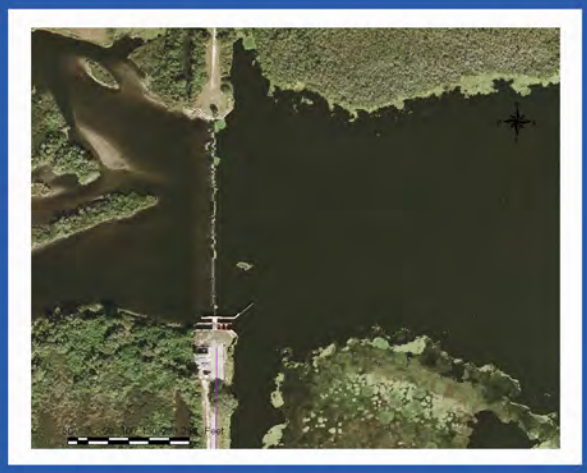
City of Punta Gorda Shell Creek
Year Five Comprehensive Summary Report



PBSJ

an Atkins company

October 2010

City of Punta Gorda Shell Creek HBMP
Year Five Comprehensive Summary Report

Required by

Southwest Florida Water Management District
Water Use Permit 200871.008

Prepared for

City of Punta Gorda
Water Treatment Facility

City of Punta Gorda Utilities

3132 Cooper Street
Punta Gorda, FL 33950

Prepared by

PBSJ
an Atkins company

4030 West Boy Scout Blvd. - Suite 700
Tampa, FL 33607

October 2010

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Acknowledgments

The raw data, as well as information described in the methods section, were provided by the following sources.

- **City of Punta Gorda** – provided background information regarding the Shell Creek Facility, measured daily rates of withdrawals and data regarding specific conductivity and chloride levels within the reservior.

- **U.S. Geological Survey (Tampa Office) –** USGS collects daily stream flow data at a wide number of gaging locations throughout southwest Florida. Data for the period of record were obtained from the USGS web site: **(http://fl.water.usgs.gov/Tampa/index.html)**

  1. Peace River at Arcadia (02296750)
  2. Joshua Creek at Nocatee (02297100)
  3. Horse Creek near Arcadia (02297310)
  4. Prairie Creek near Fort Ogden (02298123)
  5. Shell Creek near Punta Gorda (02298202)

  Conductivity data was also downloaded from the USGS web site for the continuous recorders located at the following sites.

  1. Prairie Creek at Ft. Ogden (02298124)
  2. Prairie Creek at C.R. 764 (02298170)
  3. Shell Creek at C.R. 764 (02297635)
  4. Shell Creek near Punta Gorda (2298202)

- **Southwest Florida Water Management District** – provided 1997-2005 data gathered at the USGS (RK 4.6), as well as available background District water quality information collected at the following locations.

  1. **Northern Prairie Creek Watershed and Background**
     - Mossy Gully at S.R. 70
     - Cow Slough at S.R. 70

  2. **Prairie Creek Watershed**
     - Montgomery Canal
     - Symons Canal
     - Prairie Creek at C.R. 764

  3. **Shell Creek Watershed and Background**
     - Emerald Isle Canal
     - Shell Creek at C.R. 764

Executive Summary

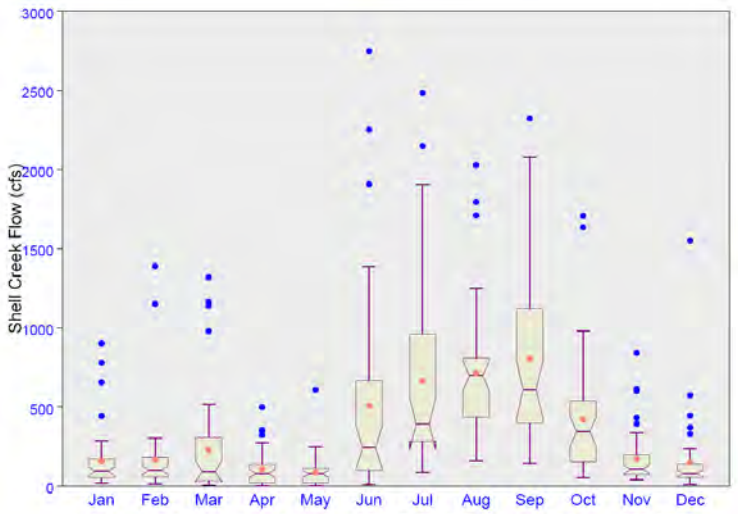
The purpose of the *Shell Creek HBMP Year Five Report* (Report) was to utilize data collected under the ongoing 1991-2009 Shell Creek Hydrobiological Monitoring Program (HBMP) and additional available resources to provide the District with sufficient information to ensure that the Shell Creek/lower Peace River estuarine system has and will not be significantly adversely impacted as a result of the City of Punta Gorda's permitted freshwater withdrawals. This Report provides overviews of the history of the Shell Creek facility, changes in permitted withdrawals, and the ongoing HBMP program monitoring elements. Presented analyses include the following major topics.

- The status and trends of hydrologic conditions within the Prairie/Shell Creek Watersheds.
- Temporal and spatial patterns of water quality characteristics measured upstream of the Hendrickson Dam (Dam), summarizing water quality differences between the Prairie and Shell Creek systems and relationships with changes in flows.
- Changes in key water quality parameters in the tidal reach of Shell Creek downstream of the Dam relative to variations in freshwater inflows.
- Comparison of the magnitude of predicted changes in salinity below the Dam associated with the City's Shell Creek withdrawals relative to natural seasonal and annual variations in freshwater flows.

Recommendations are further offered regarding potential modifications that may be considered toward improving and refocusing particular HBMP study elements in the future.

Status and Trends of Hydrologic Conditions within the Shell Creek Watershed

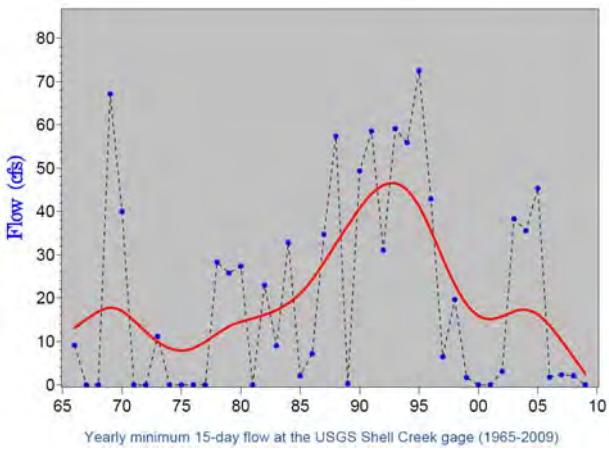
The Shell/Prairie Creek Watershed is characterized by a four month summer wet-season that on average accounts for approximately 60 percent of total annual precipitation. However, seasonal influences of rainfall on watershed hydrology and surface flows are directly linked to the preceding hydrologic conditions. Early in the summer, large proportions of rainfall are typically incorporated into filling surface and groundwater storage following the usual extended spring dry-season. Conversely, toward the end of the summer, surficial groundwater levels

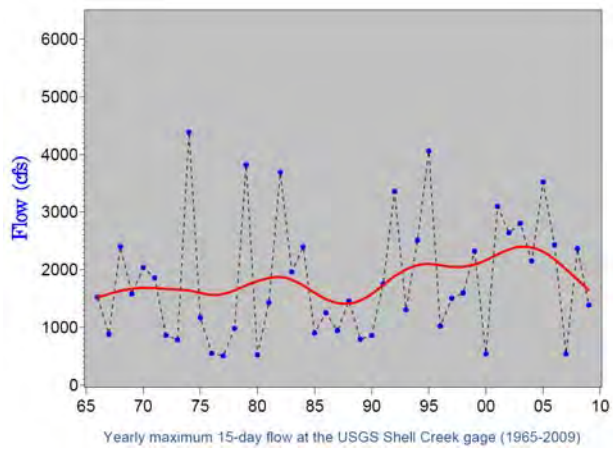


Hydrograph of annual monthly mean USGS Shell Creek gaged flow (1966-2009)

are typically near the surface, wetlands and lakes are full, and large proportions of rainfall contribute directly to surface runoff. Under such conditions, relatively small increases in rainfall can result in substantial increases in surface flows.

While the described seasonal patterns in the annual hydrologic conditions are typical, there are wide degrees of both seasonal and annual variability in rainfall, often resulting in widely divergent patterns in annual flows. This high degree of variability is shown in the following two figures of annual minimum and maximum historic U.S. Geological Survey (USGS) gaged flows over the Hendrickson Dam based on a 15-day average.





Graphical and statistical analyses were conducted to provide comprehensive overviews of both long-term and seasonal patterns of the temporal changes in Shell Creek flows to the lower Shell Creek/Peace River estuarine system. These analyses resulted in the following series of observations and conclusions.

- Historically, freshwater flows over the Hendrickson Dam have varied widely both seasonally and yearly, with clear overall long-term patterns.

- The differing monthly low flow terms indicate patterns of increasing low flows from the mid-1960s through the mid-1990s, followed by a general decline. The observed recent decline during the past 15 years probably reflects the influences of the severity of both the recent 1999-2002 and 2006-2008 droughts.

- The severity of these recent droughts was most apparent during the typical spring dry months of March, April and May and generally less apparent during the typical summer wet-season months extending from June through September.

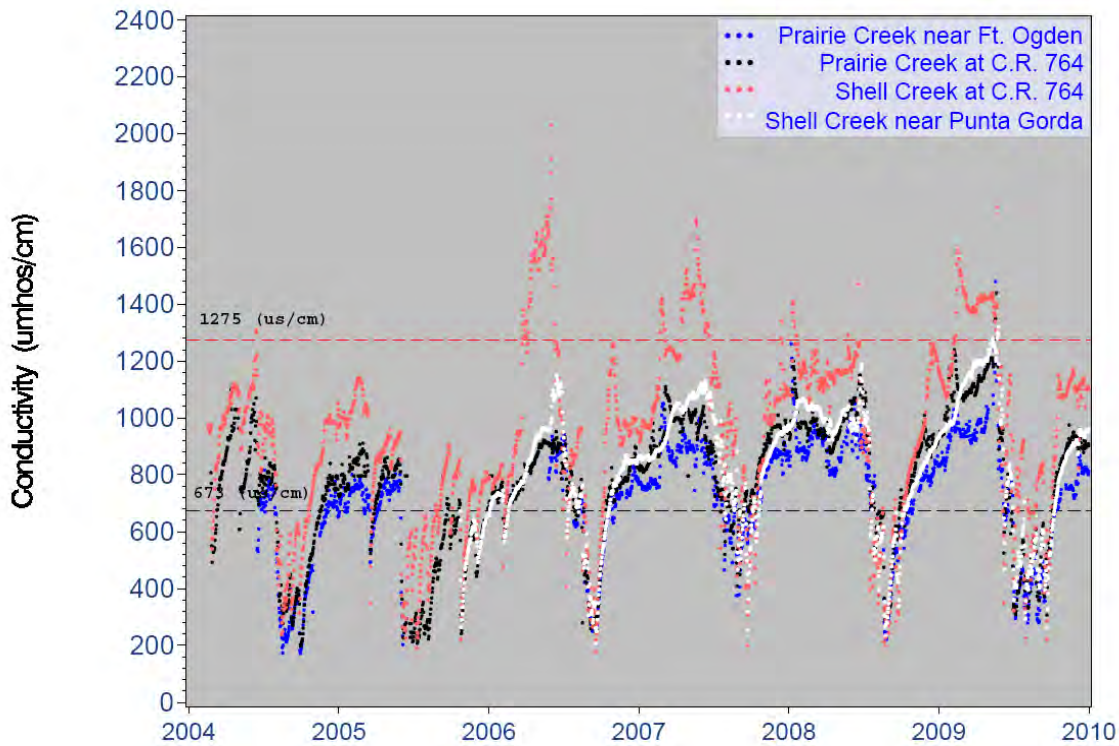
- Analyses of comparisons between the 1966-2004 and 1995-2009 time intervals supported previous observations that the period since 1995 has been characterized by somewhat wetter both overall and wet-season conditions than the previous 1966-1994 period. However, actual spring dry-season flows have actually declined in recent years due to extremely dry conditions that characterized the droughts of 1999-2002 and 2006-2008.

- None of the trend tests done for the various metrics of flows over the entire1966-2009 time interval indicated any statistically significant systematic trends.

- Comparisons of the observed seasonal and long-term patterns using a wide variety of differing flow metrics showed little discernable difference between actual USGS gaged Shell Creek flows and the baseline flows corrected for withdrawals.

Temporal and Spatial Patterns of Water Quality Differences between Prairie and Shell Creek Systems

The primary objective of the following series of analyses was to determine the current status and evaluate historical spatial/temporal patterns and trends in conductivity, major ions, nutrients and other water quality characteristics of the two major upstream freshwater sources (Shell and Prairie Creeks) and within the City's reservoir



USGS measured conductivity in the Prairie/Shell Creek Watershed upstream of the Dam

Conductivity (Specific Conductance) and Chlorides

Daily averaged conductivity measurements taken at the four USGS on-going continuous recorder sites (Prairie Creek at Ft. Ogden, Prairie and Shell Creeks at C.R. 764, and Shell Creek near the Dam) were analyzed to determine short- and long-term conductivity patterns, as well as the relationships between conductivity and flow.

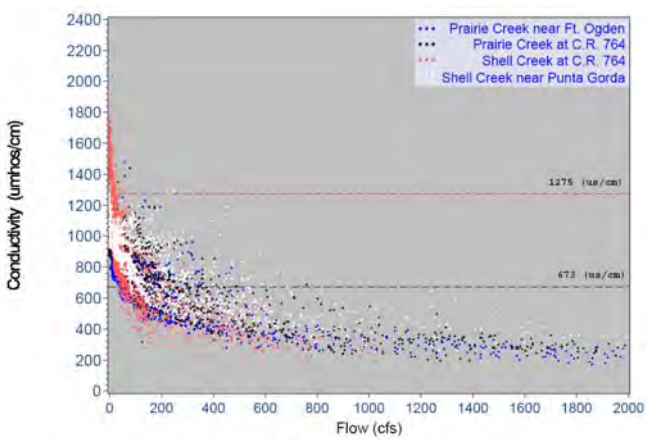
- Conductivity measured at each of the four USGS recorder sites all show very similar distinct seasonal patterns.

- Conductivity levels were generally lower during the wetter 2004-2005 time interval when compared to the drought conditions that characterized watershed rainfall patterns from early 2006 through the spring of 2009.

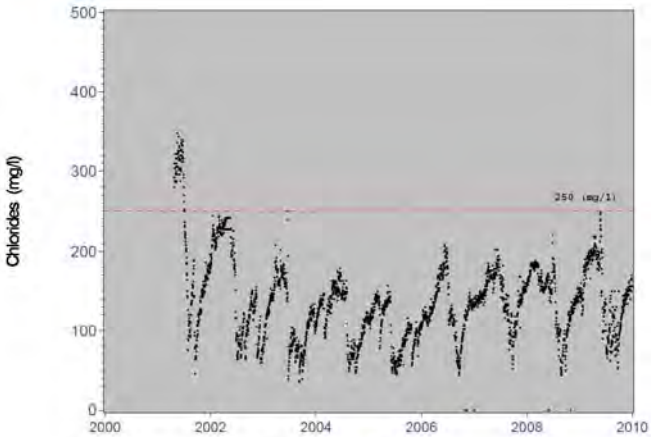
- Except for a very brief period in the spring of 2009, conductivity levels at both Prairie Creek sites and in the reservoir were below the DEP Class III Standard of 1275 µmhos/cm.

- Daily average conductivity measured at Shell Creek at C.R. 764, by comparison, exceeded the Class III standard every year with the exception of 2005, which was a very wet year.

- The USGS conductivity recorder near the Dam indicated that between 2006 and 2009 measured conductivity levels met the 673 µmhos/cm criteria needed to assure finished potable TDS levels below the Secondary Drinking Water Standard of 500 mg/l only twenty-six percent of the time.



USGS measured conductivity in the Prairie/Shell Creek Watershed upstream of the Dam



Chlorides from the City's intake

- At all four USGS monitoring sites measured conductivities logarithmically declined with increasing flow.

- However, within the reservoir relatively high levels of flow are needed to reduce conductivity levels below 673 µmhos/cm.

- Additional daily chloride levels measured by the City at the intake increased seasonally each year during the typically drier months. However, concentrations have not exceeded the 250 mg/l Secondary Drinking Water Standard since the 1999-2002 drought, and rapidly decline with increasing flows.

Long-Term Trends in Water Quality Characteristics and Changes with Flows

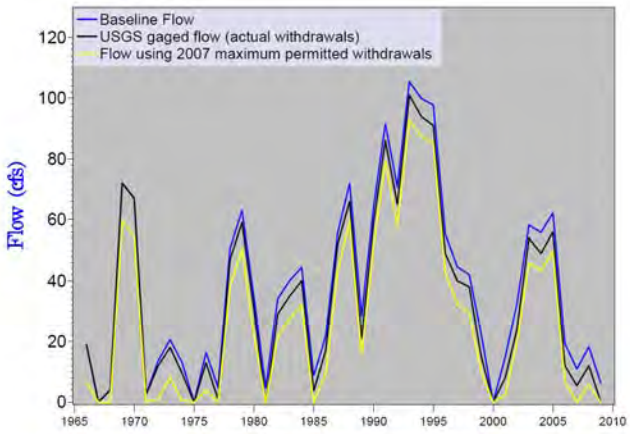
Time-series plots and Seasonal Kendall Tau Trend Tests for selected water quality characteristics were conducted of monthly data collected at the three Shell Creek HBMP monitoring sites located upstream of the Dam. The analyses of monthly data generally show that the majority of the water quality parameters measured at these three locations varied seasonally without any indications of distinct systematic increasing or decreasing changes over the historic nineteen years (1991-2009) of monitoring. In comparison, the long-term patterns of change in other parameters such as conductivity and chloride show marked increases associated with both the 1999-2001 and 2006-2008 droughts. While most of the long-term patterns simply indicate non-trending seasonal and annual variability between drier and wetter years, there were several water quality characteristics, such as silica, for which the data suggest there have been systematic, progressive changes over time.

Influences of Withdrawals on Flow Characteristics and Downstream Water Quality

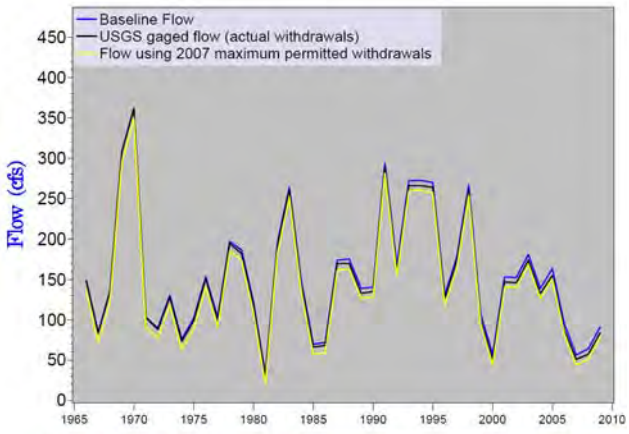
Analyses were conducted to assess the relative magnitude of changes in flows and resulting salinities due to both historic and current withdrawal scenarios.

Withdrawals and Changes in Flow Characteristics

A series of analyses were conducted to depict and contrast the relative magnitude and seasonal variation of changes in flows to the estuarine reach of Shell Creek below the Dam relative to both actual historic withdrawals and those that would have occurred if the current maximum daily average levels permitted under the new existing twenty-year Water Use Permit had been in place over the 1966-2009 time interval.



Differences in annual P10 Shell Creek flow with and without withdrawals (1966-2009)



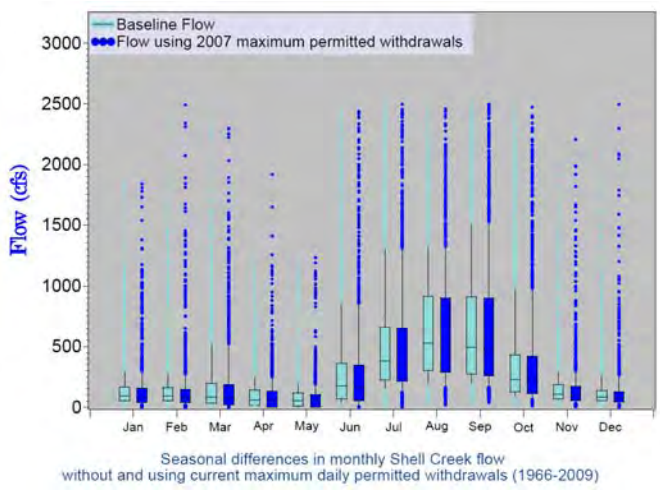
Differences in annual P50 (median) Shell Creek flow with and without withdrawals (1966-2009)

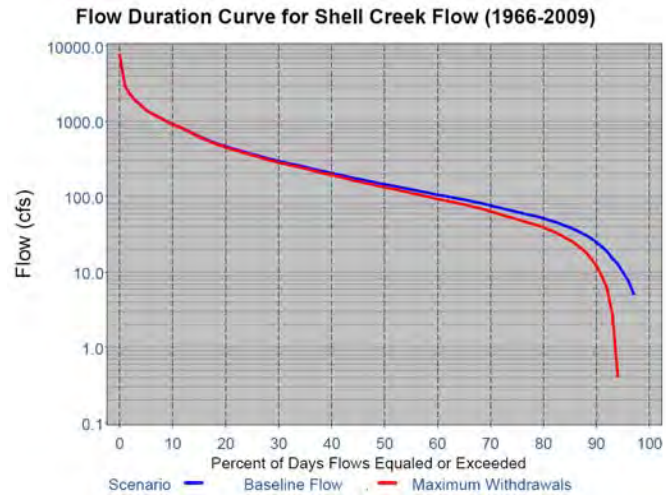
- The largest observed differences occurred between the no-withdrawal scenario and the maximum average daily withdrawals allowed under the newest permit during periods of low flow (P10 equals the flow percentile exceeded 90 percent of the time).

