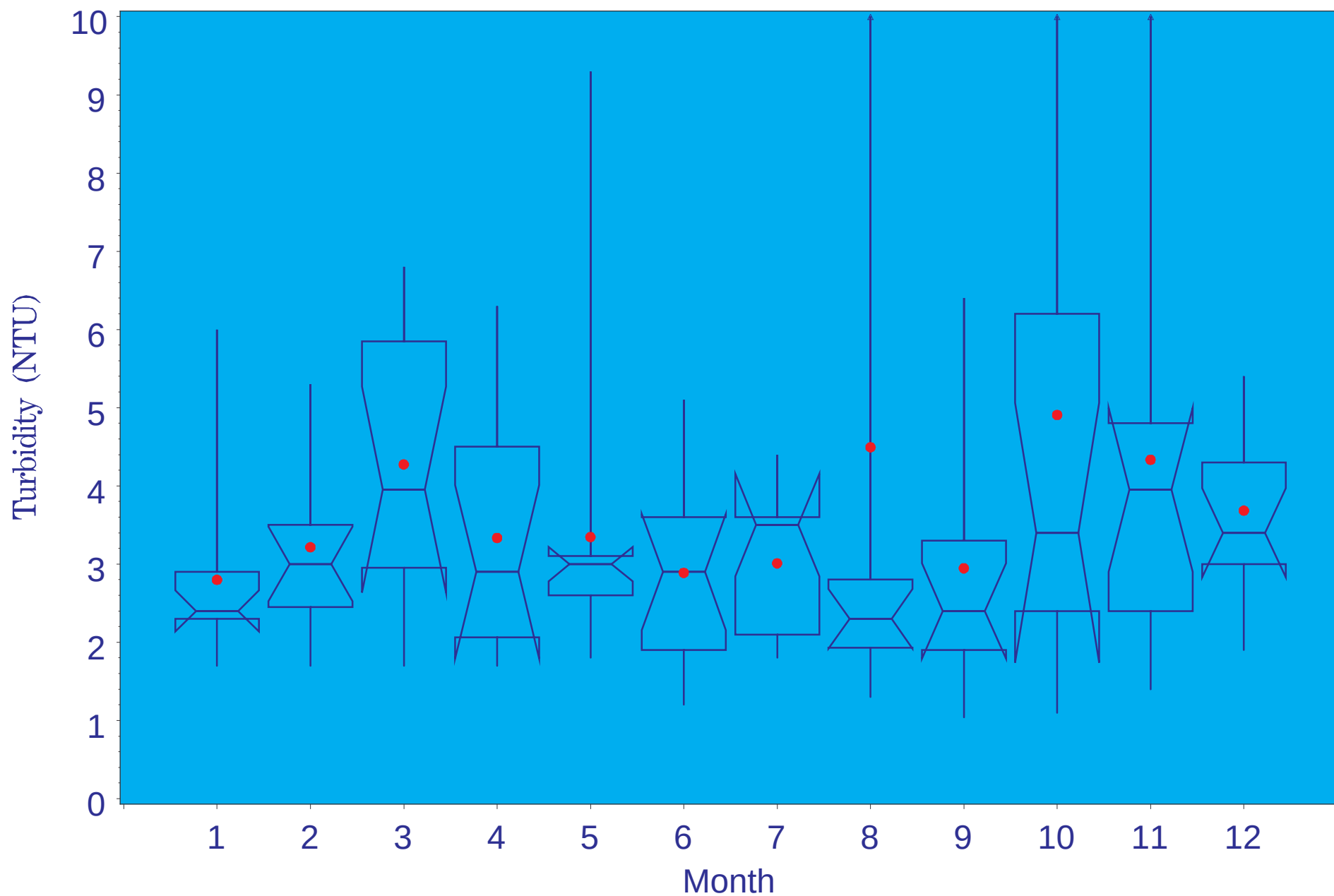


Figure 4.6.92 Mean monthly boxplots of turbidity - 12 ppt isohaline (1984-2002)

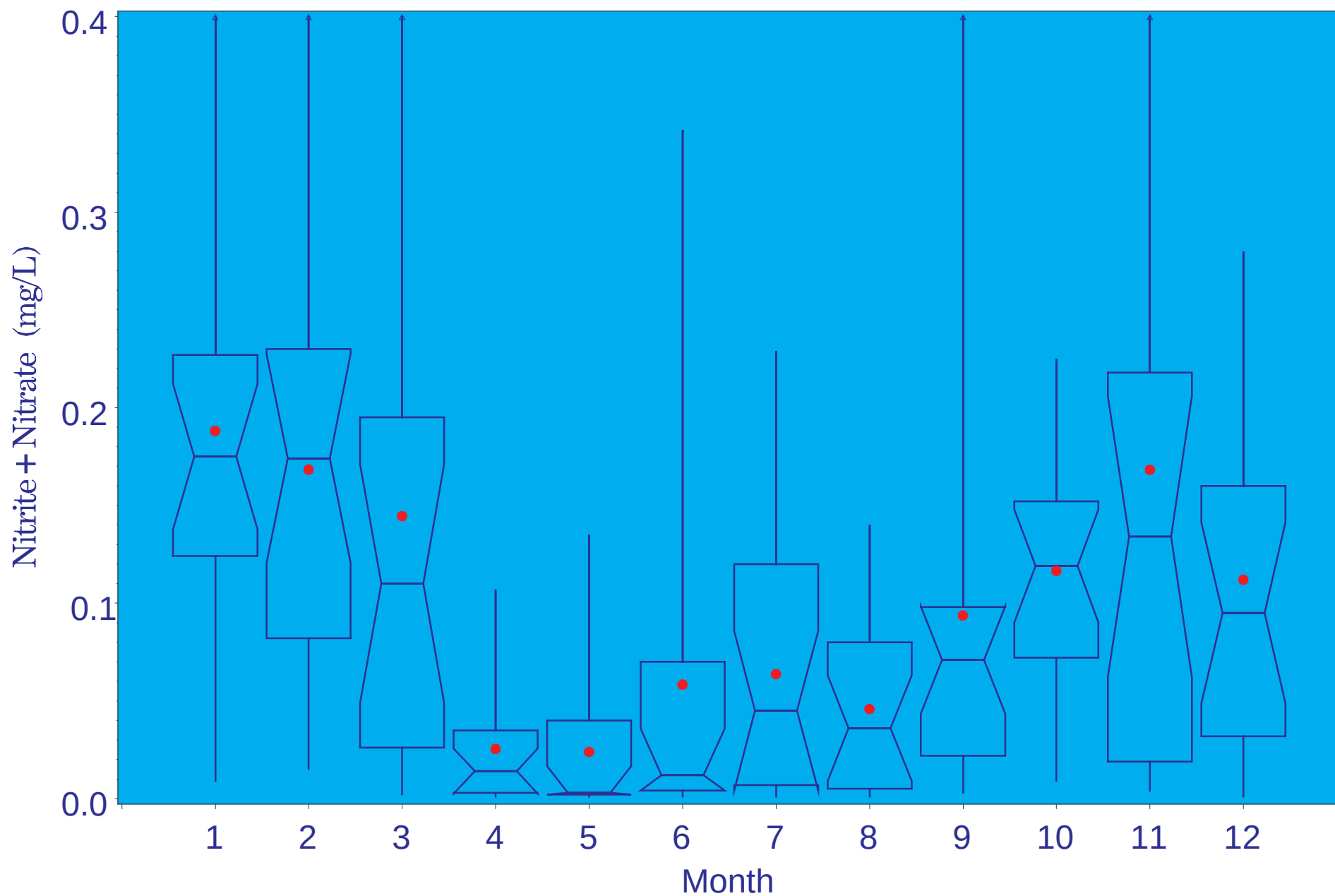


Figure 4.6.93 Mean monthly boxplots of nitrite+nitrate - 12 ppt isohaline (1984-2002)

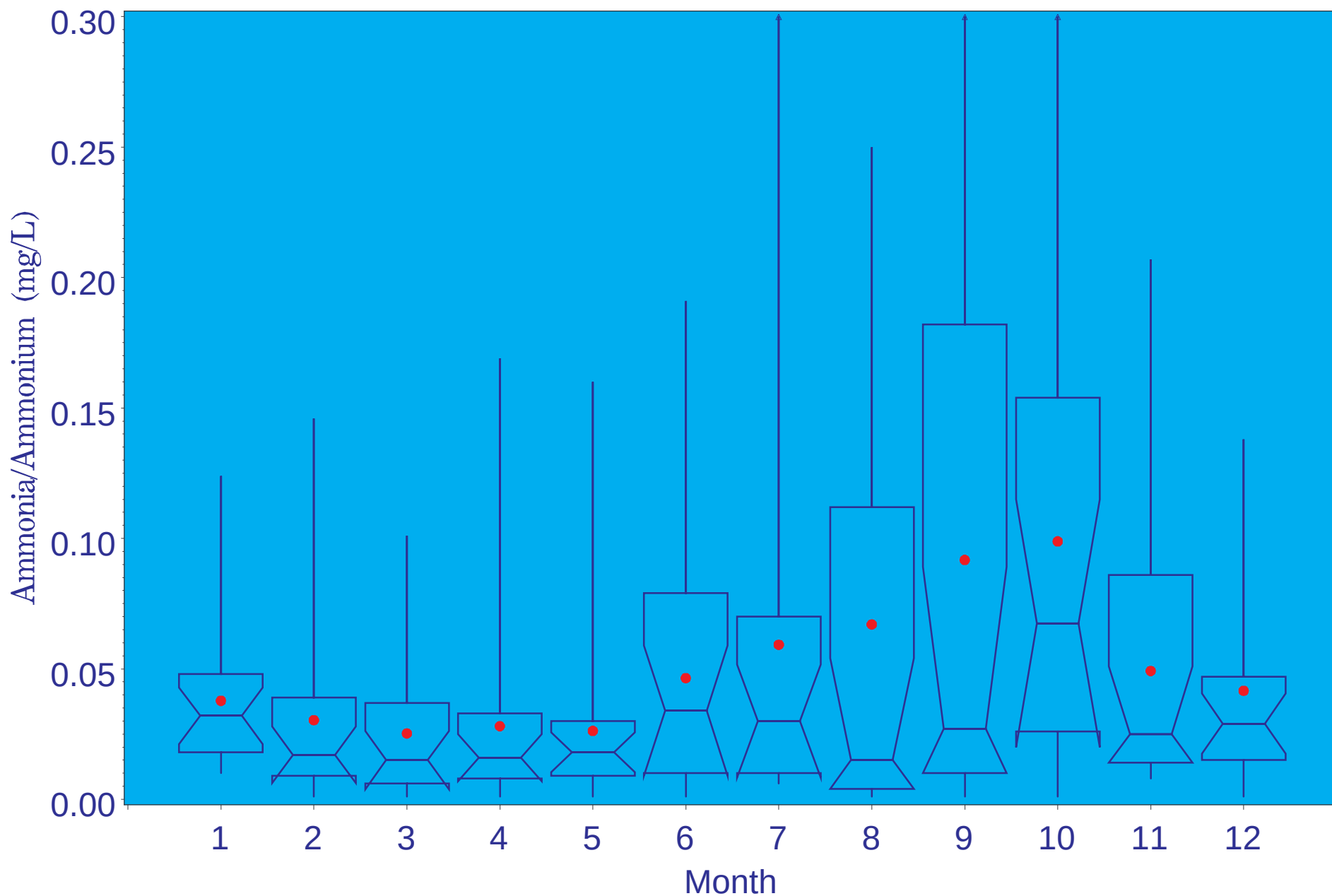


Figure 4.6.94 Mean monthly boxplots of ammonia/ammonium - 12 ppt isohaline (1984-2002)



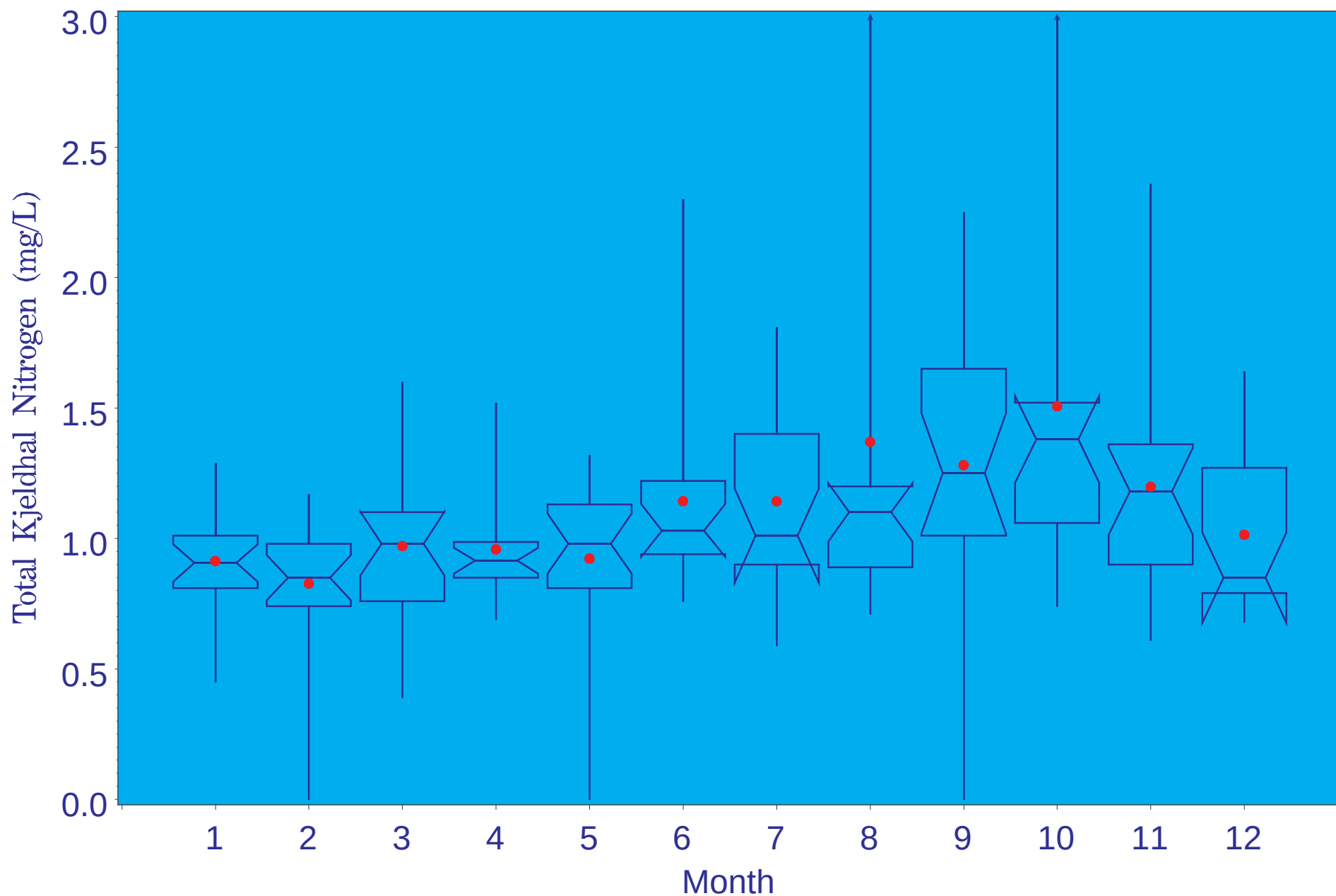


Figure 4.6.95 Mean monthly boxplots of total Kjeldhal nitrogen - 12 ppt isohaline (1984-2002)

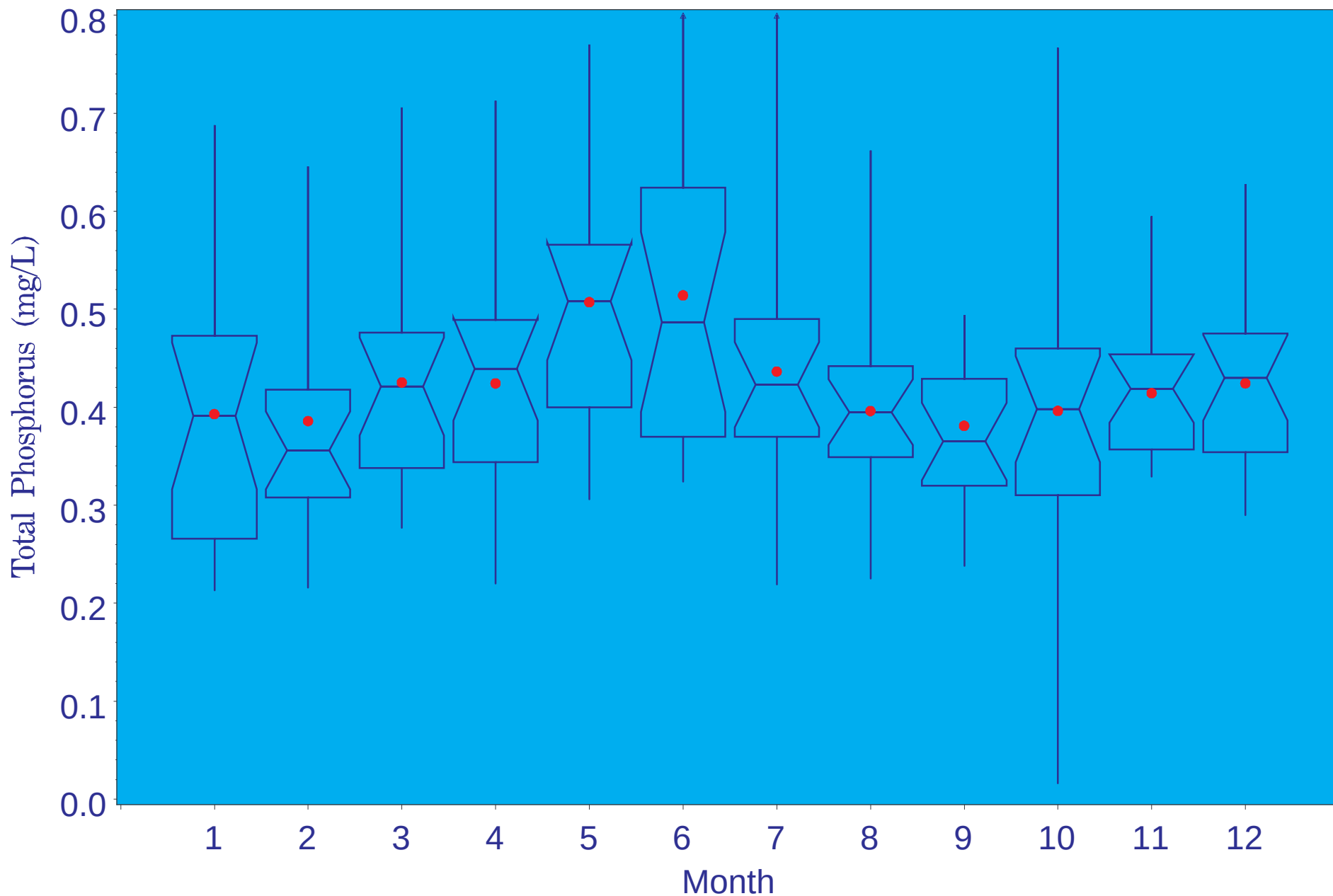


Figure 4.6.96 Mean monthly boxplots of total phosphorus - 12 ppt isohaline (1984-2002)

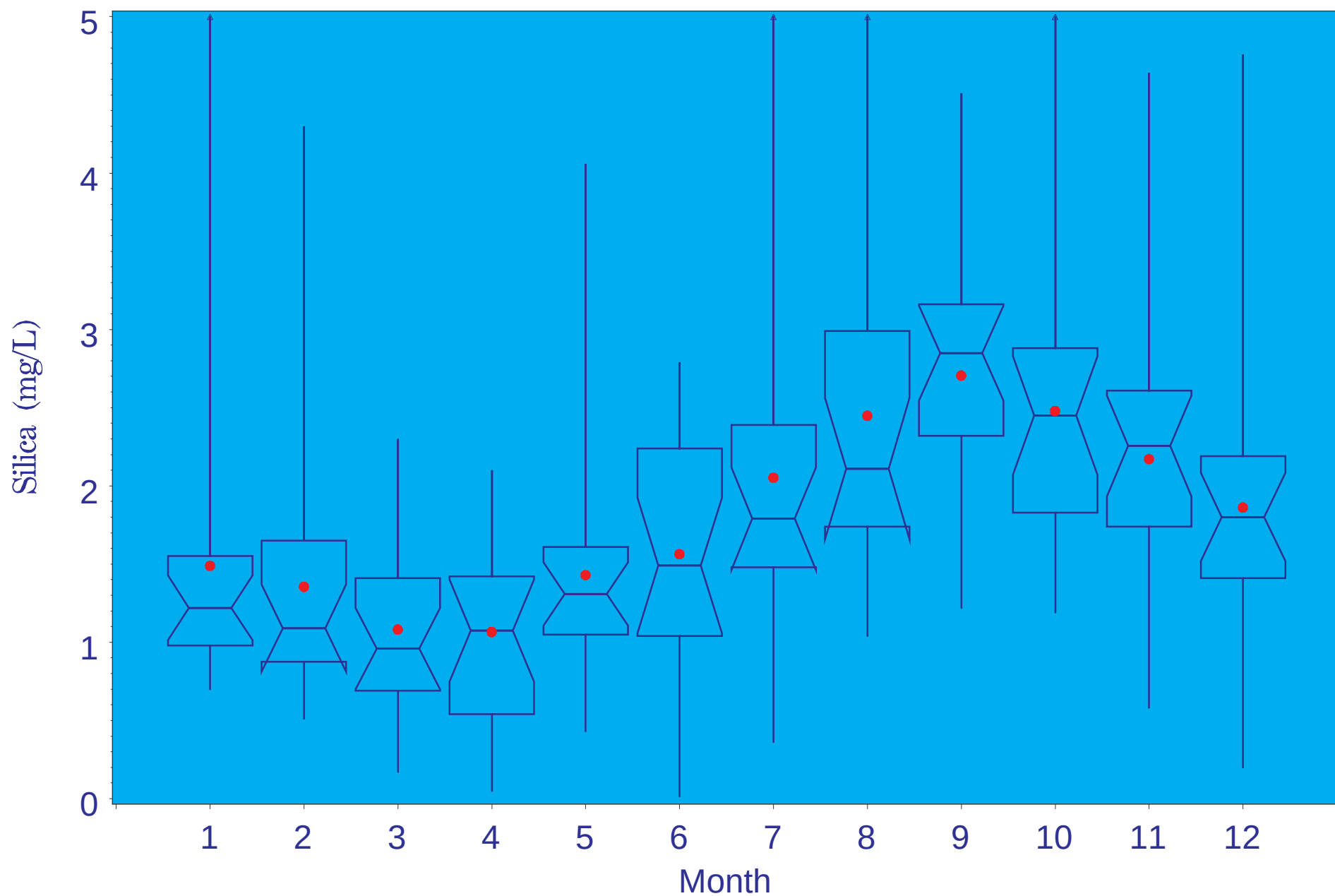


Figure 4.6.97 Mean monthly boxplots of silica - 12 ppt isohaline (1984-2002)

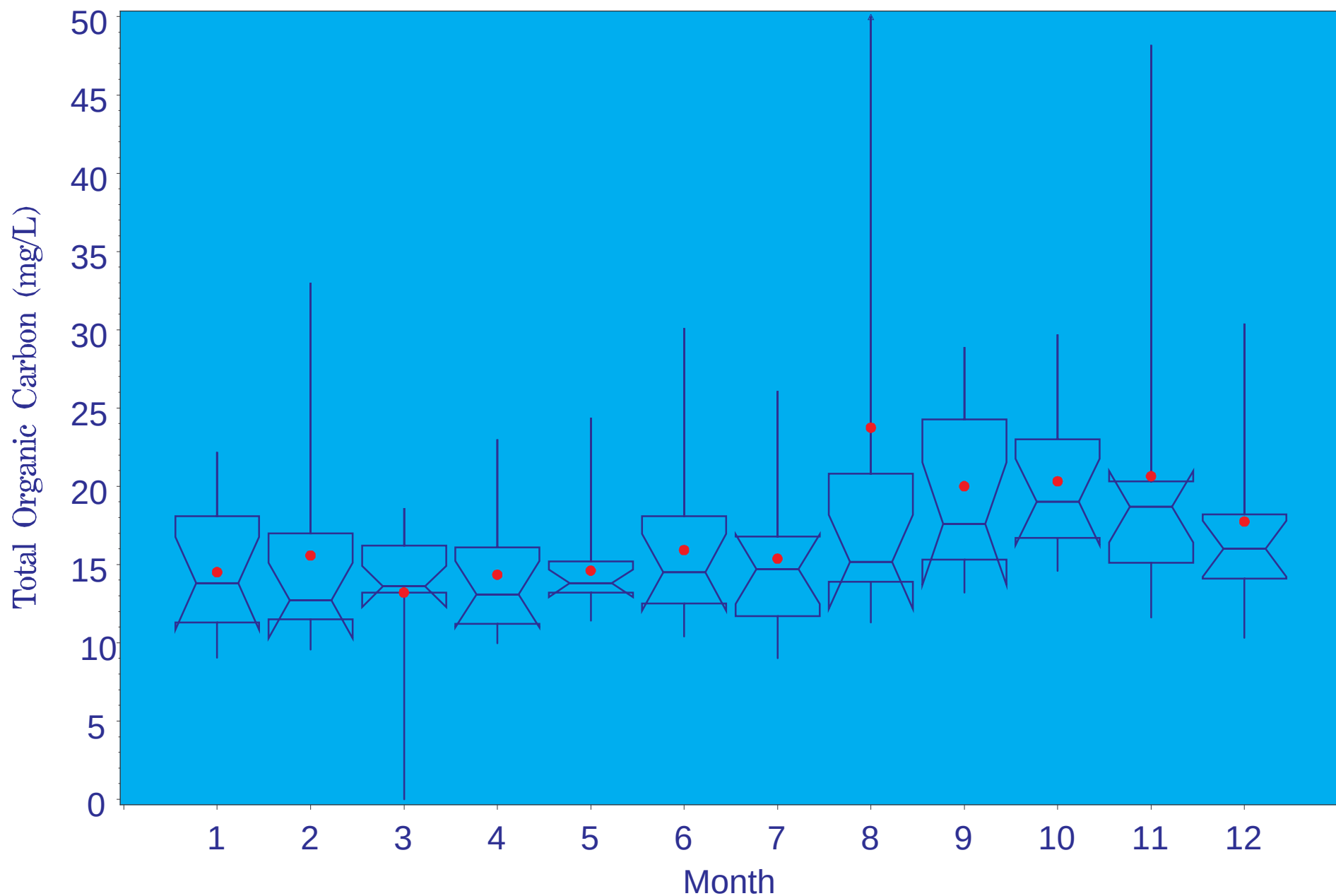


Figure 4.6.98 Mean monthly boxplots of total organic carbon - 12 ppt isohaline (1984-2002)

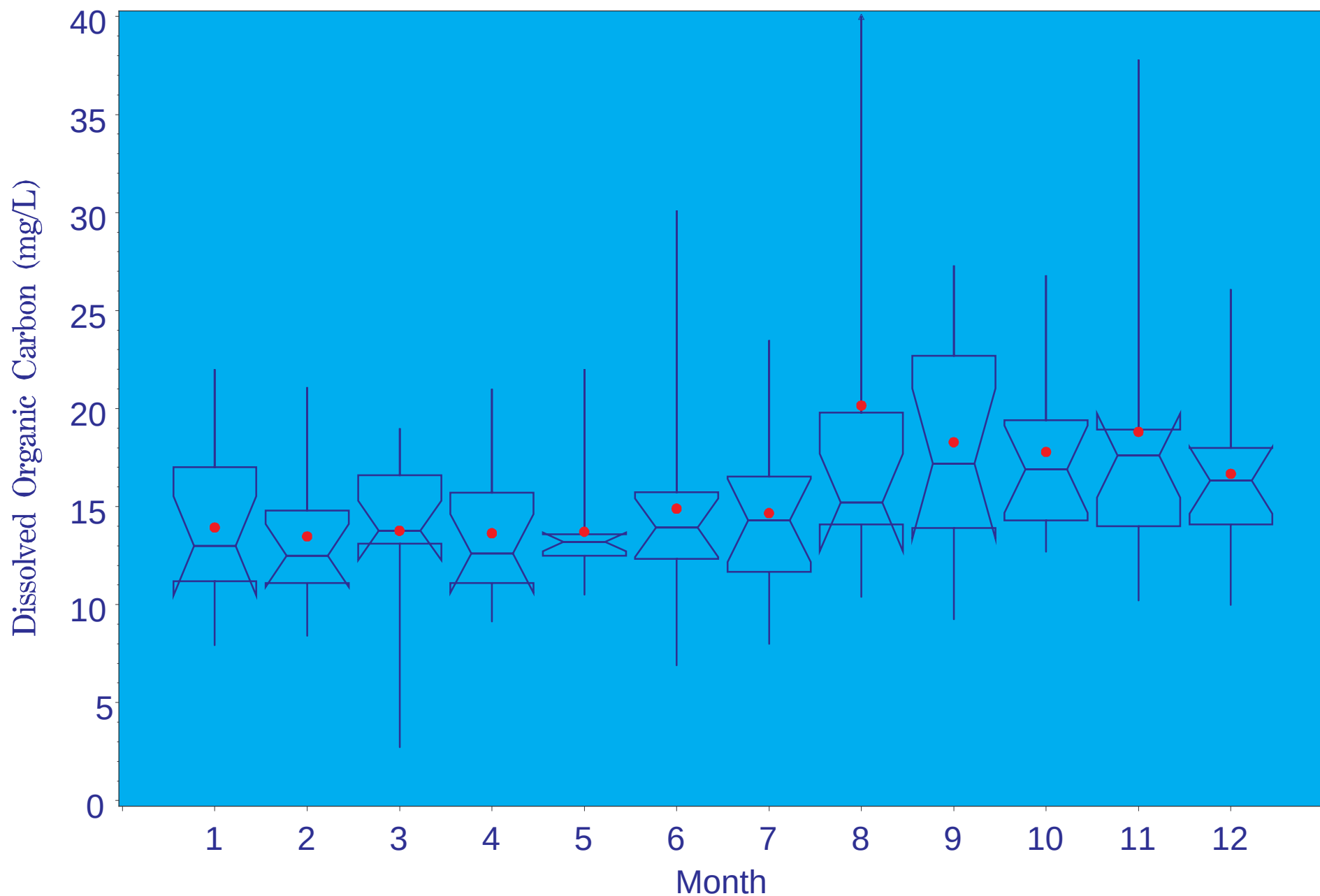


Figure 4.6.99 Mean monthly boxplots of dissolved organic carbon - 12 ppt isohaline (1984-2002)

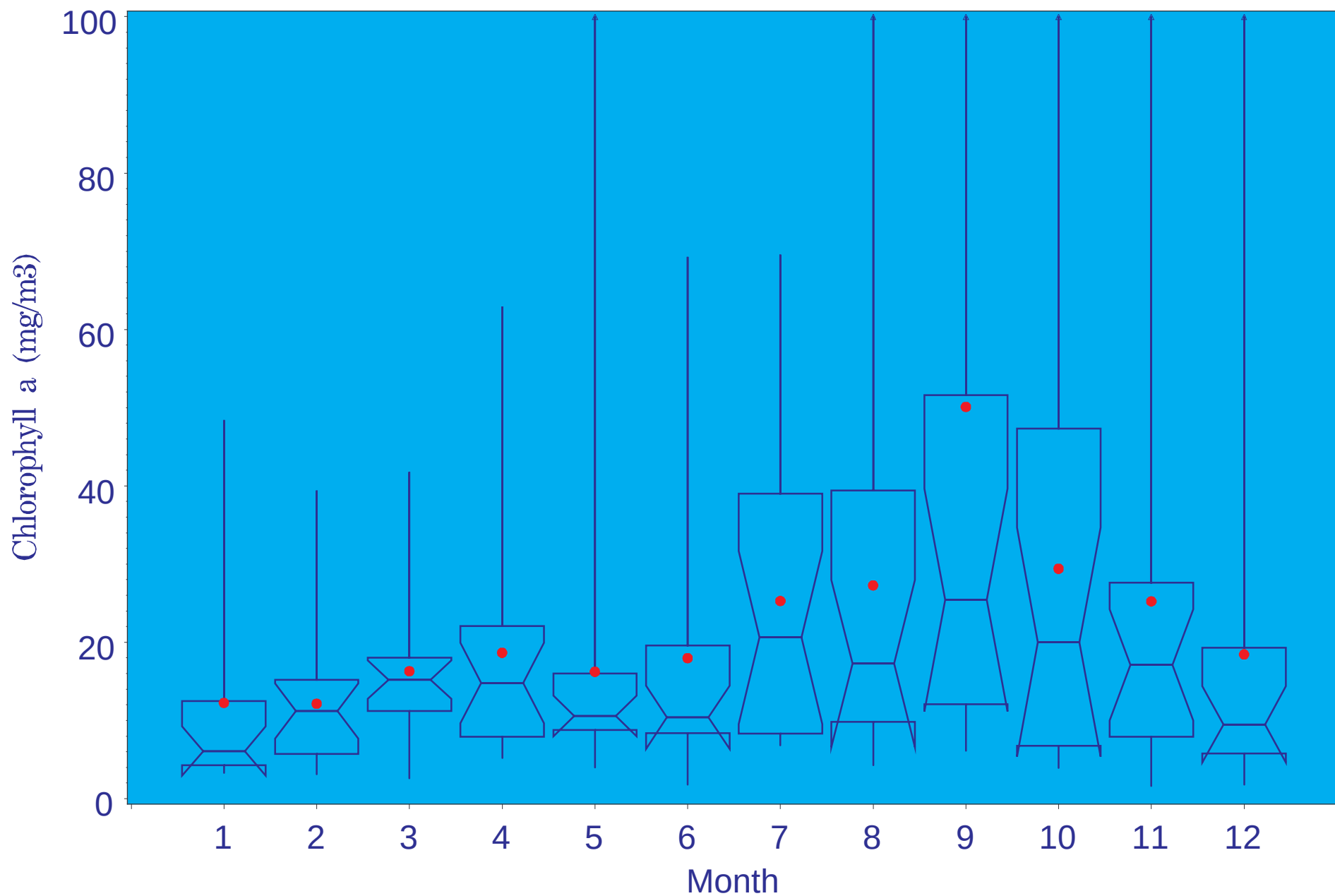


Figure 4.6.100 Mean monthly boxplots of chlorophyll a - 12 ppt isohaline (1984-2002)