- However, these differences become less and less apparent as flows increase, and would be expected to be relatively quite small at flows above the annual median.

- Overall, the observed differences between the no-withdrawal and withdrawal scenarios were found to be relatively small, when compared to the magnitude of the natural seasonal and annual variability.

- Seasonally, the relatively largest changes in flows due to withdrawals can be expected to occur during the typically drier months, under low flow conditions.



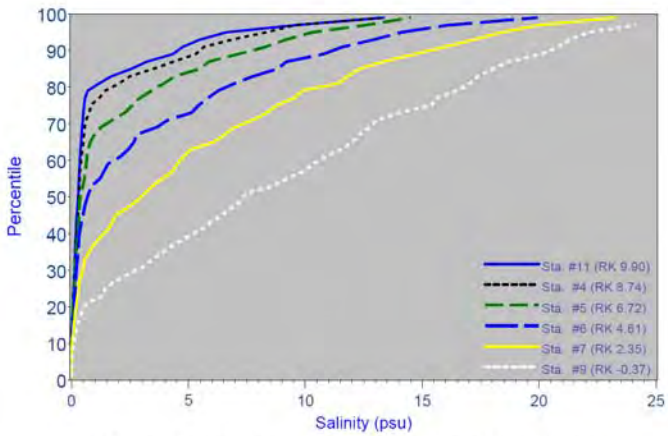


- The presented analyses indicated that actual historic withdrawals have predominantly influenced approximately only the lowest 20 percent of flows, with the most appreciable changes having been confined to the lowest 10 percent of historic flows. Under the current maximum daily average permitted withdrawal scenario, withdrawals would noticeably influence approximately the lowest 40 percent of flows, with the most appreciable changes occurring within the lowest 20 percent of flows.

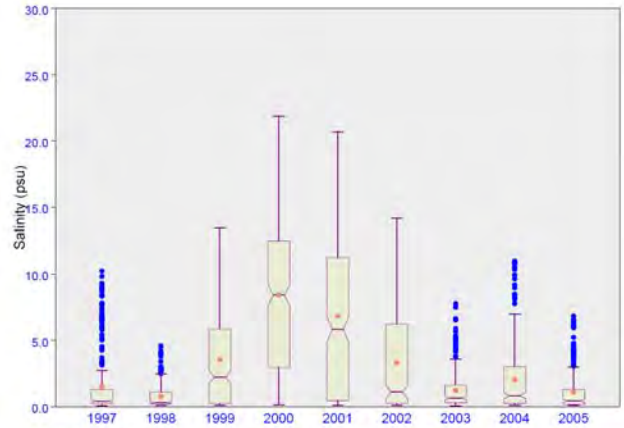
Development of Statistical Models

Statistical models were developed and subsequently used to characterize the magnitude and duration of potential salinity changes downstream of the Hendrickson Dam. The objective was to determine what changes may have occurred due to historic Shell Creek Facility withdrawals, relative to those that might be expected under the increase of the maximum average daily withdrawal to 8.09 mgd under the City's 2007 twenty-year Water Use Permit renewal. The statistical models were developed toward answering the basic question, "What would be the predicted magnitude and relative frequency of the expected spatial and temporal increases in surface and near-bottom salinities in the tidal reaches of Shell Creek due to both recent past and existing permitted City of Punta Gorda withdrawals?"

As the following two figures indicate, the tidal reach of Shell Creek downstream of the Dam is characterized by a distinct spatial gradient in salinity with lower salinities occurring upstream and much higher salinities present nearer the junction with the lower Peace River. Temporally, salinities within the tidal portion of Shell Creek also show distinct seasonal differences in response to changes between dry- and wet-season flows, as well as annual variability between wetter and drier periods.

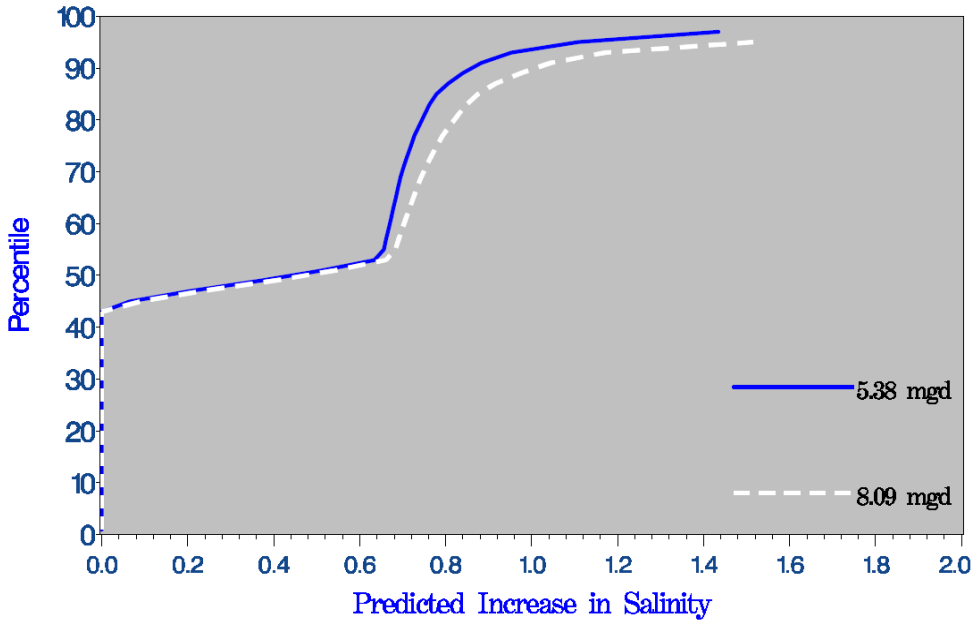


CDF plots of surface salinity among selected Shell Creek transect locations



Annual variability in daily average surface salinity at USGS continuous recorder site on Shell Creek (RK 4.6)

In the upstream segment of tidal Shell Creek below the Dam where salinities might be expected to show the greatest changes due to withdrawals, surface salinities are predominantly characterized by freshwater conditions at flows above 120 cfs. During approximately 35 percent of the time when there are either no-flow or moderate to high flows, the statistical models predict that surface and bottom salinities in this reach of the creek are not affected by City of Punta Gorda Facility withdrawals. Conversely, during approximately 45 percent of the time, when flows are low, the model results indicate that withdrawals can be expected to result in increases in surface salinities between 0.7 and 1.6 psu. Finally, during the 5 percent of the time when flows are somewhat below the rate of flow when this reach of the creek becomes fresh, withdrawals can be expected to result in salinity increases between 0.1 and 0.7 psu. The difference due to the recent increase in the average daily rate of permitted withdrawal from 5.38 to 8.09 mgd is expected to result in no increase in salinity under approximately 45 percent of flows and less than 0.2 psu during the remainder.



CDF of predicted change in surface salinities in the upstream tidal reach due to difference in withdrawals

Potential Changes to the Shell Creek Monitoring Program

Other than some changes in field collection and water quality analytical methods, the Shell Creek HBMP has remained relatively unchanged since its inception in 1991. The water quality parameters analyzed under the City of Punta Gorda's Shell Creek HBMP were initially selected to match those being monitored by the older, ongoing lower Peace River/upper Charlotte Harbor monitoring program conducted by the Peace River Manasota Regional Water Supply Authority (Authority). However, as part of the Authority's twenty-year permit renewal in 1996, an outside Scientific Review Panel was established to review the conclusions being drawn from the Peace River HBMP and make recommendations to the Authority and District regarding potential changes to improve the efficiency of monitoring.

Since that time, the Peace River Scientific Review Panel has made a number of recommendations that have sought to reduce the emphasis on background monitoring and increase the focus toward directly assessing the impacts of withdrawals. Correspondingly, the number of background water quality parameters being measured has been refocused and reduced.

It is recommended that a similar effort be made between City and District staff to use the existing nearly twenty years of Shell Creek HBMP data to potentially refocus the monitoring program while maintaining/reducing the existing level of effort. The following topics might initially be considered.

- Maintain the ongoing close monthly timing between the Shell Creek and Peace River HBMP programs to allow potential future analyses using data from both programs.

- Delete some of the background Shell Creek HBMP lower Peace River monitoring sites that are similar to those being monitored by the Authority, and reduce some of the water quality parameters being monitored downstream of the Dam to more closely match those currently being monitored by the Peace River HBMP.

- Assess the cost effectiveness of continuous recorders to provide greater levels of information towards directly assessing the potential magnitude of freshwater withdrawals.

- Determine whether the parameters being monitored above the Dam are providing the City with sufficient data relative to seasonal changes in upstream water quality.

Contents

1.0 Introduction and Overview

A condition of Water Use Permit No. 200871.003, issued by the Southwest Florida Water Management District (District) to the City of Punta Gorda (City) in 1989, required that the City implement a comprehensive Hydrobiological Monitoring Program (HBMP) to ensure the long-term protection of the Shell Creek/lower Peace River estuarine system. The conceptual design of the Shell Creek HBMP was generally modeled after the similar ongoing long-term monitoring efforts began in 1976 to assess potential impacts of freshwater withdrawals by the regional Peace River Facility to the lower Peace River/upper Charlotte Harbor estuarine system. The Shell Creek HBMP was specifically designed to provide a continuing long-term base of information regarding the following specific types of information needed to similarly assess potential environmental impacts that might be associated with the City's freshwater withdrawals from Shell Creek.

- Water quality and flow characteristics of the Prairie Creek/Shell Creek Watershed upstream of Hendrickson Dam.

- Daily average flows over the Dam relative to the City's daily withdrawals from behind the Dam.

- Seasonal and long-term temporal and spatial variability of key selected water quality characteristics within the reach of Shell Creek from downstream of the Hendrickson Dam to its confluence with the Peace River.

- Similar variability in these water quality measures within the lower Peace River immediately upstream and downstream of Shell Creek inflows.

The City implemented the ongoing Shell Creek HBMP in February 1991, and a comprehensive overview of the specific elements within the monitoring program is presented in **Chapter 2**. The following summarizes the District's primary objectives in requiring implementation of the Shell Creek HBMP.

- Gather the types of information necessary to establish long-term rainfall/flow relationships within the greater Shell Creek drainage basin.

- Monitor water treatment facility withdrawals from behind the Hendrickson Dam, and evaluate the City's withdrawals in relation to both gaged tributary flows for Prairie Creek and Shell Creek upstream of the reservoir, and flows to the estuary over the Dam.

- Temporally and spatially evaluate physical/chemical/biological ecological relationships in the Shell Creek/lower Peace River estuarine system to freshwater inflows, and determine if these ecological characteristics are undergoing changes over time.

- Determine the relative magnitude and potential influences that the City's consumptive withdrawals might be having on any such observed ecological changes.

- Determine if past, existing and future projected freshwater withdrawals from Shell Creek might significantly contribute to adverse ecological impacts the estuary may experience as a result of natural extended periods of low freshwater inflow.

Thus, the overall goal of the City's HBMP efforts has and continues to be to provide District staff with sufficient information needed to determine whether the biological communities of the Shell Creek/lower Peace River estuarine system have been, are being, or might reasonably be assumed to be, adversely impacted by existing permitted or potential future demands for freshwater withdrawals.

In mandating the requirement to implement the Shell Creek HBMP, the District's primary objective was to assure that, in conjunction with the existing Peace River HBMP, a sufficient comprehensive database would be established to assess the responses of various physical, chemical and biological estuarine characteristics to both seasonal and long-term changes in freshwater inflows. The specific area of study of the Shell Creek HBMP includes the upstream drainages of both the Prairie and Shell Creek systems from County Road 764 downstream to the Shell Creek/Peace River confluence and beyond, including lower portions of the lower Peace River Estuary. The program was designed to evaluate the consequences and significance of natural changes associated with variations in freshwater inflows with regards to the overall health of aquatic communities in the Shell Creek/lower Peace River and upper Charlotte Harbor estuarine system. Natural seasonal variations in freshwater inflows have been shown, in both temperate and tropical estuarine systems, to influence resident biological communities primarily through the following four major mechanisms.

1. Moderate changes in flow can rapidly and significantly affect the relative physical positions of salinity zones within an estuary.

2. Changes in freshwater inputs result in alterations of both the temporal and spatial variability of the concentrations and loadings of the major macro-nutrients typically associated with phytoplankton growth (nitrogen and phosphorus), as well as silica, iron and trace micronutrients, which can further affect the community structure of primary producing organisms. Such changes are subsequently reflected throughout the food web.

3. Decreases in water clarity (turbidity and color) that are often associated with increased freshwater inflows can alter the penetration of light within the water column, thus affecting phytoplankton as well as benthic autotrophic communities.

4. High freshwater inputs can create strong salinity stratification seasonally resulting in zones within an estuary characterized by hypoxic/anoxic bottom waters (little if any dissolved oxygen). Such conditions may limit the distribution of many species within the estuarine community, and result in the widespread death of many benthic organisms.

1.1 Shell Creek Facility Overview

The City of Punta Gorda's original limited public water supply system initially consisted of six groundwater wells. In 1936, the City's public works administration constructed a small dam and 0.5 mgd water treatment facility on Alligator Creek. However, expanding demand resulted in the City's construction of the Hendrickson Dam in 1965, which was set at an elevation of 5.0 feet (msl) on Shell Creek approximately eight miles east of the City. This expansion also included construction of a new treatment facility near the reservoir. Currently, the City's existing ordinances and infrastructure provide for the supply of water for domestic / municipal / industrial uses within five miles of the City. The City's existing service are covers an area of approximately 30 square miles.

The Shell Creek Reservoir is the sixth largest impounded surface water system within the Southwest Florida Water Management District's jurisdictional boundaries. The reservoir covers approximately 800 acres, with maximum depths of 10-12 feet, and a total storage capacity of roughly 765 million gallons at 5.0 feet elevation. This provides the City with sufficient storage for an estimated 110 day supply under no-rainfall conditions and a permitted maximum daily withdrawal of approximately 11.7 mgd. The estimated "safe yield capacity" of the existing Shell Creek Reservoir is approximately 7.8 mgd. Inflows to the reservoir come from Shell Creek, which receives drainage from the east, and Prairie Creek running to the northeast. Combined, these two tributaries cover a watershed of approximately 370 square miles. Flows from the Dam's weir to the downstream Shell Creek Estuary cease when the surface elevation of the reservoir drops below 5.0 feet NGVD.

1.2 Overview of the Shell Creek Facility's History and Permits

The City's water treatment facility has and continues to withdraw water for public supply from the Shell Creek Reservoir under permit by the Southwest Florida Water Management District. Table 1.1 provides a historic summary of these District permits and both the permitted average and peak monthly withdrawals.

Table 1.1
Shell Creek Permit History

Water Use Permit Number	Time Period	Average Permitted Withdrawal (mgd)	Maximum Peak Monthly Permitted Withdrawal (mgd)
200871.001	11/03/76 to 11/03/82	NA	NA
200871.002	04/06/83 to 04/06/89	3.9	7.4
200871.003	11/28/89 to 11/28/95	4.22	8.1
200871.004	08/26/97 to 07/07/99	5.38	6.9
200871.005	07/07/99 to 12/20/02	5.38	6.9
200871.006	1/1/03 to 8/26/07	5.38	6.9
200871.007	Withdrawn	5.38	6.9
200871.008	7/31/07 to 7/31/27	8.09	11.7

1.3 Summary Report Organization and Primary Objectives

The following briefly summarizes the organization and primary objectives of each of the remaining chapters of this Year Five Comprehensive Summary Report.

- **Chapter 2 – Description of the Existing Monitoring Program.**
  The primary focus of this chapter is to summarize and present the following types of information.

  1. Provide a summary of the existing HBMP study elements.

  2. Explain why these elements are part of the HBMP.

  3. Describe what physical parameters and biological communities are being monitored.

  4. Provide an overview of when and from where samples and other relevant needed information are being obtained.

- **Chapter 3 – Status and Trends in the Shell Creek/Lower Peace River Estuary.**
  This chapter focuses on describing, analyzing and evaluating both seasonal and annual variability in the physical/chemical/biological data collected downstream of the Hendrickson Dam relative to the following patterns.

  1. Provide a description and analysis of current condition, status, and importance of spatial patterns in assessing the overall health of the estuarine system.

  2. Determine the existence and importance of observed trends in key physical and biological parameters.

- **Chapter 4 – Evaluation of the Potential Impacts of Shell Creek Facility Withdrawals.**
  This chapter presents discussions and summaries of the statistical approaches used in relating selected variables to seasonal and longer term temporal variations in freshwater inflows, and the relative corresponding potential impacts of permitted Shell Creek Facility withdrawals.

- **Chapter 5 – Summary and Recommendations.** This chapter presents a summary of the overall conclusions developed from the various analyses presented in the preceding sections. Recommendations are offered regarding potential modifications that may be appropriate to improving and refocusing HBMP study elements in the future. Included are:

  1. An overview of the hydrologic conditions within the Shell Creek Watershed.

  2. Summary discussions of the status and trends in HBMP physical/chemical/biological water quality characteristics both upstream and downstream of the Hendrickson Dam.

  3. An overview of potential magnitude of any impacts that might be associated with Shell Creek freshwater withdrawals.

4. A review of differences in water quality between Prairie Creek, Shell Creek and the Peace River.

- **Data Appendix.** This provides and summarizes the water quality and other data sets used in the development of this Comprehensive Data Report, including detailed descriptions of the contents of each data set.

2.0 Description of the Existing Monitoring Program

2.1 Shell Creek Hydrobiological Monitoring Program (HBMP) Sampling Design

The overriding goal of the Shell Creek HBMP is to provide the District with sufficient information to ensure that the biological communities of the Shell Creek/lower Peace River estuarine system are not significantly adversely impacted as a result of the City of Punta Gorda's permitted freshwater withdrawals. During the initial design of the Shell Creek HBMP undertaken in late 1990, a series of nineteen sampling sites were selected to provide a comprehensive network of locations allowing for information to be obtained regarding the duration and magnitude of both seasonal and longer-term variability in selected water quality characteristics within several specific regions of the overall system.

- Within Shell and Prairie Creeks just prior to their flowing into the reservoir
- Upstream of the Hendrickson Dam
- Within the tidal portion of Shell Creek downstream of the Dam
- Within the Peace River both upstream and downstream of its confluence with Shell Creek

Descriptions and overviews of the relative distribution of the nineteen selected Shell Creek HBMP sampling locations are provided in **Tables 2.1** and **2.2**, and **Maps 2.1** and **2.2**

- **Table 2.1** – Provides descriptions of the relative locations of each monitoring site
- **Table 2.2** – Indicates the latitude and longitude of each location and the River Kilometer (RK) relative to where Shell Creek joins the lower Peace River
- **Map 2.1** – Shows an infra-red aerial view indicating all the monitoring sites
- **Map 2.2** – Is a closer view of just the Shell Creek HBMP sampling sites located downstream of the Hendrickson Dam

Prior to 2001, the HBMP sampling sites within the tidal reach of Shell Creek were assigned distances relative to their locations downstream of the Hendrickson Dam. As part of the District's conditions for the 1996 Peace River Facility's HBMP permit renewal, a Graphical Information Systems (GIS) River Kilometer centerline was developed for the lower Peace River using zero as the river's mouth as previously defined in work done by the U.S. Geological Survey (USGS). Upon request by District staff, a similar centerline was developed in 2001 for the Shell Creek HBMP merging the 1996 Peace River centerline and relative distances in river kilometers along the Shell Creek monitoring transect up and downstream of its confluence with the Peace River (see **Map 2.1**). **Table 2.2** provides comparative summaries of the distance scales used in Shell Creek summary documents prior and post 2001.

2.2 Shell Creek Monitoring

Since its inception in February 1991, the field monitoring and water chemistry components of the Shell Creek HBMP have been undertaken by several different groups.

- **February 1991 through December 2000** – All field sampling and water chemistry analyses were done by Environmental Quality Laboratory (EQL).

- **January 2001 through August 2002** – Both the field sampling and water chemistry were done by ASCI, which had purchased EQL.

- **September 2002 through September 2005** – the field sampling was done by EarthBalance and the water chemistry samples were analyzed by Benchmark Laboratory.

- **Since November 2005** – both the field sampling and the water chemistry have been done by Test America, Inc.

The Shell Creek HBMP includes monthly determinations of physical, chemical and biological water quality characteristics using the design and procedures summarized in Tables 2.3 and 2.4. The HBMP permit condition specifies that the monthly measurement of ambient physical, chemical and biological water quality characteristics be made within two calendar days of the monthly Peace River HBMP "fixed" station sampling. This coordination between the Shell Creek and Peace River HBMP programs provides the District with monthly comparable measurements of water quality characteristics throughout the lower Peace River and Shell Creek areas of the Charlotte Harbor Estuary.

Table 2.3
Shell Creek Sampling Design

	Sampling Location																		
Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Physical *In Situ* Profiles																			
Water Chemistry (surface)																			
Secchi Disk Depth																			
Extinction Coefficient *																			

* Since November 2005 Test America has done just Secchi Disk depth at all sampling sites

- *In situ* physical water column profile characteristics are measured at each of the nineteen Shell Creek HBMP sampling sites at 0.5 meter intervals from just below the surface (0.15 meters) to just above the bottom.

- Mid-water column depth water quality samples are collected and analyzed for a suite of parameters (Table 2.4) at sampling locations 1 through 9.

- Between 1991 and 2005, seasonal differences in the penetration of light into the water column were determined by Secchi depth measurements at sampling sites 1 and 2, with more accurate determinations of extinction coefficients calculated for sampling locations 3 through 9 based on *in situ* profiles of photosynthetically active radiation (PAR). However, since Test America took over monitoring in November 2005 they have taken just Secchi depth at all 19

HBMP locations. Table 2.4 summarizes differences in methods and detection limits over the monitoring period (EQL, ASCI and Benchmark chemistry methods and detection limits were comparable).

Table 2.4
Water Chemistry Parameters and Methods

	Prior to November 2005		Since November 2005	
Parameter	**Method**	**Detection Limit**	**Method**	**Detection Limit**
Color	EPA 110.2	1.0 CPU	SM 2120B	--
Chloride	EPA 325.2	0.4 mg/l	300	1 mg/L
Turbidity	EPA 180.1	0.1 mg/l	MCAWW 180.1	--
Total Suspended Solids	EPA 160.2	0.8 mg/L	SM 2540D	--
Alkalinity	EPA 310.1	0.1 mg/l	SM 2320B	--
NO2+NO3 Nitrogen	EPA 353.2	0.002 mg/l	MCAWW 353.2	0.1 mg/L
NH3+NH4 Nitrogen	EPA 350.1	0.002 mg/l	MCAWW 353.2	0.1 mg/L
Total Kjeldahl Nitrogen	EPA 351.2	0.1 mg/l	MCAWW 351.2	0.05 mg/L
Ortho-Phosphorus	EPA 365.2	0.002 mg/l	EPA 365.1	0.01 mg/L
Total Phosphorus	EPA 365.4	0.002 mg/l	EPA 365.4	0.1 mg/L
Silica	EPA 370.1	0.05 mg/l	6010 B (ICP) Dissolved	50 ug/L
Chlorophyll *a*	Flurometeric SM 10200H.3 Spectrophotometric Sm10200.H2	0.25 ug/l 2.0 ug/l	*SM19 Chlorphyll A*	0.5 ug/L

2.3 Additional Existing Data Sources

The Shell Creek HBMP summary reports have historically utilized ongoing data available from a number of additional existing long-term data sources. Such outside sources of available existing data include:

1. **Gaged Freshwater Inflows** – there exists an extensive network of UGSG flow gages with long term records within the lower Peace River and Shell Creek watersheds (see Table 2.5). Historic and current gaged flow data are available at the Tampa USGS Office Web Site (http://www-tampa.er.usgs.gov/).

Table 2.5
USGS Gages in Peace River/Shell Creek Watersheds

Location	Gage Number	Record
Peace River at Arcadia	02296750	1931 - Present
Horse Creek near Arcadia	02297100	1950 - Present
Joshua Creek at Nocatee	02296750	1950 - Present
Prairie Creek near Ft. Ogden	02296750	1963 - Present
Shell Creek near Punta Gorda	02298202	1965 - Present

2. **Rainfall** – the District receives daily area rainfall data from four long-term gages within the general region (see Table 3.2). The Arcadia and Punta Gorda sites are part of the National Oceanographic and Atmospheric Administration's (NOAA) national network, while the other two are maintained in conjunction with the two consumptive water use permits. Historic and current rainfall data from throughout the Southwest Florida Water Management District (District) are available at the District Web Site (http://www.swfwmd.state.fl.us/).

Table 2.6
Existing Network of Long-Term Rainfall Gages

Name	District Gage Number	Period of Record
Arcadia	148	1907 - Present
Peace River Water Facility	331	1980 - Present
Shell Creek Water Facility	211	1986 - Present
Punta Gorda	255	1914 - Present

3. **Continuous Tide and Conductivity Recorders** – a primary goal of both the Shell Creek and lower Peace River HBMP programs has been the accumulation of sufficient information to enable the development of detailed spatial and temporal relationships between small scale changes in freshwater inflows and corresponding salinity patterns in the Shell Creek/lower Peace River/Charlotte Harbor estuarine system. In order to develop information with greater temporal frequency, in 1996 the USGS installed an automated water level gage approximately 15.5 kilometers upstream of the mouth of the Peace River at Harbour Heights. This gage is located immediately adjacent to the Shell Creek HBMP Sampling Site 8 (which is identical to the Peace River HBMP fixed Station 14). This gaging station measures tide stage and both near surface and bottom conductivity at 15-minute intervals. In 1997, as part of the enhancement of background information associated with the District's establishment of minimum flows for the lower Peace River and Shell Creek, the USGS located a similar continuous recorder along Shell Creek downstream of the Hendrickson Dam at approximately RK 4.6. Data collection from this gage was discontinued in 2005.

Table 2.7

Existing Continuous Water Level and Conductivity USGS Gages in the Shell Creek/Lower Peace River Estuary

Name	USGS Gage Number	Record
Peace River at Harbour Heights	02297460	1996 - Present
Shell Creek	02298208	1997 - 2005
Shell Creek near Punta Gorda	02298202	1965 - Present
Shell Creek on C.R. 764 near Punta Gorda	02297635	2004 - Present
Prairie Creek on C.R. 764 near Punta Gorda	02298170	2004 - Present
Prairie Creek Downstream near Ft. Ogden	02298124	2004 - Present

4. Although the Shell Creek HBMP was established in 1991, it also has access to various relevant data sources developed in conjunction with the "older" Peace River Manasota Regional Water Supply Authority Facility's HBMP monitoring program that includes a wide variety of information dating back to 1975.

5. Additional water quality information is also available from both historic and ongoing water quality monitoring done outside of the Shell Creek HBMP (see Table 2.7).

6. The Shell Creek HBMP does not include an element that requires long-term monitoring of changes in the spatial distribution of riparian vegetation along the estuarine areas downstream of the Hendrickson Dam. However, long-term vegetation patterns in the area near the mouth of Shell Creek where it joins the lower Peace River were documented between 1976 and 2002 as part of the Peace River HBMP. In addition, the District undertook a comprehensive overview of vegetation patterns both in the lower Peace River and Shell Creek. The District contracted the Florida Marine Research Institute (FMRI) to develop a Graphical Information System (GIS) mapping of vegetation patterns in the lower estuarine reaches of the Peace River (see **Map 2.2**). This mapping effort was based on aerial surveys taken in 1994, followed by field verification. In 2006, as part of the *Shell Creek Gap Report*, PBS&J further analyzed and compared existing vegetation distributions along Shell Creek with vegetation mapped by FMRI to identify dominant vegetation communities and/or taxa along the creek below the Hendrickson Dam. E-size maps of 2004 digital orthophoto quadrangles (DOQQs) were used for vegetation mapping. Maps were verified and/or modified to reflect vegetation observed along Shell Creek in April 2006. Information from these maps was integrated into the 2004 DOQQs and compared to 1995 DOQQs to examine vegetation distributions and document possible changes in vegetation distributions since 1998. The primary vegetation components and corresponding distributions along Shell Creek were also documented.

3.0 Status and Trends in the Shell Creek/Lower Peace River Estuary

3.1 Overview

Based on discussions and subsequent District staff recommendations, a series of graphical and statistical analyses using relevant historical data through 2009 are presented in order to provide the necessary framework and basis for the next report chapter (**Chapter 4**), which evaluates the relative timing and magnitude of potential impacts associated with the City of Punta Gorda's permitted withdrawals from the Shell Creek reservoir. The primary focus of the current chapter is to describe and evaluate the primary temporal and spatial physical/chemical/biological patterns within the Shell Creek HBMP, and other, data collected both upstream and downstream of the Hendrickson Dam. The goal of these analyses is to meet the following objectives.

1. Describe and analyze past and current conditions toward assessing the status and relative overall health of the Shell Creek/lower Peace River estuarine system.

2. Determine the existence and importance of observed patterns/trends in Shell Creek freshwater inflows, and key freshwater characteristics relative to both the City's water supply and Shell Creek's biological communities. This includes graphical and statistical analyses of patterns and potential changes in the historical Shell Creek flow regime, as well as seasonal changes in conductivity and major freshwater ions both upstream and within the City's reservoir.

3.2 Characterization of Historical Shell Creek Flow Regime

Daily U.S. Geological Survey (USGS) gaged flows over the Hendrickson Dam data during the available 1966-2009 period were used to develop comprehensive overviews of both annual and seasonal variability in Shell Creek freshwater inflows. A "synthetic" withdrawal corrected baseline flow record was also constructed using City withdrawals added back into the flow. The method used to create this "synthetic" flow record followed that presented in the recent District Minimum Flows and Levels (MFL) document for the lower Peace River and Shell Creek. This method also corrects for Shell Creek Facility withdrawals for days when there was 0 cfs recorded at the Hendrickson Dam by using gaged flows in Prairie Creek (or Charlie Creek when Prairie flows were absent) to estimate flows at the dam corrected for withdrawals.

3.2.1 Monthly, Annual and Averaged Time-Series Plots

A series of summary graphics were developed providing a comprehensive overview of both long-term and seasonal patterns in temporal changes in Shell Creek flows to the lower Shell Creek/Peace River estuarine system. Actual USGS gaged and the "synthetic" estimated Shell Creek flows (withdrawals added) were used in developing the series of graphics summarized below in Table 3.1.

- Time-series plots over the period of record were developed for monthly minimum, P10, P25, P50 (median), mean, P75, P90, and maximum flows (**Figures 3.1** through **3.8**).

(Note: the P10 is the statistical flow percentile that is exceeded ninety percent of the time, while the P90 is the high flow percentile that is only exceeded ten percent of the time.)

- Analogous time-series plots of yearly minimum, P10, P25, P50 (median), mean, P75, P90, and maximum flows (**Figures 3.9** through **3.16**) are also shown.

- 3, 15, 30, 60 and 90-day moving average flows were next calculated for each day over the available 1966-2009 historic flow record. Time-series plots were then done for the minimum, P10, P25, P50 (median), mean, P75, P90, and maximum yearly values for each of these differing lagged flow terms (**Figures 3.17** through **3.56**).

Table 3.1
Time-series Plots (1966-2009) of Flow Metrics and Percentiles

Flow Metric (Actual or Synthetic Flows)	Flow Percentiles							
	Min.	P10	P25	P50 Median	Mean	P75	P90	Max.
Monthly Values (Actual)	Figure 3.1a	Figure 3.2a	Figure 3.3a	Figure 3.4a	Figure 3.5a	Figure 3.6a	Figure 3.7a	Figure 3.8a
Monthly Values (No Withdrawals)	Figure 3.1b	Figure 3.2b	Figure 3.3b	Figure 3.4b	Figure 3.5b	Figure 3.6b	Figure 3.7b	Figure 3.8b
Annual Values (Actual)	Figure 3.9a	Figure 3.10a	Figure 3.11a	Figure 3.12a	Figure 3.13a	Figure 3.14a	Figure 3.15a	Figure 3.16a
Annual Values (No Withdrawals)	Figure 3.9b	Figure 3.10b	Figure 3.11b	Figure 3.12b	Figure 3.13b	Figure 3.14b	Figure 3.15b	Figure 3.16b
3-Day Moving (Actual)	Figure 3.17a	Figure 3.18a	Figure 3.19a	Figure 3.20a	Figure 3.21a	Figure 3.22a	Figure 3.23a	Figure 3.24a
3-Day Moving (No Withdrawals)	Figure 3.17b	Figure 3.18b	Figure 3.19b	Figure 3.20b	Figure 3.21b	Figure 3.22b	Figure 3.23b	Figure 3.24b
15-Day Moving (Actual)	Figure 3.25a	Figure 3.26a	Figure 3.27a	Figure 3.28a	Figure 3.29a	Figure 3.30a	Figure 3.31a	Figure 3.32a
15-Day Moving (No Withdrawals)	Figure 3.25b	Figure 3.26b	Figure 3.27b	Figure 3.28b	Figure 3.29b	Figure 3.30b	Figure 3.31b	Figure 3.32b
30-Day Moving (Actual)	Figure 3.33a	Figure 3.34a	Figure 3.35a	Figure 3.36a	Figure 3.37a	Figure 3.38a	Figure 3.39a	Figure 3.40a
30-Day Moving (No Withdrawals)	Figure 3.33b	Figure 3.34b	Figure 3.35b	Figure 3.36b	Figure 3.37b	Figure 3.38b	Figure 3.39b	Figure 3.40b
60-Day Moving (Actual)	Figure 3.41a	Figure 3.42a	Figure 3.43a	Figure 3.44a	Figure 3.45a	Figure 3.46a	Figure 3.47a	Figure 3.48a
60-Day Moving (No Withdrawals)	Figure 3.41b	Figure 3.42b	Figure 3.43b	Figure 3.44b	Figure 3.45b	Figure 3.46b	Figure 3.47b	Figure 3.48b
90-Day Moving (Actual)	Figure 3.49a	Figure 3.50a	Figure 3.51a	Figure 3.52a	Figure 3.53a	Figure 3.54a	Figure 3.55a	Figure 3.56a
90-Day Moving (No Withdrawals)	Figure 3.49b	Figure 3.50b	Figure 3.51b	Figure 3.52b	Figure 3.53b	Figure 3.54b	Figure 3.55b	Figure 3.56b

The following series of observations and conclusions can be drawn from the graphics presented in Table 3.1.

- Comparisons of the observed patterns for these differing flow metrics between actual USGS Shell Creek gaged flows and the synthetic baseline with City of Punta Gorda withdrawals added back in show almost no discernable differences (comparisons of **Figures 3.1a** and **3.1b**).

- These graphics indicate that freshwater flows over the Hendrickson Dam have varied widely both seasonally and yearly, with clear overall long-term patterns.

- The differing monthly low flow terms indicate patterns of increasing low flows from the mid-1960s through the mid-1990s, followed by a general decline. The observed recent decline during the past 15-years probably reflects the influences of the severity of both the recent 1999-2002 and 2006-2008 droughts.

- The monthly metrics for higher flows similarly show generally declining patterns over the past decade, further reflecting the influences of the recent extended droughts (**Figure 3.8a**).

- These same patterns are further clearly evident in the low (**Figure 3.9a**) and higher flow (**Figure 3.47a**) metrics when calculated as annual values or terms presented for the various average lags.

3.2.2 Time-series Plots by Month

Similar time-series graphics over the 1966-2009 time interval were next plotted using actual USGS gaged Shell Creek flows and those "estimated" without Facility withdrawals for mean and median values for each of the twelve calendar months.

Table 3.2
Time-series Plots (1966-2009) of Median and Mean Monthly Flows

Month	Monthly Median Flow		Monthly Mean Flow	
	USGS Gaged Flows	Estimated (Without Withdrawals)	USGS Gaged Flows	Estimated (Without Withdrawals)
January	Figure 3.57a	Figure 3.57b	Figure 3.58a	Figure 3.58b
February	Figure 3.59a	Figure 3.59b	Figure 3.60a	Figure 3.60b
March	Figure 3.61a	Figure 3.61b	Figure 3.62a	Figure 3.62b
April	Figure 3.63a	Figure 3.63b	Figure 3.64a	Figure 3.64b
May	Figure 3.65a	Figure 3.65b	Figure 3.66a	Figure 3.66b
June	Figure 3.67a	Figure 3.67b	Figure 3.68a	Figure 3.68b
July	Figure 3.69a	Figure 3.69b	Figure 3.70a	Figure 3.70b
August	Figure 3.71a	Figure 3.71b	Figure 3.72a	Figure 3.72b
September	Figure 3.73a	Figure 3.73b	Figure 3.74a	Figure 3.74b
October	Figure 3.75a	Figure 3.75b	Figure 3.76a	Figure 3.76b

Table 3.2
Time-series Plots (1966-2009) of Median and Mean Monthly Flows

Month	Monthly Median Flow		Monthly Mean Flow	
	USGS Gaged Flows	Estimated (Without Withdrawals)	USGS Gaged Flows	Estimated (Without Withdrawals)
November	Figure 3.77a	Figure 3.77b	Figure 3.78a	Figure 3.78b
December	Figure 3.79a	Figure 3.79b	Figure 3.80a	Figure 3.80b

Examination of these monthly based graphics further emphasizes a number of previously observed patterns.

- Flows over the Hendrickson Dam to the Shell Creek/lower Peace River Estuary varied widely both seasonally and yearly.
- Comparisons of patterns within each of the months between actual USGS Shell Creek gaged flows and estimated "synthetic" flows with withdrawals added back in show very little difference.
- Within each month, comparisons of median and mean flows generally indicated similar patterns over the 1966-2009 time interval.
- During the typical spring dry months of March, April and May the long-term flow patterns reflect the severity of the 1999-2002 and 2006-2008 droughts (Figures **3.62a**, **3.64a** and **3.66a**).
- The influences of these recent extended droughts are less apparent during the typical summer wet-season months extending from June through September (**Figure 3.72a**).

3.2.3 Comparison of Long-Term Drier and Wetter Time Intervals

The *2006 Peace River HBMP Comprehensive Summary Report* provides an extensive discussion and analysis of regional rainfall patterns influencing the seasonal and longer term stream flow patterns in southwest Florida watersheds. The Shell Creek lays within the National Weather Service (NWS) Florida South-Central Region Four, which is characterized by a summer wet-season that accounts for approximately 60 percent of total average annual precipitation. During this summer wet-season, rainfall patterns are influenced by both frequent localized convective thunderstorm activity and periodic, widespread heavy rains associated with more infrequent tropical cyclonic events. In contrast, the remainder of the year is characterized by rainfall patterns predominantly associated with frontal systems moving down and across the Florida peninsula from the northwest.

Typically, the four month wet-season extends from June through September, with June (on average) having the highest monthly annual average rainfall. Conversely, November through January typically comprise the three driest months of the year. October characterizes the

transition from the convection based summer wet-season rainfall pattern to the frontal dry-season rainfall pattern.

Seasonal influences of rainfall on watershed hydrology and surface flows are therefore directly linked to the preceding hydrologic conditions. At the beginning of the summer wet-season, a large proportion of rainfall is typically incorporated into filling surface and ground water storage following the extended spring dry-season. Conversely, later toward the end of the summer wet-season, soil moisture content is high, ground water levels are near the surface, wetlands and lakes are full, and a large proportion of rainfall contributes directly to runoff. Under such conditions, relatively small increases in rainfall can result in substantial increases in surface flows.

While the described seasonal patterns in the annual hydrologic conditions are typical, there are wide degrees of both seasonal and annual variability in rainfall, often resulting in widely divergent annual flow patterns. Deviations from the normal pattern can span periods of months up to several years. Intense El Niño/Southern Oscillation (ENSO) events, such as occurred in 1982/1983 and 1997/1998, result in atypical extended periods of heavy rainfall during the usually drier winter/spring months and dramatically alter the annual watershed hydroperiod. In both instances, these unusually wet El Niño periods were subsequently followed by La Niña events and associated periods of extended drought. While short-term extremes of high and low flows influence the water budget in a watershed over periods of years, superimposed over these may be larger cyclic periods.

Climate researchers have suggested that natural climate cycles or phases can persist over multiple decades. One of these cycles, the Atlantic Multidecadal Oscillation (AMO), refers to long-term cool and warm phase differences of only about 1°F (0.6°C) in North Atlantic average sea surface temperatures. An analysis of Atlantic sea surface temperatures suggests that warm AMO phases occurred during 1869-1893, 1926-1969, and from 1995 to date, while cooler phases occurred predominantly during the 1894-1925 and 1970-1994 time periods. It has been suggested that slight increases in average sea surface temperature in the Atlantic and Caribbean seas during warmer AMO periods produce more summer rainfall across southern Florida, while cooler AMO phases result in decreased summer rainfall. During the warmer AMO phase (1926-1969), 33 tropical storm events affected southwest Florida, while during the subsequent cooler 1970-1994 AMO period, only 10 tropical systems impacted regional watersheds. Since 1995, when the AMO shifted from the preceding approximately 26-year cooler period (1970-1994) to a warmer phase, the frequency of major hurricanes has again increased. Based on the typical duration of alternating AMO phases, the current warm phase may persist from 10-30 more years. To date, models capable of predicting the AMO shifts from one phase to another are unavailable. However, the occurrences of 1999-2002 and 2006-2008 droughts emphasize the point that such warm/wet AMO phases only describe long-term average conditions, and that very dry intervals can (and do) occur during what might be a wetter than average longer time period, and that correspondingly very wet years have occurred during cooler/dry AMO phases.

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Table 3.3 provides comparisons of mean Shell Creek USGS gaged and “synthetic” estimated flows without withdrawal for both the historic 1966-1994 relatively dry AMO phase and the more recent 1995-2009 wetter phase. The following comparisons are presented.