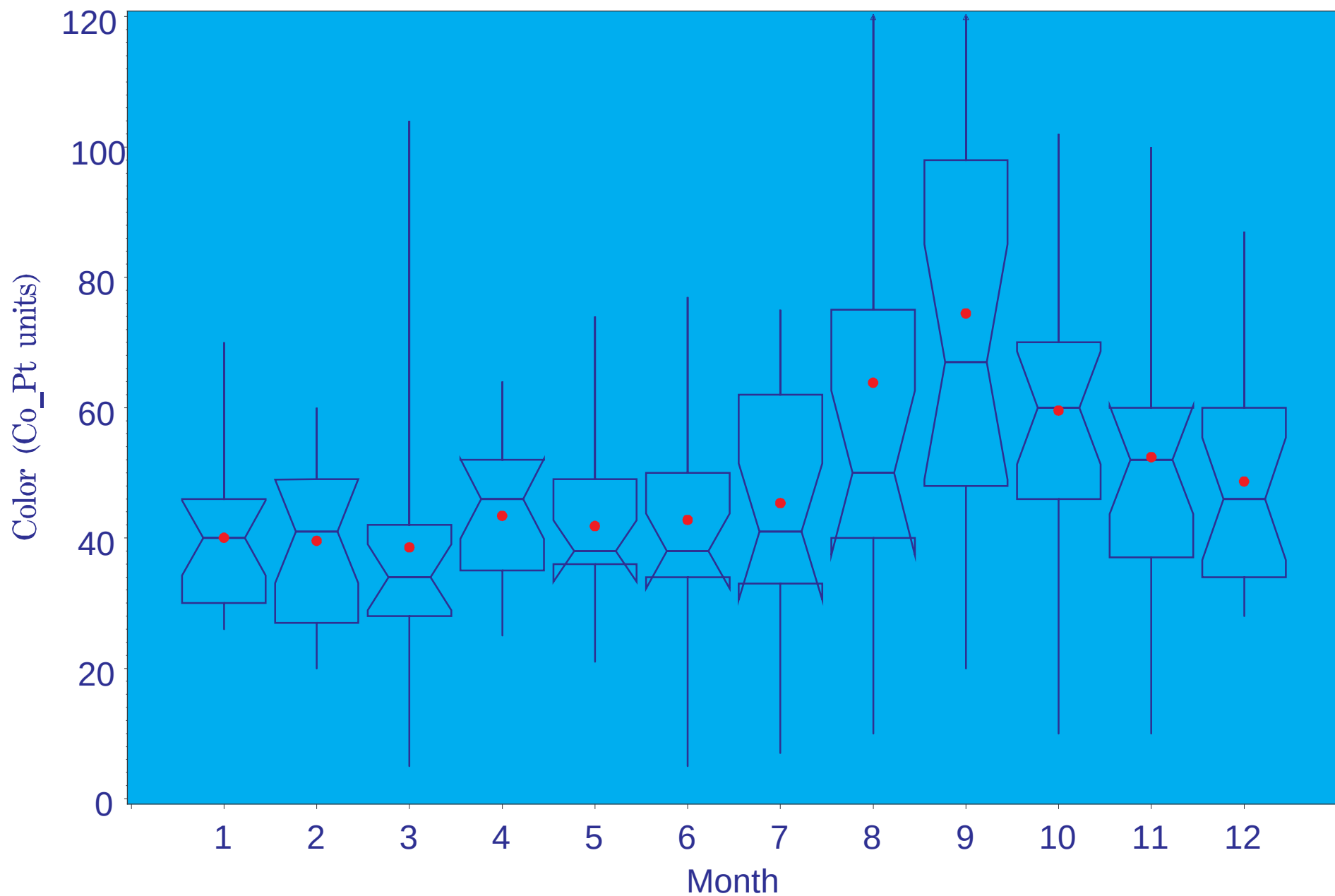


Figure 4.6.101 Mean monthly boxplots of water color - 20 ppt isohaline (1984-2002)

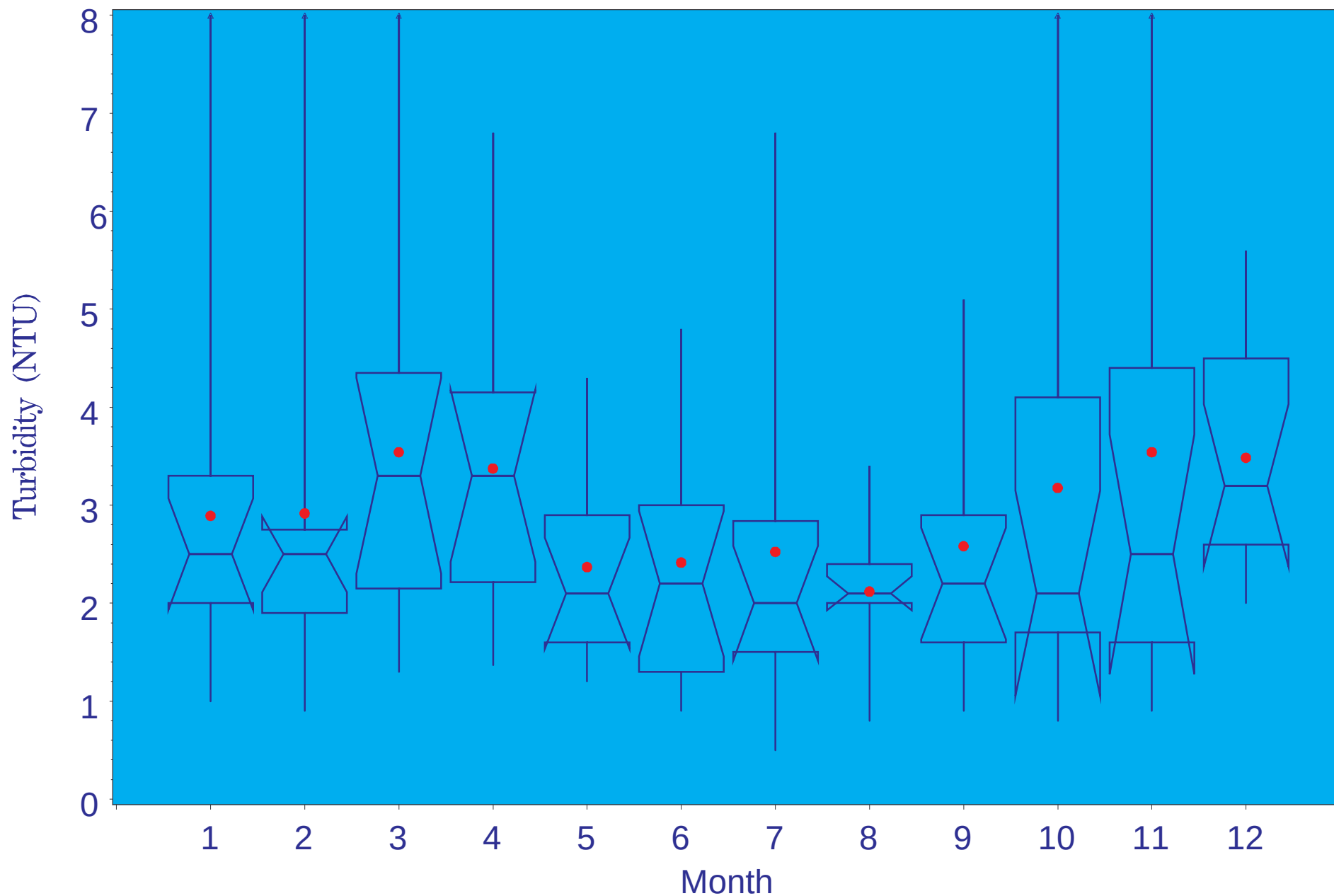


Figure 4.6.102 Mean monthly boxplots of turbidity - 20 ppt isohaline (1984-2002)



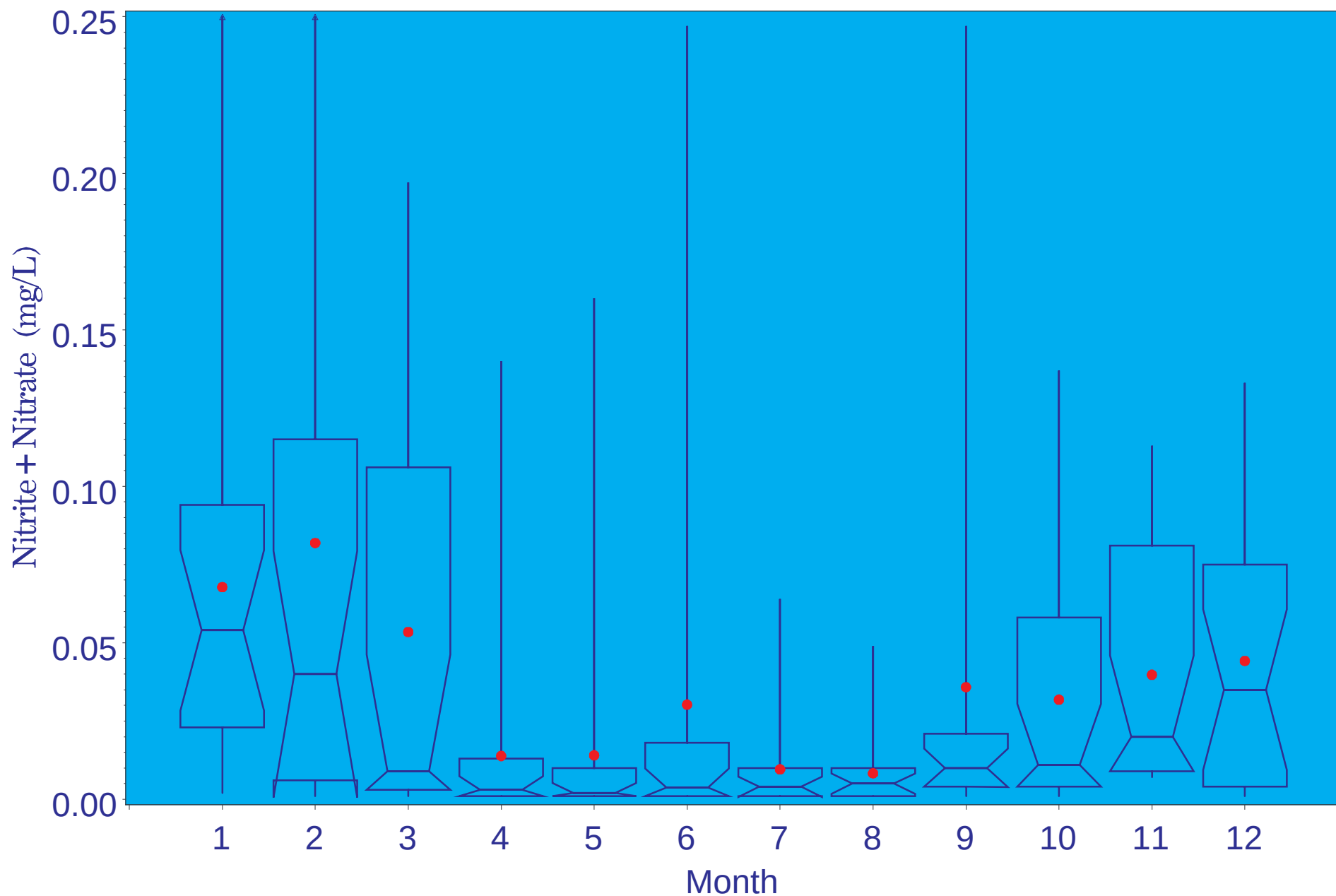


Figure 4.6.103 Mean monthly boxplots of nitrite+nitrate - 20 ppt isohaline (1984-2002)

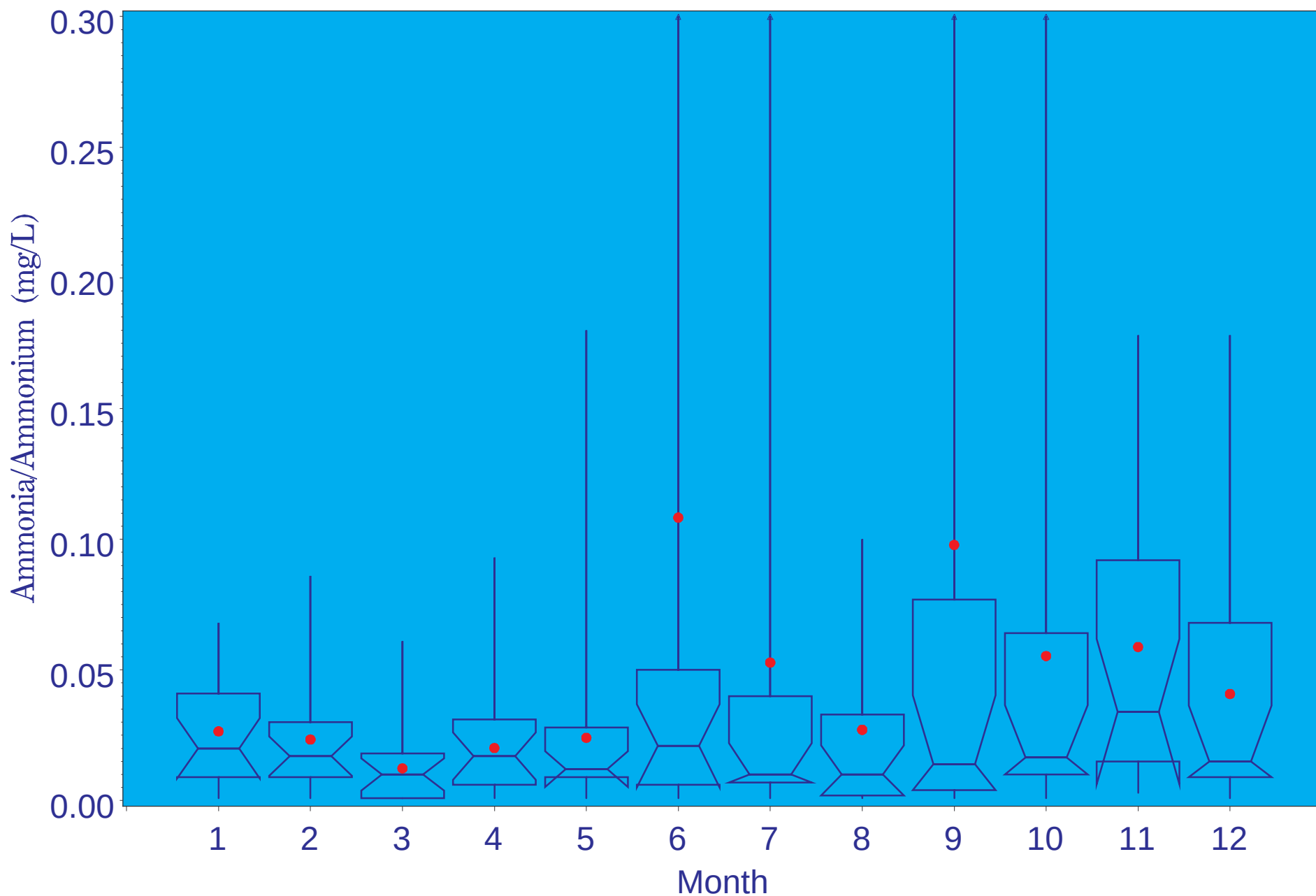


Figure 4.6.104 Mean monthly boxplots of ammonia/ammonium - 20 ppt isohaline (1984-2002)

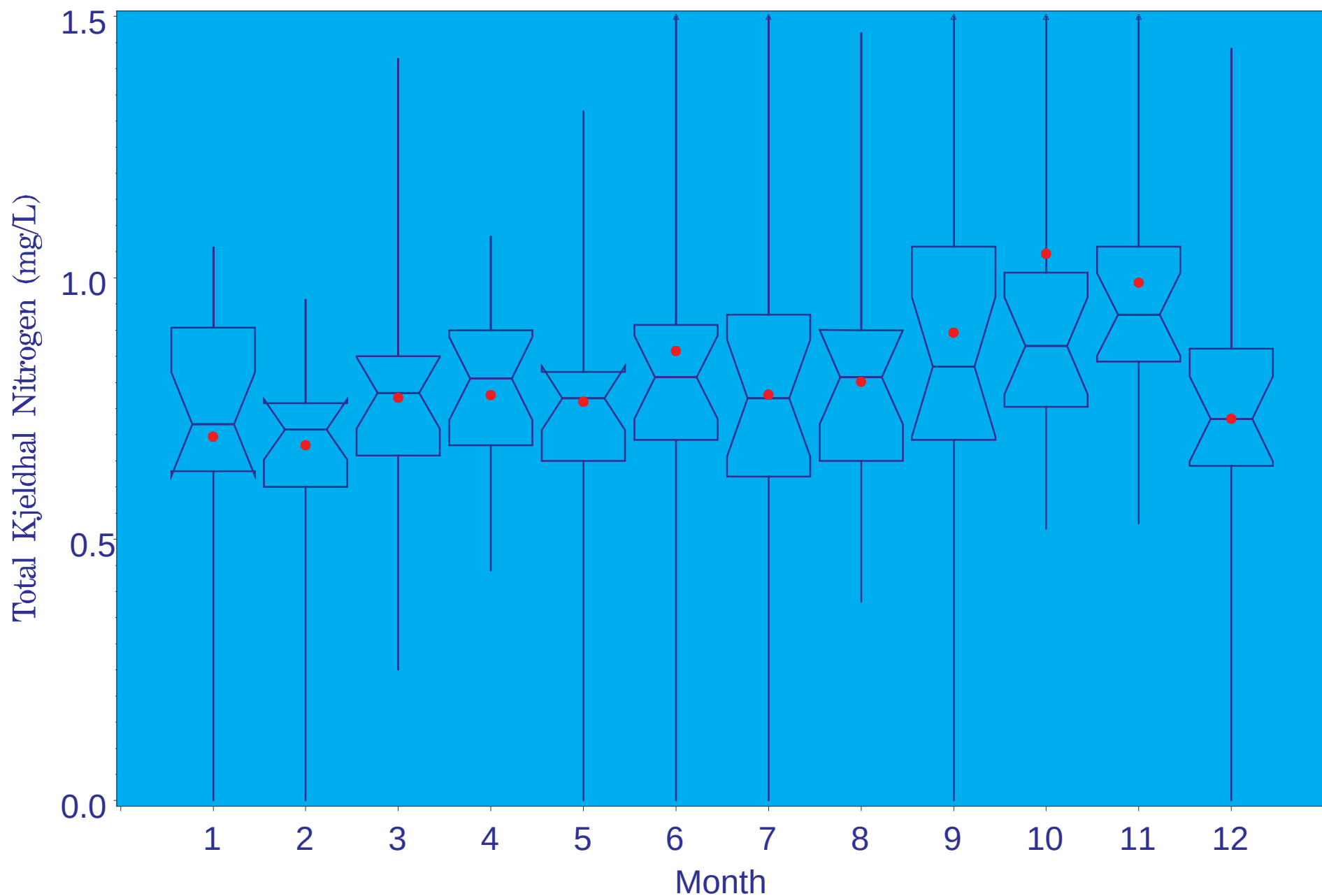


Figure 4.6.105 Mean monthly boxplots of total Kjeldhal nitrogen - 20 ppt isohaline (1984-2002)

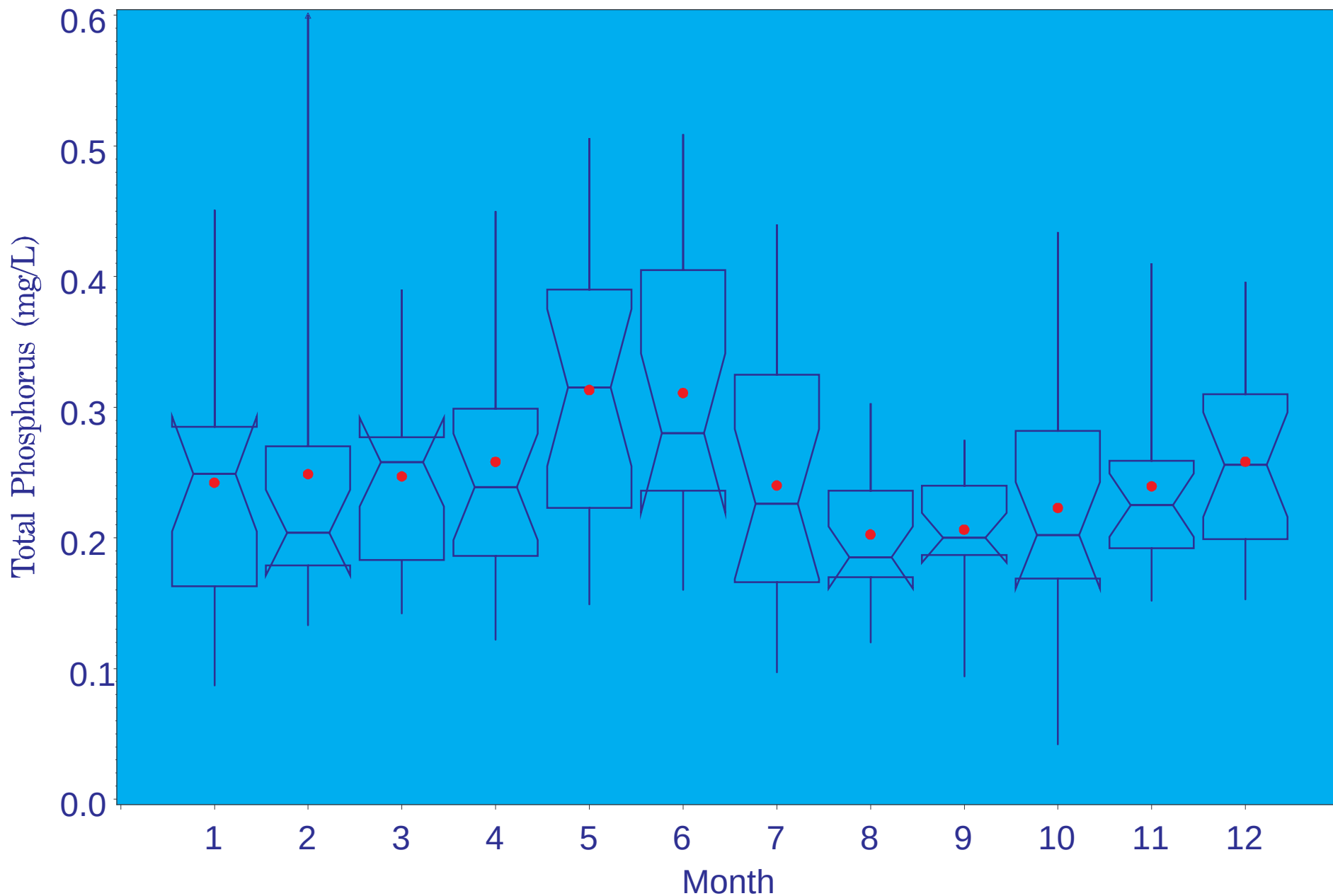


Figure 4.6.106 Mean monthly boxplots of total phosphorus - 20 ppt isohaline (1984-2002)

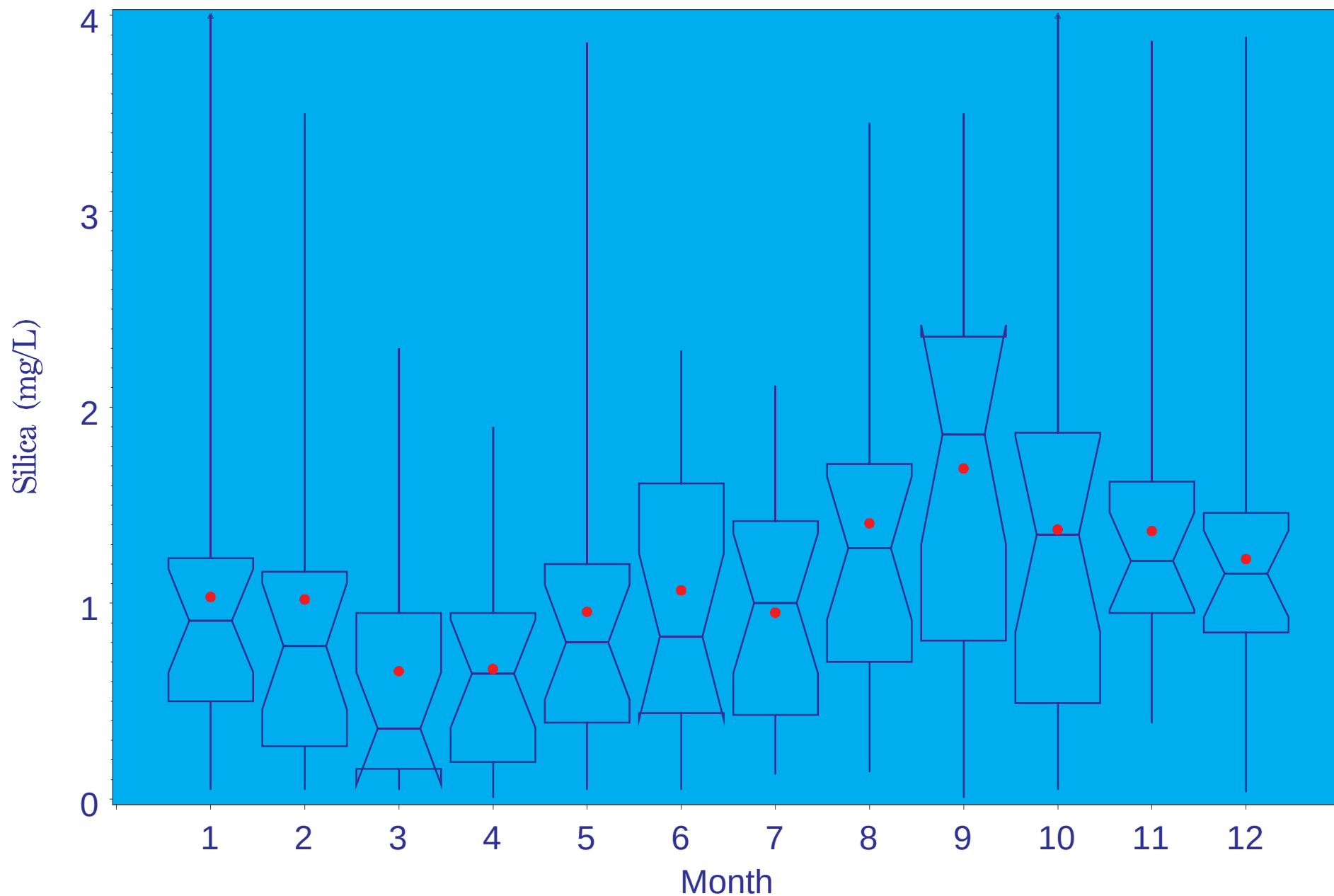


Figure 4.6.107 Mean monthly boxplots of silica - 20 ppt isohaline (1984-2002)

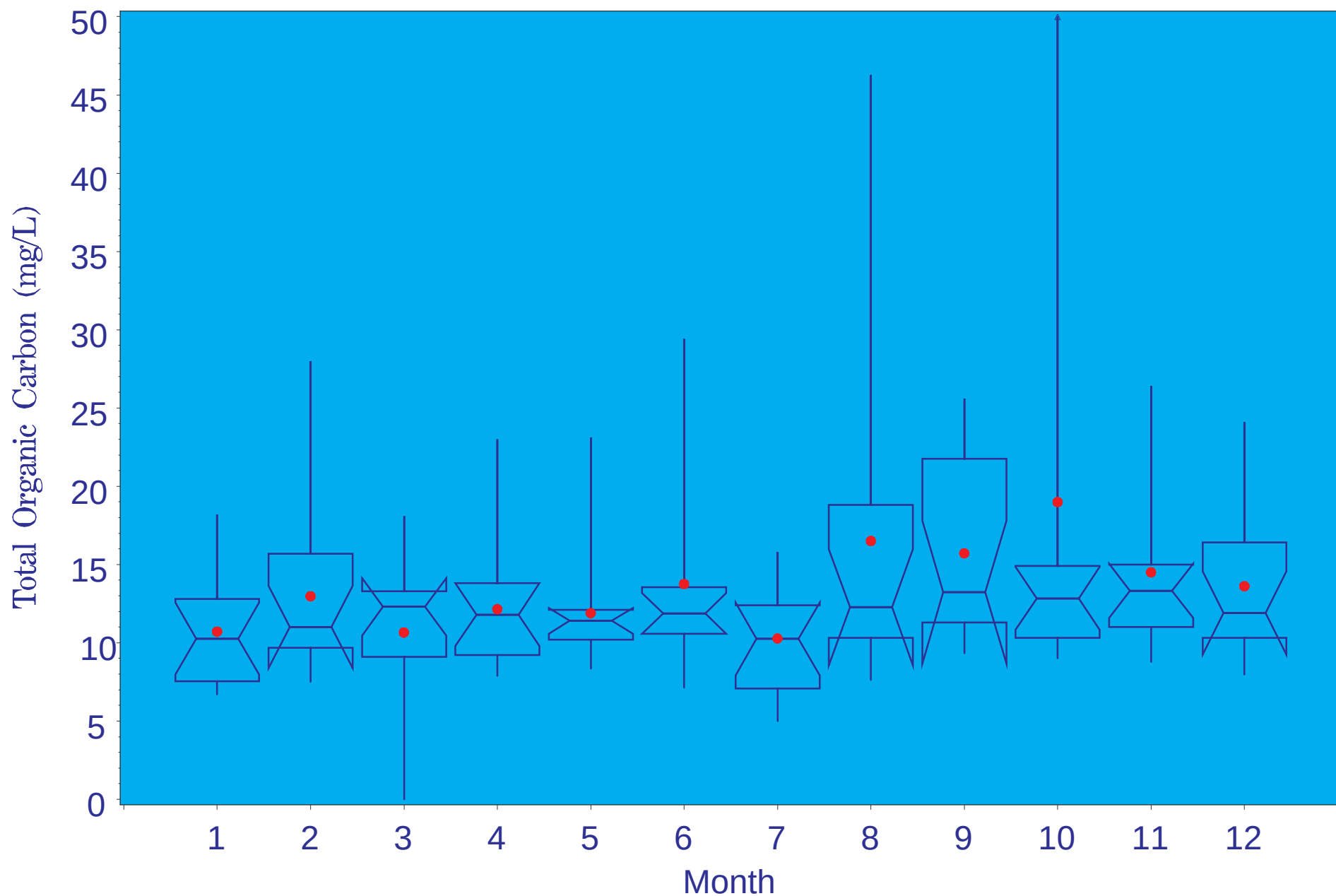


Figure 4.6.108 Mean monthly boxplots of total organic carbon - 20 ppt isohaline (1984-2002)

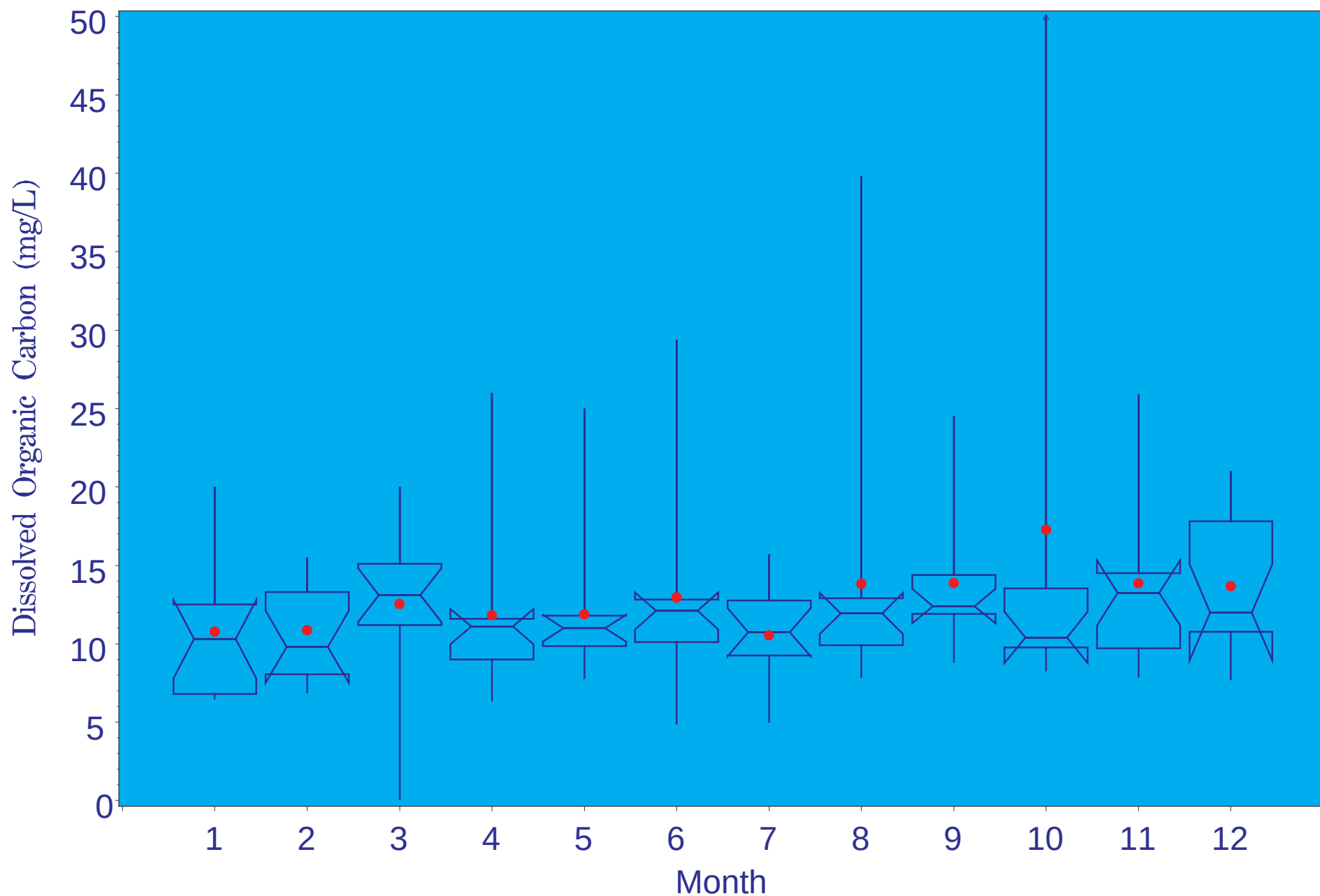


Figure 4.6.109 Mean monthly boxplots of dissolved organic carbon - 20 ppt isohaline (1984-2002)

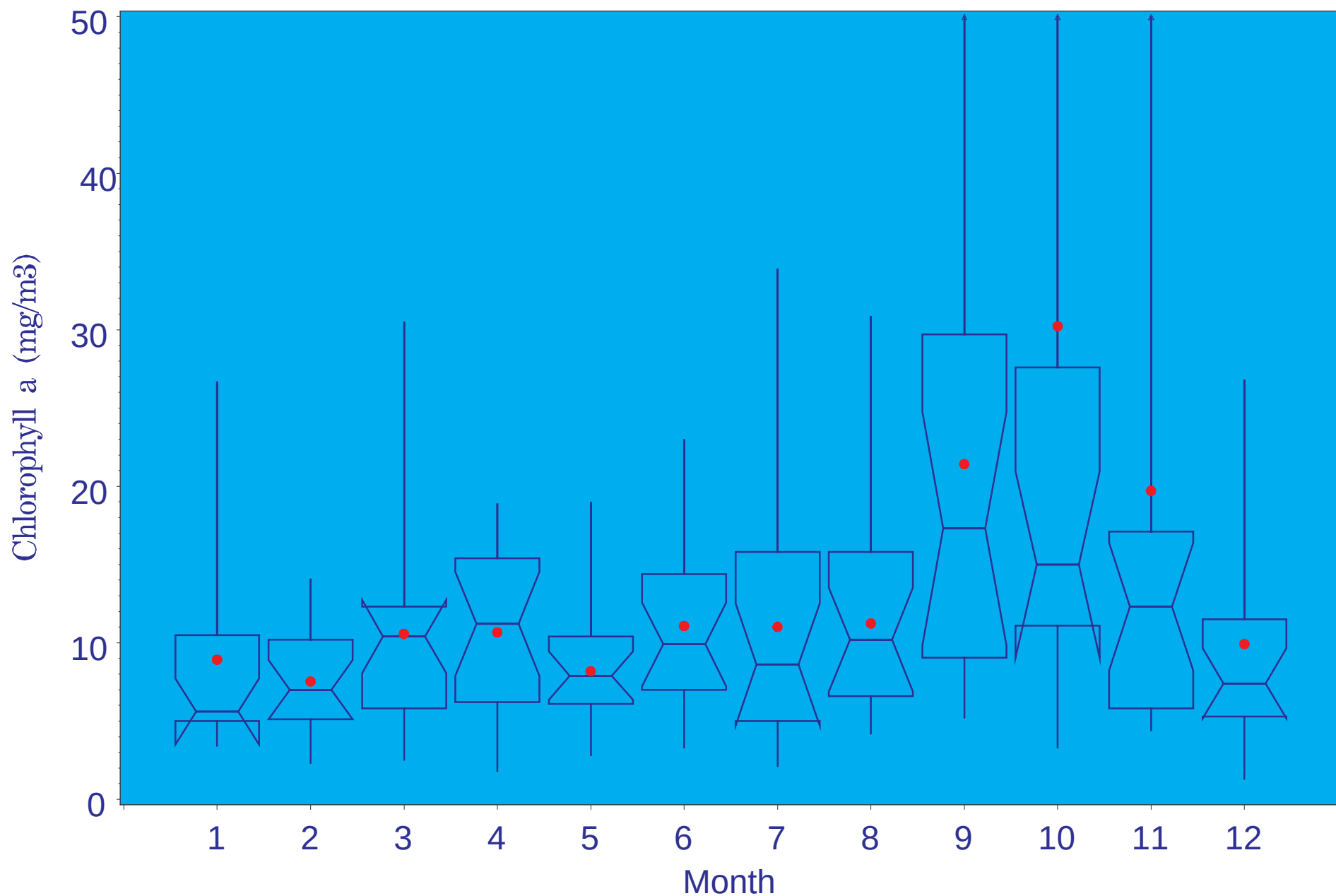


Figure 4.6.110 Mean monthly boxplots of chlorophyll a - 20 ppt isohaline (1984-2002)



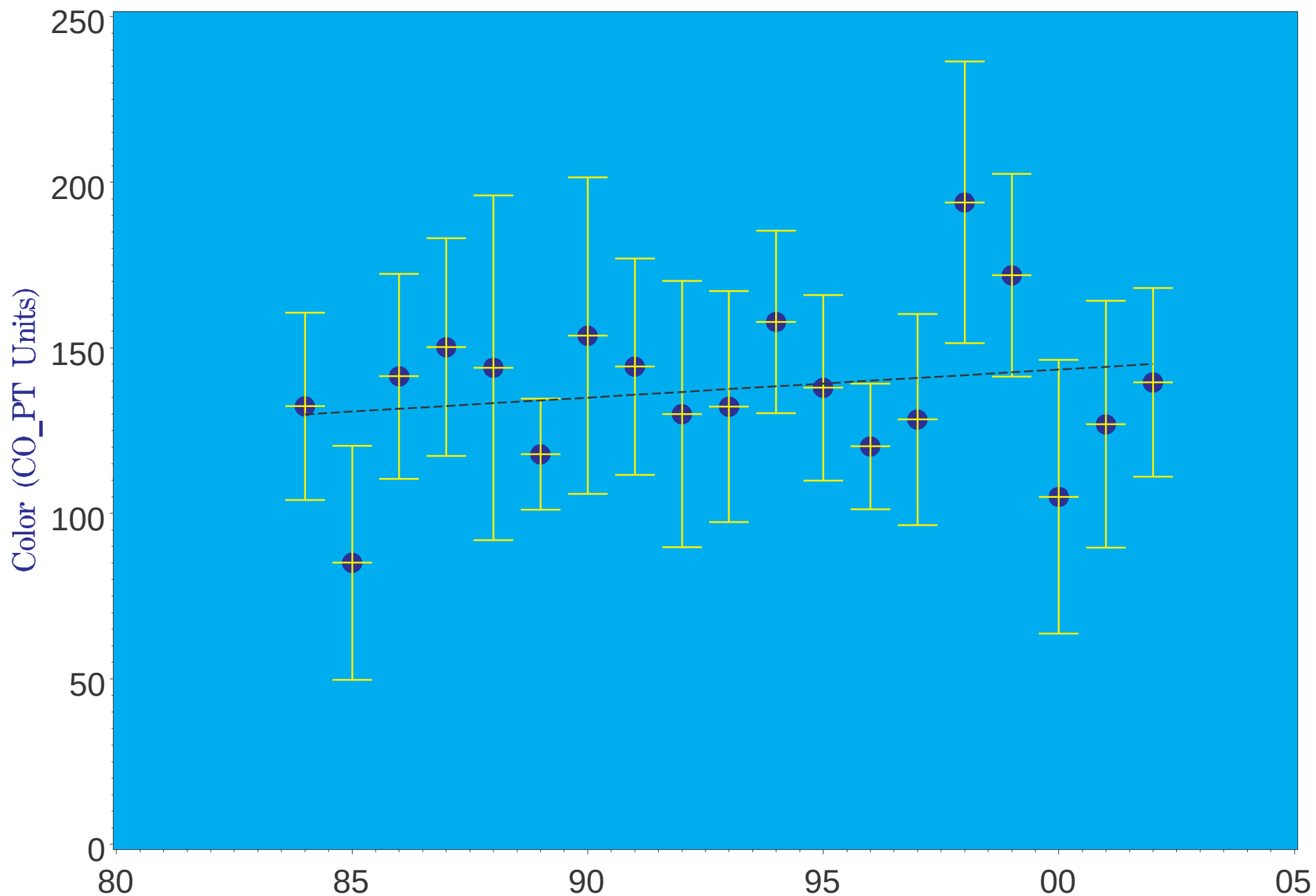


Figure 4.6.111 Annual monthly surface color at 0 o/oo isohaline (1984-2002)

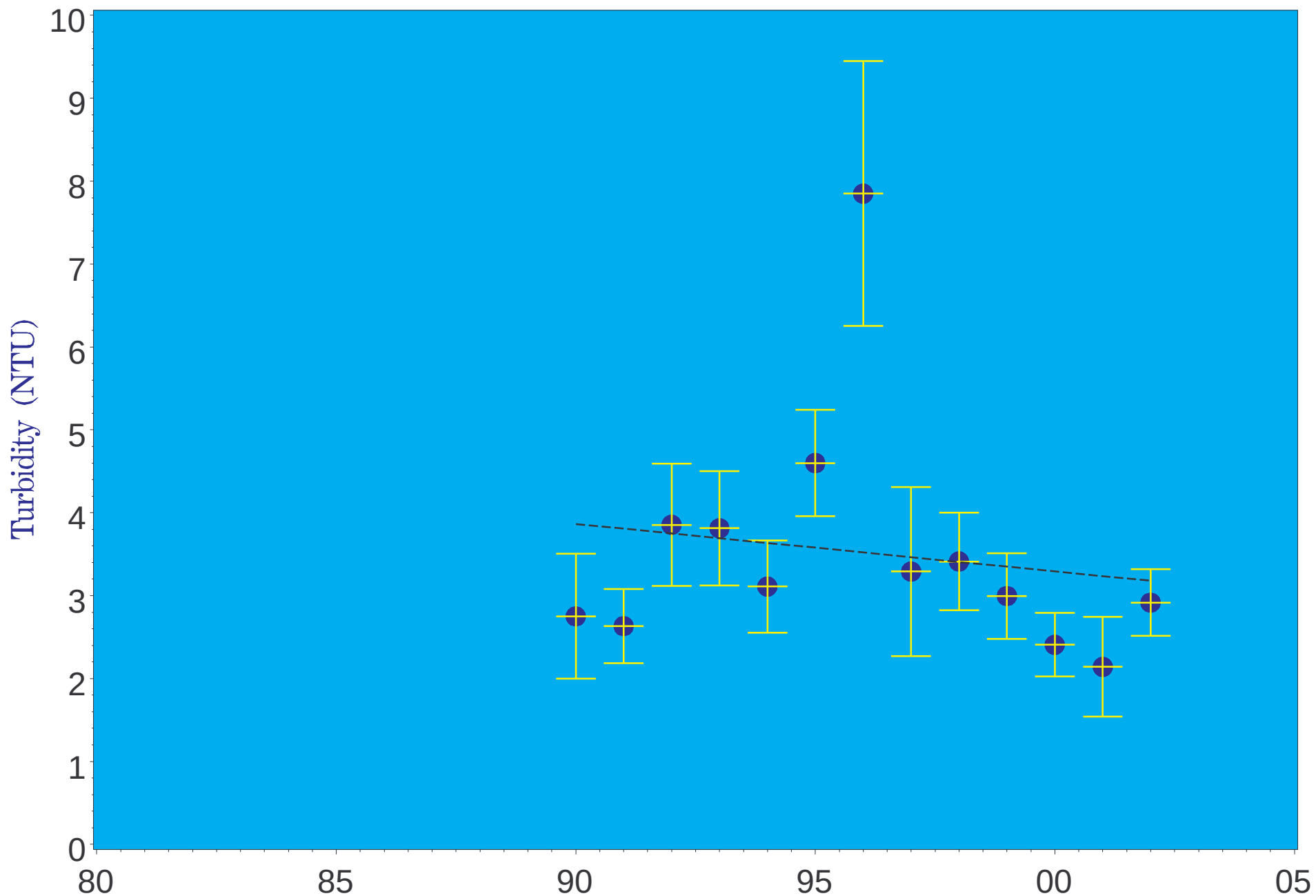


Figure 4.6.112 Annual monthly surface turbidity at 0 o/oo isohaline (1984-2002)

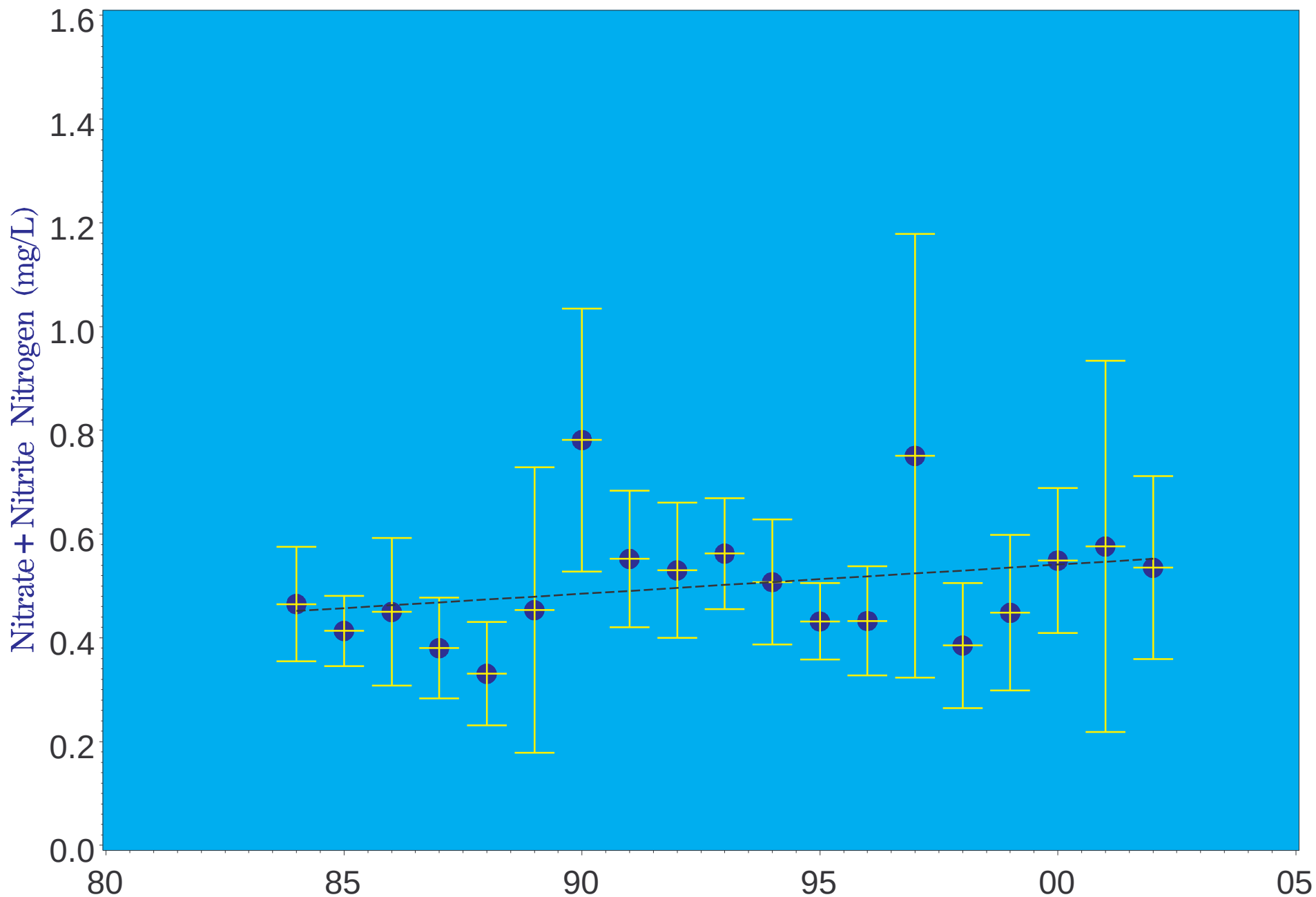


Figure 4.6.113 Annual monthly surface nitrate/nitrite nitrogen at 0 o/oo isohaline (1984-2002)

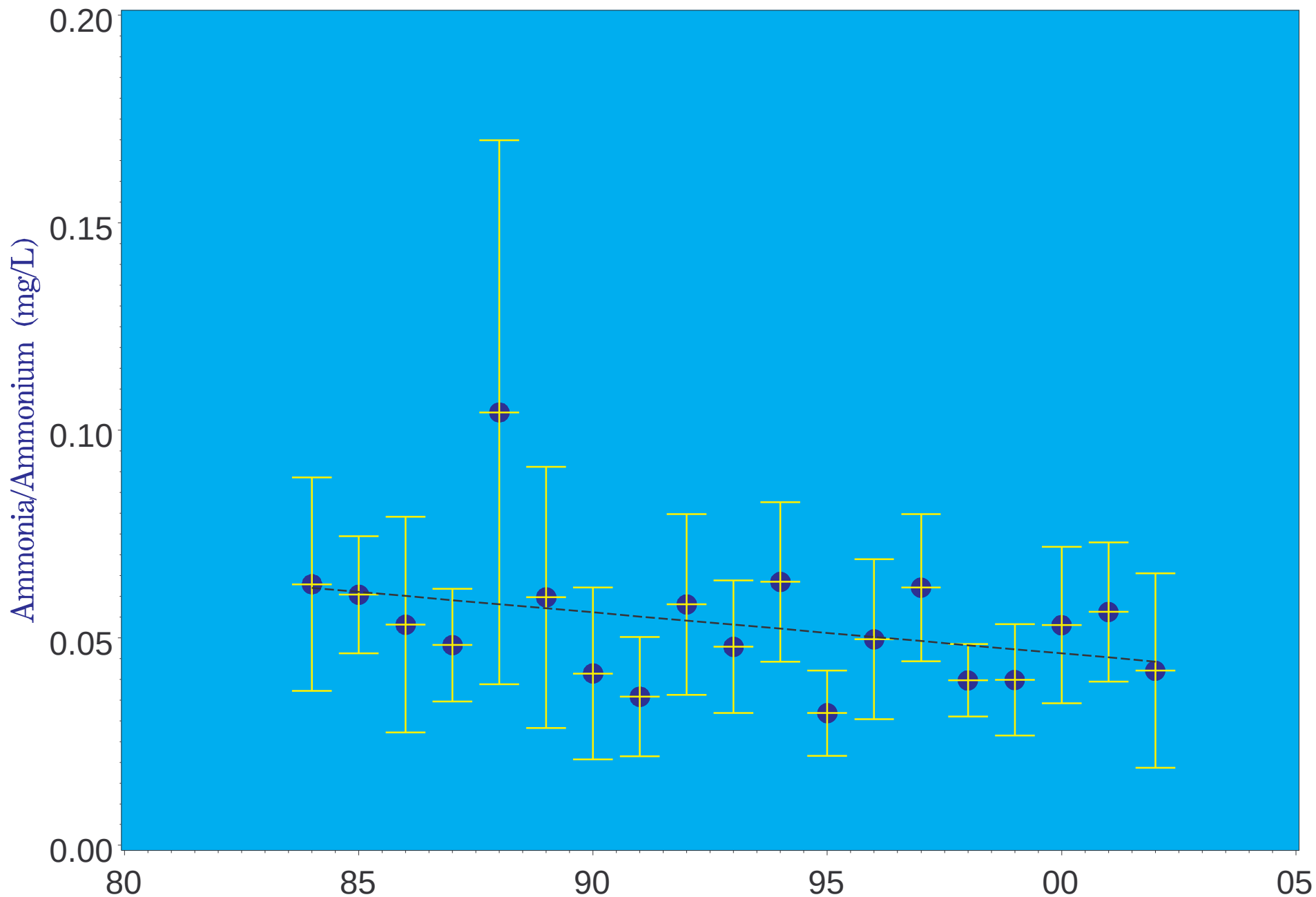


Figure 4.6.114 Annual monthly surface Ammonia/Ammonium at 0 o/oo isohaline (1984-2002)

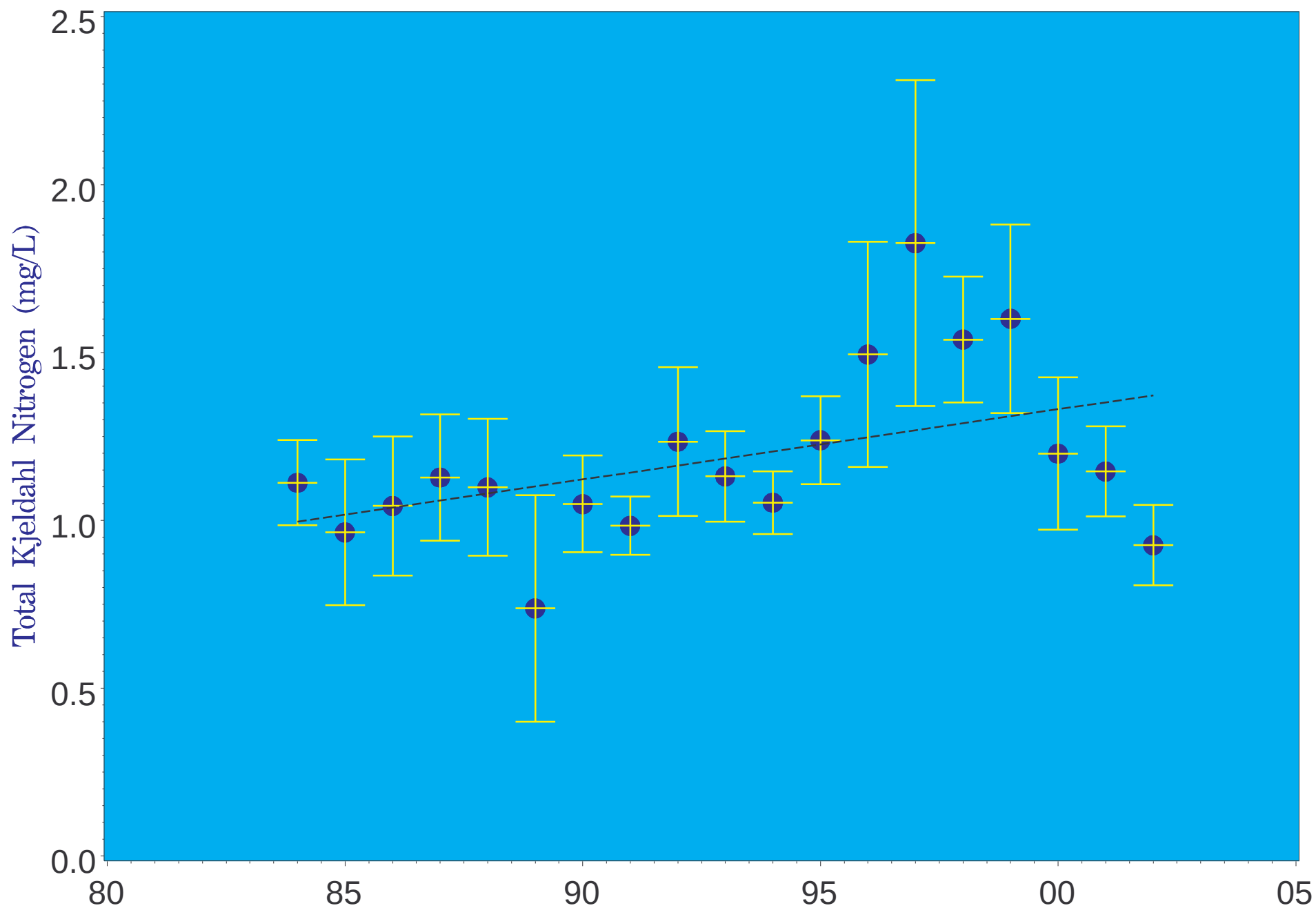


Figure 4.6.115 Annual monthly surface total Kjeldahl nitrogen at 0 o/oo isohaline (1984-2002)

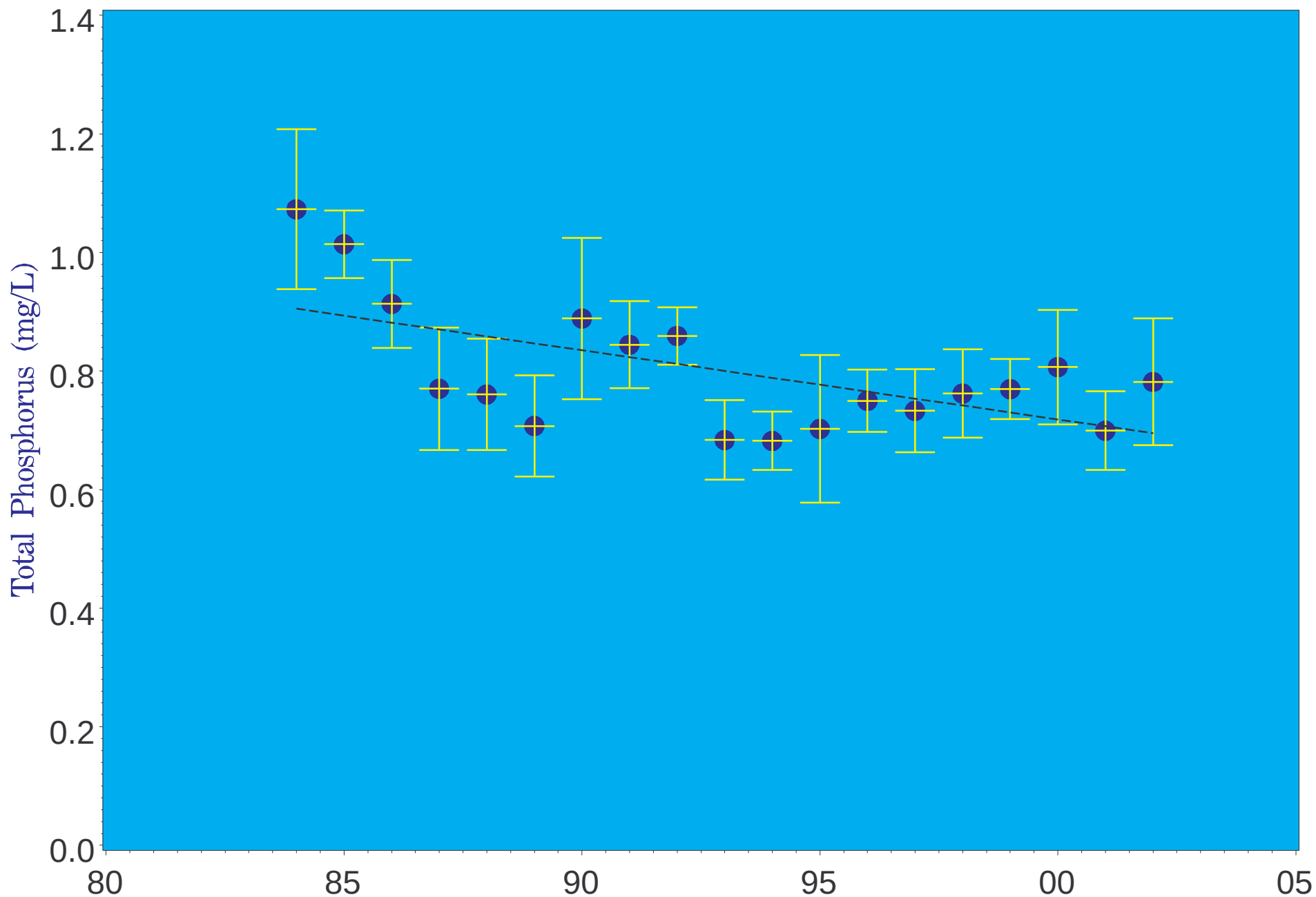


Figure 4.6.116 Annual monthly surface total phosphorus at 0 o/oo isohaline (1984-2002)

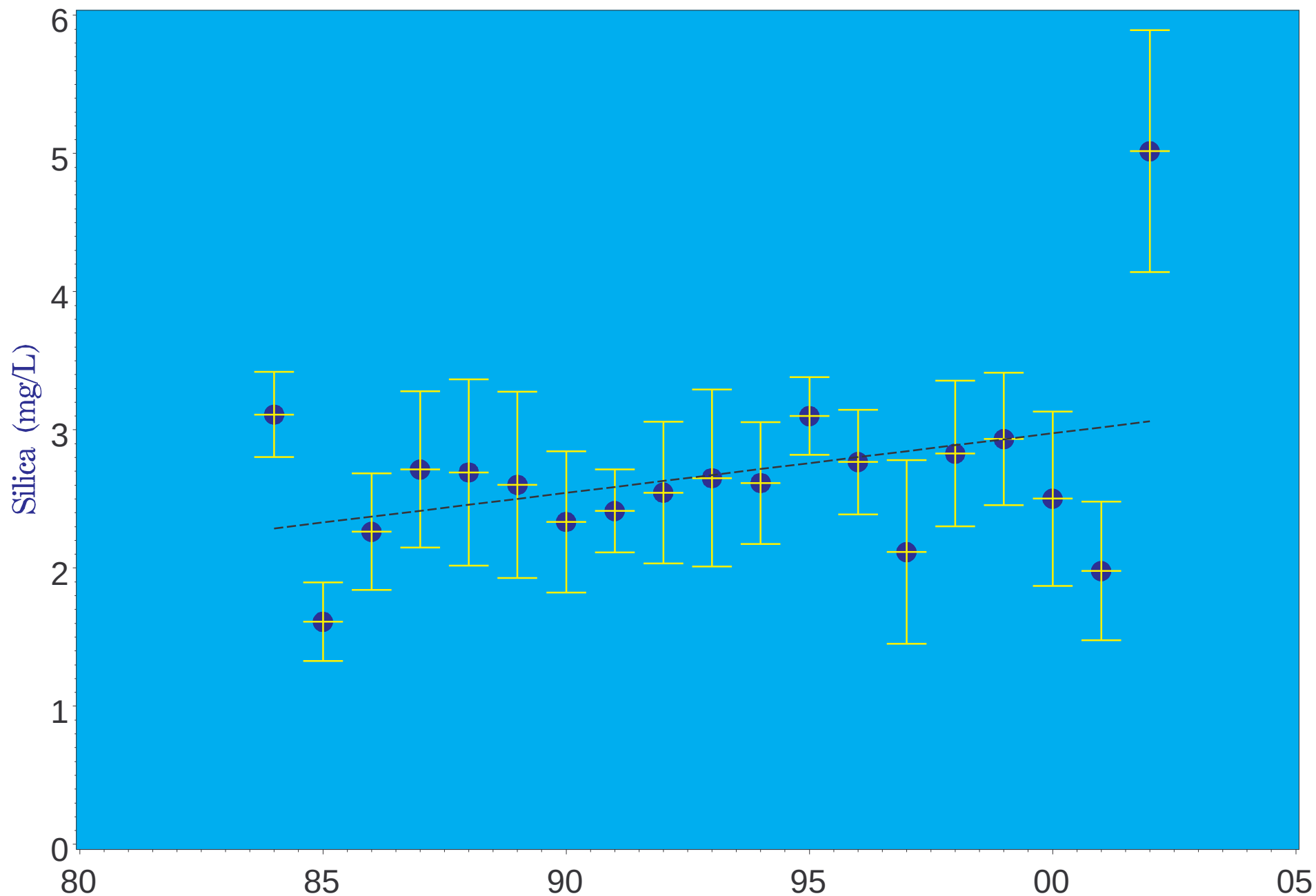


Figure 4.6.117 Annual monthly surface silica at 0 o/oo isohaline (1984-2002)

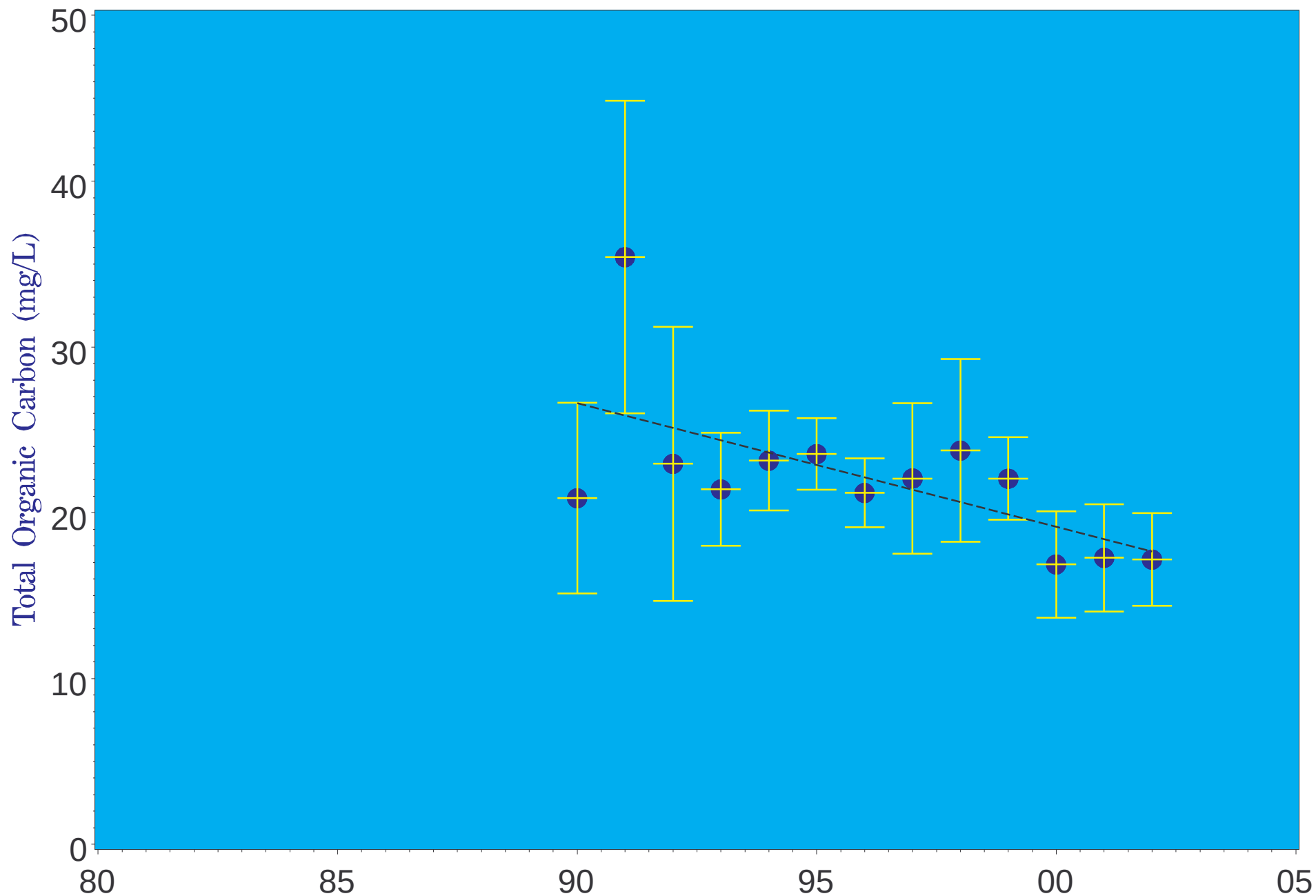


Figure 4.6.118 Annual monthly surface total organic carbon at 0 o/oo isohaline (1984-2002)