- Overall for each of the relatively dry and wet AMO time intervals
- Among each of the three time blocks used by the District in setting MFLs
- For each month of the year

Table 3.3
Comparisons of Overall and Monthly Mean Shell Creek Flows (cfs) Between the Historical Dry and Recent Wet AMO Periods

Comparisons	USGS Gaged Monthly Mean Shell Creek Flow		Estimated Monthly Mean Flow (Without Withdrawals)	
	Dry AMO 1966-1994	Wet AMO 1995-2009	Dry AMO 1966-1994	Wet AMO 1995-2009
Overall	275	304	278	310
District Block 1 April 20th through June 25th	274	338	277	343
District Block 3 June 26th through October 26th	602	745	604	751
District Block 2 October 27th through April 19th	169	157	172	163
January	155	162	158	168
February	172	161	175	168
March	271	148	274	155
April	127	71	130	78
May	93	73	96	79
June	455	603	458	608
July	590	800	592	805
August	661	812	664	818
September	742	929	744	935
October	414	439	417	445
November	165	186	168	193
December	122	210	125	216

The comparisons presented in Table 3.3 further support the previous observations that even though the period since 1995 has been characterized by somewhat wetter overall and wet-season conditions than the previous 1966-1994 period, actual spring dry-season flows have actually declined in recent years. Again these results are heavily influenced by the unusually dry conditions that characterized the droughts of 1999-2002 and 2006-2008.

The box and whisker plots of annual average hydrographs of mean and median monthly flows presented in Table 3.4 further depict seasonal differences in the statistical distributions of Shell Creek flows between these selected AMO time intervals.

Table 3.4
Annual Hydrograph of Median and Mean Shell Creek Flows

Time Period	Median Flow		Mean Flow	
	USGS Gaged Flows	Estimated (Without Withdrawals)	USGS Gaged Flows	Estimated (Without Withdrawals)
Overall 1966 - 2009	Figure 3.81a	Figure 3.81b	Figure 3.82a	Figure 3.82b
"Dry" Interval 1966 – 1994	Figure 3.83a	Figure 3.83b	Figure 3.84a	Figure 3.84b
"Wet" Interval 1995 -2009	Figure 3.85a	Figure 3.85b	Figure 3.86a	Figure 3.86b

- These figures further emphasize how small the differences are between actual USGS gaged Shell Creek flows and those estimated that would have occurred if there had been no withdrawals.

- Wet-season flows during the previous dry AMO interval were, as expected, shown to have been less than during the more recent wetter AMO phase.

- However, the recent extended droughts caused spring dry-season flows during the past "wetter" 1995-2009 AMO phase to have on average been drier than the previous 1966-1994 "drier" AMO period.

A method used to further depict differences in Shell Creek flows among the two AMO periods entailed developing comparative Cumulative Distribution Functions (CDF) plots of flows for each interval and contrast selected wet and dry intervals over the historic 1966-2009 time period. CDF plots are a useful graphical method often employed in evaluating potential differences in the statistical frequency distributions among data sets containing large series of observations, and were extensively used by the District in setting the MFL for the lower Peace River (SWFWMD 2010). In simple terms, a CDF plot indicates the probability that a measured variable (in this case daily Shell Creek flow) has a value less than or equal to x, and can be expressed by the following equation.

$$F(x) = \Pr(X < x) = \alpha$$

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

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

Were *F(x)* is the estimated accumulated probability of the integrated change in the continuous variable (flow).

CDF comparative plots comparing differences between the 1966-1994 and 1995-2009 "dry" and "wet" AMO phases are summarized in Table 3.5 for the following periods in order to further distinguish between overall and seasonal differences.

- Over the entire time interval
- For each of the three seasonal blocks used by the District in establishing the lower Peace River MFL
- For each month of the year

In these graphical analyses, periods with generally higher flows have their statistical distributions (CDF lines) moved further to the right, while relatively drier periods conversely have lines shifted to the left. The results of the CDF analyses presented in these figures further support the previous graphical and statistical analyses indicating that Shell Creek flows during the 1966-1994 cool "drier" AMO phase were generally lower than those observed during the recent warmer "wetter" AMO periods (following 1994.) The statistical distributions depicted in these graphical analyses also indicate that the summer wet-season (June-September) differences in flows between the warm and cool AMO periods were generally greater than during the rest of the year (October-May).

Table 3.5
CDF Comparisons of Shell Creek Flows (cfs) between the Historical Dry and Recent Wet AMO Periods

Comparisons	Actual USGS Gaged Flows	Estimated Flows (Without Withdrawals)
Overall	Figure 3.87a	Figure 3.87b
District Block 1 April 20th through June 25th	Figure 3.88a	Figure 3.88b
District Block 3 June 26th through October 26th	Figure 3.89a	Figure 3.89b
District Block 2 October 27th through April 19th	Figure 3.90a	Figure 3.90b
January	Figure 3.91a	Figure 3.91b
February	Figure 3.92a	Figure 3.92b
March	Figure 3.93a	Figure 3.93b
April	Figure 3.94a	Figure 3.94b
May	Figure 3.95a	Figure 3.95b
June	Figure 3.96a	Figure 3.96b
July	Figure 3.97a	Figure 3.97b
August	Figure 3.98a	Figure 3.98b
September	Figure 3.99a	Figure 3.99b
October	Figure 3.100a	Figure 3.100b
November	Figure 3.101a	Figure 3.101b
December	Figure 3.102a	Figure 3.102b

3.2.4 Kendall Tau Statistical Analyses for Trends in Shell Creek Flow

Watershed flows can vary both spatially and temporally over both small and large scales due to natural variations in rainfall, as well as anthropogenic influences. The term "trends" is used here to refer to progressive changes over time in a flow metric (such as the monthly mean level), while "seasonal" and shorter term oscillating patterns are due to repeating natural processes. Researchers have proposed a number of parametric and nonparametric (distribution-free) statistical methods for determining the presence or absence of trends, some of which are more robust, than others (see definitions below). The objective of these tests is to separate a pattern (trend) from the “noise” of repeating seasonal and/or random “unexplained variations” in the data. The ability to detect and quantify, or determine the absence of, progressive changes over time is imperative to developing a framework and basis for future management decisions.

- **Parametric versus Nonparametric Methods**. A basic assumption of most parametric statistical tests is that the data distribution is approximately normally distributed (or that it can be transformed to be so). The general overall robustness of parametric tests is dependent on this underlying assumption and provides resistance to the influence of outlier data. However, environmental data in general, and flow and rainfall data in particular, often violate this key underlying assumption of the most commonly applied parametric procedures. Therefore, nonparametric tests are usually considered more robust when analyzing many kinds of environmental data.

- **Robustness, Resistance, and Influence**. “Robustness” refers to the insensitivity to violations of the basic assumptions of a particular statistical procedure. The term “resistance” by comparison is used to refer to the insensitivity to outliers, while the word “influence” is used to describe the effect of extreme observations on summary measures.

Kendall Tau and the Seasonal Kendall Tau tests are nonparametric statistical tests widely used to analyze data for trends where normality cannot be assumed. These methods can be used to determine whether data values are increasing, declining, 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 calculate the Mann-Kendall Tau statistic. If the time-series data are systematically increasing (or decreasing) over time, then the resulting computed Tau statistic will be a relatively large positive (or negative) value. If, however, the change over time is negligible, then the number of positive pairs and the number of negative pairs will be approximately equal, and the Tau statistic will be small. The Tau statistic can thus be viewed as an estimate of the median slope of the set of slopes estimated for the lines connecting all possible pairs of data. In addition to the Tau the following additional statistics can be determined.

- P-values without correction for serial correlations (applicable for trend tests using annual values)

- P-values statistically corrected to account for serial correlations (used in testing for trends using monthly values)

- The slope, which indicates the magnitude of the relative rate of change, and the sign indicates an increasing or decreasing change over time (trend)

The Seasonal Kendall Tau test incorporates an additional factor to account for seasonal variation. When analyzing monthly data, each month is viewed as a "season" and this method is therefore directly applicable to flow (and rainfall) data, which are characterized by strong seasonal patterns. As in parametric tests, hypothesis testing for a trend is based on the null hypothesis that “there is no trend.” The null hypothesis can only be rejected if the Tau statistic is sufficiently large at a given level of probability (p-value).

Statistical tests were conducted using SAS programming code developed by the US Environmental Protection Agency (USEPA) for nonparametric analysis of water quality and other environmental data. The USEPA SAS code was based on Seasonal Kendall Tau program code originally developed by the USGS to test for trends in flows and water quality data. This SAS code provides two alternative methods for determining whether data exhibit a statistically significant trend at a given level of probability. The first method assumes that the seasonal data are independent, while the second method corrects (or de-trends) for “serial autocorrelations” within the data. Since monthly flow (and rainfall) data are often serially correlated (the values in many months are similar to either the preceding or following months), probability values corrected for serial correlations were used for tests of trends between selected intervals of time.

Actual USGS Shell Creek gaged and “synthetic” (estimated without withdrawal) flows were tested for long-term trends using the following series of analyses.

- Seasonal Kendal Tau Trend Tests were run for the monthly minimum, P5, P10, mean and median values.

- Kendall Tau Trend Tests were run for yearly maximum, P90, P75, median, mean, P25, P10, and minimum Shell Creek flows.

- Similar Kendall Tau Trend Tests were determined for the annual minimum, mean and maximum values for 3, 15, 30, 60, and 90-day moving average flows.

Summary results of these trend analyses are presented in Tables 3.6 and 3.7 for actual USGS gaged and estimated Shell Creek flows without withdrawals, respectively.

Table 3.6
Statistical Summary of Results of Kendal Tau Trend Analyses of Gaged Shell Creek Flows (1966-2009)

Monthly Flow Metric	Tau Statistic	P-Value With * and Without Serial Correlation	Slope Statistic (cfs/yr)	Trend
Shell Creek near Punta Gorda (USGS Gage 2298202) – USGS Gaged Flows				
Monthly Minimum	0.06	0.3448 *	0.17	■
Monthly P5	0.05	0.3921 *	0.16	■
Monthly P10	0.04	0.4573 *	0.15	■
Monthly Mean	0.00	0.9999 *	-0.001	■
Monthly Median	0.00	0.8931 *	0.001	■
Annual Minimum	0.07	0.4949	0.001	■
Annual P10	0.09	0.3785	0.27	■
Annual P25	0.05	0.6709	0.25	■
Annual P50 (Median)	-0.06	0.5574	-0.50	■
Annual Mean	0.06	0.5919	1.36	■
Annual P75	-0.03	0.7848	-0.82	■
Annual P90	0.04	0.7385	2.56	■
Annual Maximum	0.13	0.2210	25.90	■
Annual 3-day Minimum	0.07	0.5043	0.001	■
Annual 15-day Minimum	0.12	0.2650	0.05	■
Annual 30-day Minimum	0.11	0.2787	0.17	■
Annual 60-day Minimum	0.12	0.2531	0.36	■
Annual 90-day Minimum	0.03	0.8161	0.07	■
Annual 3-day Mean	0.05	0.6060	1.41	■
Annual 15-day Mean	0.05	0.6060	1.35	■
Annual 30-day Mean	0.05	0.6202	1.30	■
Annual 60-day Mean	0.05	0.6345	1.04	■
Annual 90-day Mean	0.05	0.6636	0.77	■
Annual 3-day Maximum	0.12	0.2448	21.4	■
Annual 15-day Maximum	0.14	0.1786	18.40	■
Annual 30-day Maximum	0.14	0.1990	12.70	■
Annual 60-day Maximum	0.14	0.1852	8.47	■
Annual 90-day Maximum	0.14	0.1954	6.78	■

■ Denotes no trend ▲ Indicates increasing trend ▼ Indicates declining trend

Table 3.7
Statistical Summary of Results of Kendal Tau Trend Analyses of "Estimated" Shell Creek Flows without City of Punta Gorda Withdrawals (1966-2009)

Monthly Flow Metric	Tau Statistic	P-Value With * and Without Serial Correlation	Slope Statistic (cfs/yr)	Trend
Shell Creek near Punta Gorda (USGS Gage 2298202) – "Synthetic" Flows (no withdrawals)				
Monthly Minimum	0.09	0.1458 *	0.38	■
Monthly P5	0.08	0.1965 *	0.37	■
Monthly P10	0.07	0.2371 *	0.36	■
Monthly Mean	0.01	0.6300 *	0.15	■
Monthly Median	0.01	0.6217 *	0.11	■
Annual Minimum	0.15	0.1383	0.12	■
Annual P10	0.14	0.1689	0.44	■
Annual P25	0.07	0.5109	0.41	■
Annual P50 (Median)	-0.04	0.7386	-0.34	■
Annual Mean	0.06	0.5643	1.58	■
Annual P75	-0.02	0.8476	-0.69	■
Annual P90	0.04	0.6784	2.70	■
Annual Maximum	0.13	0.2210	26.1	■
Annual 3-day Minimum	0.15	0.1555	0.12	■
Annual 15-day Minimum	0.16	0.1372	0.26	■
Annual 30-day Minimum	0.16	0.1265	0.35	■
Annual 60-day Minimum	0.16	0.1267	0.53	■
Annual 90-day Minimum	0.06	0.5919	0.23	■
Annual 3-day Mean	0.06	0.5643	1.63	■
Annual 15-day Mean	0.06	0.5780	1.49	■
Annual 30-day Mean	0.06	0.5643	1.53	■
Annual 60-day Mean	0.06	0.5507	1.15	■
Annual 90-day Mean	0.05	0.6202	0.93	■
Annual 3-day Maximum	0.12	0.2448	21.6	■
Annual 15-day Maximum	0.15	0.1659	18.7	■
Annual 30-day Maximum	0.14	0.1852	12.8	■
Annual 60-day Maximum	0.14	0.1786	8.69	■
Annual 90-day Maximum	0.14	0.1920	6.87	■

■ Denotes no trend ▲ Indicates increasing trend ▼ Indicates declining trend

Similar statistical analyses presented in previous studies (*Shell Creek HBMP Year Five Comprehensive Summary Report*, PBS&J 2003; *Shell Creek Gap Report*, PBS&J 2007; *Peace River Cumulative Impact Study*, PBS&J 2007) have indicated that there have been long-term increases in baseflow in Shell Creek. These findings are not unexpected, given that these and ongoing District studies that have shown that Prairie Creek and Shell Creek watershed flows are, and continue to be, augmented during the typical dry winter/spring periods by discharges associated with increased agricultural groundwater use. However, the severity of the recent droughts may have reduced dry season flows enough to obscure the influences of these augmented dry-season flows. None of the trends tests for the 1966-2009 time interval indicated any statistically significant trends.

3.2.5 Flow Frequency Analysis

The U.S. Geological Survey (USGS) has used log-Pearson Type III distributions for assessing low-flow frequency changes for a number of its long-term continuous stream flow gaging sites in southwest Florida. The primary objectives of these analyses have been to assess potential changes in flow-duration and lowest mean-discharges for various consecutive-day periods as a method of forecasting and determining potential impacts related to water management alternatives. Statistical Analysis System (SAS) code was provided by District staff that replicates this USGS methodology. This SAS code was modified using the 1966-2009 flows derived from the USGS Shell Creek gage, and the results are presented for the following series of analyses.

- "Synthetic" flows were used to estimate the frequency distribution over the 1966-2009 period of record without withdrawals (**Figure 3.103** and **Table 3.8**).
- Actual USGS gaged flows were used to determine changes in flow distributions after accounting for actual City withdrawals over the 1966-2009 time interval (**Figure 3.104** and **Table 3.9**).
- "Synthetic flows, after subtracting the maximum average daily withdrawal of 8.09 mgd, were used to determine changes in flow distributions if maximum current permitted withdrawals had occurred over the 1966-2009 time interval (**Figure 3.105** and **Table 3.10**).

Table 3.11 provides a summary of the findings of these analyses. Given the previously described magnitude of annual and seasonal variability in Shell Creek flows (see Section 3.2.1 above), the predicted changes in the distribution of flows due to City of Punta Gorda withdrawals as shown in Table 3.11 has and is expected to continue to be relatively small.

Table 3.11
Lowest Average Flow (cfs) for Indicated Recurrence Intervals (years)

Consecutive Days	Years				
	2	3	5	15	25
"Synthetic" Estimated Baseline Without Withdrawals					
1	0.9	0.2	0.0	0.0	0.0
3	1.0	0.2	0.0	0.0	0.0
10	1.9	0.4	0.1	0.0	0.0
30	7.7	2.4	0.7	0.2	0.0
60	24.1	13.4	7.3	3.7	1.8
90	39.3	25.9	17.1	10.7	6.7
120	56.3	38.9	27.0	18.2	12.2
USGS Gaged Flows (Includes Actual Withdrawals)					
1	0.3	0.1	0.0	0.0	0.0
3	0.4	0.1	0.0	0.0	0.0
10	0.9	0.2	0.0	0.0	0.0
30	4.6	1.2	0.3	0.1	0.0
60	17.9	8.6	4.0	1.7	0.7
90	34.0	21.2	13.2	7.8	4.5
120	51.1	34.3	23.0	15.0	9.7
Estimated Flow After Subtracting Current Maximum Averaged Daily Permitted Withdrawals					
1	0.1	0.0	0.0	0.0	0.0
3	0.1	0.0	0.0	0.0	0.0
10	0.2	0.0	0.0	0.0	0.0
30	1.1	0.2	0.0	0.0	0.0
60	6.7	2.0	0.6	0.1	0.0
90	20.4	9.7	4.4	1.8	0.7
120	37.4	22.2	13.1	7.3	4.0

3.3 Characterization of Trends and Seasonal Changes in Conductivity/Major Freshwater Ions

The primary objective of the following series of analyses was to determine the current status, and evaluate historical spatial/temporal patterns and trends in conductivity, major ions, nutrients and other water quality characteristics of the two major upstream freshwater sources (Shell and Prairie Creeks) and within the City's reservoir. Long-term monitoring gathered by the City, USGS, the District's ambient monitoring program, and the Shell Creek HBMP, were utilized in these analyses.

3.3.1 Conductivity (Specific Conductance)

Marked seasonal increases in conductivity (or specific conductance) in the Shell/Prairie Creek Watershed have been shown to be due to the influences of water from highly mineralized aquifers on otherwise low-conductivity surface waters (PBS&J 2007, 2009). These increases in conductivity have been linked to agricultural off-site discharge of irrigation waters originating from the more highly mineralized intermediate and Upper Floridan aquifers. In 2004, the District and the Florida Department of Environmental Protection (FDEP) completed the *Shell Creek and Prairie Creek Watersheds Management Plan* (SWFWMD 2004). The Plan's purpose was to provide "reasonable assurance" that the Shell Creek and Prairie Creek Watersheds would be restored and maintained to meet the water quality criteria set forth in Chapter 62-302.530(23), Florida Administrative Code (F.A.C.) for Class III waters which states:

"Specific conductance (micromhos/cm) shall not be increased more than 50 percent above background or to 1275, whichever is greater."

The stakeholder's group responsible for initiating the *Shell Creek and Prairie Creek Watersheds Management Plan* was formed in 2001 to address water quality issues related to elevated total dissolved solids (TDS) concentrations in the City of Punta Gorda's water supply that became apparent during the 1999-2002 drought. This stakeholder group consisted of members representing 18 state, local government, agricultural, association, and commodity groups. The resulting Management Plan identified potential alternative programs projects specifically designed to address water quality impairments resulting from elevated concentrations of chloride, TDS, and specific conductance. The Management Plan also sought to address additional potential nutrient impairment in the Prairie, Shell and Joshua Creek watersheds. The Management Plan's goals were to reduce at all times specific conductance levels to no more than 775 µmhos/cm, chloride levels to below 250 mg/l, and total dissolved solids (TDS) levels to below 500 mg/l. An additional goal of the Reasonable Assurance Plan, which makes up part of the larger Management Plan, was to reduce conductivity to levels below the existing state standard "never to exceed" value of 1275 µmhos/cm. The Management Plan mandates that these objectives be accomplished by 2014.

While conductivity itself is not a drinking water standard, it is directly related to the amount of TDS in the water. TDS is one of the U.S. Environmental Protection Agency's Secondary "Technical" Drinking Water Standards associated with increased hardness, deposits and taste. In order to meet the Secondary Drinking Water TDS standard of 500 mg/l, the City's drinking water process needs the raw water supply from the Shell Creek reservoir to have a conductance less than 673 µmhos/cm.

This level and the 1275 µmhos/cm Class III waters standard are shown as vertical dashed reference lines in the following presented conductivity graphics. Table 3.12 summarizes graphics showing both average daily conductivity measurements made at the four USGS recorder sites established to assess short- and long-term conductivity patterns in the Prairie and Shell Creek Watersheds, as well as the relationships between conductivity and estimated flow at each of the recorder sites. Flows at Prairie Creek at Ft. Ogden and Shell Creek near Punta Gorda (at the Dam) came from direct USGS gaging data, while the flow estimates used for Prairie and

Shell Creeks at C.R. 764 were calculated using the relative proportions of each upstream sub-basin relative to the size of the total basin for Shell Creek near Punta Gorda.

Table 3.12
Conductivity (µmhos/cm) Over Time and in Relation to Flow at the USGS Recorder Sites

Plots	Prairie Creek at Ft. Ogden	Prairie Creek at C.R. 764	Shell Creek at C.R. 764	Shell Creek near Punta Gorda (Reservoir)	Comparison Among USGS Sites
Time-series	Figure 3.106a	Figure 3.107a	Figure 3.108a	Figure 3.109a	Figure 3.110a
Conductivity vs. Flow	Figure 3.106b	Figure 3.107b	Figure 3.108b	Figure 3.109b	Figure 3.110b

These graphics depict patterns that support the following conclusions.