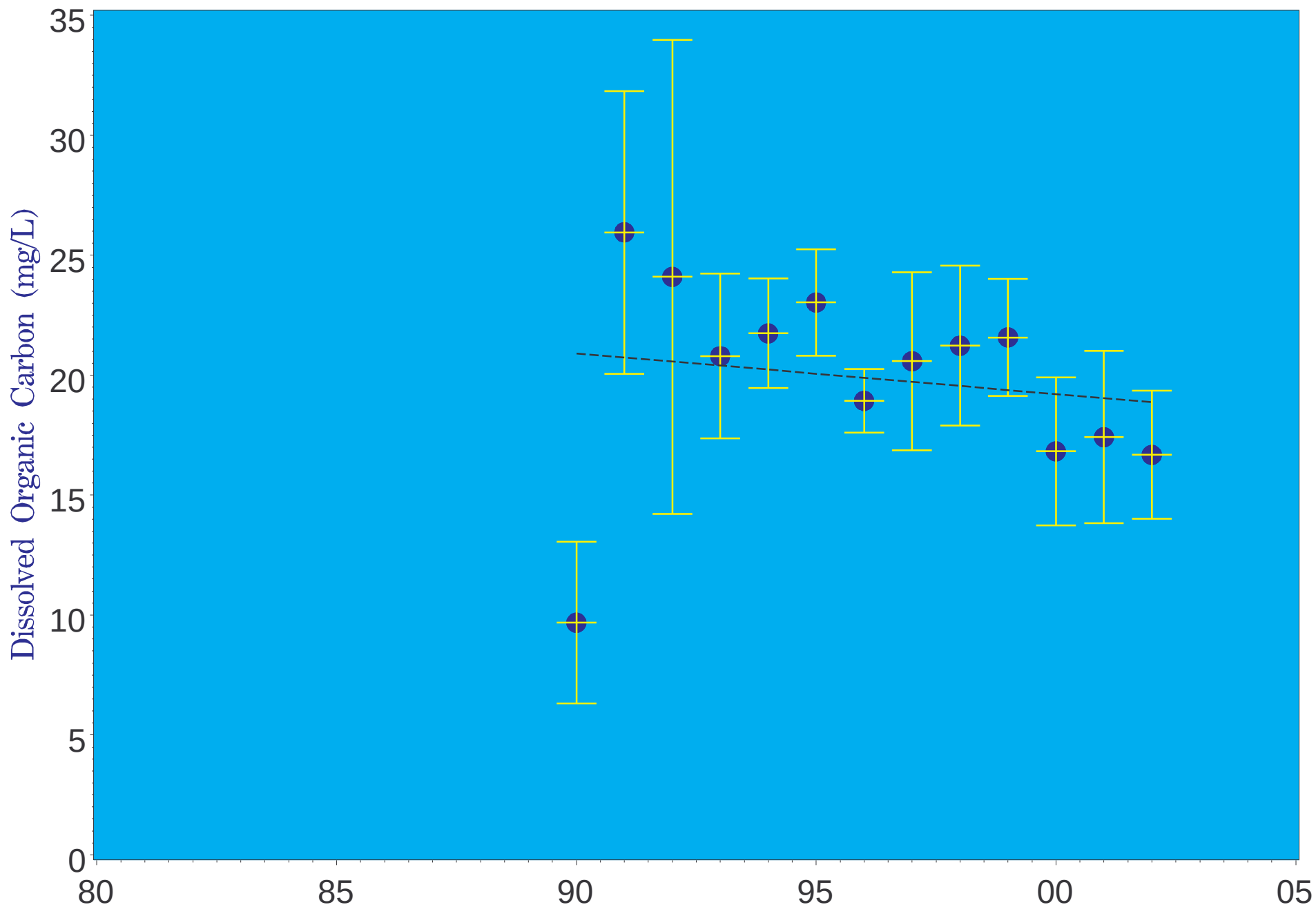


Figure 4.6.119 Annual monthly surface dissolved organic carbon at 0 o/oo isohaline (1984-2002)

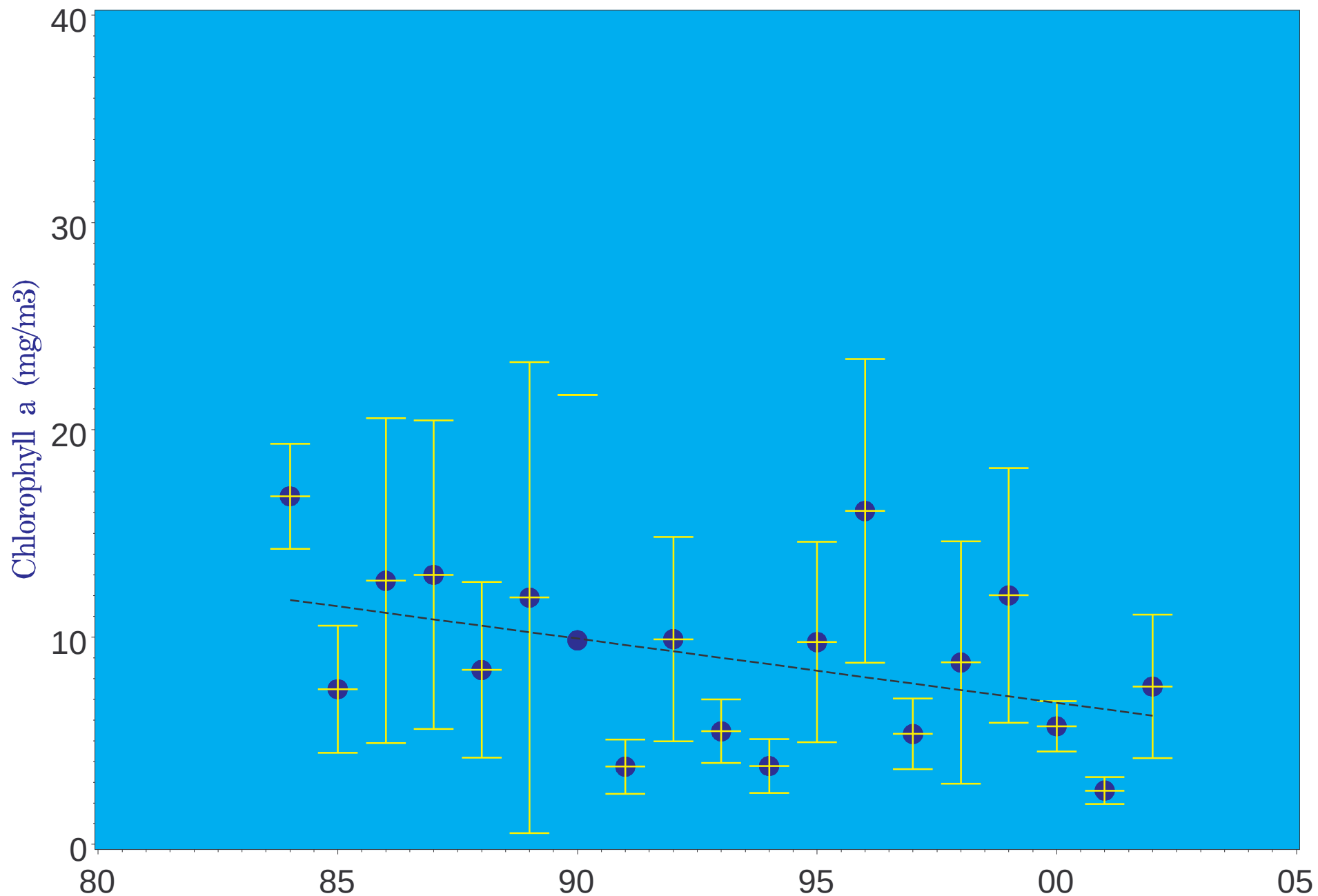


Figure 4.6.120 Annual monthly surface chlorophyll a at 0 o/oo isohaline (1984-2002)

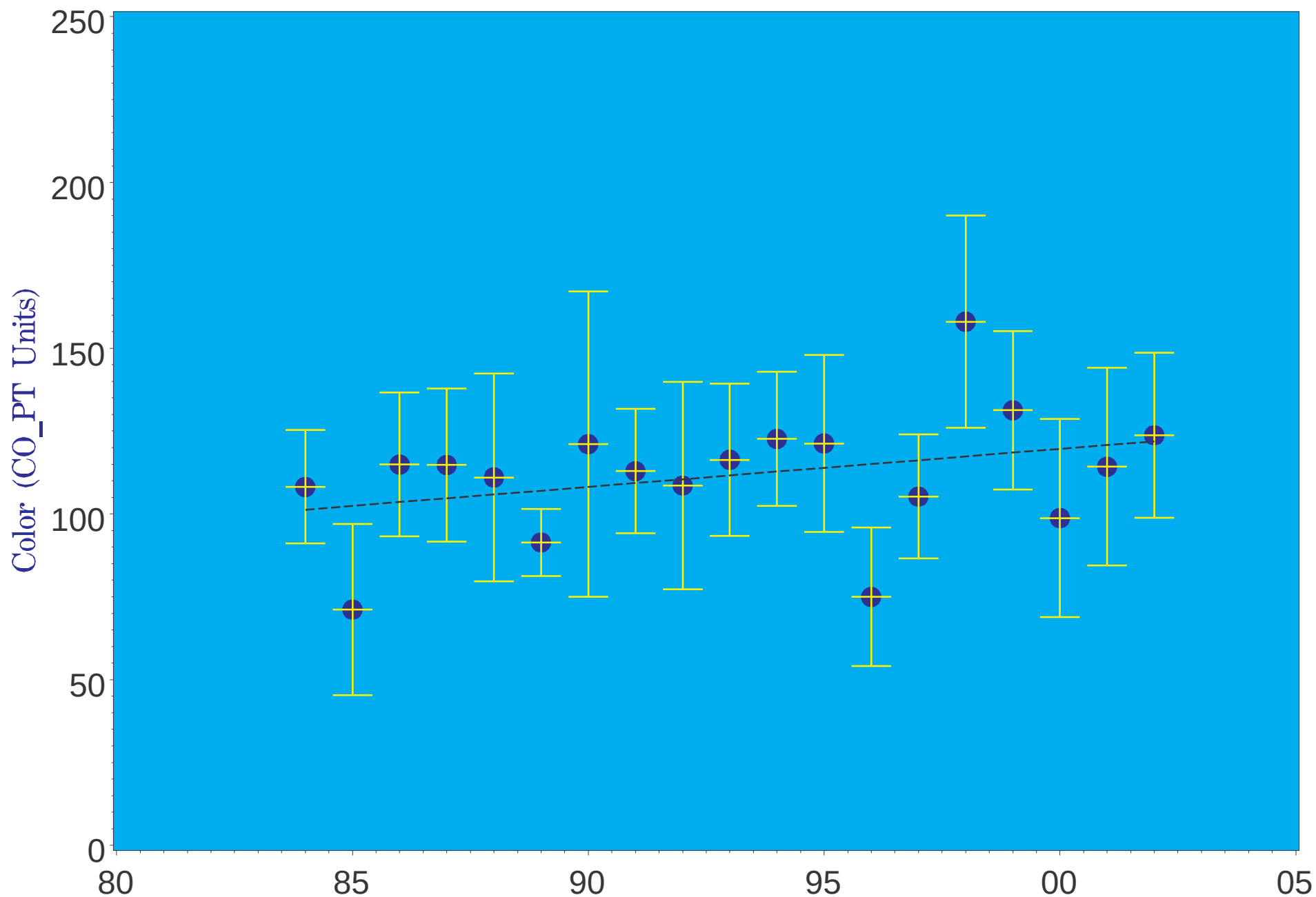


Figure 4.6.121 Annual monthly surface color at 6 o/oo isohaline (1984-2002)

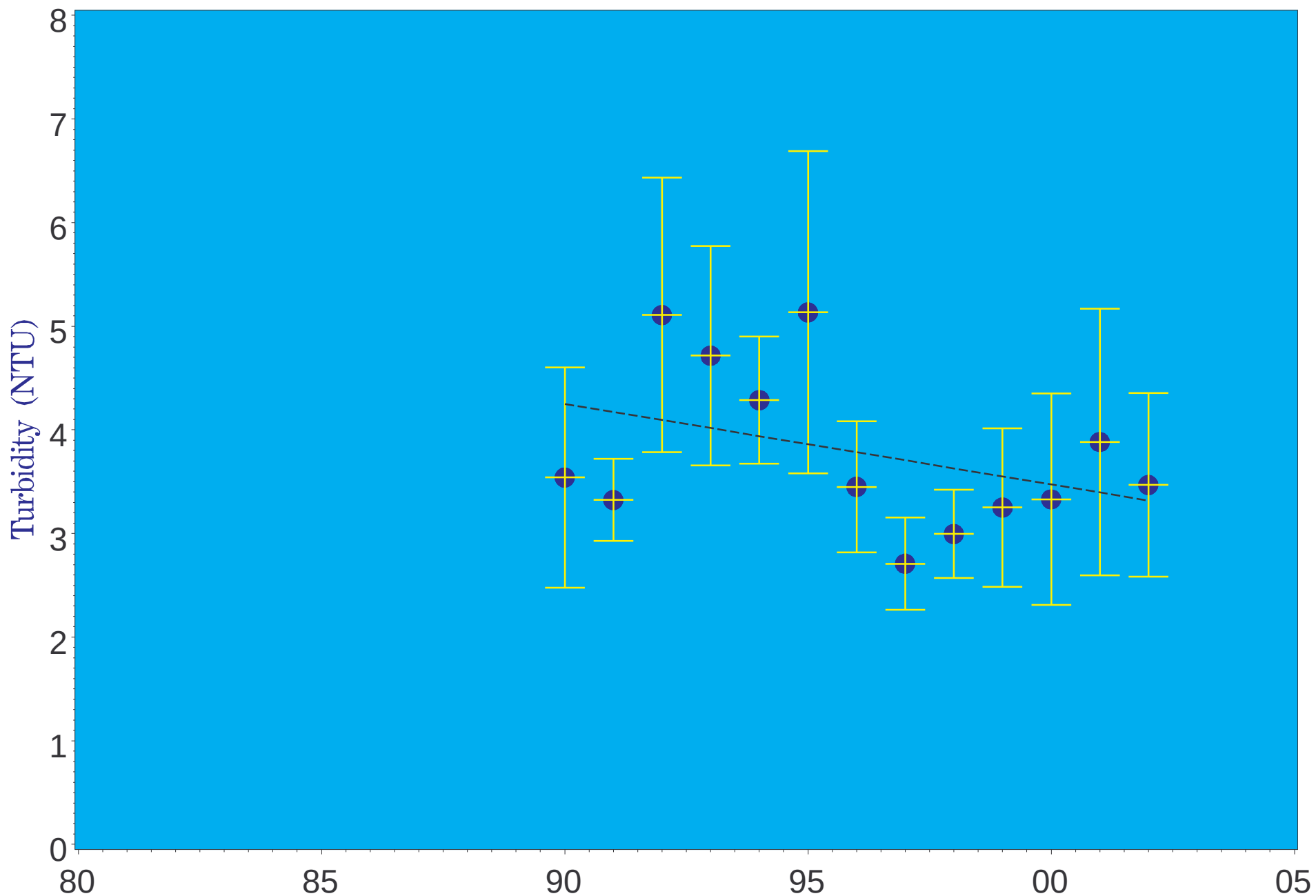


Figure 4.6.122 Annual monthly surface turbidity at 6 o/oo isohaline (1984-2002)

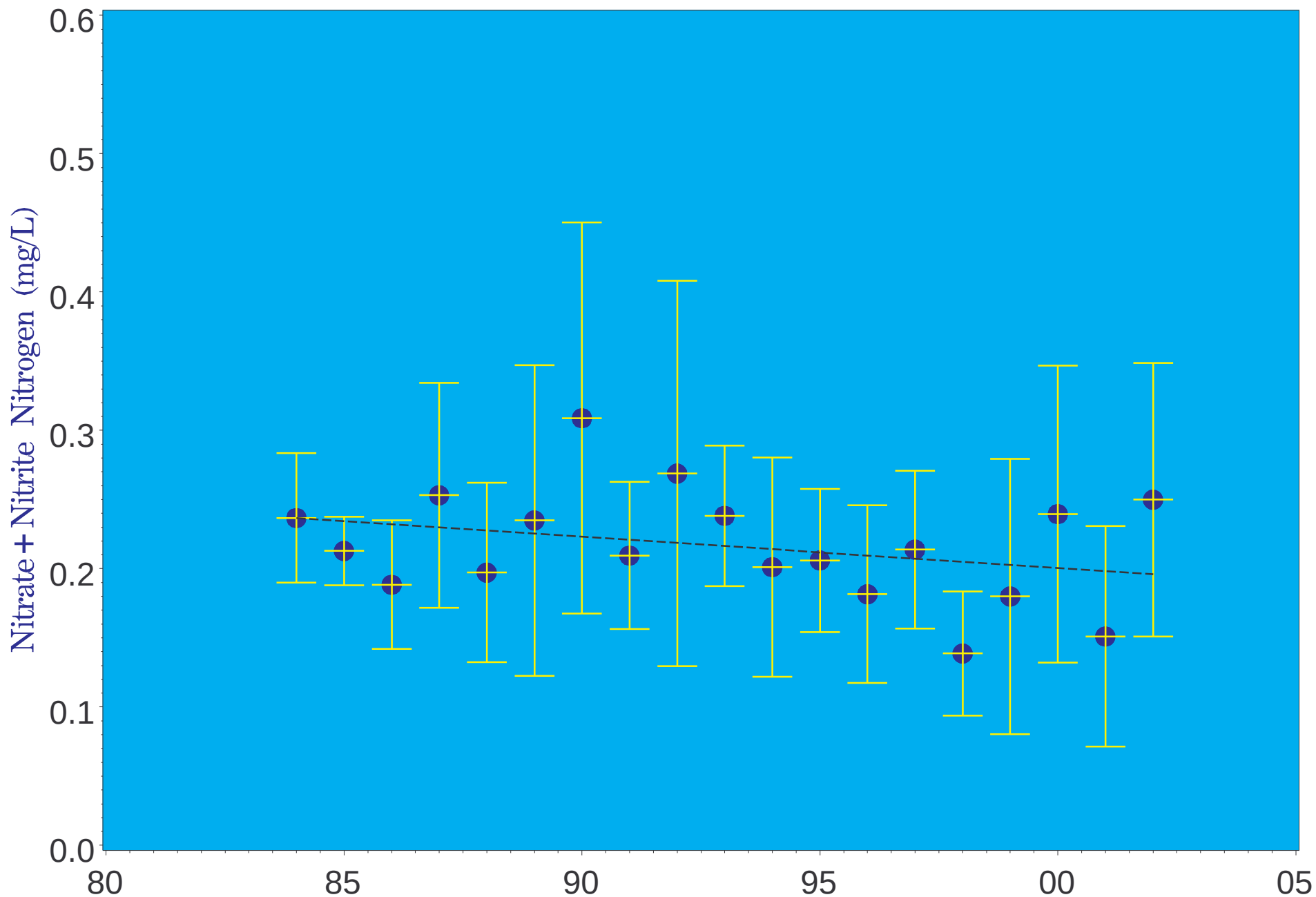


Figure 4.6.123 Annual monthly surface nitrate/nitrite nitrogen at 6 o/oo isohaline (1984-2002)

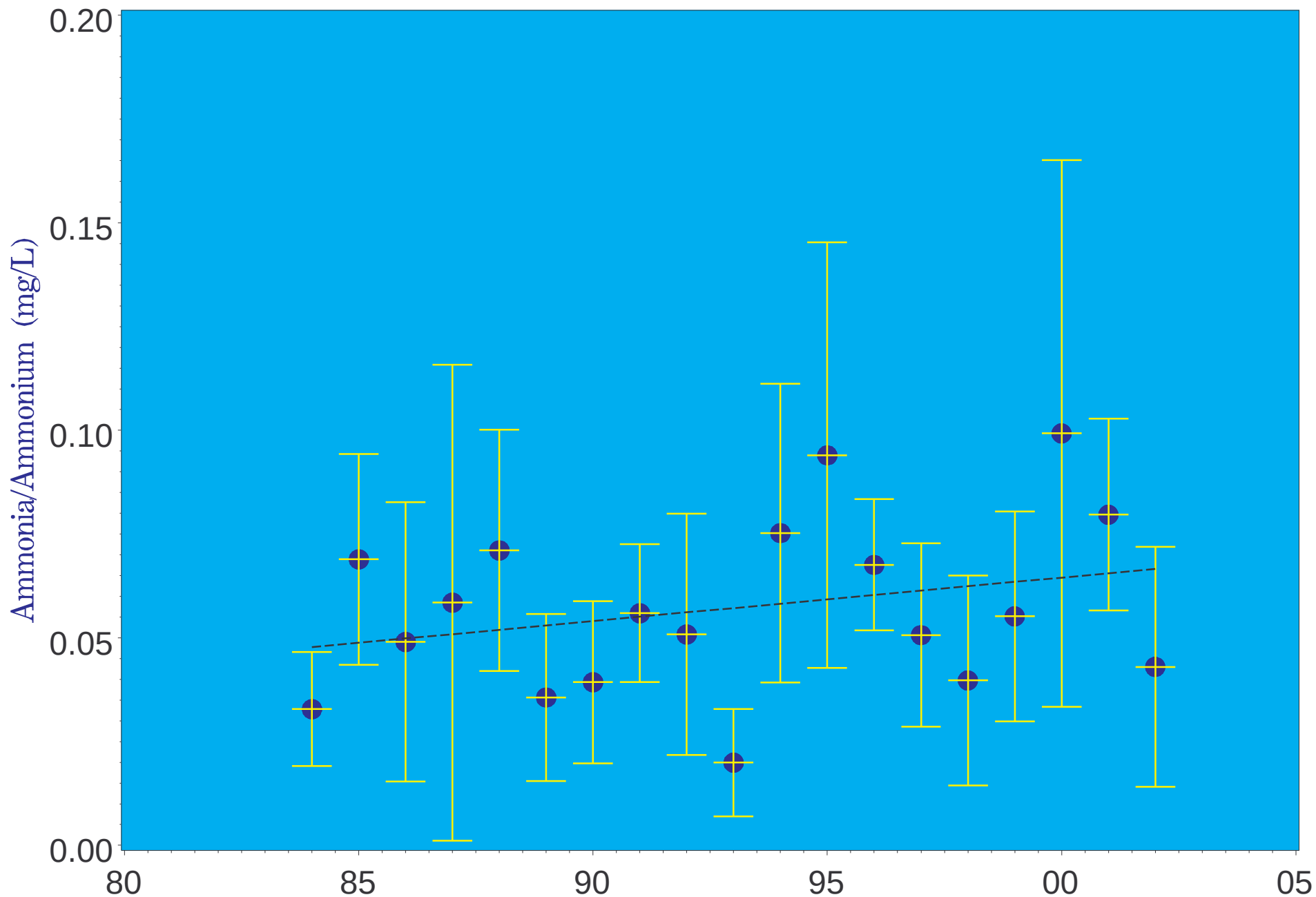


Figure 4.6.124 Annual monthly surface Ammonia/Ammonium at 6 o/oo isohaline (1984-2002)

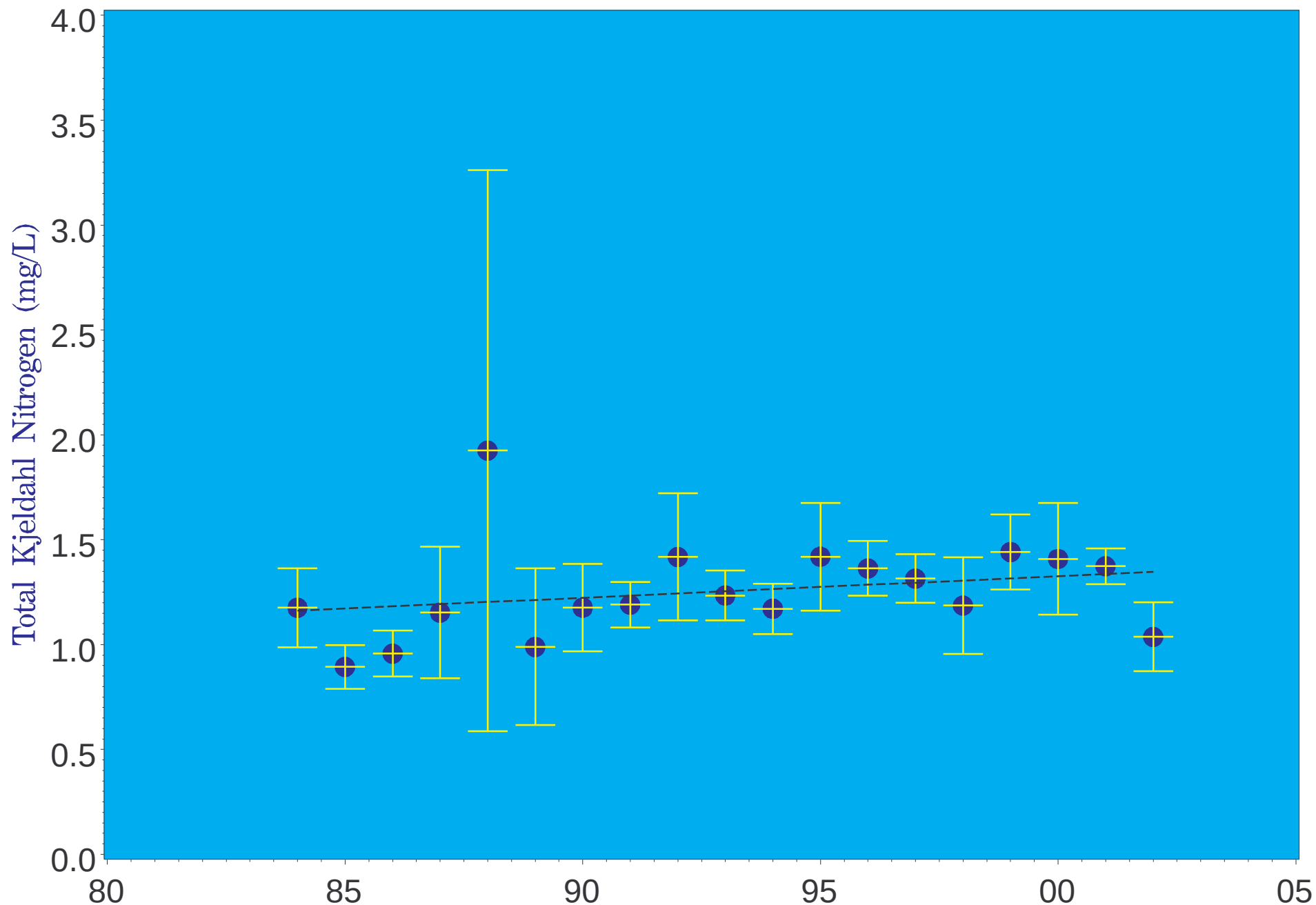


Figure 4.6.125 Annual monthly surface total Kjeldahl nitrogen at 6 o/oo isohaline (1984-2002)

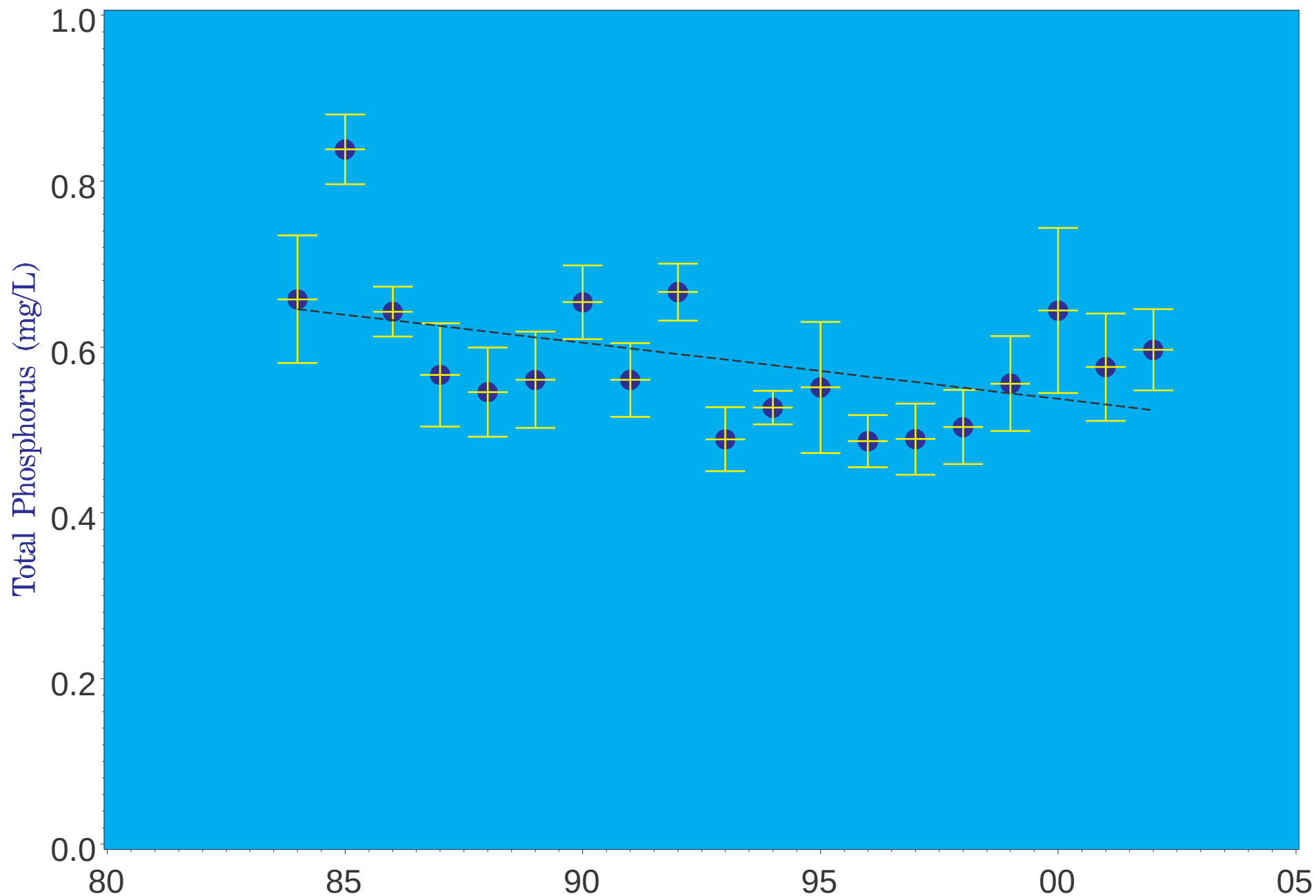


Figure 4.6.126 Annual monthly surface total phosphorus at 6 o/oo isohaline (1984-2002)



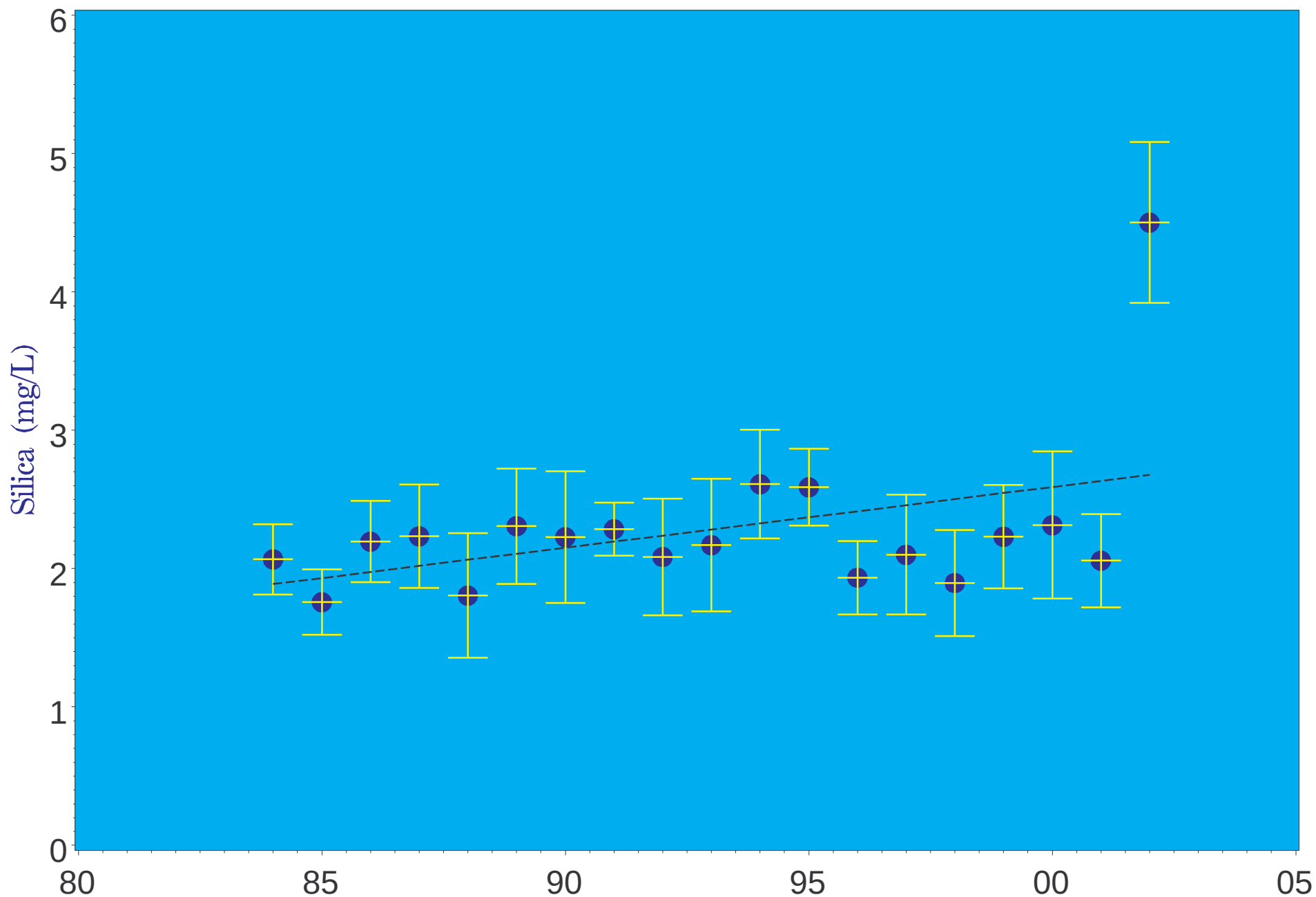


Figure 4.6.127 Annual monthly surface silica at 6 o/oo isohaline (1984-2002)