- Conductivity measured at each of the four USGS recorder sites all show very similar distinct seasonal patterns.
- Conductivity levels were generally lower during the wetter 2004-2005 time interval when compared to the drought conditions that characterized watershed rainfall patterns from early 2006 through the spring of 2009.
- Except for a very brief period in the spring of 2009, conductivity levels at both Prairie Creek sites and in the reservoir were below the DEP Class III Standard of 1275 µmhos/cm.
- Daily average conductivity measured at Shell Creek at C.R. 764, by comparison, exceeded the Class III standard every year with the exception of 2005, which was a very wet year.
- The USGS conductivity recorder near the Dam indicated that between 2006 and 2009 measured conductivity levels met the 673 µmhos/cm criteria needed to assure finished potable TDS levels below the Secondary Drinking Water Standard of 500 mg/l only twenty-six percent of the time.
- At all four USGS monitoring sites measured conductivities logarithmically declined with increasing flow.
- However, within the reservoir relatively high levels of flow are needed to reduce conductivity levels below 673 µmhos/cm.

Similar plots over time and relative to USGS gaged flow over the Dam are further shown for daily conductivity and chloride levels in the Shell Creek reservoir measured by the City from the Facility intake.

Conductivity – Although dry-season conductivities in the reservoir have declined from the very high levels observed during the 1999-2001 drought **(Figure 3.111a)**, they continue to be above the 673 µmhos/cm level needed for the City to meet the ideal Secondary Drinking Water TDS Standard of 500 mg/l. **Figure 3.111b** shows that relatively high levels of flow are needed before conductivities in the reservoir are reduced enough to assure meeting the TDS Standard.

Chlorides – Although chloride levels in the reservoir continue to seasonally increase each year during the typically drier months **(Figure 3.112a)**, they have not exceeded the 250 mg/l Secondary Drinking Water Standard since the 1999-2002 drought. Chloride levels are shown to rapidly decline with increasing flows **(Figure 3.112b)**.

3.3.2 Time-Series of Water Quality Characteristics at the HBMP Sites Upstream of the Hendrickson Dam

Table 3.13 presents time-series plots of selected water quality characteristics for the three Shell Creek HBMP monitoring sites located upstream of the Dam. These graphical analyses of monthly data generally show that the majority of the water quality parameters measured at these three locations have varied seasonally without any indication of distinct systematic increasing or decreasing changes over the historic nineteen years (1991-2009) of monitoring. In comparison, the long-term patterns of change in other parameter such as conductivity and chloride show marked increases associated with both the 1999-2001 and 2006-2008 droughts. As previously discussed, these changes have been shown to be directly associated with increases in groundwater use and "tail water" agricultural discharges to natural surface waters (SWFWMD 2004, PBS&J 2007).

Table 3.13
Time-Series Plots of Water Quality Characteristics

Water Quality Parameter	Sampling Location/Monitoring Program Site Number		
	Prairie Creek at C.R. 764 HBMP Site #1 City of Punta Gorda	Shell Creek at C.R. 764 HBMP Site #2 City of Punta Gorda	Shell Creek Reservoir HBMP Site #3 City of Punta Gorda
Dissolved Oxygen	Figure 3.113a	Figure 3.113b	Figure 3.113c
Specific Conductance	Figure 3.114a	Figure 3.114b	Figure 3.114c
Chloride	Figure 3.115a	Figure 3.115b	Figure 3.115c
Alkalinity	Figure 3.116a	Figure 3.116b	Figure 3.116c
Total Suspended Solids	Figure 3.117a	Figure 3.117b	Figure 3.117c
Color	Figure 3.118a	Figure 3.118b	Figure 3.118c
Turbidity	Figure 3.119a	Figure 3.119b	Figure 3.119c
Total Organic Carbon	Figure 3.120a	Figure 3.120b	Figure 3.120c
Ammonia/Ammonium	Figure 3.121a	Figure 3.121b	Figure 3.121c
Nitrite + Nitrate Nitrogen	Figure 3.122a	Figure 3.122b	Figure 3.122c
Total Kjeldahl Nitrogen	Figure 3.123a	Figure 3.123b	Figure 3.123c
Ortho-phosphorus	Figure 3.124a	Figure 3.124b	Figure 3.124c

Table 3.13
Time-Series Plots of Water Quality Characteristics

Water Quality Parameter	Sampling Location/Monitoring Program Site Number		
	Prairie Creek at C.R. 764 HBMP Site #1 City of Punta Gorda	Shell Creek at C.R. 764 HBMP Site #2 City of Punta Gorda	Shell Creek Reservoir HBMP Site #3 City of Punta Gorda
Total Phosphorus	Figure 3.125a	Figure 3.125b	Figure 3.125c
Silica	Figure 3.126a	Figure 3.126b	Figure 3.126c
Chlorophyll *a*	Figure 3.127a	Figure 3.127b	Figure 3.127c

While most of the long-term patterns depicted in these graphical analyses simply indicate non-trending seasonal and annual variability between drier and wetter years, there are a number of water quality characteristics for which the data suggest there have been systematic, progressive changes over time. Seasonal Kendall Tau tests (see previous discussion above in Section 3.2.4) were run in order to determine if these apparent changes over the 1991-2009 time interval were statistically significant. The results of these analyses are summarized in Table 3.14.

Table 3.14
Statistical Summary of Results of Seasonal Kendall Tau Trend Analyses of Selected Water Quality Characteristics at the Three HBMP Sites Upstream of the Hendrickson Dam

Monthly Flow Metric	Tau Statistic	P-Value With Serial Correlation	Slope Statistic	Trend
Prairie Creek at C.R. 764				
Dissolved Oxygen	0.06	0.407	0.022	■
Specific Conductance	0.14	0.142	8.624	■
Chloride	0.15	0.117	1.227	■
Alkalinity	0.07	0.488	0.565	■
Total Suspended Solids	0.14	0.054	0.075	▲
Color	-0.09	0.211	-0.85	■
Turbidity	-0.03	0.700	-0.016	■
Ammonia/Ammonium	-0.05	0.556	-0.001	■
Nitrite + Nitrate Nitrogen	-0.06	0.392	-0.002	■
Total Kjeldahl Nitrogen	-0.06	0.325	-0.004	■
Ortho-phosphorus	0.00	0.961	0.001	■
Total Phosphorus	0.03	0.563	0.001	■
Silica	0.38	0.002	0.198	▲
Chlorophyll *a*	0.10	0.177	0.037	■
Shell Creek at C.R. 764				
Dissolved Oxygen	-0.09	0.193	-0.027	■
Specific Conductance	-0.01	0.918	-0.550	■

Table 3.14
Statistical Summary of Results of Seasonal Kendall Tau Trend Analyses of Selected Water Quality Characteristics at the Three HBMP Sites Upstream of the Hendrickson Dam

Monthly Flow Metric	Tau Statistic	P-Value With Serial Correlation	Slope Statistic	Trend
Chloride	-0.09	0.414	-1.221	■
Alkalinity	0.12	0.193	0.955	■
Total Suspended Solids	0.01	0.886	0.001	■
Color	0.01	0.988	0.001	■
Turbidity	-0.14	0.096	-0.050	■
Ammonia/Ammonium	0.16	0.055	0.001	▲
Nitrite + Nitrate Nitrogen	-0.22	0.007	-0.005	▼
Total Kjeldahl Nitrogen	-0.12	0.042	-0.007	▼
Ortho-phosphorus	-0.14	0.085	-0.001	■
Total Phosphorus	-0.02	0.793	-0.002	■
Silica	0.36	0.004	0.188	▲
Chlorophyll *a*	0.01	0.878	0.001	■
Shell Creek Reservoir near Dam				
Dissolved Oxygen	-0.05	0.413	-0.018	■
Specific Conductance	0.11	0.288	6.829	■
Chloride	0.07	0.535	0.696	■
Alkalinity	0.15	0.114	1.029	■
Total Suspended Solids	0.12	0.036	0.066	▲
Color	-0.04	0.596	-0.088	■
Turbidity	0.07	0.486	0.025	■
Ammonia/Ammonium	0.14	0.098	0.005	■
Nitrite + Nitrate Nitrogen	0.01	0.932	0.001	■
Total Kjeldahl Nitrogen	-0.14	0.010	-0.008	▼
Ortho-phosphorus	-0.02	0.738	0.002	■
Total Phosphorus	-0.02	0.758	-0.002	■
Silica	0.34	0.009	0.180	▲
Chlorophyll *a*	-0.06	0.249	-0.063	■

■ Denotes no trend ▲ Indicates increasing trend ▼ Indicates declining trend

In some instances the patterns and trends observed in these analyses differ somewhat from those presented in previous Shell Creek Summary Reports (PBS&J, 2003, 2006). Agriculture remains the dominate land use in both the Prairie and Shell Creek Watersheds (PBS&J 2007), and a number of the observed long-term patterns and changes in water quality characteristics at the HBMP monitoring sites over the 1991-2009 time interval have been influenced by the two extended, extreme periods of drought (1999-2001 and 2006-2008) that have occurred during the past decade.

3.3.3 Relationships between Water Quality Characteristics and Flow

The relative relationships between changes in freshwater flows and monthly measures of water quality parameters at the three HBMP monitoring sites upstream of the Hendrickson Dam are presented in Table 3.15. Flow data from the USGS site at the Dam were used for HBMP Site #3 (the reservoir near the Dam), while flow estimates used for Prairie and Shell Creeks at C.R. 764 were calculated using the relative proportions of each upstream sub-basin relative to the size of the total basin for Shell Creek near Punta Gorda.

Table 3.15
Relationships between Water Quality Parameters and Flows

Water Quality Parameter	Sampling Location/Monitoring Program Site Number					
	Prairie Creek at C.R. 764 HBMP Site #1 City of Punta Gorda		Shell Creek at C.R. 764 HBMP Site #2 City of Punta Gorda		Shell Creek Reservoir HBMP Site #3 City of Punta Gorda	
Dissolved Oxygen	Figure 3.128a	◄	Figure 3.128b	■	Figure 3.128c	◄
Specific Conductance	Figure 3.129a	◄	Figure 3.129b	◄	Figure 3.129c	◄
Chloride	Figure 3.130a	◄	Figure 3.130b	◄	Figure 3.130c	◄
Alkalinity	Figure 3.131a	◄	Figure 3.131b	◄	Figure 3.131c	◄
Total Suspended Solids	Figure 3.132a	►	Figure 3.132b	►	Figure 3.132c	■
Color	Figure 3.133a	►	Figure 3.133b	►	Figure 3.133c	►
Turbidity	Figure 3.134a	►	Figure 3.134b	►	Figure 3.134c	►
Total Organic Carbon	Figure 3.135a	►	Figure 3.135b	►	Figure 3.135c	►
Ammonia/Ammonium	Figure 3.136a	■	Figure 3.136b	■	Figure 3.136c	►
Nitrite + Nitrate Nitrogen	Figure 3.137a	■	Figure 3.137b	■	Figure 3.137	■
Total Kjeldahl Nitrogen	Figure 3.138a	►	Figure 3.138b	►	Figure 3.138c	►
Ortho-phosphorus	Figure 3.139a	►	Figure 3.139b	►	Figure 3.139c	►
Total Phosphorus	Figure 3.140a	►	Figure 3.140b	►	Figure 3.140c	►
Silica	Figure 3.141a	■	Figure 3.141b	■	Figure 3.141c	■
Chlorophyll *a*	Figure 3.142a	■	Figure 3.142b	◄	Figure 3.142c	◄

■ Denotes no change with flow ► Increasing concentrations with flow ◄ Indicates declining levels with flow

The following generalized patterns and relationships relative to seasonal and annual variations in freshwater flows are apparent in these graphics.

- As expected, dissolved oxygen concentrations were found show an inverse relationship with the rate of flow at both the Prairie Creek and reservoir sites. The summer wet-season not only results in high flows, but increases in water temperature increases both biological respiration and oxygen demand, as well as physically reduces the saturation level of dissolved gases in water.

- Dissolved constituents such as conductivity, chlorides, and alkalinity that reflect higher groundwater contributions all decline with increasing flows and greater surface water influences.

- Higher contributions of sheet and surface water flows are also positively related to increases in water quality characteristics such as total suspended solids, color and turbidity.

- Measures of total organic carbon, total Kjeldahl nitrogen and phosphorus concentrations are also positively correlated with increasing flows.

- Inorganic nitrogen and silica concentrations, by comparison, failed to show any such relationships to changes in flow.

- Increases in color that reduce the availability of light, and reduced residence time, result in the observed inverse patterns between higher flows and observed lower chlorophyll *a* levels.

3.3.4 Time-Series Analyses of Major Ions at District Watershed Monitoring Sites

The District's ambient monitoring program has a number of background and monitoring sites in and near the Prairie and Shell Creek Watersheds (**Map 3.1**). Available water quality information collected at the following sites was provided by the District and analyzed to assess spatial and temporal patterns in ion concentrations, in order to reflect both natural seasonal and anthropogenic influences on water quality upstream of the City of Punta Gorda's reservoir. The District's monitoring program currently includes the following seven sampling sites in the Prairie/Shell Creek Watersheds.

Northern Prairie Creek Watershed and Background

- Mossy Gully at S.R. 70
- Cow Slough at S.R. 70

Prairie Creek Watershed

- Montgomery Canal
- Symons Canal
- Prairie Creek at C.R. 764

Shell Creek Watershed and Background

- Emerald Isle Canal
- Shell Creek at C.R. 764

Time-series plots of major ion concentrations at each of these sites are summarized in Table 3.16. With the exception of measures of conductivity, relevant District data for these water quality constituents only extends back to the early part of 2005.

Table 3.16
Time-Series Plots of Water Quality Characteristics at District's Monitoring Sites

Water Quality Parameter	Watershed/Monitoring Location		
	Northern Prairie Creek / Background	Prairie Creek	Shell Creek / Background
Conductivity (us/cm)	Figure 3.143a	Figure 3.143b	Figure 3.143c
Total Dissolved Solids (mg/L)	Figure 3.144a	Figure 3.144b	Figure 3.144c
Chlorides (mg/L)	Figure 3.145a	Figure 3.145b	Figure 3.145c
Alkalinity (mg/L)	Figure 3.146a	Figure 3.146b	Figure 3.146c
Fluoride (mg/L)	Figure 3.147a	NA	NA
Calcium (mg/L)	Figure 3.148a	Figure 3.148b	Figure 3.148c
Magnesium (mg/L)	Figure 3.149a	Figure 3.149b	Figure 3.149c
Potassium (mg/L)	Figure 3.150a	Figure 3.150b	Figure 3.150c
Sulfur (mg/L)	Figure 3.151a	Figure 3.151b	Figure 3.151c
Iron (ug/L)	NA	Figure 3.152b	Figure 3.152c
Silica (mg/L)	NA	Figure 3.153b	Figure 3.153c

The presented graphical analyses indicate a number of generalized patterns that provide the basis for the following relative comparisons between watersheds and among sampling site locations.

- Conductivity, total dissolved solids, alkalinity, chloride and other ion concentrations at the District's Mossy Gully at S.R. 70 sampling site were observed to be notably higher over the 2006-2009 time interval than at the corresponding Cow Slough background station located further to the east along S.R. 70. **Map 3.1** shows that the Mossy Gully site is located toward the northern end of the Prairie Creek Watershed, just south of an extensive area that was converted to intense agricultural use. Conductivity and chloride levels at the Mossy Gully at S.R. 70 sampling site were generally lower and sulfur concentrations were found to be higher than at the District's sampling locations that receive drainage from the Prairie Creek Watershed agricultural areas located further to the south (the Montgomery and Symons Canals). These observations probably reflect general differences in the quality of the agricultural groundwater between the two watershed areas used during the intense drought that characterized most of the period during which the available District data at these sites was collected.

- Comparisons of conductivity, total dissolved solids, alkalinity, chloride and other ion levels indicate relatively higher concentrations (poorer water quality) at the District's Symons Canal monitoring site relative to corresponding upstream measurements made at the Montgomery Canal which receives drainage from the more eastern portions of the Prairie Creek Watershed **(Map 3.1)**.

- The downstream Prairie Creek at C.R. 764 sampling site is located just upstream of where Prairie Creek flows into the City's reservoir. Comparisons of water quality characteristics between those taken at this downstream site and measurements made at the upstream Symons Canal location suggest that the additional watershed drainage

between these two sites results in some dilution and reductions in measured levels of conductivity, total dissolved solids, chlorides and a number of other ions in the waters entering the reservoir.

- The District's background Emerald Isle Canal site is located near the headwaters of the Shell Creek Watershed **(Map 3.1)**. Corresponding measures taken at this background location and at the downstream Shell Creek at C.R. 764 site again show that agricultural discharges of irrigation groundwater between the two sites result in measured increases in conductivity, total dissolved solids, alkalinity, chlorides and other ion concentrations.

- Comparisons between the Shell Creek and Prairie Creek sampling sites at C.R. 764 indicate that the water quality at the Shell Creek site generally exhibits higher concentrations of dissolved ions and is thus of relatively poorer quality with regard to the City's water treatment standards.

- However, the USGS estimates that 24 percent of the reservoir's watershed is upstream of Shell Creek at C.R. 764, while Prairie Creek at C.R. 764 represents approximately 70 percent of the reservoir's watershed. As a result, water quality characteristics within the City's reservoir are more relatively heavily influenced by the upstream land use practices and the quality and quantity of agricultural discharges in the Prairie Creek Watershed.

4.0 Influences of Withdrawals on Flow Characteristics

Based on discussions with District staff, a baseline "un-impacted" flow record was developed by adding actual City of Punta Gorda Facility's withdrawals back into USGS gaged Shell Creek flows over the historic 1966-2009 period of record. This "synthetic", withdrawal corrected, baseline flow record was also corrected for certain days when there was no flow from the reservoir. This method, applied in the District draft Shell Creek MFL report, used gaged flows in Prairie Creek (or Charlie Creek when Prairie flows were absent) to estimate flows over the Hendrickson Dam corrected for withdrawals under certain no-flow conditions.

The series of analyses presented in this chapter depict and contrast the relative magnitude and seasonal variation of changes in flows to the estuarine reach of Shell Creek below the dam that have occurred due to historic withdrawals; and that would be expected to occur under the City's newest permitted 20-year withdrawal schedule. This methodology is analogous to those previously used to estimate the relative magnitude of long-term and seasonal changes in freshwater flows to the Charlotte Harbor estuarine system due to withdrawals by the City of Punta Gorda (*Shell Creek Gap Report*) and the Peace River Manasota Regional Water Supply Authority (*2006 Peace River Comprehensive Summary Report*).

4.1 Time-Series of Annual Differences in Percentiles

Time-series line plots of the following differing annual flow percentiles are provided in order to present a thorough overview of the relative magnitude of year-to-year variations relative to both actual historic withdrawals and those that would have occurred if the current maximum permitted levels had been in place over the 1966-2009 time interval.

- Minimum – the lowest annual daily flow
- P10 – the annual daily flow exceeded ninety percent of the time
- P25 – the annual daily flow exceeded seventy-five percent of the time
- P50 (median) – the annual daily flow exceeded fifty percent of the time
- Mean – the annual average daily flow
- P75 – the annual daily flow exceeded twenty-five percent of the time
- P90– the annual daily flow exceeded only ten percent of the time
- Maximum– the highest annual daily flow

Annual values of the following three estimates of Shell Creek flows over the historic (1966-2009) period are depicted in **Figures 4.1** through **4.8** (Table 4.1).

- Baseline Flow – "synthetic" flow without City of Punta Gorda withdrawals calculated using the method used by the District in the recent MFL analyses.

- USGS gaged flows – which include actual City withdrawals.

- Flows that would have occurred if the City had taken the maximum daily amount allowed under the recent 2007 twenty-year permit renewal.

The following summarizes the observed patterns and primary conclusions that can be drawn from these time-series analyses.

- As expected, the largest observed differences shown are between the no-withdrawal condition and the maximum daily withdrawals allowed under the City's new permit.

- However, these differences become less and less apparent as flows increase, and are relatively quite small at flows above the annual median.

- The observed differences between the no-withdrawal and withdrawal scenarios are relatively small, when compared to the magnitude of the natural yearly variability in these flow percentiles.

Table 4.1
Time-Series Plots (1966-2009) of Flow Metrics and Percentiles

Analyses	Flow Percentiles							
	Min.	P10	P25	P50 Median	Mean	P75	P90	Max.
Annual Values	Figure 4.1	Figure 4.2	Figure 4.3	Figure 4.4	Figure 4.5	Figure 4.6	Figure 4.7	Figure 4.8
Monthly Values	Figure 4.9	Figure 4.10	Figure 4.11	Figure 4.12	Figure 4.13	Figure 4.14	Figure 4.15	Figure 4.16

4.2 Monthly Differences

Line plots similar to the above time-series analyses of annual differences were also developed for monthly (January-December) flows, depicting differences between the idealized baseline condition and both historic and current maximum permitted withdrawals. Annual hydrographs are presented in **Figures 4.9** through **4.16** (Table 4.1) for the monthly minimum, P10, P25, P50 (median), mean, P75, P90 and maximum flow percentiles.