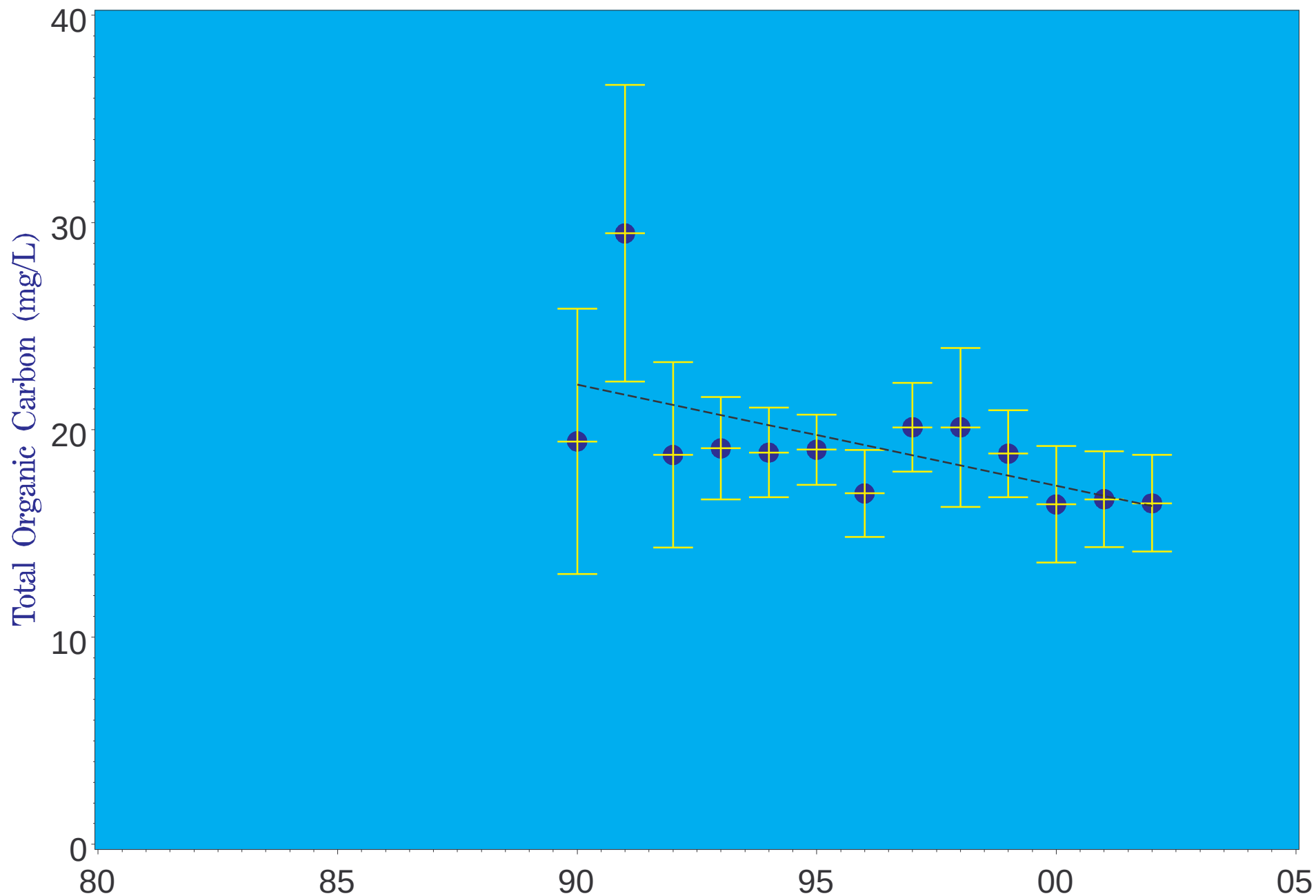


Figure 4.6.128 Annual monthly surface total organic carbon at 6 o/oo isohaline (1984-2002)

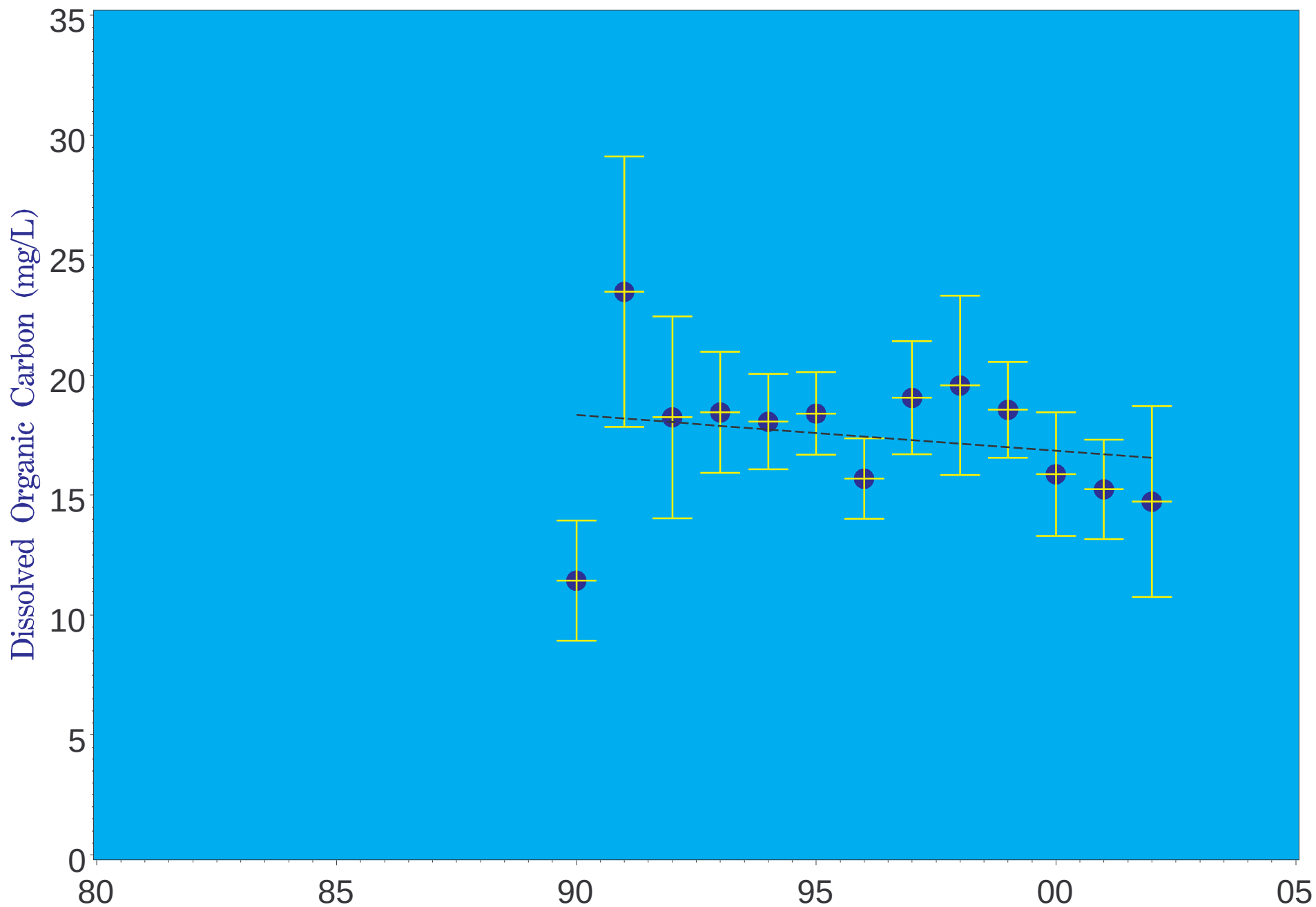


Figure 4.6.129 Annual monthly surface dissolved organic carbon at 6 o/oo isohaline (1984-2002)

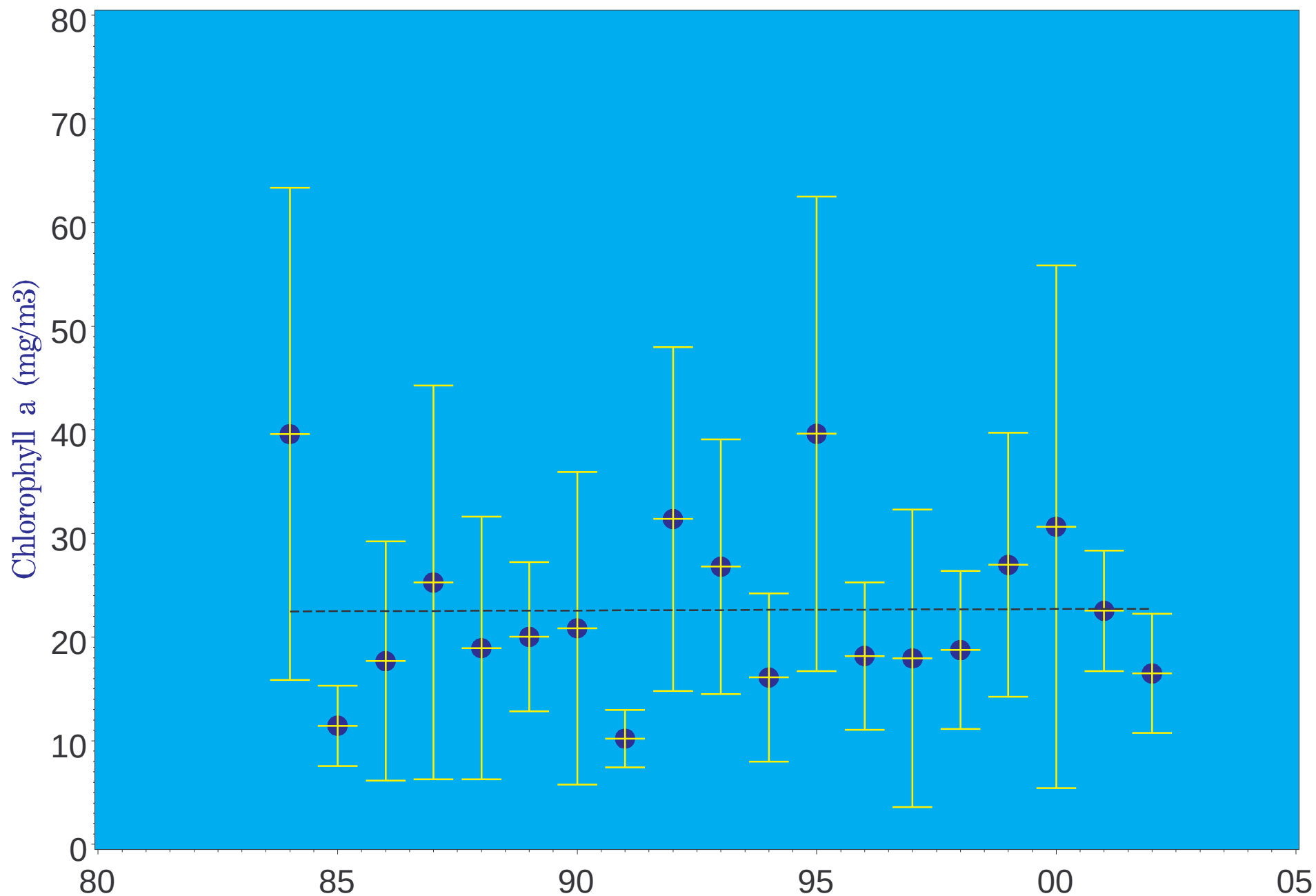


Figure 4.6.130 Annual monthly surface chlorophyll a at 6 o/oo isohaline (1984-2002)

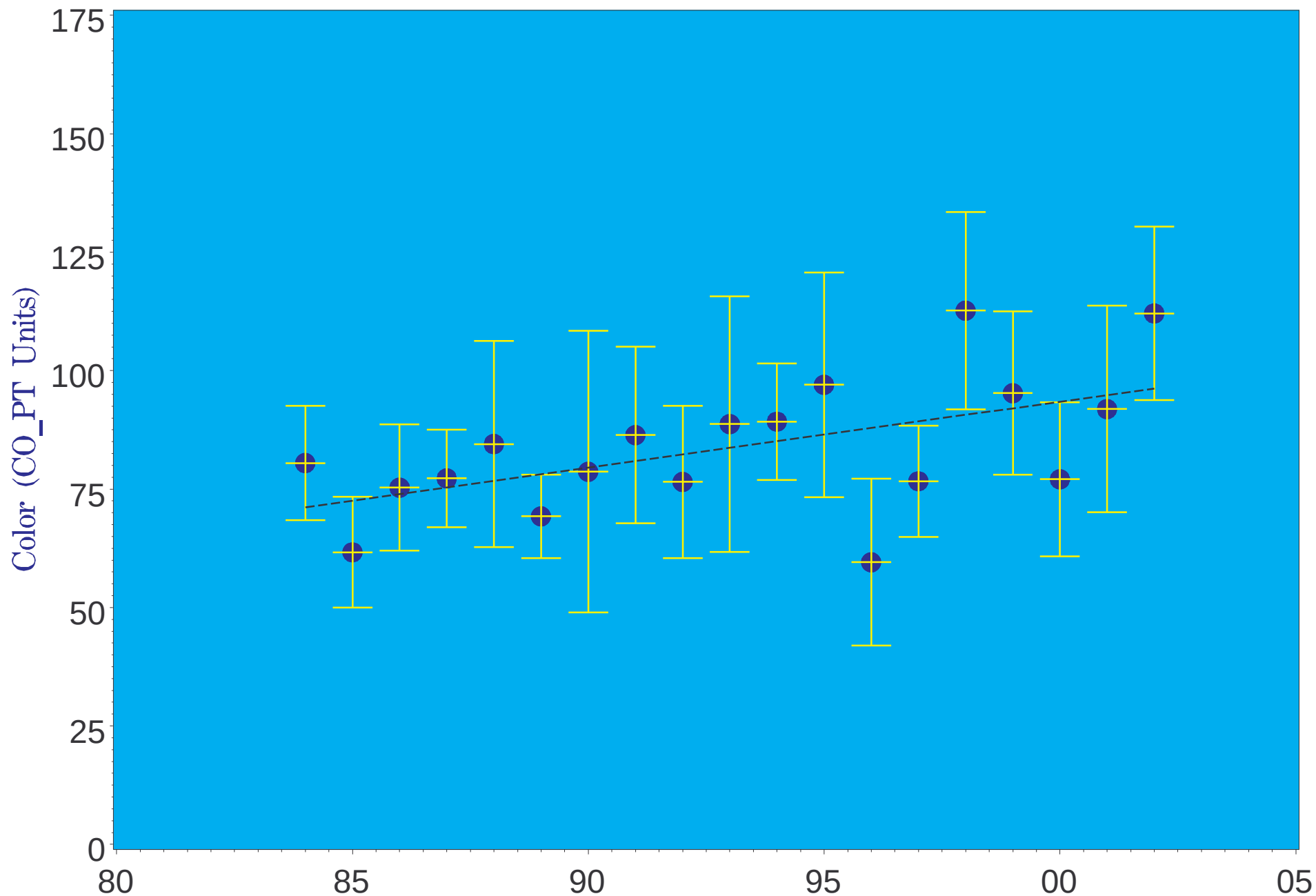


Figure 4.6.131 Annual monthly surface color at 12 o/oo isohaline (1984-2002)

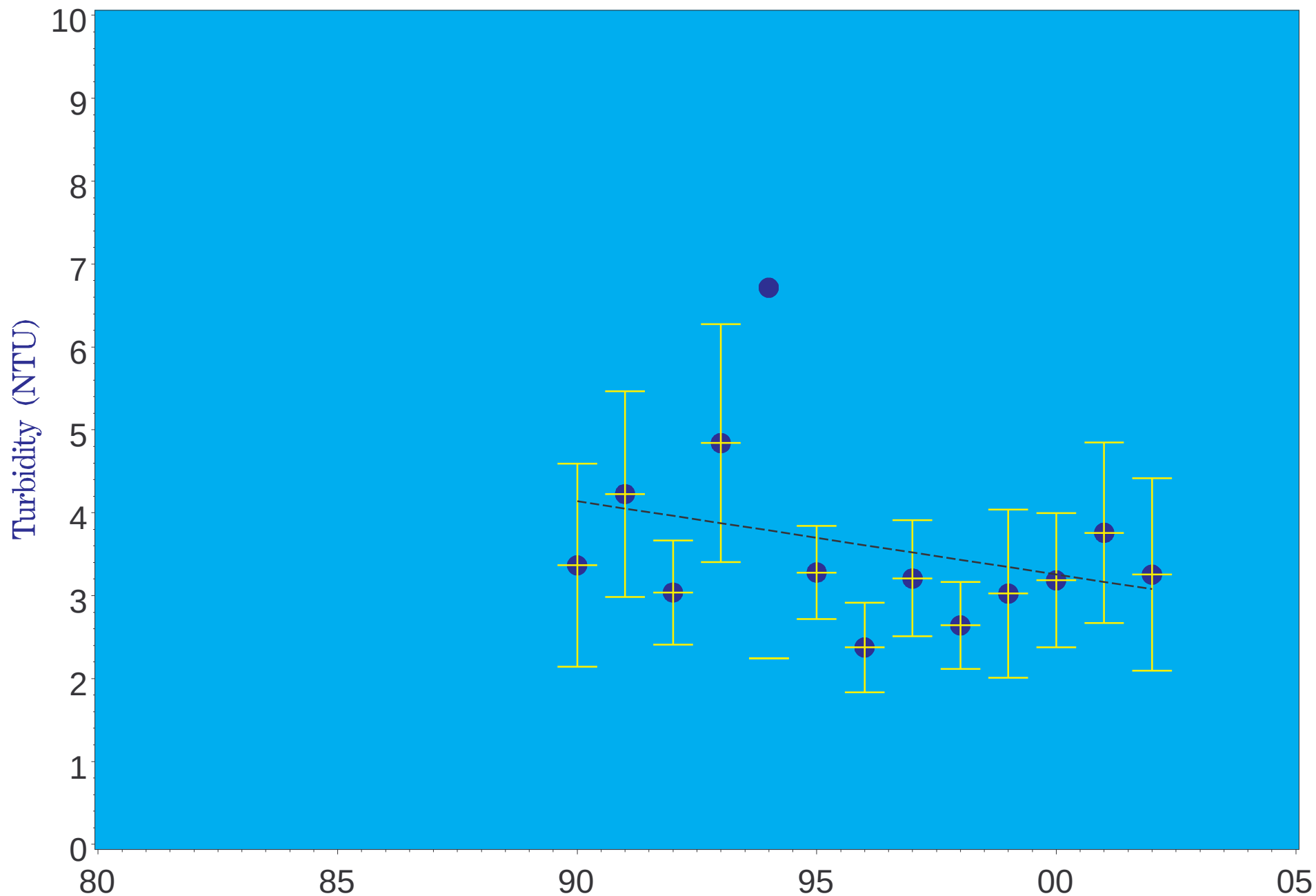


Figure 4.6.132 Annual monthly surface turbidity at 12 o/oo isohaline (1984-2002)

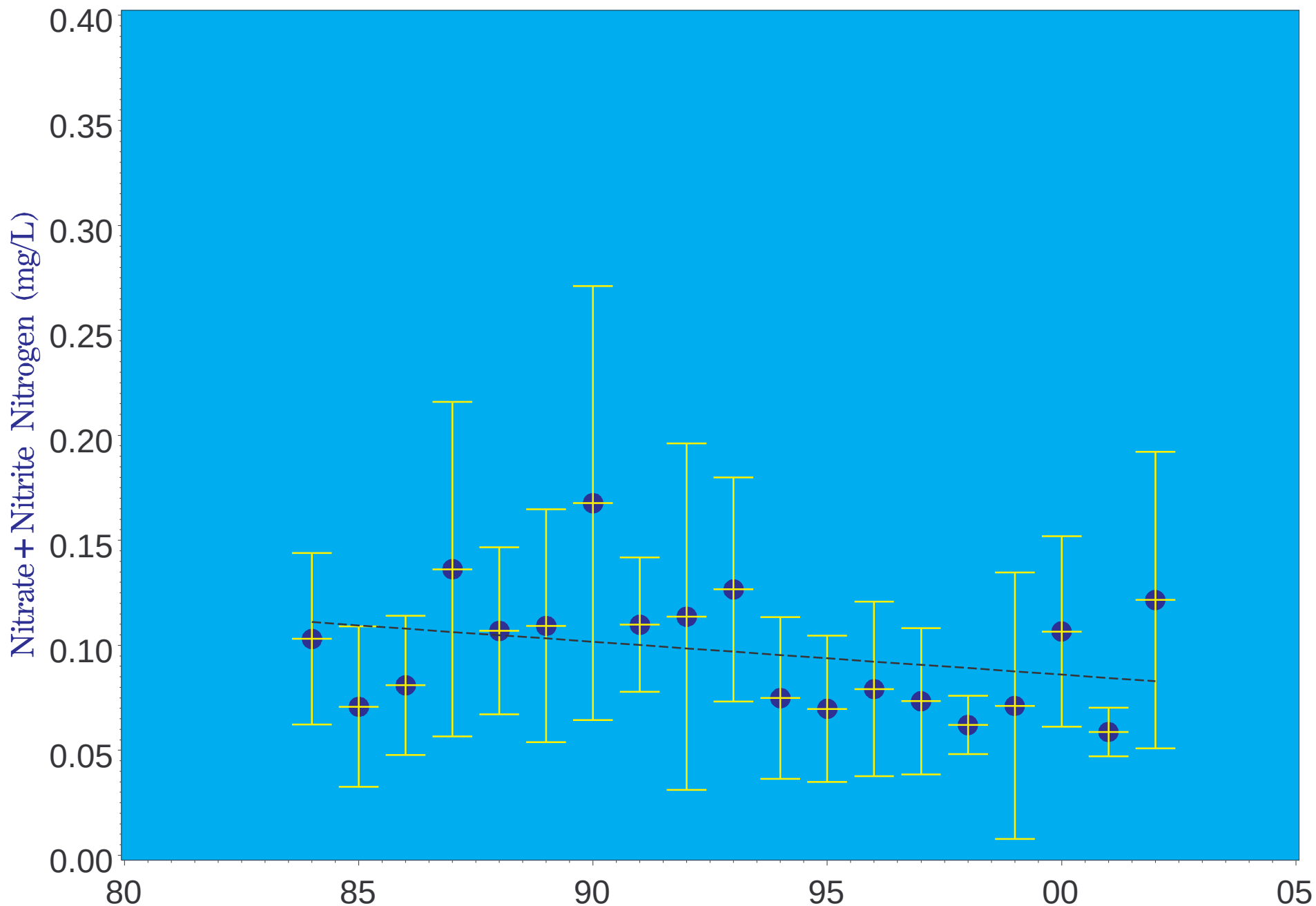


Figure 4.6.133 Annual monthly surface nitrate/nitrite nitrogen at 12 o/oo isohaline (1984-2002)

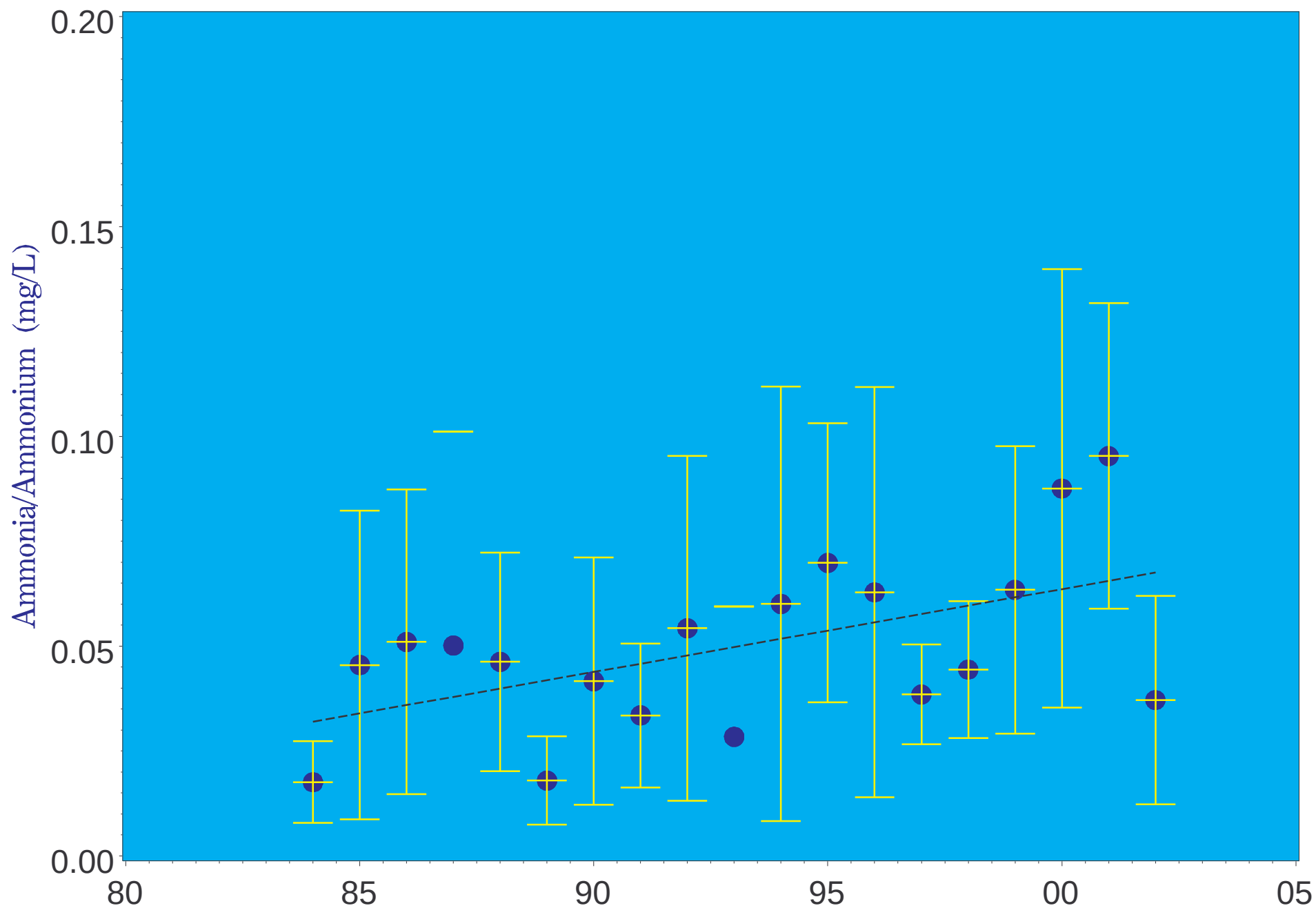


Figure 4.6.134 Annual monthly surface Ammonia/Ammonium at 12 o/oo isohaline (1984-2002)



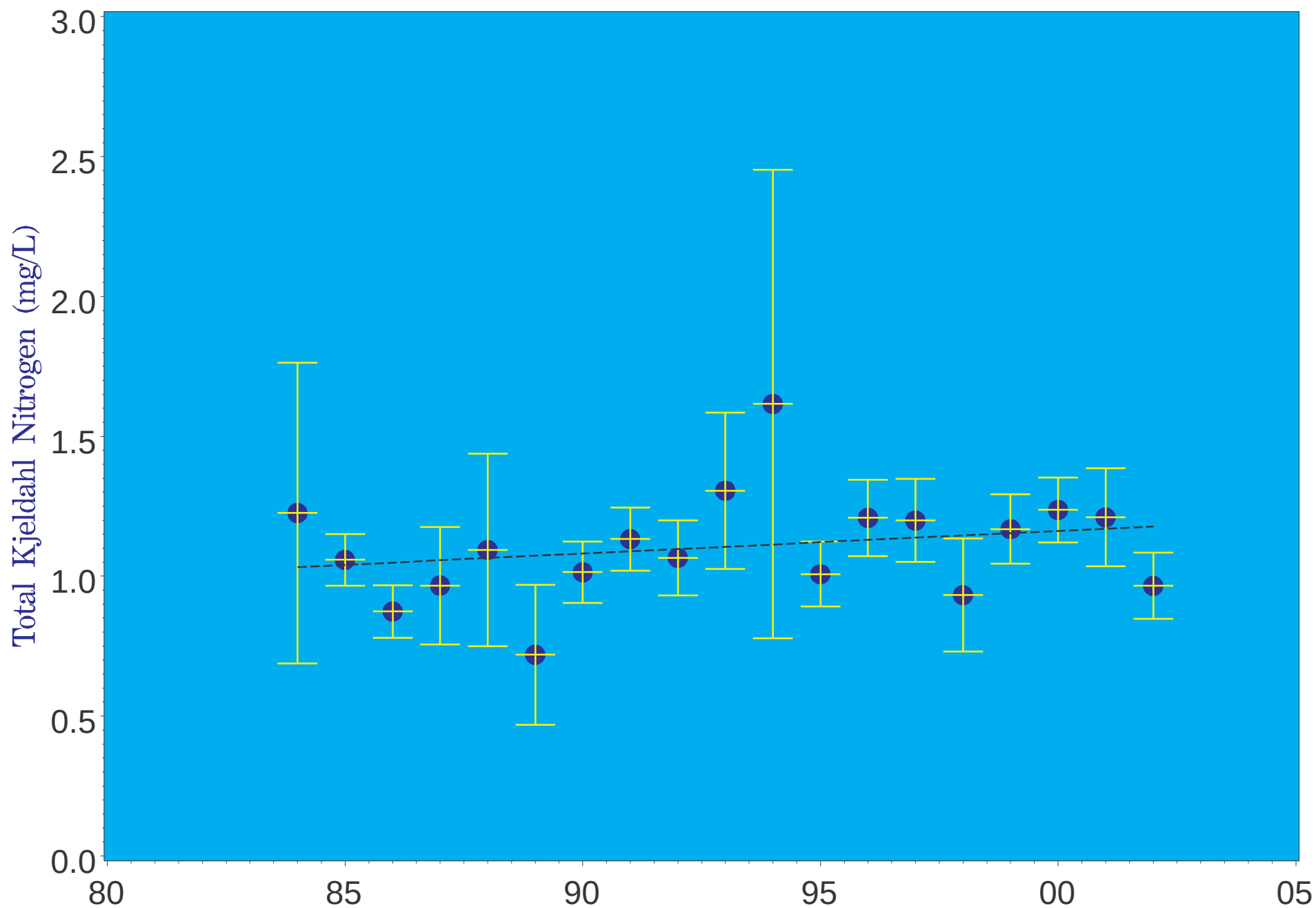


Figure 4.6.135 Annual monthly surface total Kjeldahl nitrogen at 12 o/oo isohaline (1984-2002)

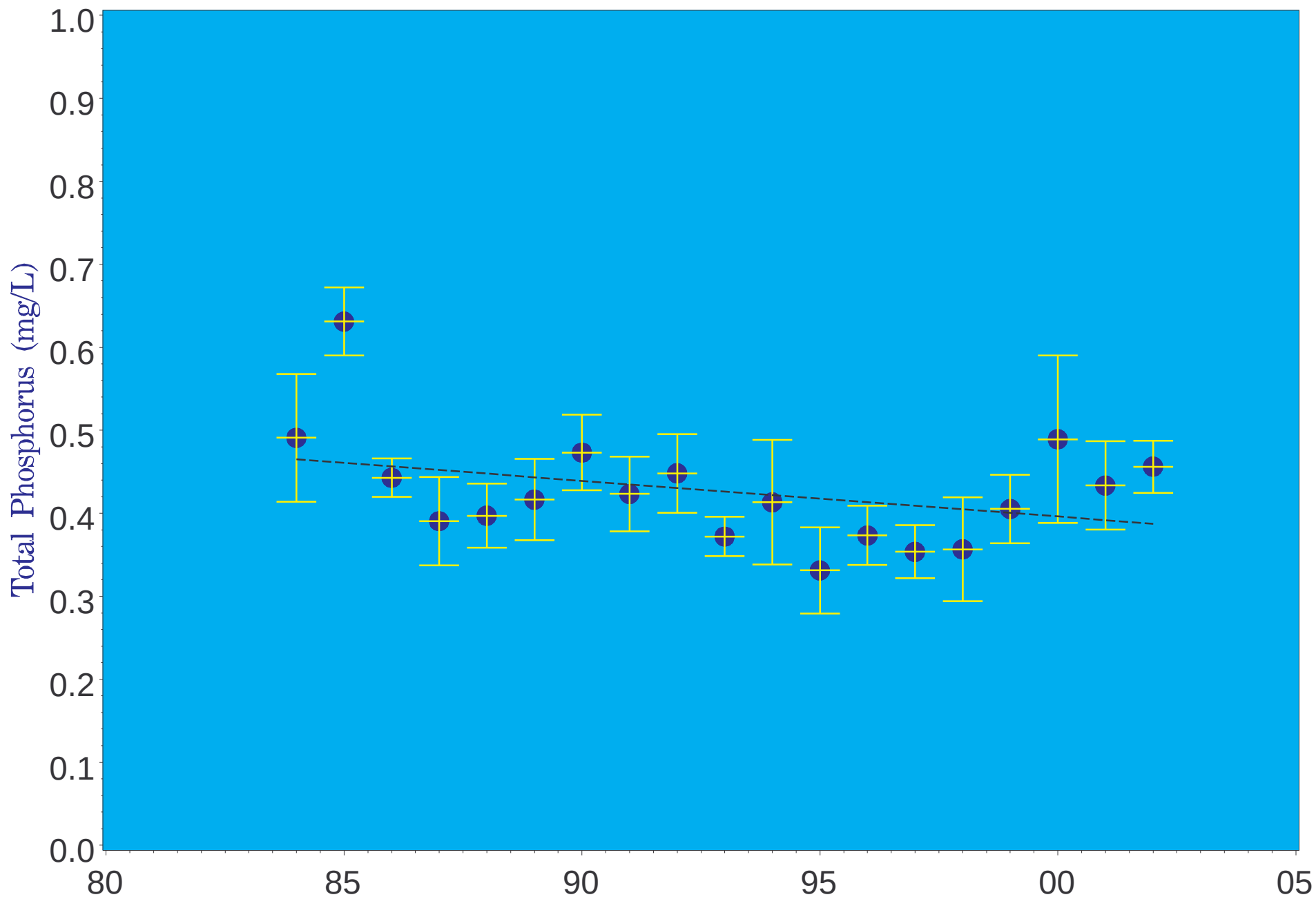


Figure 4.6.136 Annual monthly surface total phosphorus at 12 o/oo isohaline (1984-2002)

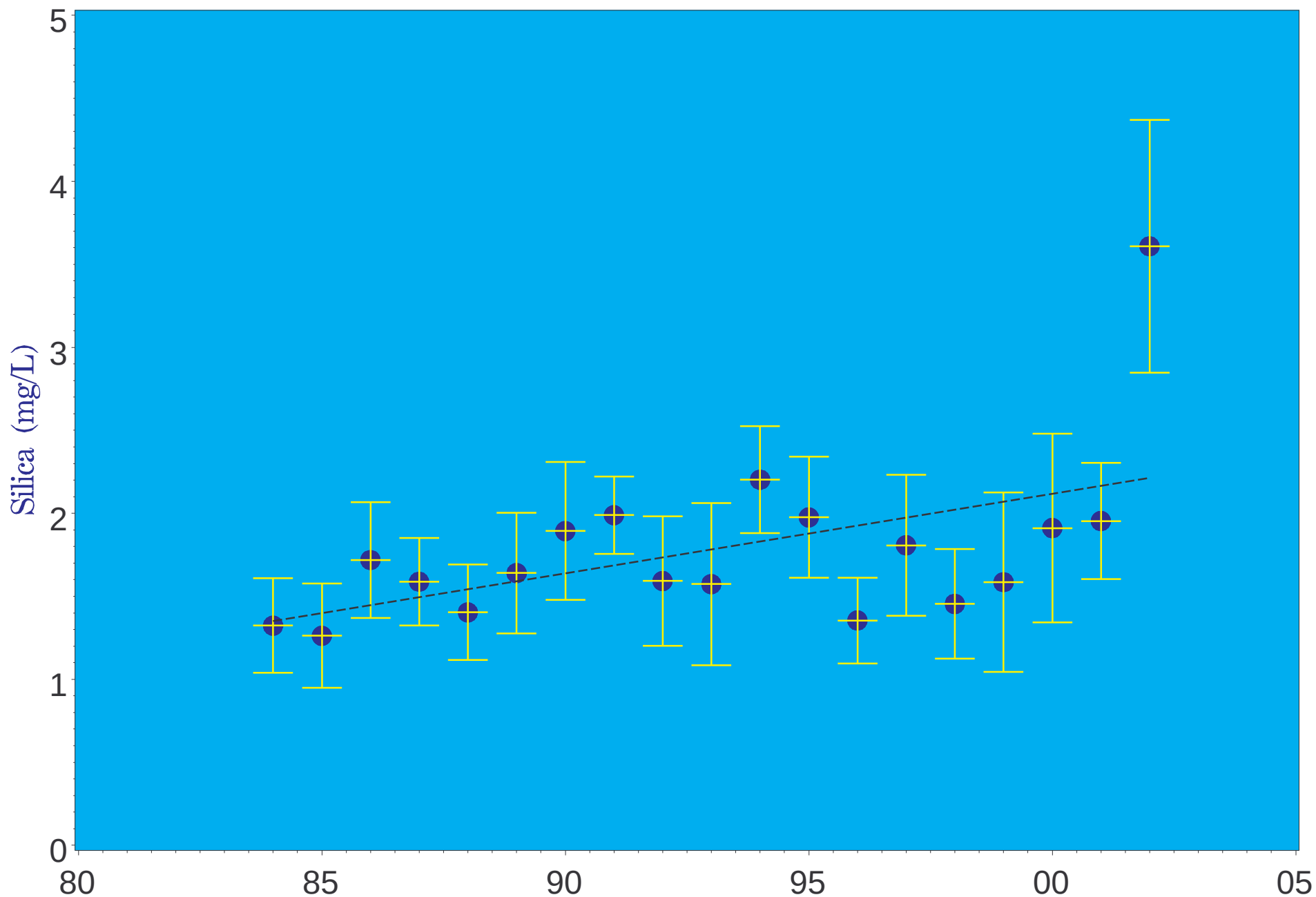


Figure 4.6.137 Annual monthly surface silica at 12 o/oo isohaline (1984-2002)

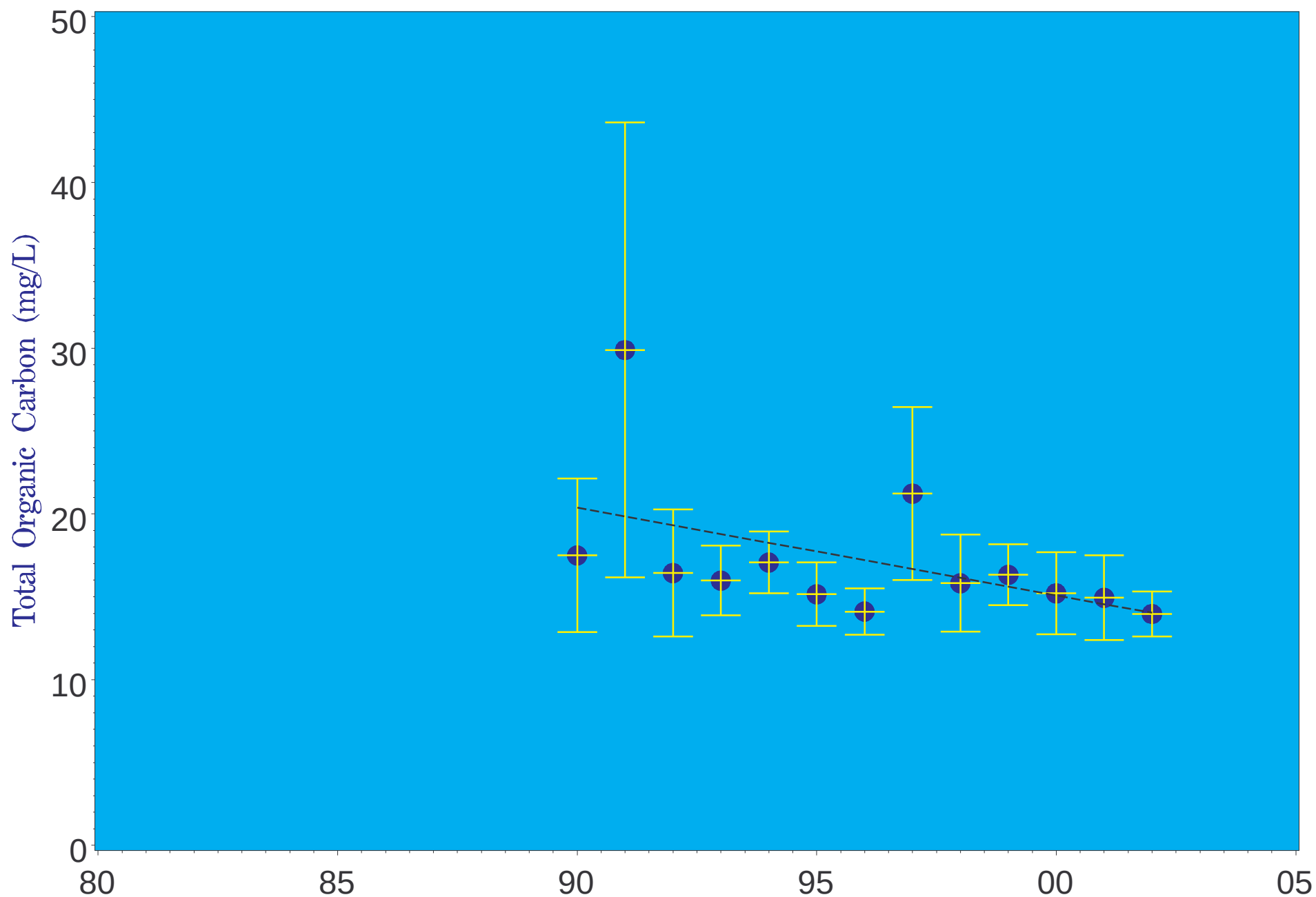


Figure 4.6.138 Annual monthly surface total organic carbon at 12 o/oo isohaline (1984-2002)

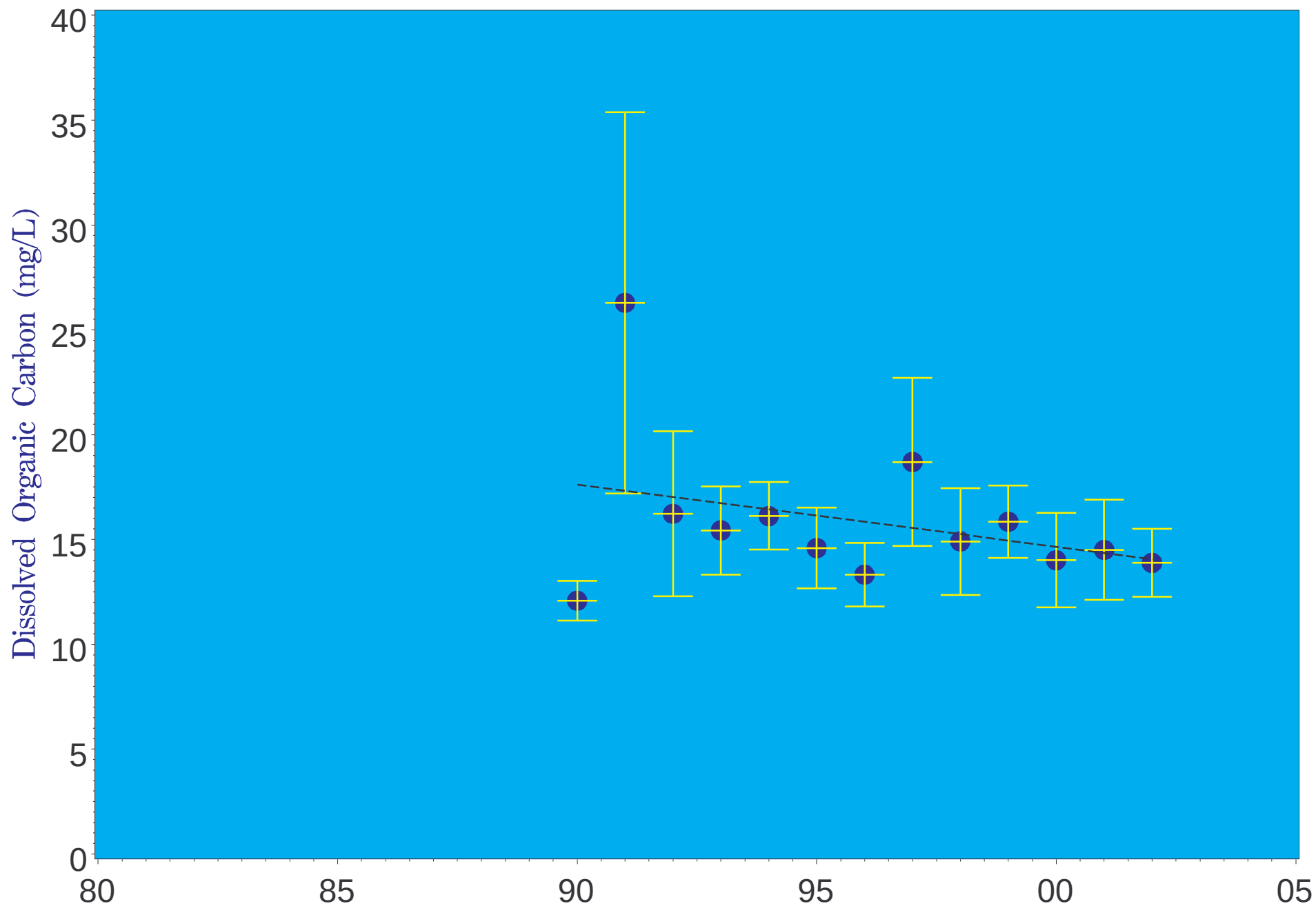


Figure 4.6.139 Annual monthly surface dissolved organic carbon at 12 o/oo isohaline (1984-2002)

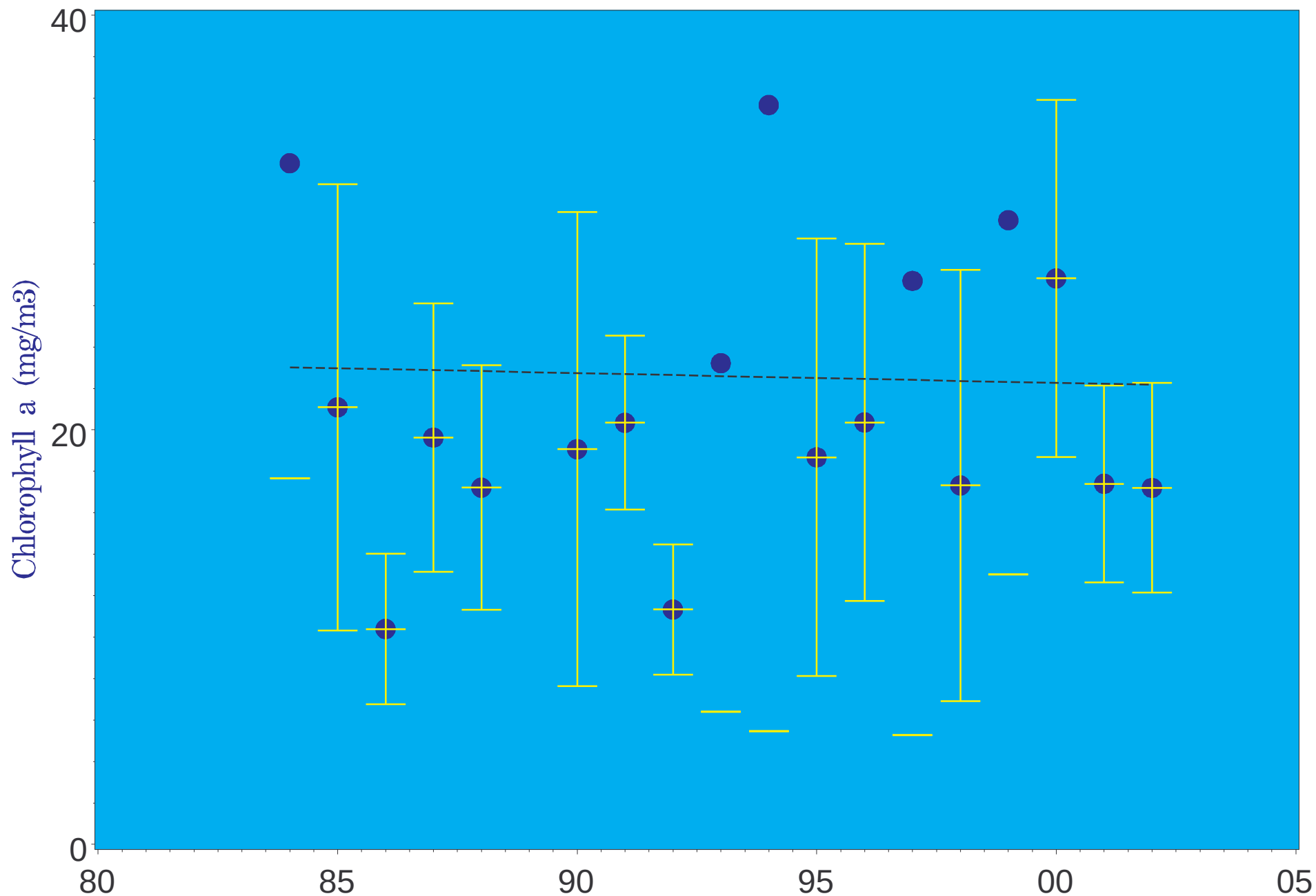


Figure 4.6.140 Annual monthly surface chlorophyll a at 12 o/oo isohaline (1984-2002)

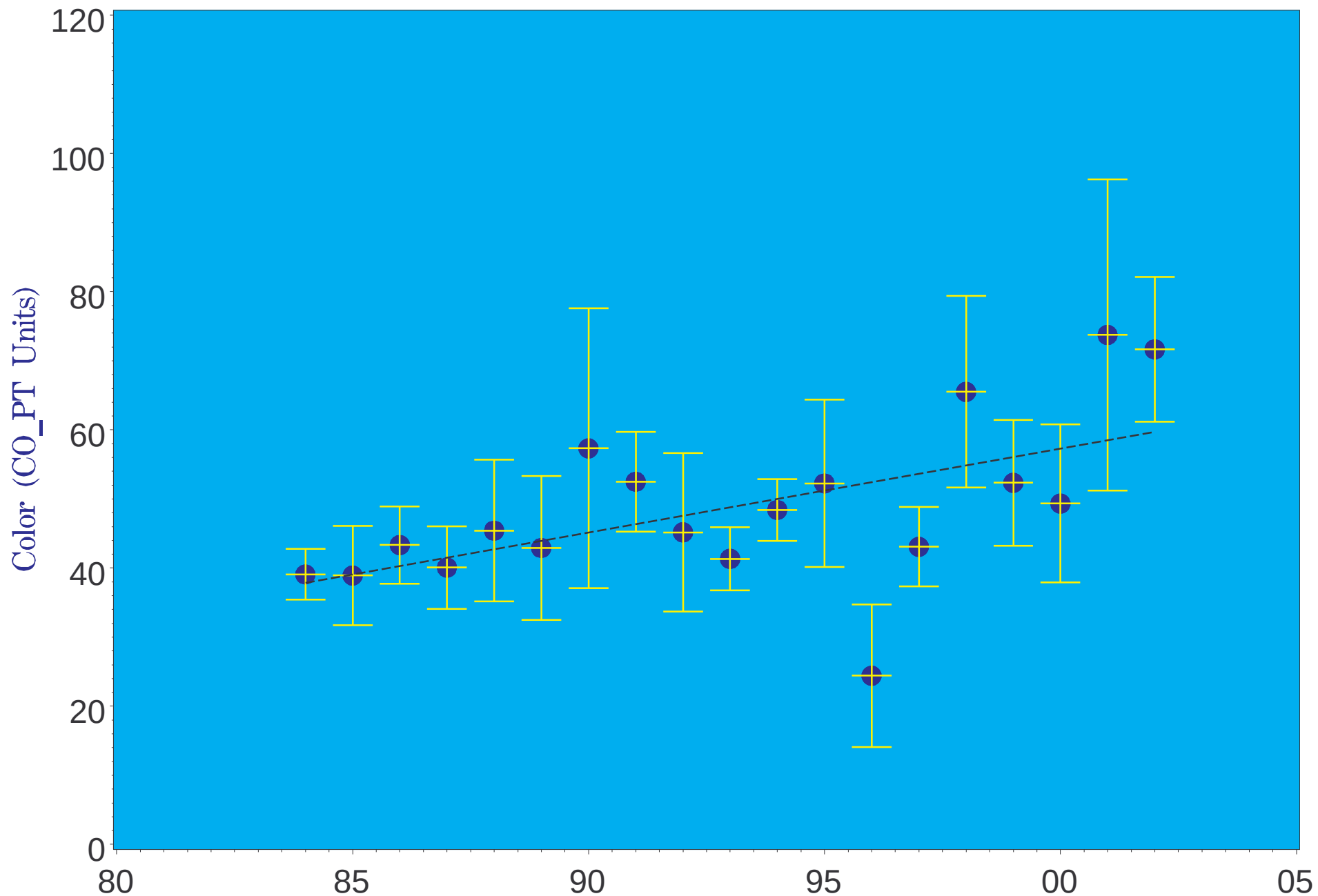


Figure 4.6.141 Annual monthly surface color at 20 o/oo isohaline (1984-2002)

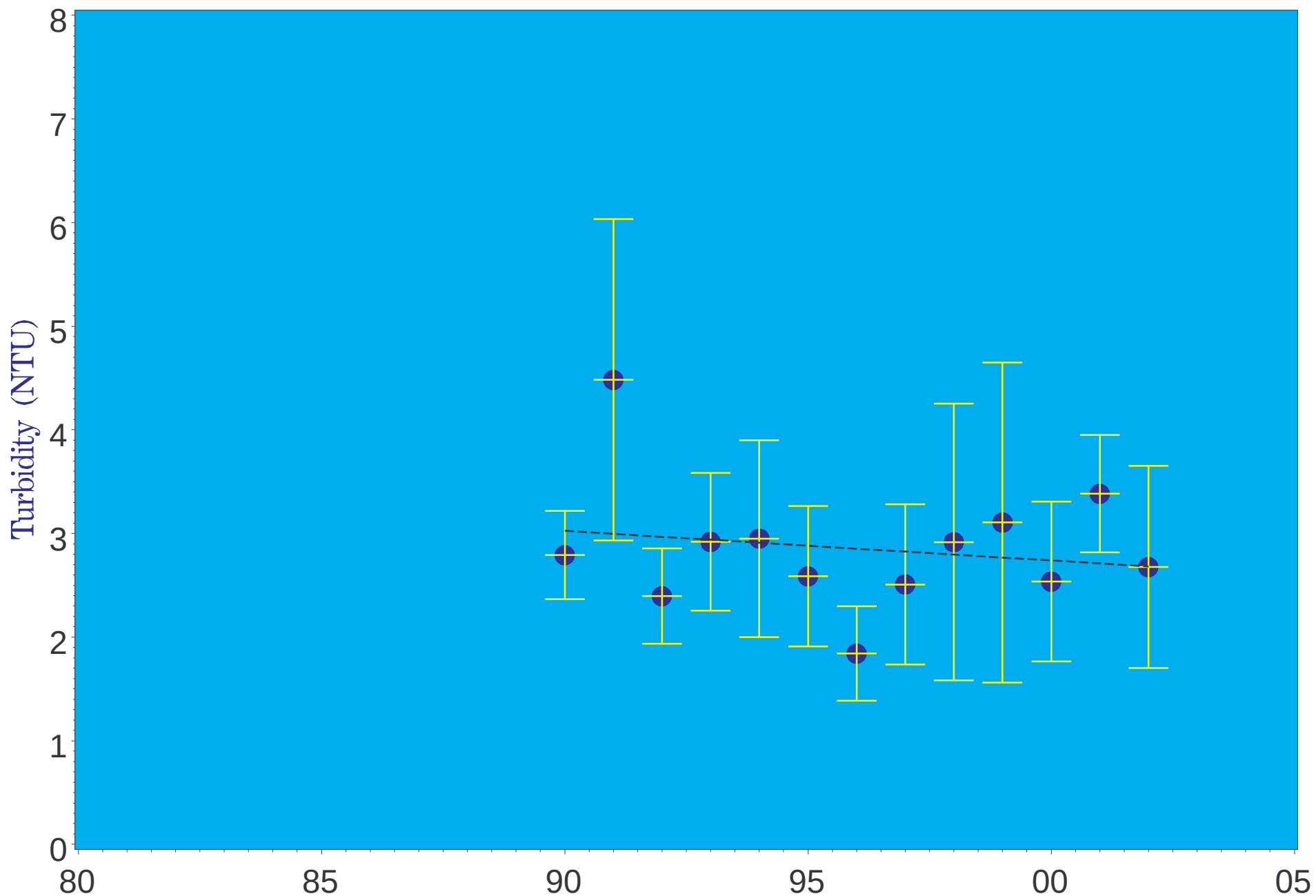


Figure 4.6.142 Annual monthly surface turbidity at 20 o/oo isohaline (1984-2002)



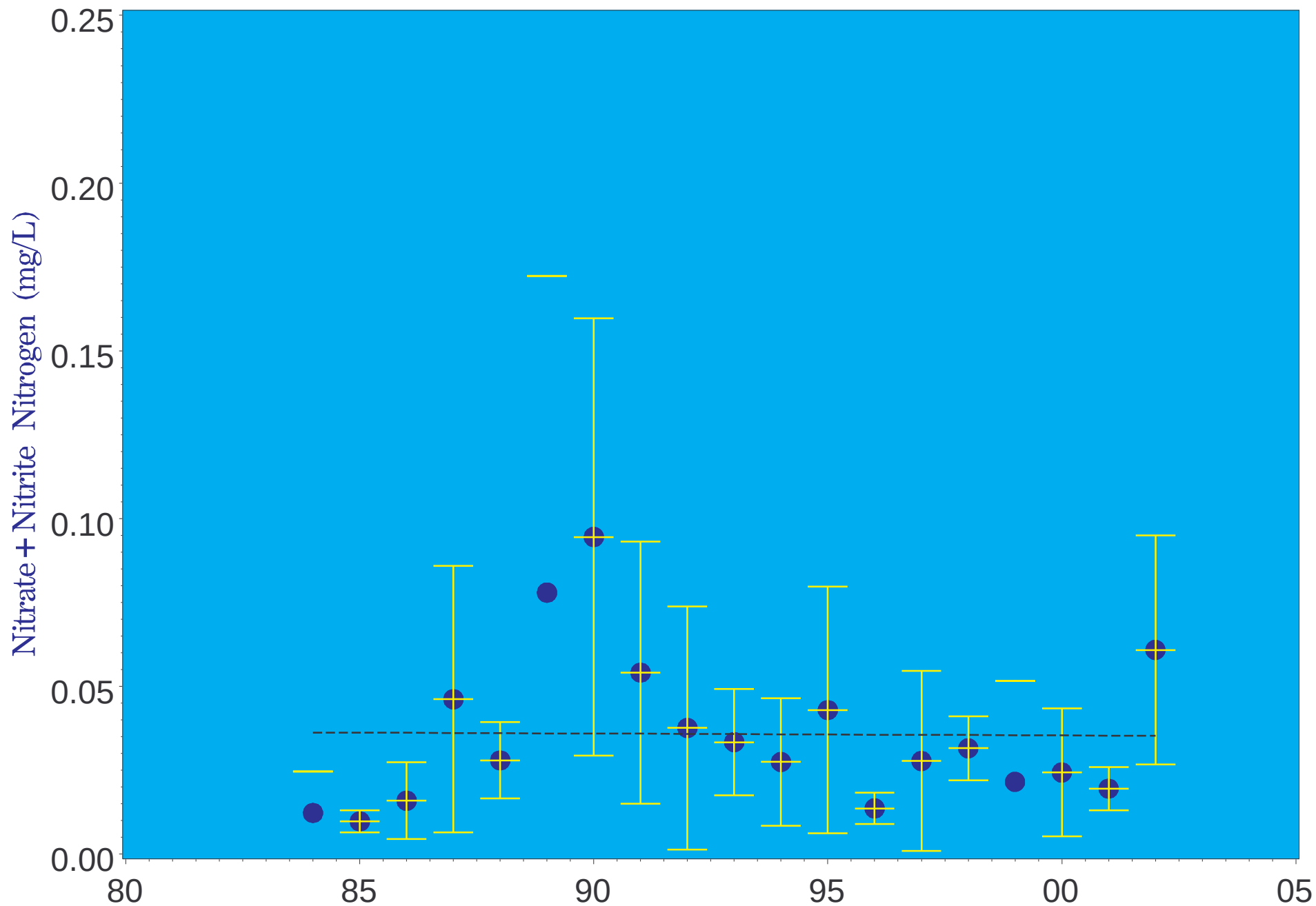


Figure 4.6.143 Annual monthly surface nitrate/nitrite nitrogen at 20 o/oo isohaline (1984-2002)

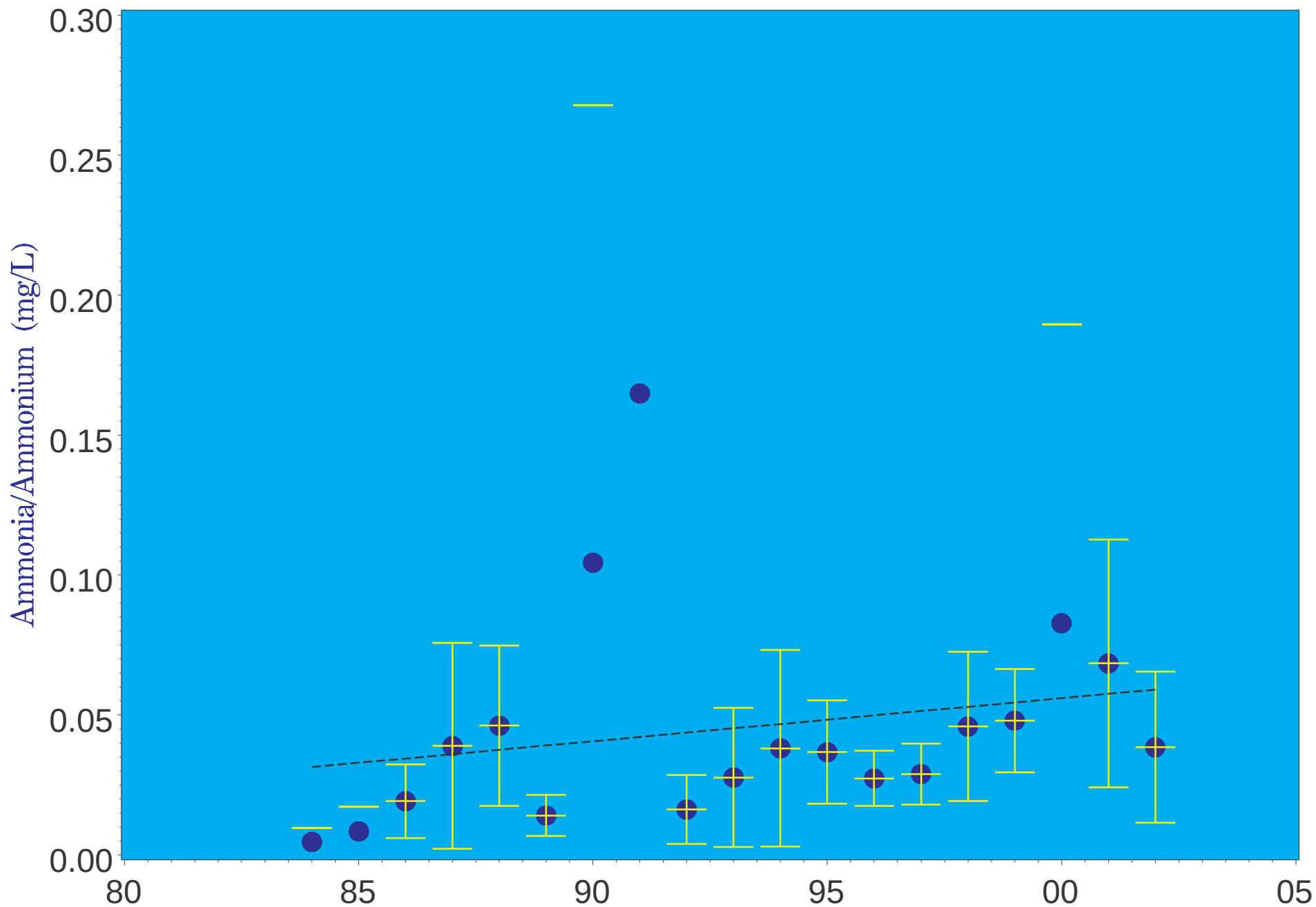


Figure 4.6.144 Annual monthly surface Ammonia/Ammonium at 20 o/oo isohaline (1984-2002)

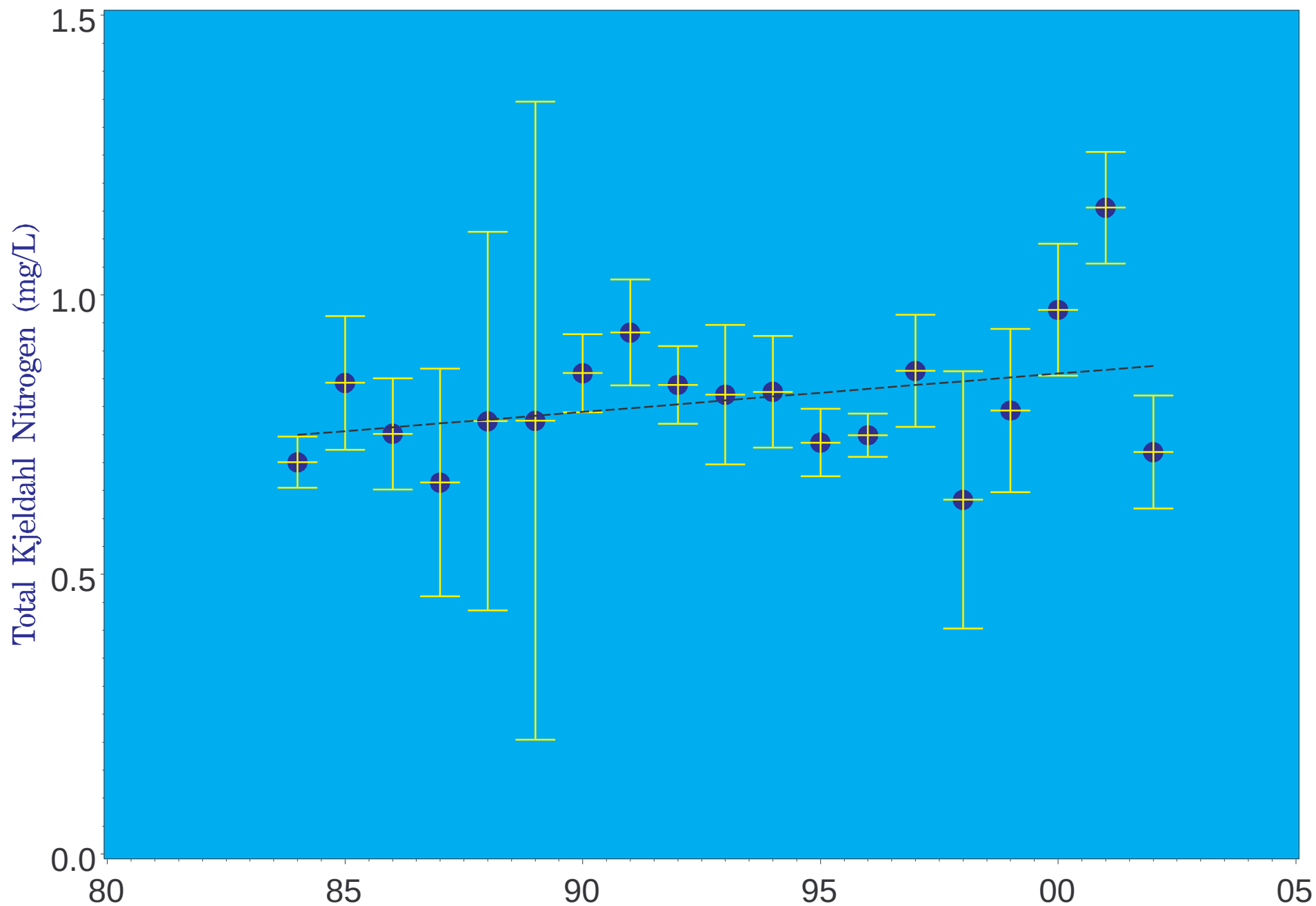


Figure 4.6.145 Annual monthly surface total Kjeldahl nitrogen at 20 o/oo isohaline (1984-2002)