- As previously shown by the time-series plots, the largest differences occurred between the no-withdrawal condition and the maximum daily average withdrawals allowed under the City's 2007 twenty-year Water Use Permit.

- Changes in flows are far less apparent as flows increase, and are relatively quite small at flows above the annual median.

- Seasonally, the relatively largest changes in flows due to withdrawals occur during the typically drier months, under low flow conditions.

4.3 Annual Statistical Variability

Box and whisker plots of monthly annual seasonal differences between baseline and withdrawal alternatives using same day and 3, 15, 30, 60 and 90-day moving averages are presented in Table 4.2. (Note: all graphics only depict flows up to 2500 cfs in order to provide sufficient scaling to allow showing differences between the baseline (no-withdrawal) condition, and actual historical and current maximum permitted withdrawals).

Table 4.2
Box and Whisker Plots of Changes in Flows (1966-2009) Due to Actual and Current Maximum Daily Average Shell Creek Withdrawals

Comparison	Flows	3-day Average	15-day Average	30-day Average	60-day Average	90-day Average
Baseline to Actual Withdrawals	Figure 4.17a	Figure 4.18a	Figure 4.19a	Figure 4.20a	Figure 4.21a	Figure 4.22a
Baseline to Current Maximum Daily Average Permitted Withdrawals	Figure 4.17b	Figure 4.18b	Figure 4.19b	Figure 4.20b	Figure 4.21b	Figure 4.22b

The following patterns and conclusions are apparent based on the presented box and whisker plots of seasonal changes in flows due to the two withdrawal scenarios.

- As expected, the largest differences occur between the no-withdrawal condition and the maximum daily average withdrawals allowed under the City's 2007 twenty-year Water Use Permit. It should be noted that the actual withdrawal scenario includes earlier long intervals when demands were relatively much smaller.

- Both scenarios show withdrawals to be relatively small given the proportionally much greater magnitude of both seasonal and annual variability in freshwater Shell Creek flows.

4.4 Differences between Withdrawal Scenarios Relative to Monthly Annual Percent Change and Resulting Flow Duration Curves

Figure 4.23 presents a box & whisker plot of expected annual monthly percent changes in flows between the historic and current maximum daily City of Punta Gorda withdrawals. The figure clearly demonstrates that as expected, the largest percent changes in flow due to withdrawals can be expected to occur during those spring months typically characterized by low flow conditions. Conversely, the summer wet-season months have a far lower frequency of withdrawals that appreciably reduce freshwater inflows to the downstream estuarine system. The relative influences of the 2007 permitted increase in maximum average daily withdrawals are also evident in comparison to the City's history of actual withdrawals. Differences in flows between the baseline condition and the withdrawal scenarios are further evident in comparing the flow duration curves presented in **Figures 4.24a** and **4.24b**. These graphics indicate that historically, withdrawals have noticeably only influenced approximately the lowest 20 percent of flows, with the most appreciable changes confined to the lowest 10 percent of historic flows. Using the

current maximum daily permitted withdrawals over the historic period, withdrawals noticeably influence approximately the lowest 40 percent of flows, with the most appreciable changes occurring within the lowest 20 percent of flows.

4.5 Influences of Flow on Selected Water Quality Characteristics

The following series of graphical analyses use 1991-2009 fixed station Shell Creek HBMP data to present and summarize the direct influences that Shell Creek freshwater inflows have on selected key water quality parameters in the tidal reaches of Shell Creek downstream of the dam.

4.5.1 Surface and Bottom Salinity

The graphical analyses summarized in Table 4.3a indicate the relationships between Shell Creek flow and both sub-surface and near-bottom salinity at nine selected locations along the Shell Creek HBMP monitoring transect (see **Map 2.1** and **2.2**).

Table 4.3a
Surface and Bottom Salinities Relative to Shell Creek Flows

Station	Shell Creek River Kilometer (relative to its confluence with the Peace River)	Same-Day Shell Creek Flow		Seven-Day Average Shell Creek Flow	
		Surface Salinity	Bottom Salinity	Surface Salinity	Bottom Salinity
11	9.9	Figure 4.25a	Figure 4.25b	Figure 4.34a	Figure 4.34b
4	8.74	Figure 4.26a	Figure 4.26b	Figure 4.35a	Figure 4.35b
5	6.72	Figure 4.27a	Figure 4.27b	Figure 4.36a	Figure 4.36b
6	4.61	Figure 4.28a	Figure 4.28b	Figure 4.37a	Figure 4.37b
7	2.35	Figure 4.29a	Figure 4.29b	Figure 4.38a	Figure 4.38b
16	1.26	Figure 4.30a	Figure 4.30b	Figure 4.39a	Figure 4.39b
17	0.43	Figure 4.31a	Figure 4.31b	Figure 4.40a	Figure 4.40b
9	-0.37	Figure 4.32a	Figure 4.32b	Figure 4.41a	Figure 4.41b
8	Lower Peace River	Figure 4.33a	Figure 4.33b	Figure 4.42a	Figure 4.42b

The following patterns and conclusions are evident based on reviewing these figures.

- Under very low or no-flow conditions, upstream salinities near the Dam can reach the range of 14-18 psu (practical salinity units) during extended drought conditions such as occurred between 1999-2002, and again during 2006-2008.

- Both sub-surface and near-bottom salinities decrease rapidly with increasing flow and reach and remain zero at and beyond some rate of freshwater inflow.

- The rate of the decline in salinity with increasing flow is less, and the flow needed to result in zero salinity increases moving downstream along the HBMP monitoring transect.

- The variation in the relationship between salinity and flow (the observed spread of data points) also increases moving downstream along the monitoring transect. This result reflects greater variability due to increased stream volume and the greater influences of wind and tide, as well as seasonal variations in the ratio of total flow to the estuary originating in both the Shell Creek and Peace River Watersheds.

- There are a number of higher salinity observations that do not seem to fit the normal salinity/flow relationships. These high salinity values probably result from unusually high tides, or very strong, extended periods of southerly winds that push higher salinity water upstream into the lower Peace River/Shell Creek estuarine system.

The time-series plots of sub-surface and near bottom salinities at these same nine HBMP sites along the Shell Creek monitoring transect are shown in Table 4.3b. These graphics were added to the report at the District's request following their review of the initial draft document. In order to maintain the original numbering system, these added figures were designated A1 through A9.

Table 4.3b
Surface and Bottom Salinities Over Time (1991-2009)

Station	Shell Creek River Kilometer (relative to its confluence with the Peace River)	Surface Salinity	Bottom Salinity
11	9.9	Figure 4.A1a	Figure 4.A1b
4	8.74	Figure 4.A2a	Figure 4.A2b
5	6.72	Figure 4.A3a	Figure 4.A3b
6	4.61	Figure 4.A4a	Figure 4.A4b
7	2.35	Figure 4.A5a	Figure 4.A5b
16	1.26	Figure 4.A6a	Figure 4.A6b
17	0.43	Figure 4.A7a	Figure 4.A7b
9	-0.37	Figure 4.A8a	Figure 4.A8b
8	Lower Peace River	Figure 4.A9a	Figure 4.A9b

These time-series plots of monthly salinity data collected along Shell Creek and in the lower Peace River show distinct patterns resulting from both seasonal and annual changes in freshwater flows (rainfall). As expected, the frequency and duration of freshwater habitat increases moving upstream toward the Dam.

4.5.2 Mean Water Column Salinity and Stratification

Mean water column salinity, and the relative degree of stratification (defined for this purpose as the difference between surface and bottom salinity) as functions of both stream flow and mean water column salinity were graphically analyzed at selected locations along the tidal HBMP monitoring transect (Table 4.4).

Table 4.4
Mean Water Colum Salinity and Stratification Relative to Shell Creek Flows

Station	Shell Creek River Kilometer (relative to its confluence with the Peace River)	Seven-Day Average Shell Creek Flow		Stratification Versus Mean Water Column Salinity
		Mean Water Column Salinity	Stratification	
11	9.9	Figure 4.43a	Figure 4.43b	Figure 4.43c
4	8.74	Figure 4.44a	Figure 4.44b	Figure 4.44c
5	6.72	Figure 4.45a	Figure 4.45b	Figure 4.45c
6	4.61	Figure 4.46a	Figure 4.46b	Figure 4.46c
7	2.35	Figure 4.47a	Figure 4.47b	Figure 4.47c
16	1.26	Figure 4.48a	Figure 4.48b	Figure 4.48c
17	0.43	Figure 4.49a	Figure 4.49b	Figure 4.49c
9	-0.37	Figure 4.50a	Figure 4.50b	Figure 4.50c
8	Lower Peace River	Figure 4.51a	Figure 4.51b	Figure 4.51c

- Plots of mean water column salinity versus seven-day average USGS gaged Shell Creek flow again show that salinity decreases rapidly with increasing flow, and reach and remain near zero at and beyond some rate of freshwater inflow. The rate of the decline in salinity with increasing flow is less, and the flow needed to result in zero salinity increases moving downstream.

- Upstream, nearest the Dam, salinity stratification increases slightly initially at very low flows. However, as flows increase observed differences between surface and bottom salinity begin to decline. Thus, when stratification is plotted versus mean water column salinity, the highest degree of salinity stratification occurs when mean water column salinities in the upstream reach of tidal Shell Creek are 5-10 psu.

- Moving downstream along the Shell Creek HBMP monitoring transect, instances of much higher degrees of stratification become more common and stratification occurs over a somewhat broader range of mean water column salinities.

4.5.3 Dissolved Oxygen (D.O.)

Graphical analyses are presented in Table 4.5 of the relationships between flow and both sub-surface and near bottom D.O. at eight selected creek locations and one lower Peace River background site along the Shell Creek HBMP monitoring transect. The data were seasonally divided into two groups: 1) December through February; and 2) April through September, to show the relative magnitude and interactions of seasonal differences in both flow and temperature on water column D.O. concentrations. Mean water column D.O. levels and differences between surface and bottom concentrations are also shown relative to seven-day average flow for both cooler and warmer months.

Table 4.5
Dissolved Oxygen Flow Relationships

Station	Shell Creek River Kilometer	Seven-Day Average Shell Creek Flow			
		Surface D.O.	Bottom D.O.	Mean Water Column D.O.	Difference Between Top and Bottom D.O.
11	9.9	Figure 4.52a	Figure 4.52b	Figure 4.52c	Figure 4.52d
4	8.74	Figure 4.53a	Figure 4.53b	Figure 4.53c	Figure 4.53d
5	6.72	Figure 4.54a	Figure 4.54b	Figure 4.54c	Figure 4.54d
6	4.61	Figure 4.55a	Figure 4.55b	Figure 4.55c	Figure 4.55d
7	2.35	Figure 4.56a	Figure 4.56b	Figure 4.56c	Figure 4.56d
16	1.26	Figure 4.57a	Figure 4.57b	Figure 4.57c	Figure 4.57d
17	0.43	Figure 4.58a	Figure 4.58b	Figure 4.58c	Figure 4.58d
9	-0.37	Figure 4.59a	Figure 4.59b	Figure 4.59c	Figure 4.59d
8	Lower Peace River	Figure 4.60a	Figure 4.60b	Figure 4.60c	Figure 4.60d

These figures indicate the flowing distinct patterns.

- As expected, bottom dissolved oxygen levels are generally lower than corresponding surface levels along the Shell Creek transect regardless of flow.
- This difference between surface and bottom D.O. levels becomes less distinct under very high flow conditions, regardless of season.
- Upstream, near the Hendrickson Dam, very low bottom D.O. levels occur under low flow conditions, regardless of season.
- These low bottom D.O. levels under low flows become increasingly less apparent moving downstream.
- Both surface and bottom D.O. levels generally decline with increasing flow during the summer. However, this pattern of declining D.O. levels during periods of increasing flow is not similarly apparent during cooler (December-February) months. These seasonal differences between D.O. levels and flow are an indication that higher flows during the summer are also related to higher water temperatures. Higher water temperatures increase respiration rates and decrease the ability of water to physically hold oxygen, both of which result in lower D.O. levels.

4.5.4 Chlorophyll *a* and Inorganic Nutrients

Relationships of mid-depth chlorophyll *a* levels, as well as inorganic nitrogen and phosphorus concentrations are graphically compared relative to seven-day average USGS gaged Shell Creek flow as presented in Table 4.6. Potential differences are indicated at the five HBMP fixed water

chemistry transect sampling sites and one lower Peace River background location for the following three seasonal groups.

1. The cool, drier months of December through February
2. The warm, dry months of March through May
3. The typically hot, wet months of June through November

Table 4.6
Water Quality Relative to Shell Creek Flows

Station	Shell Creek River Kilometer (relative to its confluence with the Peace River)	Seven-Day Average Shell Creek Flow		
		Mid-Depth Chlorophyll *a*	Mid-Depth Nitrite+Nitrate Nitrogen	Mid-Depth Inorganic Phosphorus
4	8.74	Figure 4.61	Figure 4.67	Figure 4.73
5	6.72	Figure 4.62	Figure 4.68	Figure 4.74
6	4.61	Figure 4.63	Figure 4.69	Figure 4.75
7	2.35	Figure 4.64	Figure 4.70	Figure 4.76
9	-0.37	Figure 4.65	Figure 4.71	Figure 4.77
8	Lower Peace River	Figure 4.66	Figure 4.72	Figure 4.78

- Seasonally, the highest chlorophyll *a* levels in tidal Shell Creek generally occur during the spring dry-season.

- The relationships between chlorophyll *a* and flow indicate that chlorophyll *a* levels generally decline with increasing freshwater inflows. This probably reflects the combined influences of increases in water color and decreases in residence time (wash-out). Similar relationships between chlorophyll *a* and flow have also been observed from lower Peace River HBMP data.

- Inorganic nitrite+nitrate nitrogen concentrations within the upper tidal reaches of Shell Creek increase as flows increase, plateau and then slightly decline at high flows as the rate of sheet flow across the watershed increases.

- Ortho-phosphorus concentrations at the sampling sites along the HBMP transect are shown by comparison to be relatively stable in relation to changes in freshwater inflows.

- Both inorganic nitrogen and phosphorus concentrations increase moving downstream, indicating the much higher concentrations of both nutrients coming downstream from the Peace River Watershed.

4.5.5 Cumulative Distribution Function (CDF) Analyses of Salinity, Dissolved Oxygen and Chlorophyll

Additional graphical analyses were prepared to further clarify the spatial differences in salinity, dissolved oxygen, chlorophyll *a*, and inorganic nitrogen and phosphorus that at occur along the tidal portion of the Shell Creek monitoring transect. Six Shell Creek HBMP sampling sites (numbers 11, 4, 5, 6, 7 and 9) spaced relatively equally along the monitoring transect were selected to investigate potential differences in salinity and dissolved oxygen. Only five of these sites were used in the analyses of chlorophyll *a*, nitrogen and phosphorus levels, since they are not measured at site #11.

- **Figure 4.79** – CDF curves of surface salinities at monitoring sites
- **Figure 4.80** – CDF curves of bottom salinities at monitoring sites
- **Figure 4.81** – CDF curves of surface D.O. at monitoring sites
- **Figure 4.82** – CDF curves of bottom D.O. at monitoring sites
- **Figure 4.83** – CDF curves of mid-depth chlorophyll at monitoring sites
- **Figure 4.84** – CDF curves of mid-depth nitrite+nitrate nitrogen at monitoring sites
- **Figure 4.85** – CDF curves of mid-depth ortho-phosphorus at monitoring sites

The presented CDF plots depict differences in the distributions of these parameters among the water quality monitoring locations. These figures clearly show the presences of strong spatial gradients in both salinity and ortho-phosphorus along the Shell Creek HBMP monitoring transect. Similar distinct spatial differences were not correspondingly observed for dissolved oxygen, chlorophyll *a* or inorganic nitrogen concentrations.

4.6 Development of Statistical Models

The primary objectives of the following described development of statistical models and subsequent analyses were undertaken in order to characterize the magnitude and duration of potential salinity changes downstream of the Hendrickson Dam. The primary objective was to determine what changes may have occurred due to historic Shell Creek Facility withdrawals, relative to those that might be expected under the increased of the maximum average daily withdrawal to 8.09 mgd under the City's 2007 twenty-year Water Use Permit Renewal.
Generally, estuarine species such as those that typically occur in the upper estuarine reaches of tidal systems such as Shell Creek can persist and flourish despite the physiological stresses associated with short-term and seasonal changes in salinity levels. Black needlerush (*Juncus roemerianus*), for example, occurs in areas where salinities often range seasonally between 0 and 30 psu. While the physiological hardiness of this species may be an extreme example, many estuarine fishes and benthic invertebrates are similarly tolerant of wide salinity ranges over short time scales.

However, despite such tolerances to wide ranges of salinity fluctuations, the observed distribution and abundance of most estuarine plants and animals still often tend to be segregated along measurable salinity gradients. Such tendencies have been interpreted as indicating that many estuarine species often have narrower "optimal" salinity ranges with respect to environmental physiology and competitive interactions. While black needlerush can tolerate

extreme salinity ranges, the actual spatial distribution of this species is generally limited to those portions of the estuary where long-term average salinities only range between 5 and 15 psu (practical salinity units) and suitable shoreline habitat exists.

In conjunction with the *2001 Shell Creek HBMP Summary Report*, a series of conductivity/flow models were developed using the 1991-2000 fixed station *in situ* water column profile data to estimate the potential salinity impacts of the City's then permitted 6.9 mgd maximum monthly average withdrawal. The results of the *2001 Shell Creek HBMP Summary Report* indicated that at flows of 25 cfs, the maximum salinity impacts along the tidal Shell Creek reach would be between 1.0 and 1.2 psu (practical salinity units). Two factors associated with the results of this previous salinity modeling effort should be clarified. First the models used a number of conservative assumptions and thus the actual impacts probably would be expected to be somewhat less. Importantly, the model fit at low flows (less than 25 cfs) was very poor and thus no estimates were made of potential salinity impacts at very low flows.

In August 2006 PBS&J completed the *Assessment of Potential Shell Creek Impacts Resulting from Changes in City of Punta Gorda* study or "Gap" Report. This study included developing an updated, more comprehensive series of statistical models using 1991-2004 fixed station, *in situ* Shell Creek HBMP water column profile data. The "Gap" report then used the developed statistical models to evaluate the potential impacts on salinity levels in the tidal reach of Shell Creek under conditions of further increasing withdrawals to 10, 12, 14 or 16 mgd, rather than the planned increase to approximately 8.0 mgd.

The new analyses presented in the current report updates the previous developed statistical models using 1991-2009 data to estimate the responses of sub-surface and near-bottom salinities to changes in freshwater inflows along the tidal Shell Creek HBMP monitoring transect. The resulting statistical models were then used to compare salinity changes between the no-withdrawal scenario and the previous daily average withdrawal of 5.38 mgd, as well as the recently permitted increase to a daily average withdrawal of 8.09 mgd.

The following briefly describes the methodology and assumptions that were applied in developing these updated statistical models.

- The graphical analyses of salinity/flow relationships presented above in Section 4.5.1 were used to evaluate and determine the appropriate range of flow data to be used in the development of both the sub-surface and near-bottom salinity models. The flows used in the development of the models were limited to the normal ranges of gaged freshwater inflows at each depth over which measured salinities were typically greater than zero.

- Same day flow, as well as a series of preceding average flow terms (3, 5, 10, 20, 30 and 60-day averages) were tested in developing each of the statistical models to establish background conditions and the "resident memory" associated with the characteristic of the longer-term salinity gradient within the Shell Creek system. In addition, long-term lags (30 and 60-day averages) of total gaged lower Peace River flow (Peace River at Arcadia + Horse Creek near Arcadia + Joshua Creek at Nocatee + Shell Creek near Punta Gorda) were also tested for potential inclusion in the final models.

- Based on a series of preliminary statistical analyses, the data from the eleven fixed HBMP salinity monitoring locations along the Shell Creek transect (Table 4.7) were subdivided for modeling into three segments (A-C) based on relative differences in flow, after which each of the three creek segments was then characterized by freshwater conditions. Thus, surface salinities were assumed to generally be near zero in Segment A when flows were greater than 120 cfs, and observations during higher flows were excluded from the models. However, when the resulting models were subsequently applied in assessing the potential impacts of the proposed withdrawal schedule, the complete daily record of all gaged flows was used, which included both high and low flow events. The Shell Creek HBMP monitoring sites closest to the Peace River were excluded since salinities at these locations are often predominately driven by freshwater inflows from the Peace River watershed.

Table 4.7
Approximate Shell Creek Flow when Salinity Approaches Zero (psu)

Station #	River Kilometer	Subsurface	Near Bottom	Segment Group
# 11	9.90	120 cfs	150 cfs	A
# 4	8.74	120 cfs	150 cfs	A
# 12	8.09	250 cfs	300 cfs	B
# 13	7.40	300 cfs	300 cfs	B
# 5	6.72	300 cfs	300 cfs	B
# 14	5.73	350 cfs	400 cfs	B
# 6	4.61	400 cfs	450 cfs	C
# 15	3.66	500 cfs	550 cfs	C
# 7	2.35	600 cfs	650 cfs	C

4.6.1 Statistical Models of Salinity Flow Relationships using HBMP Data

A series of summary statistics and modeling procedures were used to determine potential "best-fit" relationships between freshwater inflows and sub-surface and near bottom salinities within each of the three designated (A-C) creek segments.