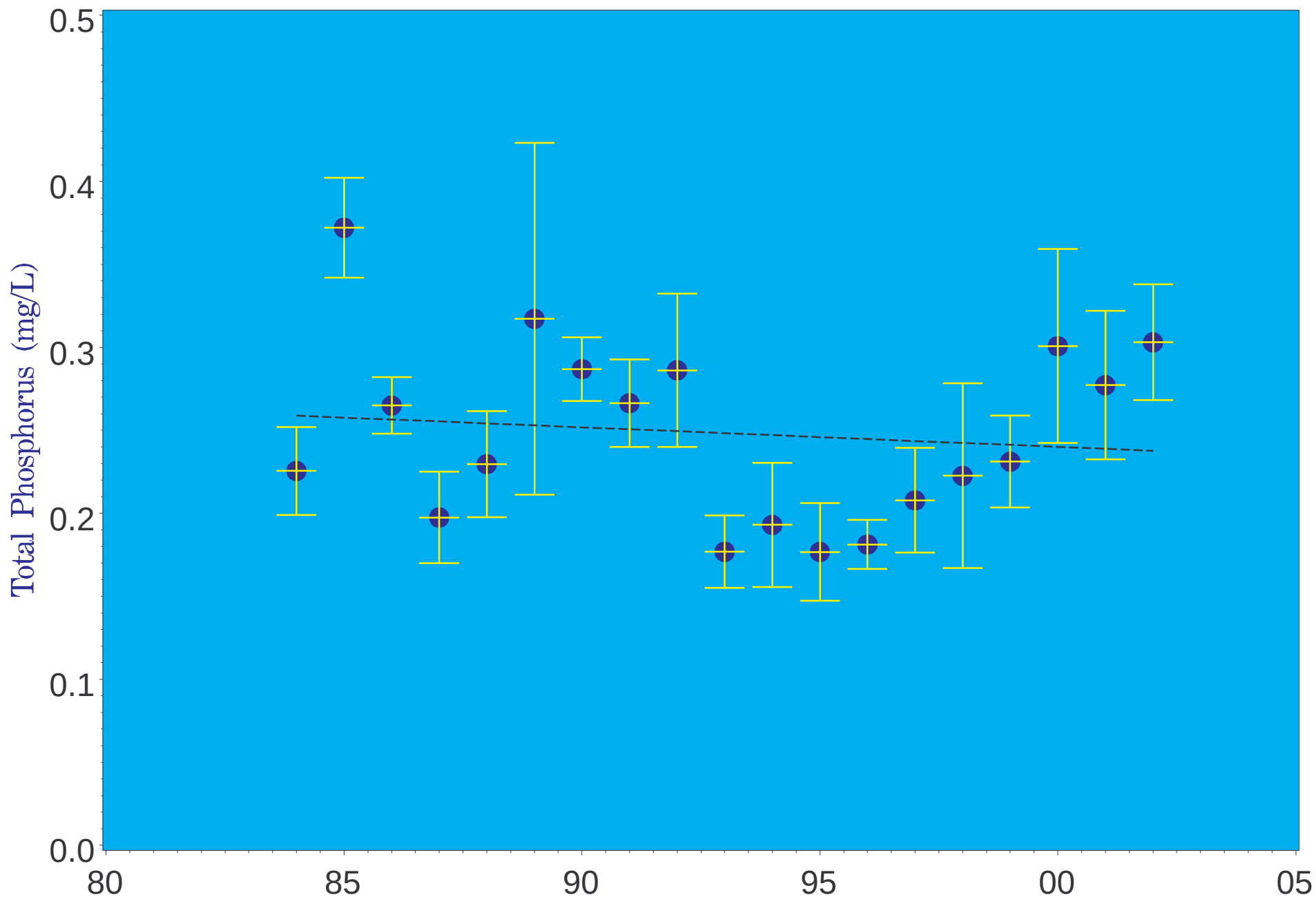


Figure 4.6.146 Annual monthly surface total phosphorus at 20 o/oo isohaline (1984-2002)

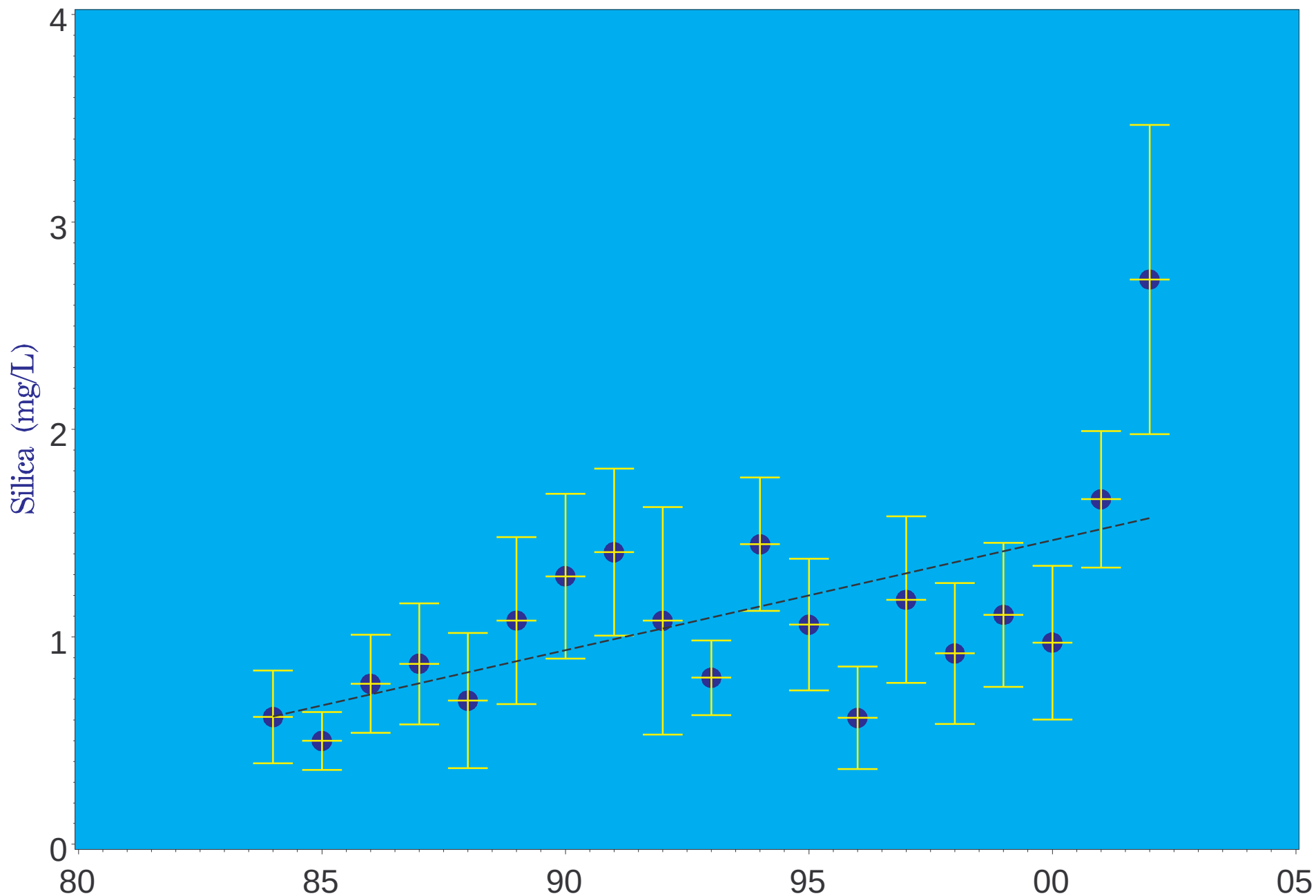


Figure 4.6.147 Annual monthly surface silica at 20 o/oo isohaline (1984-2002)

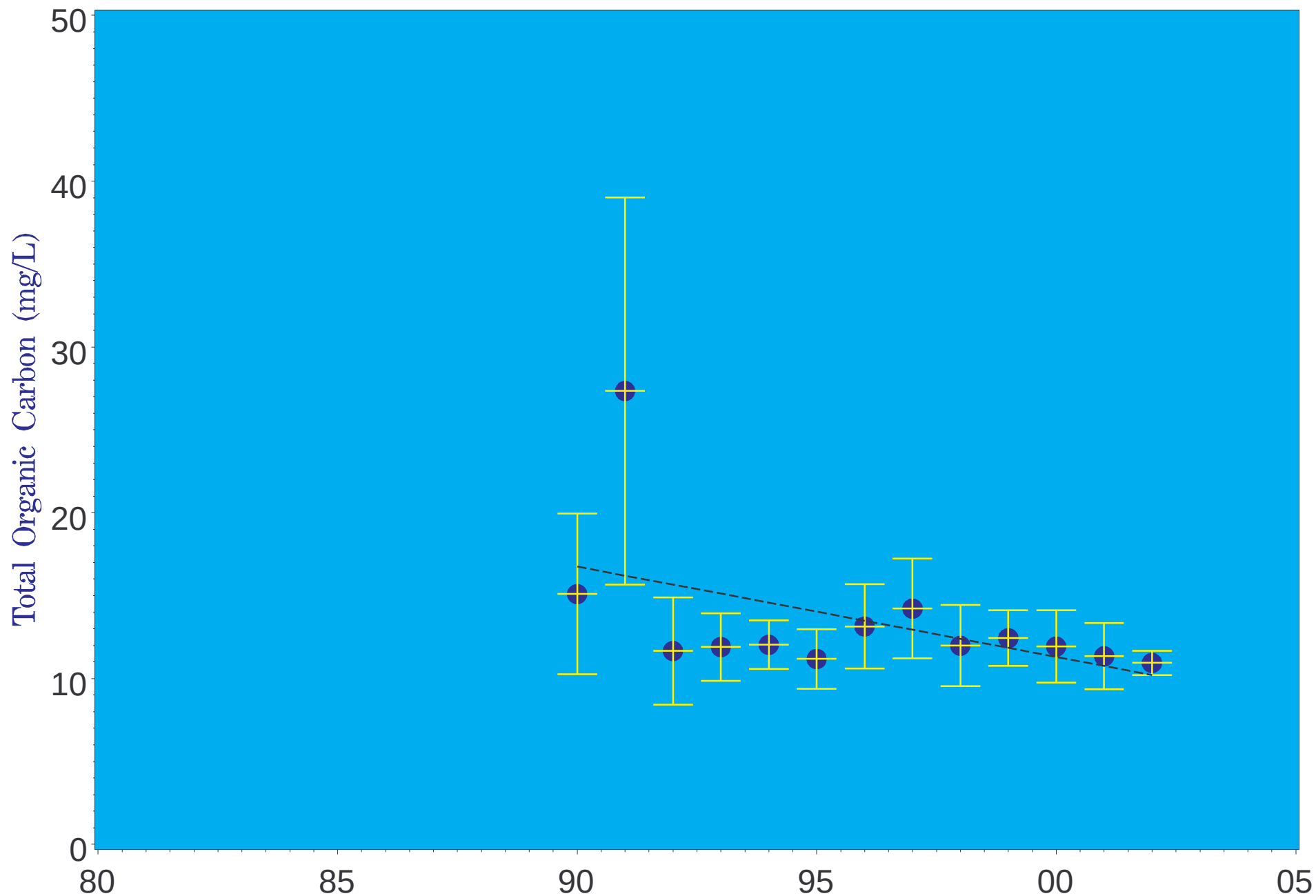


Figure 4.6.148 Annual monthly surface total organic carbon at 20 o/oo isohaline (1984-2002)

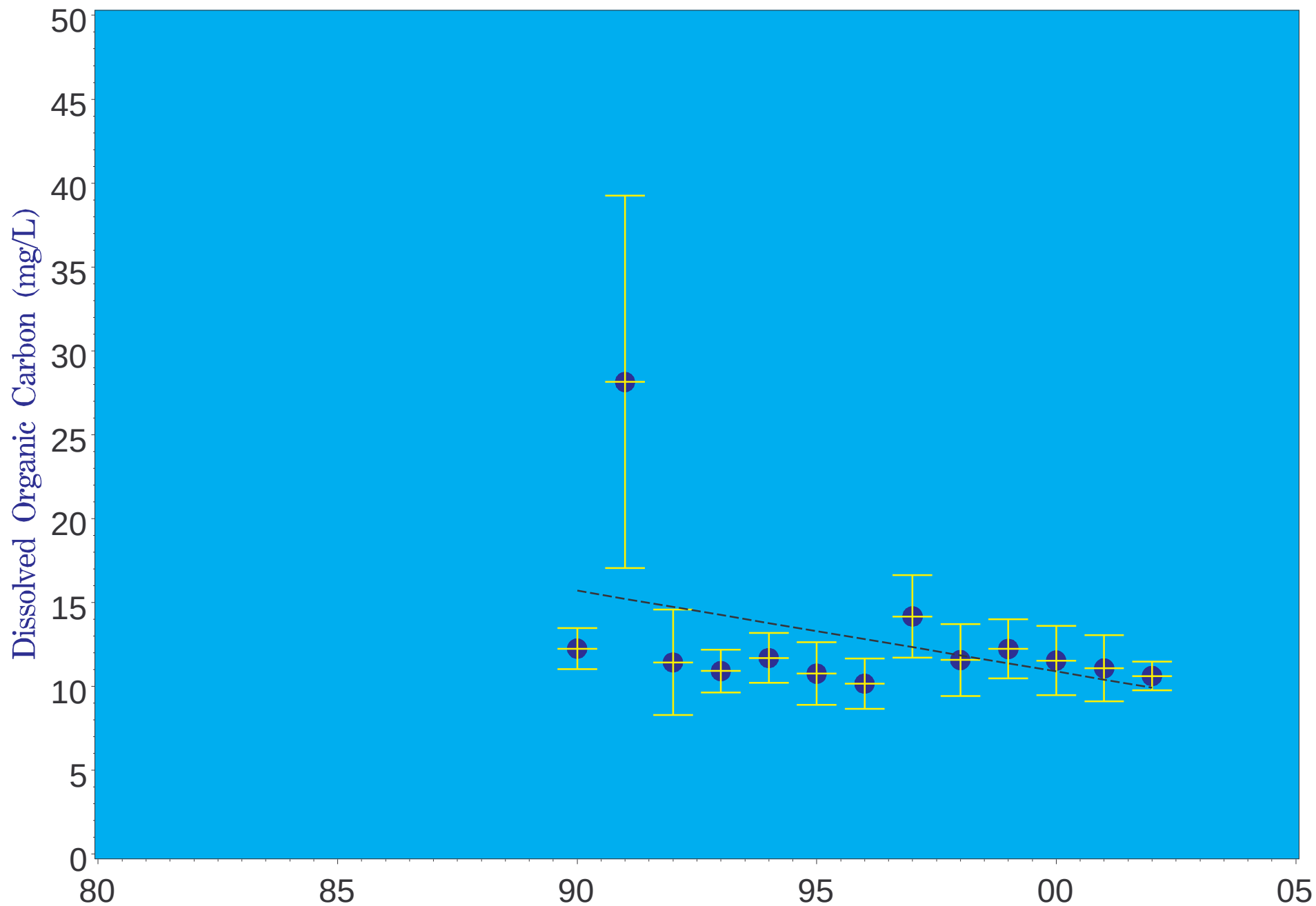


Figure 4.6.149 Annual monthly surface dissolved organic carbon at 20 o/oo isohaline (1984-2002)

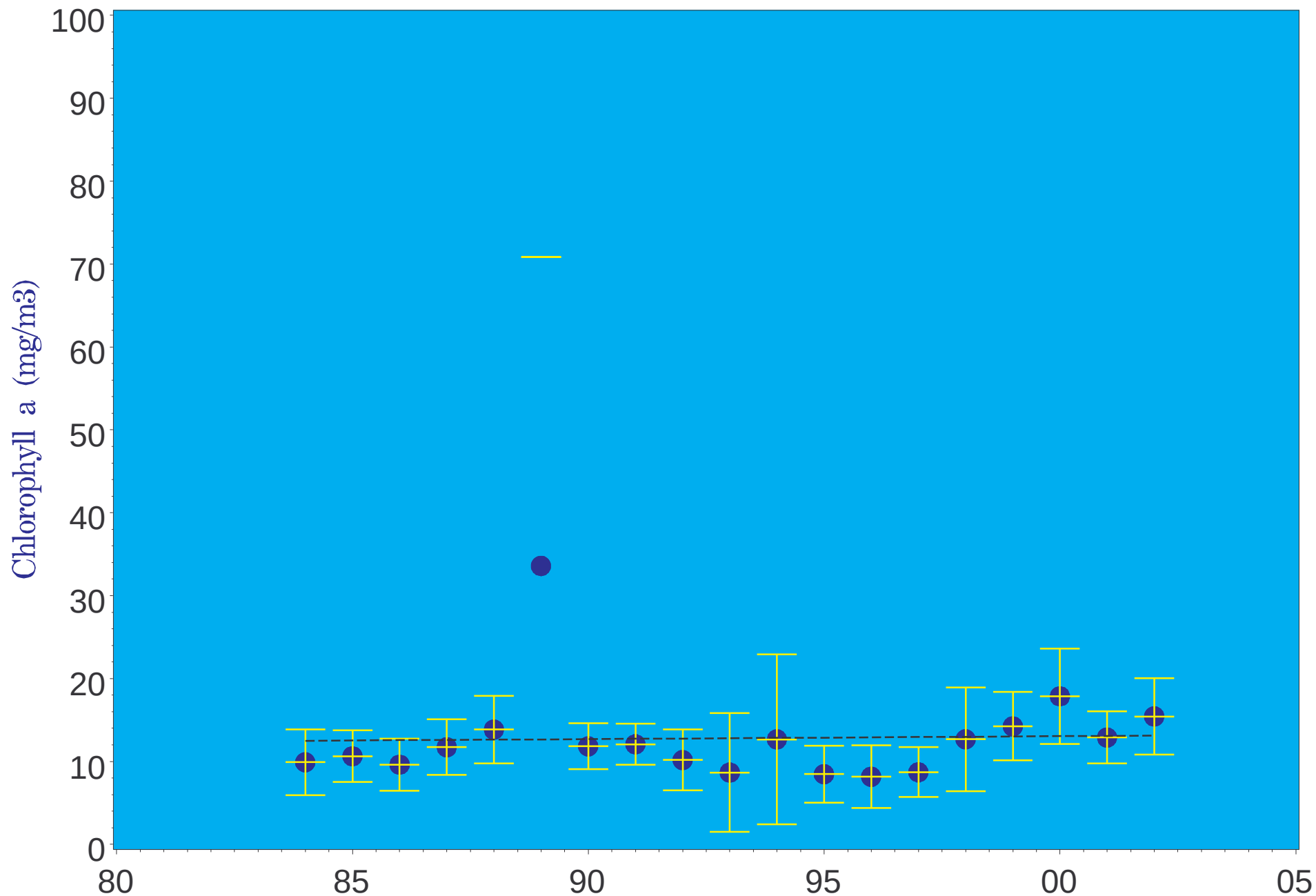


Figure 4.6.150 Annual monthly surface chlorophyll a at 20 o/oo isohaline (1984-2002)



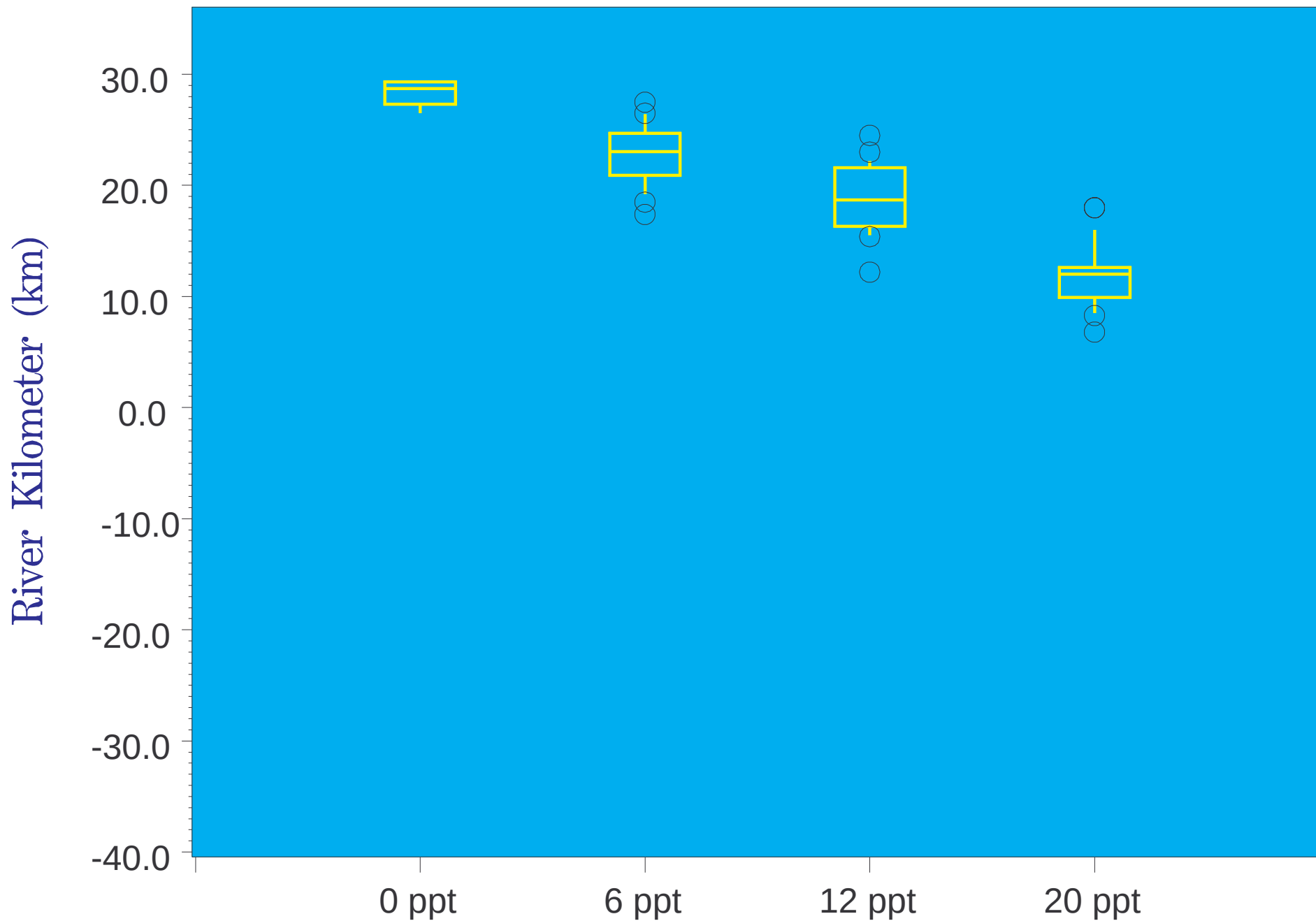


Figure 4.6.151 Box & whiskers of isohaline sampling location (0 to 90 cfs)

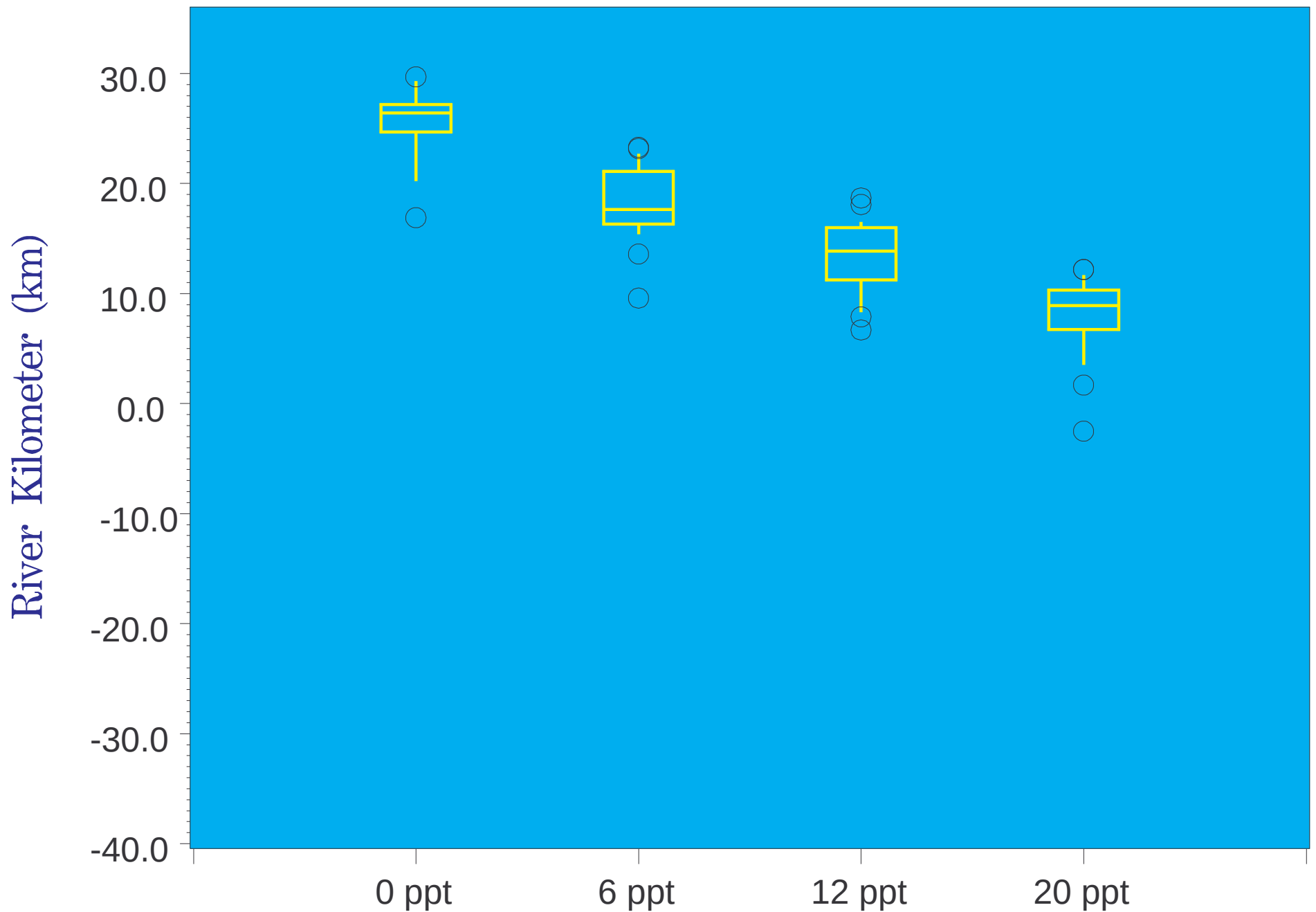


Figure 4.6.152 Box & whiskers of isohaline sampling location (90 to 160 cfs)

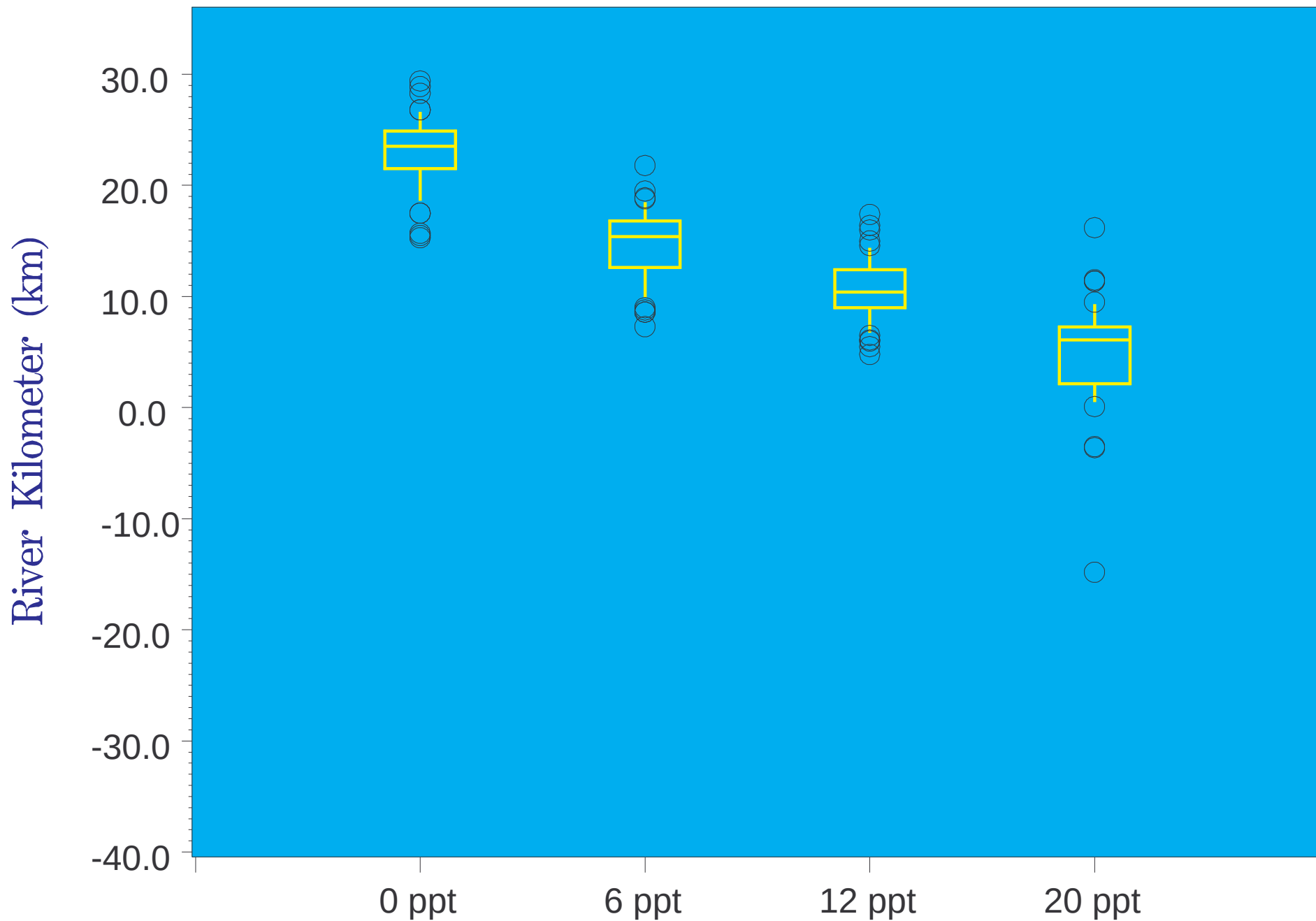


Figure 4.6.153 Box & whiskers of isohaline sampling location (160 to 360 cfs)

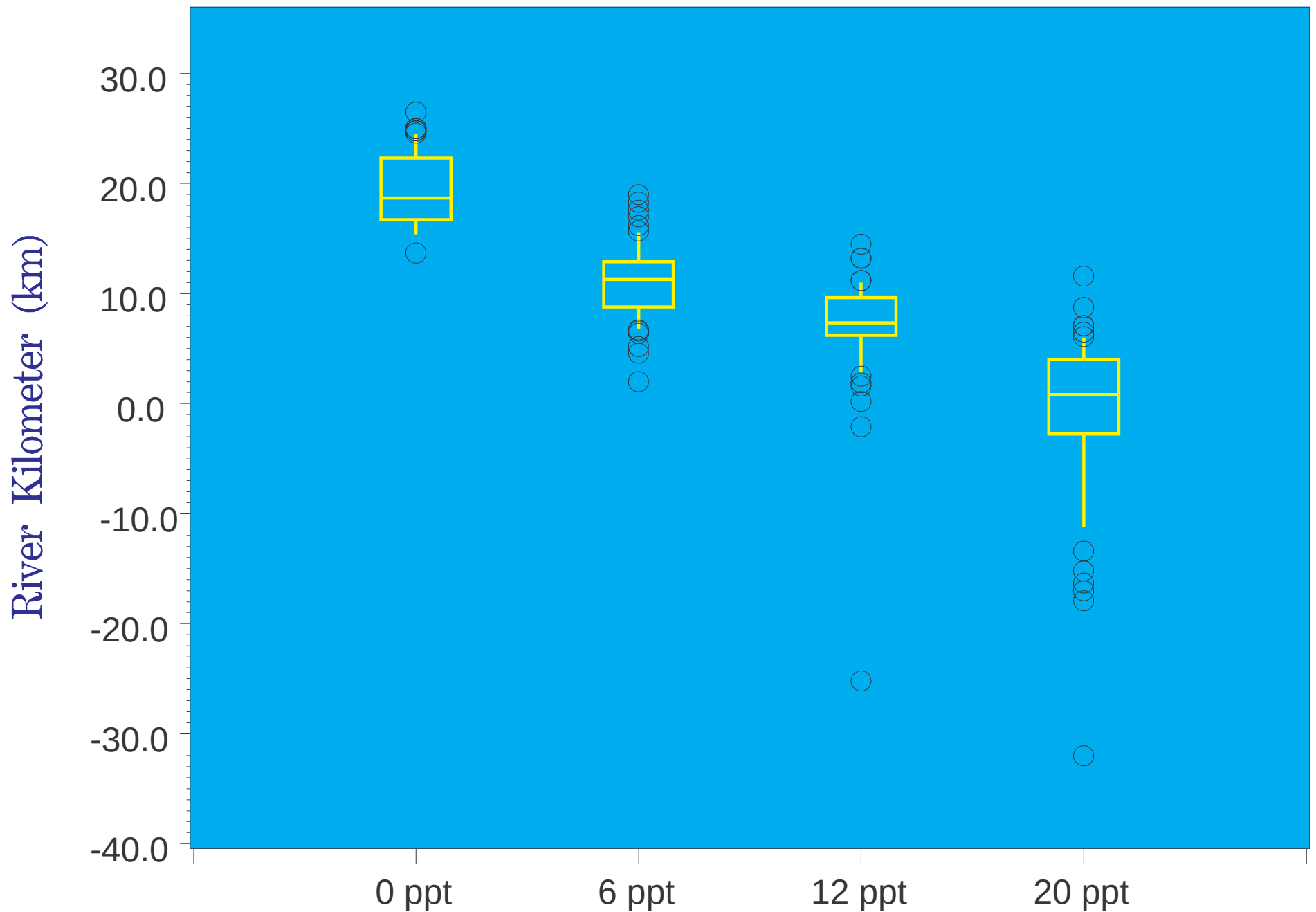


Figure 4.6.154 Box & whiskers of isohaline sampling location (360 to 920 cfs)