- Simple linear regressions
- Correlation matrices
- The SAS RSREG procedure
- Stepwise regression
- General Multi-linear Model (GLM) regression using both log transformed and non-transform of variables to attain the best-fit for the tested terms.

The following methodology was applied in developing the resulting GLM models presented below in Table 4.9.

- As an initial step, potential interactions among variables were tested using a combination of both simple regressions and correlation matrices. Next, the SAS RSREG and Stepwise General Linear Model procedures were applied in the development of each statistical model to screen the potential significance of a number of possible applied linear, non-linear (squared and cubic), and interactive terms. Flow terms were then log transformed to account for the curvilinear response of salinity to increasing freshwater flow. Conversely, non-transformed variables were used in modeling those independent terms with more linear relationships.

- Using an iterative process, surface and bottom salinity models were developed using the fewest number of independent variables that were both significant at the 0.05 level and added appreciably (at least two percent) to the overall explained error of the model. Only a single long-term preceding average flow term was used in the models to eliminate increasing the model fit simply due to autocorrelation. 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).

Independent models using the same general form were developed for surface and bottom salinities within each of the three defined Shell Creek segments (Table 4.7) using the following generalized formula:

$$Log(Salinity) = \beta_{\alpha} + (\beta_1 x\ Log(Flow_1)) + (\beta_2 \times Log(Flow_2)) + (\beta_3 x(RiverKilometer))$$

Where:
β_{α} = specific intercept
β_1 = "short-terms" flow slopes (linear and/or non-linear)
β_2 = "long-terms" flow slopes (linear and/or non-linear)
β_3 = river kilometer specific slope

$Flow_1$ = daily or short term lagged flow
$Flow_2$ = longer lagged flow term

The relationships between the paired predicted modeled salinities and the actual observed salinities (relative fit), as well as the distribution of modeled residual errors with salinity are graphically presented in Table 4.8. Overall, the graphical plots of predicted versus observed salinities indicate that the developed statistical models are generally accurate in predicting salinity flow relationships (Table 4.9), accounting for approximately seventy percent of the observed variation in observed salinity within each transect segment.

Table 4.8
Model Fit and Residual Errors

Water Column Depth	Segment A (RK 8.74 to 9.90)		Segment B (RK 5.73 to 8.09)		Segment C (RK 2.35 to 4.61)	
	Model Fit	Residuals	Model Fit	Residuals	Model Fit	Residuals
Subsurface	Figure 4.86a	Figure 4.86b	Figure 4.88a	Figure 4.88b	Figure 4.90a	Figure 4.90b
Near Bottom	Figure 4.87a	Figure 4.87b	Figure 4.89a	Figure 4.89b	Figure 4.91a	Figure 4.91b

Table 4.9
Results of Statistical GLM Analyses by Group and Depth

Group/Depth	Intercept	River Kilometer	Log 3-Day* or Log 10-Day** Average Shell Creek Flow	Log 30-Day Average Lower River USGS Gaged Flow	RSquare
Segment A, Center = RK 9.32 (8.74 to 9.90 River Kilometers)					
Surface	18.8	-0.410	-0.550*	-1.788	0.71
Bottom	29.8	-0.687	-0.439**	-3.005	0.71
Segment B, Center = RK 6.91 (5.73 to 8.09 River Kilometers)					
Surface	19.8	-0.141	-0.760**	-1.626	0.72
Bottom	22.3	-0.148	-0.671**	-2.356	0.71
Segment C, Center = RK 3.54 (2.35 to 4.61 River Kilometers)					
Surface	31.3	-1.047	-0.630**	-3.056	0.69
Bottom	34.6	-1.291	-0.520**	-3.407	0.68

* Log 3-day average Shell Creek flow used in the model
** Log 3-day average Shell Creek flow used in the model

However, a review of the presented information indicates that there are a number of observations within each of the three defined creek segments when the models noticeably under predict unusual higher salinities during periods of relatively higher flows. These instances of unusually high salinities when compared to the corresponding rates of freshwater inflow probably reflect instances of seasonally very high tides or unusually strong sustained south winds pushing higher salinity water from upper Charlotte Harbor into the lower Peace River and tidal portions of Shell Creek.

4.6.2 Salinity Flow Relationships using District/USGS Continuous Recorder Data

In conjunction with its work on the Shell Creek MFL, the District contracted with USGS to install a continuous recorder within the tidal portion of Shell Creek downstream of the Dam (**Map 4.1**) at approximately RK 4.6 (see **Map 2.1**) This recorder collected 15-minute sub-surface (1.7 feet) and near-bottom (1 foot above) temperature and conductivity measurements as well as variations in tidal gage height between March 1997 and October 2005. The relative

statistical distributions of the recorded 15-minute sub-surface and near-bottom salinities over the nine year time interval are summarized in Table 4.10. Although relatively high salinities (10-30 psu) were recorded during the seasonally drier periods each year, median salinities were generally less than 1.0 psu, except during the extended drought conditions that characterized southwest Florida rainfall patterns between 1999 and 2001.

Table 4.10
Metrics Characterizing Annual Variability in Salinity at RK 4.6

Annual Salinity	Percentiles						
	Min.	P10	P25	P50 Median	P75	P90	Max.
1997* surface	0.1	0.2	0.2	0.4	1.2	5.6	16.5
1997* bottom	0.1	0.2	0.2	0.4	1.3	6.1	16.3
1998 surface	0.1	0.2	0.2	0.3	0.9	2.4	10.4
1998 bottom	0.1	0.2	0.2	0.3	0.8	2.3	10.6
1999 surface	0.1	0.2	0.2	2.1	6.2	9.8	19.2
1999 bottom	0.1	0.2	0.2	1.9	6.6	10.4	19.6
2000 surface	0.2	0.4	2.7	8.0	12.8	18.5	25.2
2000 bottom	0.2	0.4	2.9	8.6	13.6	19.7	30.4
2001 surface	0.1	0.3	4.2	5.6	11.8	16.0	24.7
2001 bottom	0.1	0.3	0.4	6.0	12.4	16.1	24.7
2002 surface	0.1	0.2	0.2	1.0	6.0	9.4	17.9
2002 bottom	0.1	0.2	0.2	1.0	6.4	10.1	18.3
2003 surface	0.1	0.2	0.3	0.5	1.5	3.5	12.7
2003 bottom	0.1	0.2	0.3	0.5	1.5	3.6	12.6
2004 surface	0.1	0.2	0.3	0.6	3.0	6.2	16.5
2004 bottom	0.1	0.2	0.3	1.0	3.4	6.4	16.9
2005 surface*	0.0	0.1	0.2	0.4	1.1	3.5	15.0
2005 bottom*	0.1	0.1	0.2	0.4	1.3	4.0	15.8

* Note: The USGS continuous recorder data for 1997 covered only 10 complete months, and the 2005 data included only 9 complete months.

The first two of the following figures further depict both the seasonal and annual variability in recorded salinities at the USGS Shell Creek continuous recorder location, while the next two figures indicate the relationships between gaged Shell Creek freshwater inflows and average daily salinities.

- **Figure 4.92a** – Annual variability in daily average surface salinity at USGS continuous recorder site.

- **Figure 4.92b** – Annual variability in daily average bottom salinity at USGS continuous recorder site.

- **Figure 4.93a** – Daily average surface salinity at USGS continuous recorder site versus same day gaged Shell Creek flow.

- **Figure 4.93b** – Daily average bottom salinity at USGS continuous recorder site versus same day gaged Shell Creek flow.

The pair of figures of salinity versus flow clearly indicate the non-linear relationship between salinity concentrations and the rate of freshwater flow over the Dam. Both surface and bottom salinities become and remain low in this tidal reach of the creek when the rate of Shell Creek flow exceeds 500 cfs. The high degree of observed variability in this relationship at lower flows shows that other factors, such as wind, tides and the duration of flow may all be contributing factors influencing the salinity/flow relationship.

Statistical models, similar to those presented above for surface and bottom salinities using the Shell Creek HBMP data, were developed using average hourly values of the 15-minute salinity and gage height data collected at the USGS continuous recorder site, as well as short and longer lags in freshwater inflows for both Shell Creek and the combined gaged flow to the lower Peace River/upper Charlotte Harbor estuarine system (Peace River at Arcadia, plus Horse, Joshua and Shell Creeks). The resulting terms for the best-fit statistical models are presented in Table 4.11.

Table 4.11
Results of Statistical GLM Analyses of USGS Continuous Recorder Data

USGS Continuous Recorder at RK 4.6	Intercept	Gage Height	Log 3-DayAverage Shell Creek Flow	Log 30-Day Average Lower River USGS Gaged Flow	RSquare
Surface Salinity	10.2	1.143	-0.627	-2.232	0.76
Bottom Salinity	9.9	1.302	-0.686	-2.341	0.78

As indicated, a fairly simple model using only the following three terms can be used to account for approximately 75 percent of the observed hourly, long-term (1997-2005) annual and seasonal variability in both sub-surface and near-bottom salinities at this location (RK 4.6) in the tidal portion of Shell Creek.

- **Gage Height** – This parameter measures the combined influences of tide stage, north and south winds blowing water either out of or up into the lower river, and flow. The influences of flow on gage height in the model are expected to be small, since the model was developed using only instances when Shell Creek flows were less than 600 cfs (when salinities might be expected to be greater than zero).

- **Log of Average 3-day Shell Creek Flow** – This non-linear term accounts for short-term variability in Shell Creek gaged flows over the Dam. The application of such a term in the model is important since the Shell Creek watershed often characteristically produces high levels of flow over relatively short durations.

- **Log of 30-Day Average Lower River USGS Gaged Flow** – This second non-linear flow term accounts for the salinity conditions in the lower Peace River/Shell Creek estuarine system, or preceding "resident memory" by using the combined USGS gaged freshwater inflows to the lower Peace River.

4.6.3 Predicted Changes in Salinity Due to Shell Creek Facility Withdrawals

The statistical models developed for each of the three HBMP tidal Shell Creek transect segments (Section 4.6.1) and for the USGS continuous recorder location (Section 4.6.2) were next applied toward answering the basic question, "What would be the predicted magnitude and relative frequency of the expected spatial and temporal increases in surface and near-bottom salinities in the tidal reaches of Shell Creek due to both recent past and existing permitted City of Punta Gorda withdrawals?" The following series of procedures were used in answering this question.

- The previously described "synthetic" baseline flow record developed applying the methods used in the District draft Shell Creek MFL report was used to estimate flows at the Hendrickson Dam corrected for City of Punta Gorda withdrawals both under flow and certain no-flow conditions.

- This "un-impacted" flow record and the equation coefficients presented above in Tables 4.9 and 4.11 were used to predict sub-surface and near bottom salinities under a no-withdrawal scenario within the center of each of the three tidal Shell Creek transect segments (Table 4.7) and at the USGS continuous recorder site.

- The statistical models were also used to predict daily average corresponding salinities under two alternative withdrawal scenarios. Under the first, the daily un-impacted flows were reduced by 5.38 mgd, which was the City of Punta Gorda's permitted rate of daily average withdrawals for the 10-year period between August 1997 and August 2007. The second withdrawal scenario used the current 20-year permitted average daily rate of 8.09 mgd. (Under both withdrawal scenarios, any reductions that would have resulted in negative values were set to zero.)

- The relative predicted impacts of withdrawals on salinity were then calculated by determining the difference in predicted salinities between the un-impacted baseline condition and each of the withdrawal scenarios.

- The method used to predict differences in salinities at the USGS recorder site differed only in that hourly values were calculated using average hourly gage height in addition to average daily flows and withdrawals.

- Flows over the past thirty years (1980-2009) were used as the reference period in analyzing the expected range and frequency of salinity changes due to withdrawals expected using the Shell Creek HBMP statistical models (Table 4.9).

- Since the models at the USGS continuous recorder site (Table 4.11) included gage height as a required parameter, the analyses at this location was limited to the 1997-2005 time interval.

The resulting predicted changes in salinities due to the alternative withdrawal scenarios (relative to the theoretical un-impacted, no-withdrawal condition) were graphically summarized by plotting the resulting Cumulative Distribution Functions (CDF). A CDF depicts the probability that a measured variable (in this case a predicted change in salinity) has a value less than or equal to x, as expressed by the following equations.

$$F(x) = \Pr(X < x) = \alpha$$

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

Where *F(x)* is the estimated accumulated probability of the integrated change in the continuous predicted change in salinity under each of the alternative tested withdrawal scenarios.

Table 4.12
Cumulative Distribution Functions (CDF) of Predicted Salinity Increases Due to Shell Creek Facility Withdrawals

Water Column Depth	HBMP Monitoring Transect			USGS Continuous Recorder (RK 4.6)
	Segment A (RK 8.74 to 9.90)	Segment B (RK 5.73 to 8.09)	Segment C (RK 2.35 to 4.61)	
Sub-Surface	Figure 4.94a	Figure 4.95a	Figure 4.96a	Figure 4.97a
Near-Bottom	Figure 4.94b	Figure 4.95b	Figure 4.96b	Figure 4.97b

The results of these analyses summarized in Table 4.12 depict a number of patterns, which support the following conclusions regarding the potential salinity impacts of both the recent past and current City of Punta Gorda's District permitted withdrawals.

4.6.3.1 Segment A, River Kilometers 8.74 to 9.90 (Center = RK 9.32)

- **Figure 4.94a** shows the expected frequency of predicted differences (relative to the no-withdrawal scenario) in surface salinities in tidal Shell Creek Segment A resulting from recent and current permitted daily average rates of withdrawals. In this upstream segment below the Dam, surface salinities are predominantly characterized by freshwater conditions at flows above 120 cfs. Thus, during approximately 35 percent of the time when there are either no-flow or moderate to high flows, surface salinities in this reach of the creek are not affected by City of Punta Facility withdrawals. Conversely, during approximately 45 percent of the time, when flows are low, the model results indicate that withdrawals can be expected to result in increases in surface salinities between 0.7 and 1.6 psu. Finally, during the 5 percent of the time when flows are somewhat below the rate of flow when this reach of the creek becomes fresh, withdrawal can be expected to result in salinity increases between 0.1 and 0.7 psu. The expected difference due to the

recent increase in the average daily rate of permitted withdrawal from 5.38 to 8.09 mgd is expected to result in no increase in salinity under approximately 45 percent of flows and less than 0.2 psu during the remainder.

- The frequency of differences in near-bottom salinities in Segment A resulting from withdrawals (**Figure 4.94b**) was predicted to be very similar to those observed for surface salinities.

4.6.3.2 Segment B, River Kilometers 5.73 to 8.09 (Center = RK 6.91)

- **Figure 4.95a** depicts the frequency distribution of the predicted differences in surface salinities in Segment B of tidal Shell Creek under both recent and current permitted rates of average daily withdrawals. Surface salinities become predominantely fresh in this tidal segment only when flows exceed 350 cfs. The modeled results suggest that there is only approximately 10 percent of the time, either under no-flow or higher flows, that surface salinities in this reach of the creek are not affected by City of Punta Gorda Facility withdrawals. The results further indicate that the expected increase in surface salinities due to withdrawals is expected to be less than 0.5 psu approximately 90 percent of the time, and that the difference due to the increased permitted rate from 5.38 to 8.09 mgd is predicted to be small.

- The modeled differences in near-bottom salinities due to Facility withdrawals (**Figure 4.95b**) are predicted to be less than at the surface.

4.6.3.3 Segment C, River Kilometers 2.35 to 4.61 (Center = RK 3.54)

- **Figure 4.96a** shows the predicted frequency distribution of modeled differences in surface salinities in Segment C under both the City of Punta Gorda's recent past and current permitted rates of average daily withdrawals. Surface salinities become predominantly fresh in this tidal segment when flows exceed 600 cfs. Similar to the results observed for Segment B, the modeled results for Segment C show the expected increase in surface salinities due to withdrawals to be less than 0.5 psu approximately 90 percent of the time, and that differences in salinity due to the increased average daily permitted rate from 5.38 to 8.09 mgd are predicted to be small in comparison to the observed natural short- and long-term variability (see Tables 4.3 and 4.4 above).

- Modeled differences in near-bottom salinities (**Figure 4.96b)** due to City of Punta Gorda Facility withdrawals are predicted to be slightly less than at the surface.

4.6.3.4 USGS Continuous Recorder (RK 4.6)

Located at RK 4.6 the USGS recorder site was established approximately at the upstream boundary of HBMP Segment C (see Table 4.7).

- **Figure 4.97a** shows the expected frequency of predicted differences (relative to the no-withdrawal scenario) in surface salinities between the recent past and current withdrawal

scenarios. Surface salinities were observed to be predominantly characterized by freshwater conditions when flows exceeded 500 cfs. The plot of the cumulative frequency distribution of the predicted changes indicated that during approximately 35 percent of the time surface salinities in this reach of the creek were not affected by Facility withdrawals. The CDF plot also indicates that approximately 60 percent of the time withdrawals can be expected to result in increases in surface salinities between 0.7 and 1.4 psu. The expected difference due to the recent increase in the average daily rate of permitted withdrawal from 5.38 to 8.09 mgd is expected to result in no increase in salinity under approximately 45 percent of flows and less than 0.2 psu during the remainder.

- The CDF plot of predicted differences in near-bottom salinities (**Figure 4.97b**) using the model derived from the USGS continuous recorder data was generally similar to that observed for surface salinities.

A comparison of **Figure 4.96a** and **Figure 4.97a** indicates that while the general range of salinity changes predicted was similar between the model developed using continuous recorder data and that predicted from the HBMP data, there were marked differences in the predicted distributions of these changes. This is not totally unexpected since the predicted changes in salinities due to Facility withdrawals based on modeled USGS data and those derived from the HBMP data can be anticipated to different due to the combined influences of a number of factors.

1. The underlying HBMP model data were collected monthly without accounting for tide, while the USGS models were based on hourly averages that included gage height (a proxy for the combined influences of both tide and wind).

2. The predicted salinity changes from the HBMP models were calculated as daily predicted values, while the predicted salinity changes (and frequency) at the USGS site were calculated using hourly gage heights, or 24 predicted values per day.

3. The frequency distributions of the predicted differences in salinity between the two withdrawal scenarios (CDF plots) were further based on different yearly time intervals. The models for the three segments of tidal Shell Creek were run over the last 30-year (1980-2009) time interval, while the timeframe for the USGS site was necessarily limited to the period of actual measured gage heights (1997-2005).

4. The period of analysis (1997-2005) applied to the model developed for the continuous recorder site was highly influenced by the extended severe drought conditions that occurred from 1999 through the spring of 2002, and should have resulted in higher frequencies of greater predicted changes in salinity resulting from withdrawals.

5.0 Summary and Recommendations

The purpose of this report is to provide the District with sufficient information to ensure that the Shell Creek/lower Peace River estuarine system has and will not be significantly adversely impacted as a result of the City of Punta Gorda's permitted freshwater withdrawals. This chapter provides a general overview and summarizes the primary results and conclusions presented in the preceding technical chapters. This summary chapter provides a brief overview and presents the summary conclusions relative to the following topics that are presented in far greater detail in the preceding chapters.

- The status and trends of hydrologic conditions within the Shell Creek Watershed.
- The status and trends of water quality characteristics measured upstream of the Hendrickson Dam.
- Temporal and spatial patterns in water quality differences between Prairie and Shell Creek systems.
- A comparison of the magnitude of predicted potential impacts associated with Shell Creek withdrawals relative to natural seasonal and annual variations in freshwater flows.

Recommendations are further offered regarding potential modifications that may be considered toward improving and refocusing particular HBMP study elements in the future.

5.1 Status and Trends of Hydrologic Conditions within the Shell Creek Watershed

The Shell/Prairie Creek Watershed is characterized by a summer wet-season that on average accounts for approximately 60 percent of total annual precipitation. During this summer wet-season, rainfall patterns are influenced by both frequent localized convective thunderstorm activity and periodic, widespread heavy rains associated with more infrequent tropical cyclonic events. In contrast, the remainder of the year is characterized by rainfall patterns predominantly associated with frontal systems moving down and across the Florida peninsula from the northwest. The four month wet-season extends from June through September, with June often having the highest monthly annual average rainfall. Conversely, November through January typically comprise the three driest months of the year. October characterizes the transition from the convection based summer wet-season rainfall pattern to the frontal dry-season rainfall pattern.

Seasonal influences of rainfall on watershed hydrology and surface flows are directly linked to the preceding hydrologic conditions. At the beginning of the summer wet-season, a large proportion of rainfall is typically incorporated into filling surface and groundwater storage following the extended spring dry-season. Conversely, later toward the end of the summer wet-season, soil moisture content is high, ground water levels are near the surface, wetlands and lakes

are full, and a large proportion of rainfall contributes directly to runoff. Under such conditions, relatively small increases in rainfall can result in substantial increases in surface flows.

While the described seasonal patterns in the annual hydrologic conditions are typical, there are wide degrees of both seasonal and annual variability in rainfall, often resulting in widely divergent annual flow patterns. Deviations from the normal pattern can span periods of months or up to several years. Intense El Niño/Southern Oscillation (ENSO) events, such as occurred in 1982/1983 and 1997/1998, result in atypical extended periods of heavy rainfall during the usually drier winter/spring months and dramatically alter the annual watershed hydroperiod. In both instances, these unusually wet El Niño periods were subsequently followed by La Niña events and associated periods of extended drought. Thus, while short-term extremes of high and low flows can influence the water budget in a watershed over periods of years, superimposed over these may be much larger cyclic patterns.