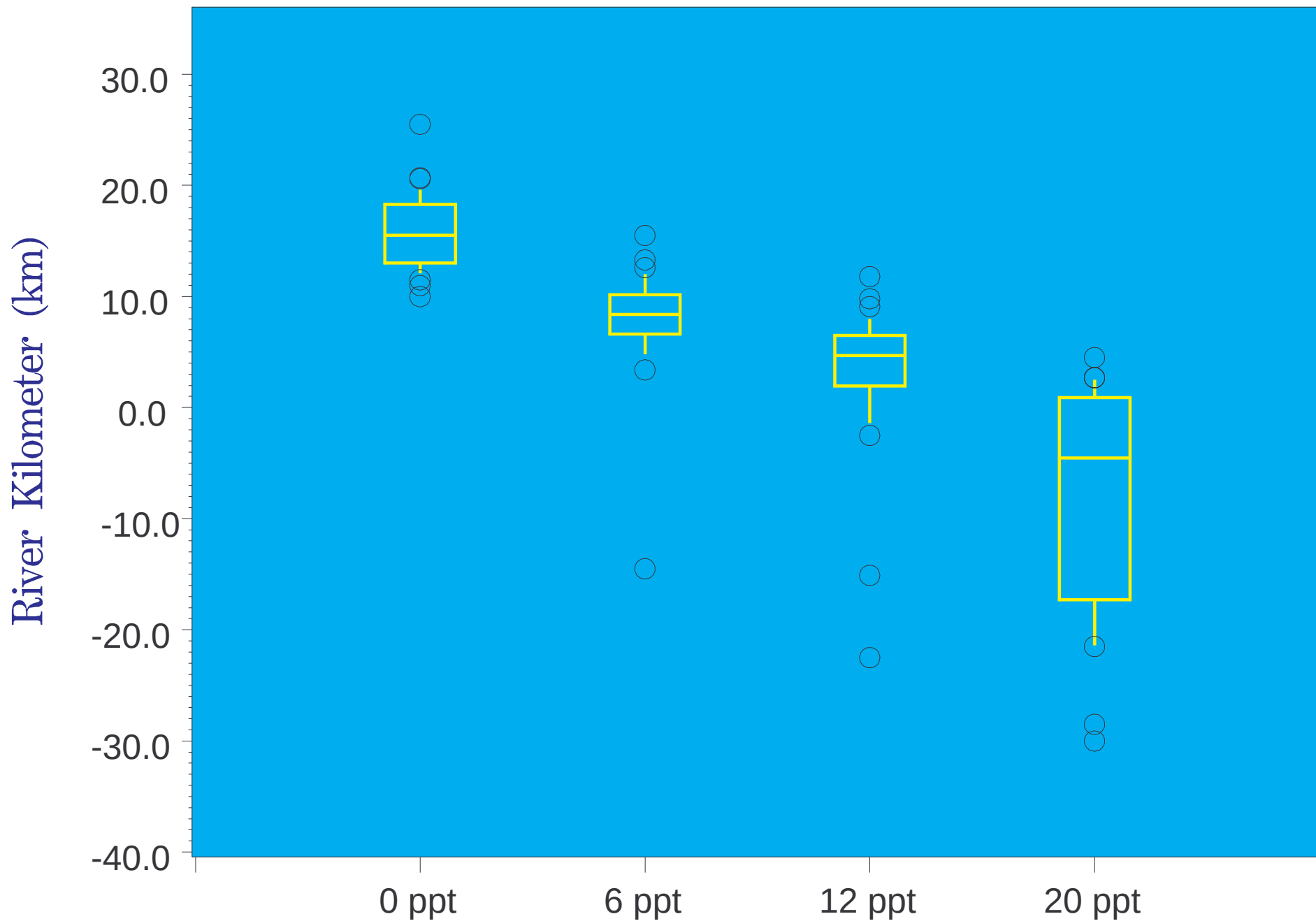


Figure 4.6.155 Box & whiskers of isohaline sampling location (920 to 2100 cfs)

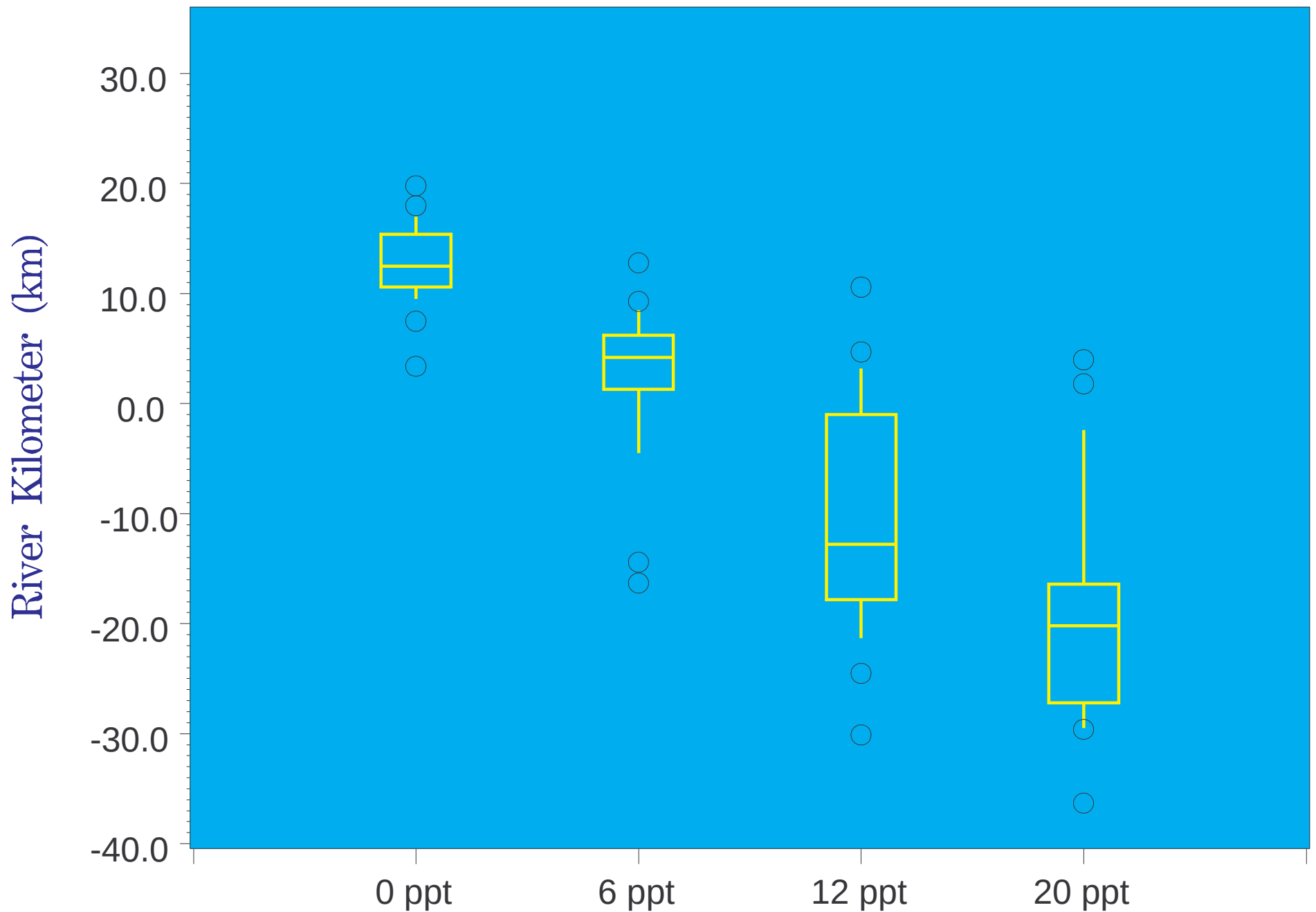


Figure 4.6.156 Box & whiskers of isohaline sampling location (> 2100 cfs)

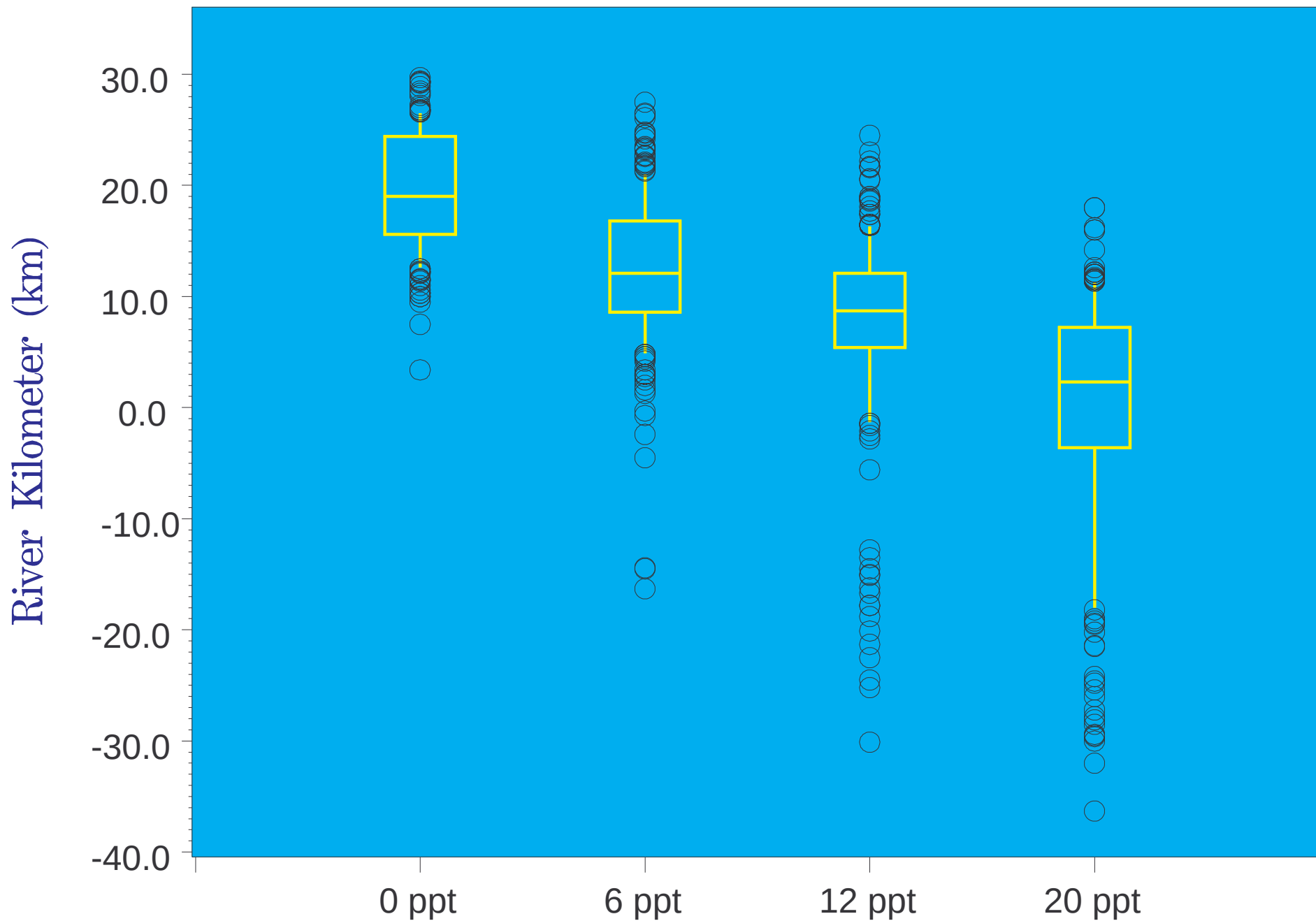


Figure 4.6.157 Box & whiskers of isohaline sampling location (all flows)

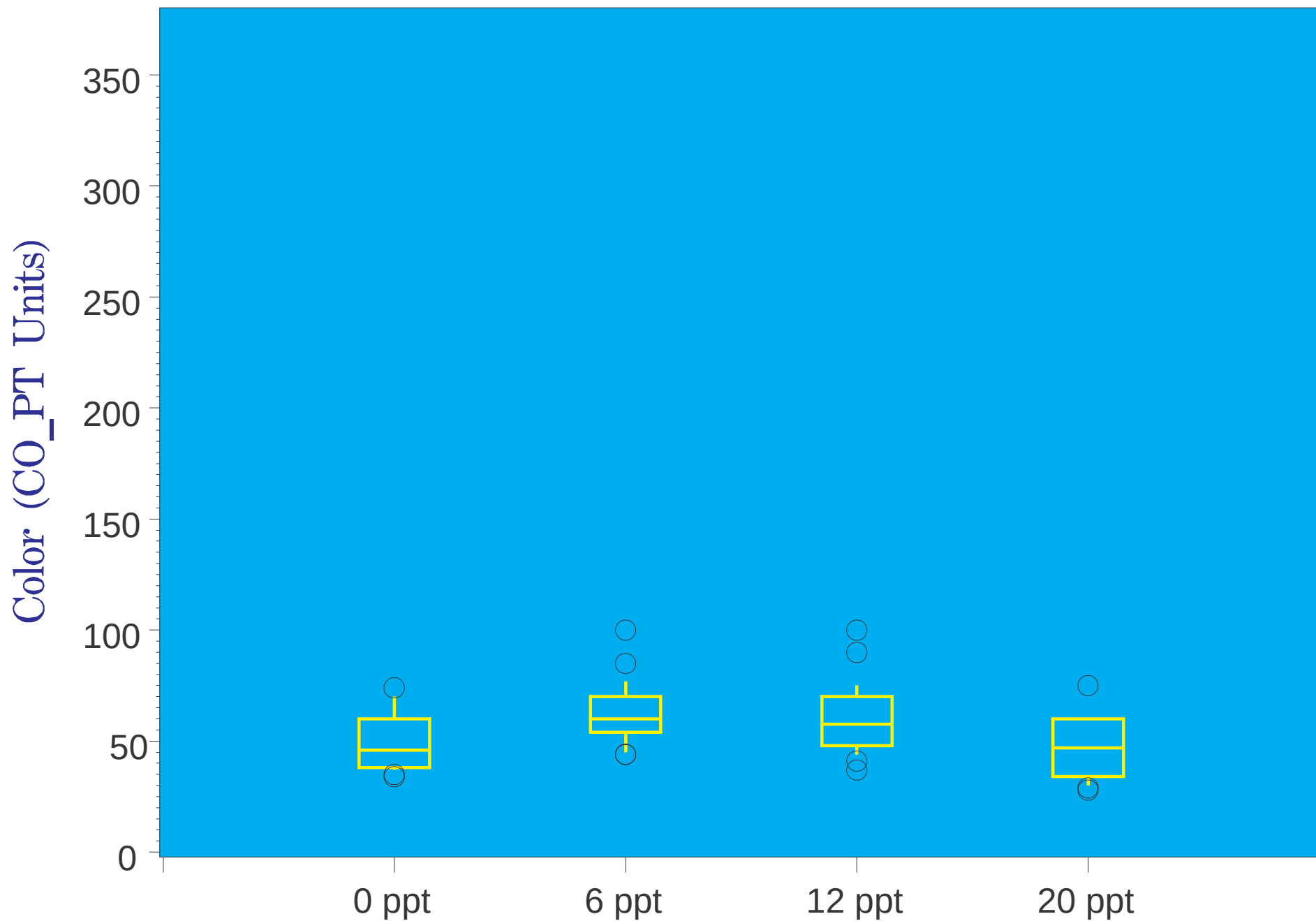


Figure 4.6.158 Box & whiskers of surface color by isohaline sampling location (0 to 90 cfs)



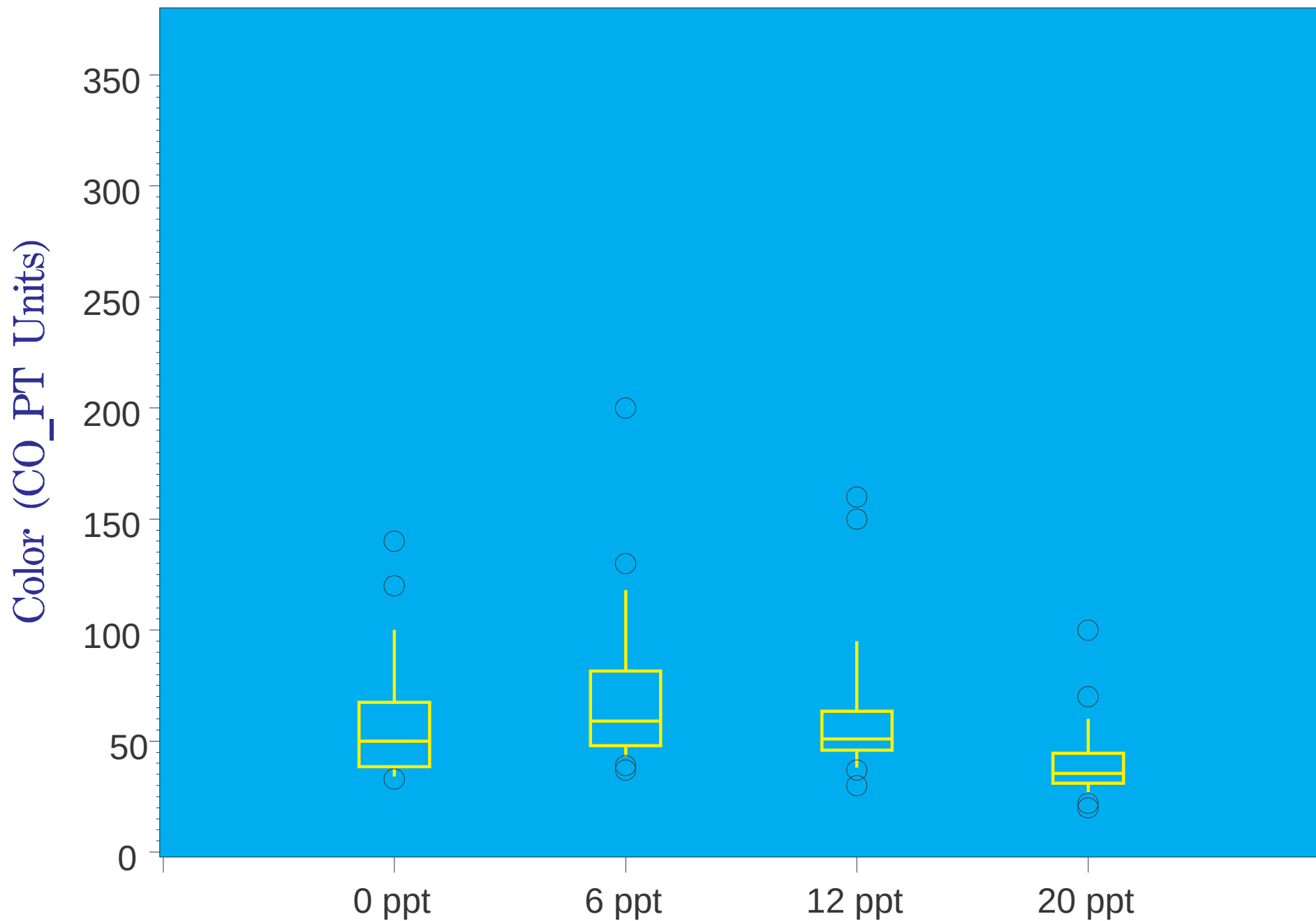


Figure 4.6.159 Box & whiskers of surface color by isohaline sampling location (90 to 160 cfs)

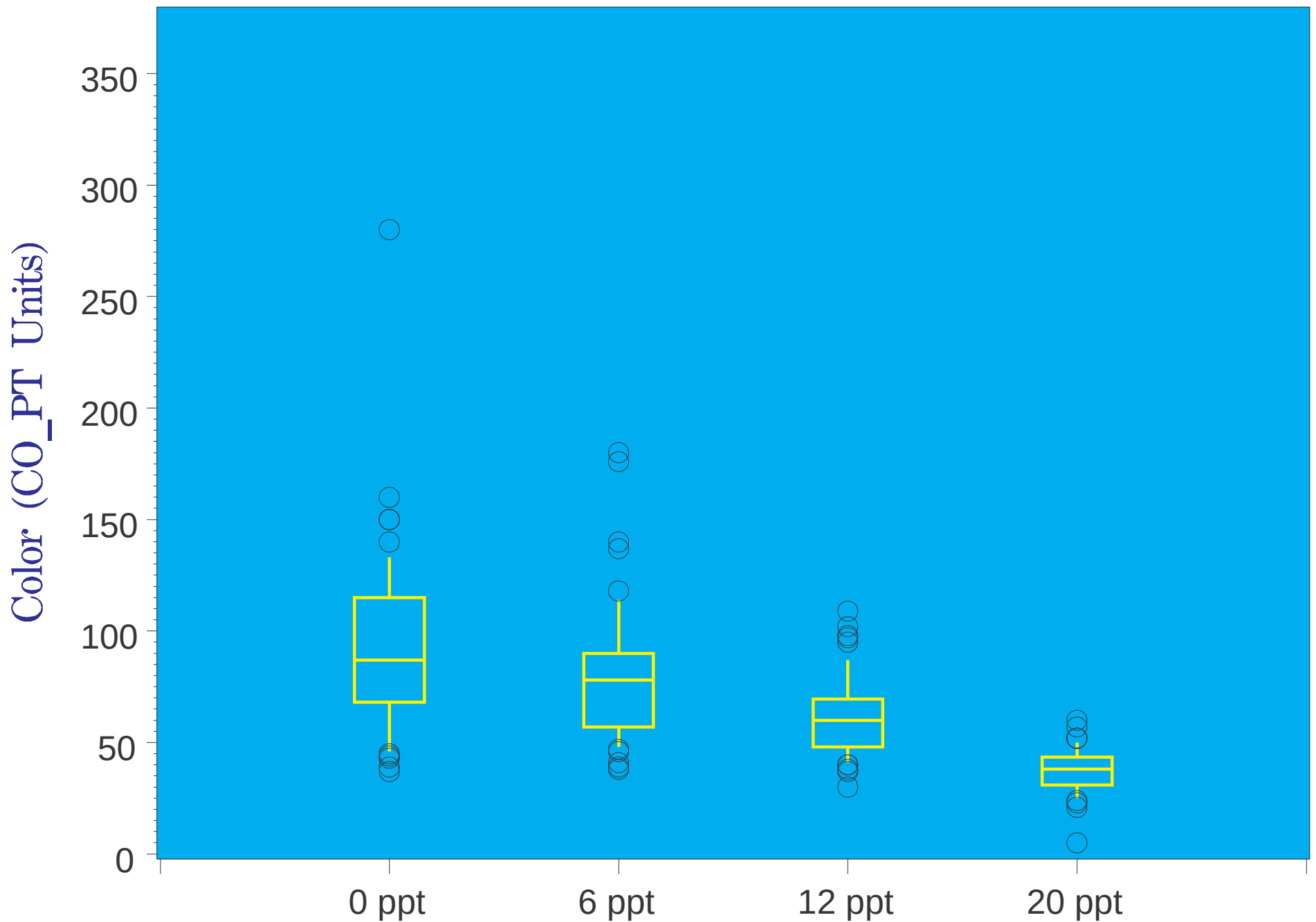


Figure 4.6.160 Box & whiskers of surface color by isohaline sampling location (160 to 360 cfs)

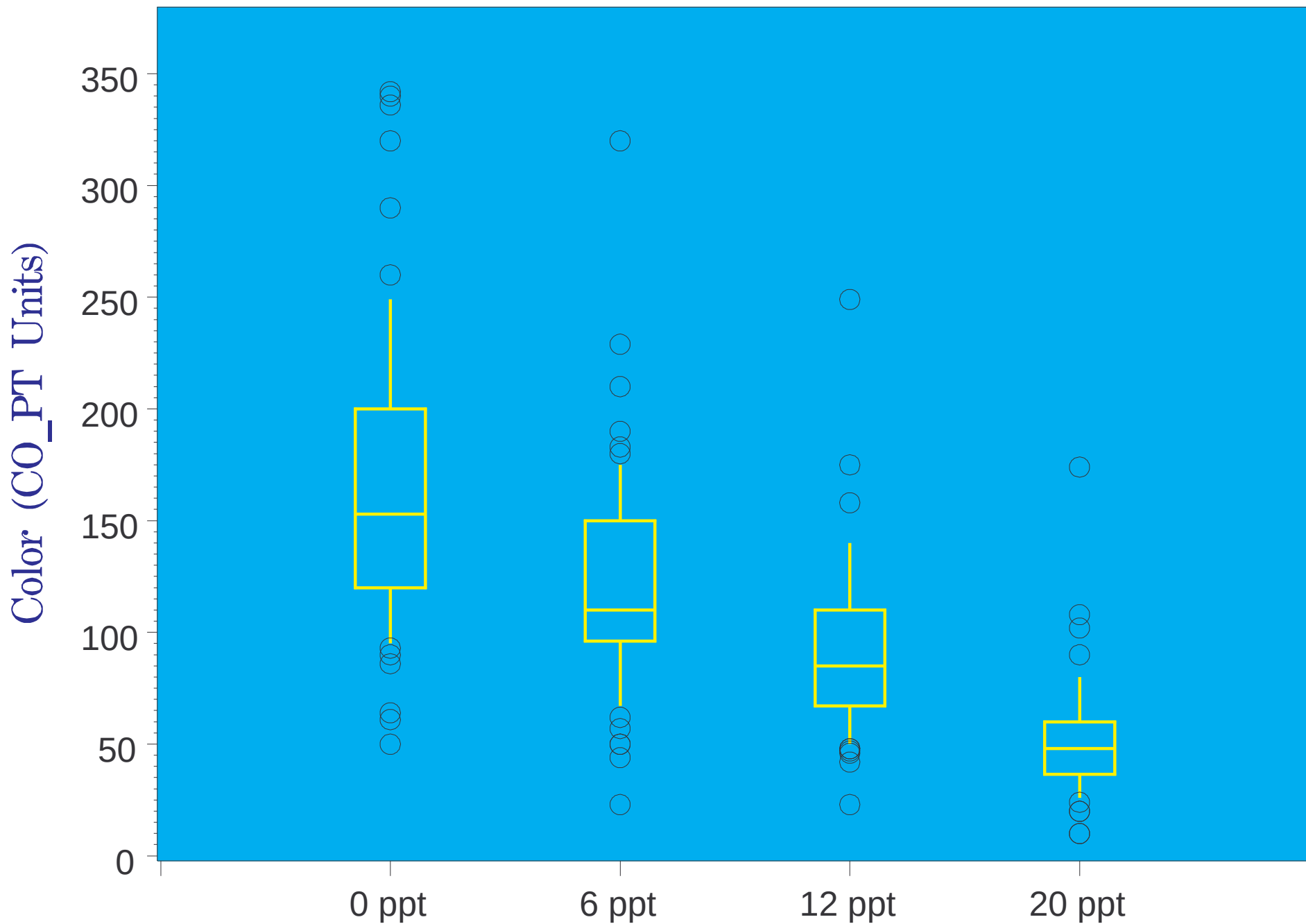


Figure 4.6.161 Box & whiskers of surface color by isohaline sampling location (360 to 920 cfs)

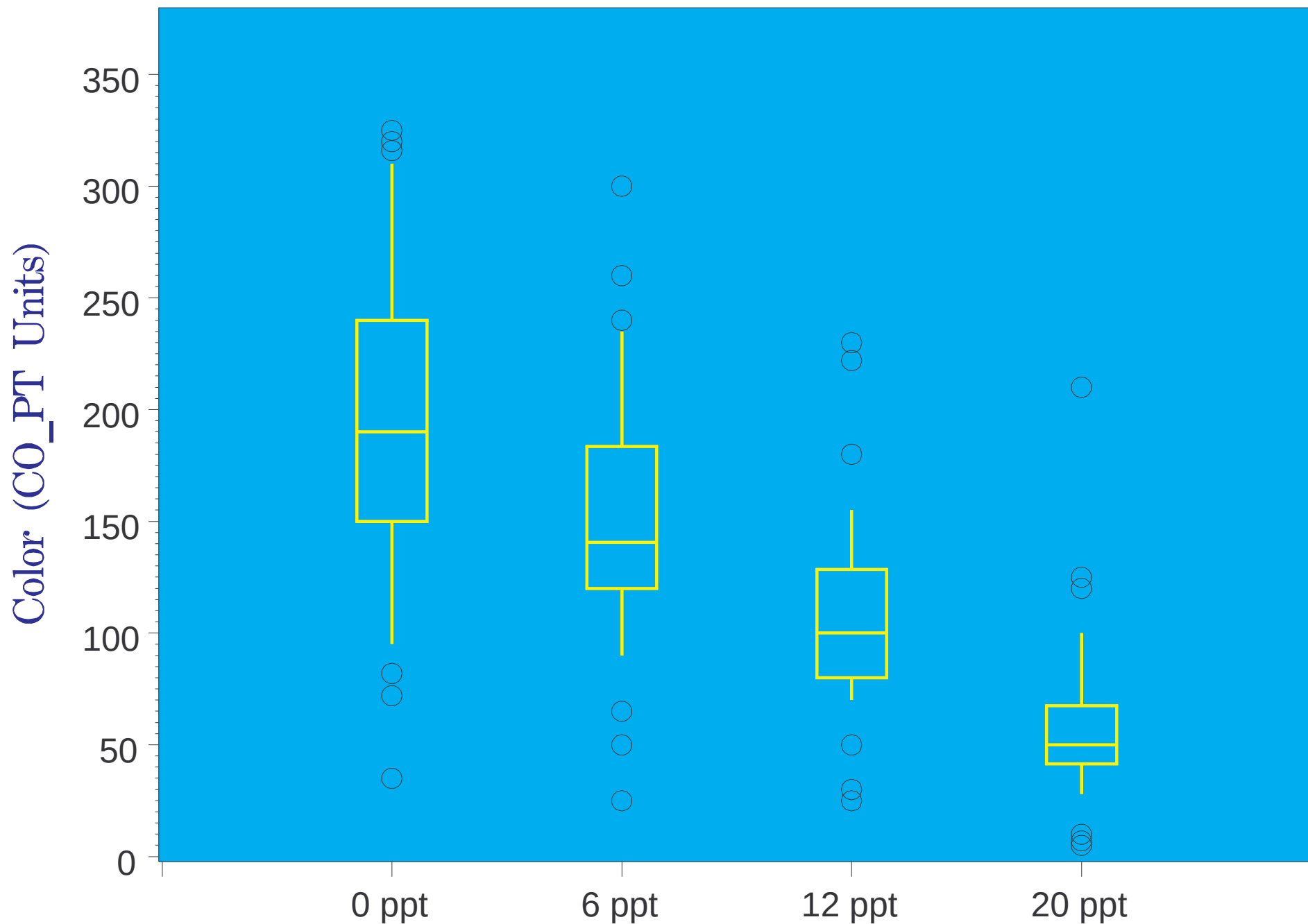


Figure 4.6.162 Box & whiskers of surface color by isohaline sampling location (920 to 2100 cfs)

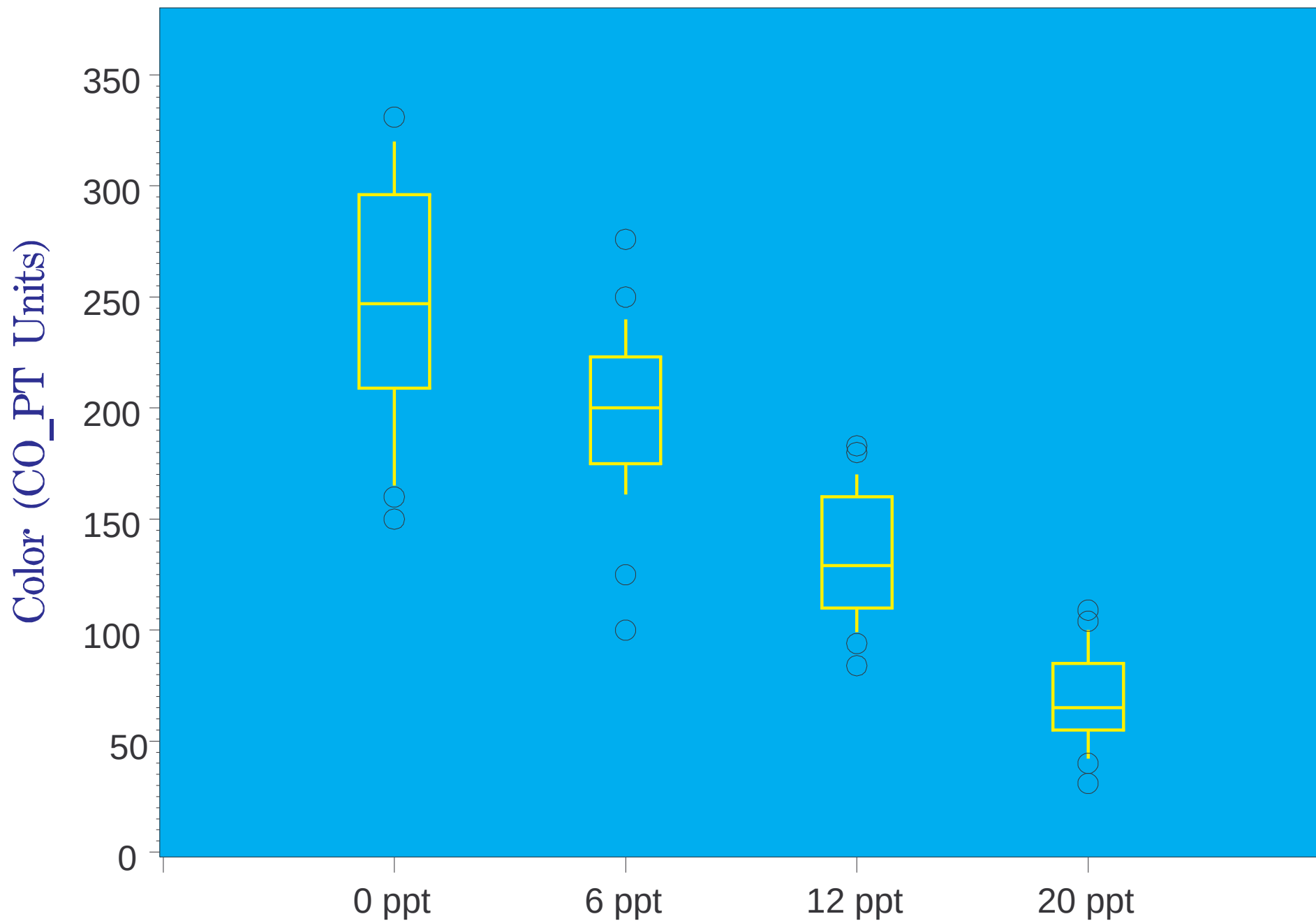


Figure 4.6.163 Box & whiskers of surface color by isohaline sampling location (> 2100 cfs)