Daily U.S. Geological Survey (USGS) gaged flow over the Hendrickson Dam data during the available 1966-2009 period of record was used to develop comprehensive overviews of both annual and seasonal variability in Shell Creek freshwater inflows. A "synthetic" withdrawal corrected baseline flow record was also constructed using City withdrawals added back into the flow in order to assess the timing, frequency and magnitude of such withdrawals. A series of graphical and statistical analyses were conducted using actual USGS gaged data and the estimated Shell Creek flows (withdrawals added) in order to provide comprehensive overviews of both long-term and seasonal patterns of the temporal changes in Shell Creek flows to the lower Shell Creek/Peace River estuarine system.

These analyses resulted in the following series of observations and conclusions.

- Historically, freshwater flows over the Hendrickson Dam have varied widely both seasonally and yearly, with clear overall long-term patterns.

- The differing monthly low flow terms indicate patterns of increasing low flows from the mid-1960s through the mid-1990s, followed by a general decline. The observed recent decline during the past 15-years probably reflects the influences of the severity of both the recent 1999-2002 and 2006-2008 droughts.

- The severity of these recent droughts was most apparent during the typical spring dry months of March, April and May and generally less apparent during the typical summer wet-season months extending from June through September.

- Comparisons of the observed seasonal and long-term patterns using a wide variety of differing flow metrics showed little discernable difference between actual USGS gaged Shell Creek flows and the "synthetic" baseline withdrawal corrected flows.

- Analyses of comparisons between the 1966-2004 and 1995-2009 time intervals supported previous observations that the period since 1995 has been characterized by somewhat wetter overall and wet-season conditions than the previous 1966-1994 period. However,

actual spring dry-season flows have actually declined in recent years due to extremely dry conditions that characterized the droughts of 1999-2002 and 2006-2008.

- Statistical analyses presented in previous studies (*Shell Creek HBMP Year Five Comprehensive Summary Report*, PBS&J 2003; *Shell Creek Gap Report*, PBS&J 2007; *Peace River Cumulative Impact Study*, PBS&J 2007) have indicated that there have been long-term increases in baseflow in Shell/Prairie Creek watershed due to agricultural discharges during the typical dry winter/spring periods. However, the severity of the recent droughts reduced dry-season flows enough to obscure the influences of these augmented dry-season flows.

- None of the trend tests done for the various metrics in this report of flows over the 1966-2009 time interval indicated any statistically significant trends.

- Flow Frequency Analysis using log-Pearson Type III distributions after the method used by USGS was used to assess potential changes in flow-duration and lowest mean-discharges for various consecutive-day periods in order to determine potential impacts of Shell Creek withdrawals. The summary of the findings of these analyses indicated that the predicted changes in the distribution of flows due to withdrawals were expected to continue to be relatively small.

5.2 Temporal and Spatial Patterns of Water Quality Differences between Prairie and Shell Creek Systems

The primary objective of the following series of analyses was to determine the current status, and evaluate historical spatial/temporal patterns and trends in conductivity, major ions, nutrients and other water quality characteristics of the two major upstream freshwater sources (Shell and Prairie Creeks) and within the City's reservoir

5.2.1 Conductivity (Specific Conductance) and Chlorides

Marked seasonal increases in conductivity (or specific conductance) in the Shell/Prairie Creek Watershed have been shown to be due to the influences of water from highly mineralized aquifers on otherwise low-conductivity surface waters (PBS&J 2007, 2009). These increases in conductivity have been linked to agricultural off-site discharge of irrigation waters originating from the intermediate and Upper Floridan aquifers. In 2004, the District and the Florida Department of Environmental Protection (FDEP) completed the *Shell Creek and Prairie Creek Watersheds Management Plan* (SWFWMD 2004). The Plan's purpose was to provide "reasonable assurance" that the Shell Creek and Prairie Creek Watersheds would be restored and maintained to meet the water quality criteria set forth in Chapter 62-302.530(23), Florida Administrative Code (F.A.C.) for Class III waters. While conductivity itself is not a drinking water standard, it is directly related to the amount of Total Dissolved Solids (TDS) in the water. TDS is one of the U.S. Environmental Protection Agency's Secondary "Technical" Drinking Water Standards associated with increased hardness, deposits and taste. In order to meet the Secondary Drinking Water TDS standard of 500 mg/l, the City's drinking water process needs

the raw water supply from the Shell Creek reservoir to have a conductance less than 673 µmhos/cm.

Analyses were conducted of daily averaged conductivity measurements made at the four USGS on-going continuous recorder sites (Prairie Creek at Ft. Ogden, Prairie and Shell Creeks at C.R. 764, and Shell Creek near the Dam) to assess short- and long-term conductivity patterns, as well as the relationships between conductivity and flow.

- Conductivity measured at each of the four USGS recorder sites all show very similar distinct seasonal patterns.

- Conductivity levels were generally lower during the wetter 2004-2005 time interval when compared to the drought conditions that characterized watershed rainfall patterns from early 2006 through the spring of 2009.

- Except for a very brief period in the spring of 2009, conductivity levels at both Prairie Creek sites and in the reservoir were below the DEP Class III Standard of 1275 µmhos/cm.

- Daily average conductivity measured at Shell Creek at C.R. 764, by comparison, exceeded the Class III standard every year with the exception of 2005, which was a very wet year.

- The USGS conductivity recorder near the Dam indicated that between 2006 and 2009 measured conductivity levels met the 673 µmhos/cm criteria needed to assure finished potable TDS levels below the Secondary Drinking Water Standard of 500 mg/l only twenty-six percent of the time.

- At all four USGS monitoring sites measured conductivities logarithmically declined with increasing flow.

- However, within the reservoir relatively high levels of flow are needed to reduce conductivity levels below 673 µmhos/cm.

- Additional daily chloride levels measured by the City at the intake increased seasonally each year during the typically drier months. However, concentrations have not exceeded the 250 mg/l Secondary Drinking Water Standard since the 1999-2002 drought, and rapidly decline with increasing flows.

5.2.2 Long-Term Trends in Water Quality Characteristics and Changes with Flows

Time-series plots and Seasonal Kendall Tau Trend Tests of selected water quality characteristics were conducted of monthly data collected at the three Shell Creek HBMP monitoring sites located upstream of the Dam. These graphical analyses of monthly data generally show that the majority of the water quality parameters measured at these three locations have varied seasonally without any indication of distinct systematic increasing or decreasing changes over the historic

nineteen years (1991-2009) of monitoring. In comparison, the long-term patterns of change in other parameters such as conductivity and chloride show marked increases associated with both the 1999-2001 and 2006-2008 droughts. While most of the long-term patterns depicted in these graphical analyses simply indicate non-trending seasonal and annual variability between drier and wetter years, there are a number of water quality characteristics for which the data suggest there have been systematic, progressive changes over time. In some instances the patterns and trends observed in these analyses differ somewhat from those presented in previous Shell Creek Summary Reports (PBS&J 2003, 2006). Agriculture remains the dominant land use in both the Prairie and Shell Creek Watersheds (PBS&J 2007), and a number of the observed long-term patterns and changes in water quality characteristics at the HBMP monitoring sites over the 1991-2009 time interval have been influenced by the two extended, extreme periods of drought (1999-2002 and 2006-2008) that have occurred during the past decade.

The relative relationships between changes in freshwater flows and monthly measures of water quality parameters at the three upstream freshwater HBMP monitoring sites were further analyzed and depicted the following generalized patterns relative to seasonal and annual variations in freshwater flows.

- As expected, dissolved oxygen concentrations were found to show an inverse relationship with the rate of flow at both the Prairie Creek and reservoir sites. The summer wet-season not only results in high flows, but increases in water temperature increases both biological respiration and oxygen demand, as well as physically reduces the saturation level of dissolved gases in water.

- Dissolved constituents such as conductivity, chlorides, and alkalinity that reflect higher groundwater contributions all decline with increasing flows and greater surface water influences.

- Higher contributions of sheet and surface water flows are also positively related to increases in water quality characteristics such as total suspended solids, color and turbidity.

- Measures of total organic carbon, total Kjeldahl nitrogen and phosphorus concentrations are also positively correlated with increasing flows.

- Inorganic nitrogen and silica concentrations, by comparison, failed to show any such relationships to changes in flow.

- Increases in color that reduce the availability of light, and reduced residence time, result in the observed inverse patterns between higher flows and observed lower chlorophyll *a* levels.

5.2.3 Time-Series Analyses of Major Ions at District Watershed Monitoring Sites

The District's ambient monitoring program has a number of background and monitoring sites in and near the Prairie and Shell Creek Watersheds. Available water quality information was

analyzed to assess spatial and temporal patterns in ion concentrations, in order to reflect both natural seasonal and anthropogenic influences on water quality upstream of the City of Punta Gorda's reservoir.

- Conductivity, total dissolved solids, alkalinity, chloride and other ion concentrations at the District's Mossy Gully at S.R. 70 sampling site were observed to be notably higher over the 2006-2009 time interval than at the corresponding Cow Slough background station located further to the east along S.R. 70. The Mossy Gully site is located toward the northern end of the Prairie Creek Watershed, just south of an extensive area that was converted to intense agricultural use. Conductivity and chloride levels at the Mossy Gully at S.R. 70 sampling site were generally lower and sulfur concentrations were found to be higher than at the District's sampling locations that receive drainage from the Prairie Creek Watershed agricultural areas located further to the south (the Montgomery and Symons Canals). These observations probably reflect general differences in the quality of the agricultural groundwater between the two watershed areas used during the intense drought that characterized most of the period during which the available District data at these sites was collected.

- Comparisons of conductivity, total dissolved solids, alkalinity, chloride and other ion levels indicate relatively higher concentrations (poorer water quality) at the District's Symons Canal monitoring site relative to corresponding upstream measurements made at the Montgomery Canal which receives drainage from the more eastern portions of the Prairie Creek Watershed.

- The downstream Prairie Creek at C.R. 764 sampling site is located just upstream of where Prairie Creek flows into the City's reservoir. Comparisons of water quality characteristics between those taken at this downstream site and measurements made at the upstream Symons Canal location suggest that the additional watershed drainage between these two sites results in some dilution and reductions in measured levels of conductivity, total dissolved solids, chlorides and a number of other ions in the waters entering the reservoir.

- The District's background Emerald Isle Canal site is located near the headwaters of the Shell Creek Watershed. Corresponding measures taken at this background location and at the downstream Shell Creek at C.R. 764 site again show that agricultural discharges of irrigation groundwater between the two sites result in measured increases in conductivity, total dissolved solids, alkalinity, chlorides and other ion concentrations.

- Comparisons between the Shell Creek and Prairie Creek sampling sites at C.R. 764 indicate that the water quality at the Shell Creek site generally exhibits higher concentrations of dissolved ions and is thus of relatively poorer quality with regard to the City's water treatment standards.

- However, the USGS estimates that 24 percent of the reservoir's watershed is upstream of Shell Creek at C.R. 764, while Prairie Creek at C.R. 764 represents approximately 70 percent of the reservoir's watershed. As a result, water quality characteristics within the

City's reservoir are relatively more heavily influenced by the upstream land use practices and the quality and quantity of agricultural discharges in the Prairie Creek Watershed.

5.3 Influences of Withdrawals on Flow Characteristics and Downstream Water Quality

Analyses were conducted to assess the relative magnitude of changes in salinities due to both historic and current withdrawal scenarios. Changes in other water quality characteristics along the tidal reach of Shell Creek downstream of the Dam due to larger natural variations in flows were also analyzed.

5.3.1 Withdrawals and Changes in Flow Characteristics

A series of analyses were conducted to depict and contrast the relative magnitude and seasonal variation of changes in flows to the estuarine reach of Shell Creek below the Dam relative to both actual historic withdrawals and those that would have occurred if the current maximum daily average levels permitted under the new existing twenty-year Water Use Permit had been in place over the 1966-2009 time interval.

The following summarizes the observed patterns and primary conclusions drawn from time-series analyses of differing flow percentiles relative to the alternative withdrawal scenarios.

- The largest observed differences occurred between the no-withdrawal scenario and the maximum average daily withdrawals allowed under the newest permit.

- However, these differences become less and less apparent as flows increase, and would be expected to be relatively quite small at flows above the annual median.

- Overall, the observed differences between the no-withdrawal and withdrawal scenarios were found to be relatively small, when compared to the magnitude of the natural seasonal and annual variability.

- Seasonally, the relatively largest changes in flows due to withdrawals can be expected to occur during the typically drier months, under low flow conditions.

- The presented analyses indicated that actual historic withdrawals have predominantly influenced approximately only the lowest 20 percent of flows, with the most appreciable changes having been confined to the lowest 10 percent of historic flows. Under the current maximum daily average permitted withdrawal scenario, withdrawals would noticeably influence approximately the lowest 40 percent of flows, with the most appreciable changes occurring within the lowest 20 percent of flows.

5.3.2 Influences of Flow on Selected Water Quality Characteristics

Graphical analyses of the 1991-2009 data from the HBMP fixed station downstream of the Dam were used to assess the influences of freshwater inflows on selected key water quality parameters. The following patterns and conclusions were evident based on the presented analyses.

- Under very low or no-flow conditions, upstream salinities near the Dam can reach the range of 14-18 psu (practical salinity units) during extended drought conditions such as occurred between 1999-2002, and again during 2006-2008.

- Both sub-surface and near-bottom salinities decrease rapidly with increasing flow and reach and remain zero at and beyond some rate of freshwater inflow.

- The rate of the decline in salinity with increasing flow is less, and the flow needed to result in zero salinity increases moving downstream along the HBMP monitoring transect.

- The variation in the relationship between salinity and flow (the observed spread of data points) also increases moving downstream along the monitoring transect. This result reflects greater variability due to increased stream volume and the greater influences of wind and tide, as well as seasonal variations in the ratio of total flow to the estuary originating in both the Shell Creek and Peace River Watersheds.

- There are a number of higher salinity observations that do not seem to fix the normal salinity/flow relationships. These high salinity values probably result from unusually high tides, or very strong, extended periods of southerly winds that push higher salinity water upstream into the lower Peace River/Shell Creek estuarine system.

- Plots of mean water column salinity versus seven-day average USGS gaged Shell Creek flow again show that salinity decreases rapidly with increasing flow, and reach and remain near zero at and beyond some rate of freshwater inflow. The rate of the decline in salinity with increasing flow is less, and the flow needed to result in zero salinity increases moving downstream.

- Upstream, nearest the Dam, salinity stratification increases slightly initially at very low flows. However, as flows increase observed differences between surface and bottom salinity begin to decline. Thus, when stratification is plotted versus mean water column salinity, the highest degree of salinity stratification occurs when mean water column salinities in the upstream reach of tidal Shell Creek are 5-10 psu.

- Moving downstream along the Shell Creek HBMP monitoring transect, instances of much higher degrees of stratification become more common and stratification occurs over a somewhat broader range of mean water column salinities.

- Bottom dissolved oxygen (D.O.) levels were observed to generally be lower than corresponding surface levels along the Shell Creek transect regardless of flow.

- This difference between surface and bottom D.O. levels becomes less distinct under very high flow conditions, regardless of season.

- Upstream, near the Hendrickson Dam, very low bottom D.O. levels occur under low flow conditions, regardless of season.

- These low bottom D.O. levels under low flows become increasingly less apparent moving downstream.

- Both surface and bottom D.O. levels generally decline with increasing flow during the summer. However, this pattern of declining D.O. levels during periods of increasing flow is not similarly apparent during cooler (December-February) months. These seasonal differences between D.O. levels and flow are an indication that higher flows during the summer are also related to higher water temperatures. Higher water temperatures increase respiration rates and decrease the ability of water to physically hold oxygen, both of which result in lower D.O. levels.

- Seasonally, the highest chlorophyll *a* levels in tidal Shell Creek generally occur during the spring dry-season.

- The relationships between chlorophyll *a* and flow indicate that chlorophyll *a* levels generally decline with increasing freshwater inflows. This probably reflects the combined influences of increases in water color and decreases in residence time (wash-out). Similar relationships between chlorophyll *a* and flow have also been observed from lower Peace River HBMP data.

- Inorganic nitrite+nitrate nitrogen concentrations within the upper tidal reaches of Shell Creek increase as flows increase, plateau and then slightly decline at high flows as the rate of sheet flow across the watershed increases.

- Ortho-phosphorus concentrations at the sampling sites along the HBMP transect are shown by comparison to be relatively stable in relation to changes in freshwater inflows.

- Both inorganic nitrogen and phosphorus concentrations increase moving downstream, indicating the much higher concentrations of both nutrients coming downstream from the Peace River Watershed.

5.4 Development of Statistical Models

Statistical models were developed and subsequently used to characterize the magnitude and duration of potential salinity changes downstream of the Hendrickson Dam. The objective was to determine what changes may have occurred due to historic Shell Creek Facility withdrawals,

relative to those that might be expected under the increased of the maximum average daily withdrawal to 8.09 mgd under the City's 2007 twenty-year Water Use Permit Renewal. The statistical models developed for each of the three HBMP tidal Shell Creek transect segments (Section 4.6.1) and for the USGS continuous recorder location (Section 4.6.2) were applied toward answering the basic question, "What would be the predicted magnitude and relative frequency of the expected spatial and temporal increases in surface and near-bottom salinities in the tidal reaches of Shell Creek due to both recent past and existing permitted City of Punta Gorda withdrawals?" The following procedures and results were used in answering this question.

The relative predicted impacts of withdrawals on salinity were calculated by determining the difference in predicted salinities between the un-impacted baseline condition and historic and current withdrawal scenarios. The results of these analyses depict a number of patterns, which support the following observations regarding the potential salinity impacts of both the recent past and current City of Punta Gorda's District permitted withdrawals.

5.4.1 River Kilometers 8.74 to 9.90 (Center = RK 9.32)

In the upstream segment of tidal Shell Creek below the Dam, surface salinities are predominantly characterized by freshwater conditions at flows above 120 cfs. During approximately 35 percent of the time when there are either no-flow or moderate to high flows, the statistical models predict that surface and bottom salinities in this reach of the creek are not affected by City of Punta Gorda Facility withdrawals. Conversely, during approximately 45 percent of the time, when flows are low, the model results indicate that withdrawals can be expected to result in increases in surface salinities between 0.7 and 1.6 psu. Finally, during the 5 percent of the time when flows are somewhat below the rate of flow when this reach of the creek becomes fresh, withdrawal can be expected to result in salinity increases between 0.1 and 0.7 psu. The difference due to the recent increase in the average daily rate of permitted withdrawal from 5.38 to 8.09 mgd is expected to result in no increase in salinity under approximately 45 percent of flows and less than 0.2 psu during the remainder.

5.4.2 River Kilometers 5.73 to 8.09 (Center = RK 6.91)

Salinities in this middle reach of tidal Shell Creek become predominantly fresh in this segment only when flows exceed 350 cfs. The modeled results suggest that there is only approximately 10 percent of the time, either under no-flow or higher flows, that surface salinities in this reach of the creek are not affected by City of Punta Gorda Facility withdrawals. The model results further indicate that the expected increase in surface salinities due to withdrawals is expected to be less than 0.5 psu approximately 90 percent of the time, and that the difference due to the increased permitted rate from 5.38 to 8.09 mgd is predicted to be small.

5.4.3 River Kilometers 2.35 to 4.61 (Center = RK 3.54)

Salinities in the lower reach of Shell Creek near where it joins the lower Peace River become predominantly fresh in this tidal segment when flows exceed 600 cfs. The modeled results show the expected increase in surface salinities due to withdrawals to be less than 0.5 psu

approximately 90 percent of the time, and that differences in salinity due to the increased average daily permitted rate of withdrawals are predicted to be small in comparison to the observed natural short- and long-term variability.

5.4.4 USGS Continuous Recorder Site (RK 4.6)

Salinities at this site become characterized by freshwater conditions when flows exceeded 500 cfs. The developed statistical models indicated that during approximately 35 percent of the time salinities in this reach of the creek were predicted to not be affected by Facility withdrawals. The analyses also indicate that approximately 60 percent of the time withdrawals can be expected to result in increases in salinities between 0.7 and 1.4 psu. The expected difference due to the recent increase in the average daily rate of permitted withdrawal is expected to result in no increase in salinity under approximately 45 percent of flows and less than 0.2 psu during the remainder.

5.5 Potential Changes to the Shell Creek Monitoring Program

Other than some changes in field collection and water quality analytical methods, the Shell Creek HBMP has remained relatively unchanged since its inception in 1991. The water quality parameters analyzed under the City of Punta Gorda's Shell Creek HBMP were initially selected to match those being monitored by the older, ongoing lower Peace River/upper Charlotte Harbor monitoring program conducted by the Peace River Manasota Regional Water Supply Authority (Arthority). However, as part of the Authority's twenty-year permit renewal in 1996, an outside Scientific Review Panel was established to review the conclusions being drawn from the Peace River HBMP and make recommendations to the Authority and District regarding potential changes to improve the efficiency of monitoring.

Since that time, the Peace River Scientific Review Panel has made a number of recommendations that have sought to reduce the emphasis on background monitoring and increase the focus toward directly assessing the impacts of withdrawals and providing the Authority greater levels of information relative to upstream water quality. Correspondingly, the number of background water quality parameters being measured has been refocused and reduced.

It is recommended that a similar effort be made between City and District staff to use the existing nearly twenty years of Shell Creek HBMP data to potentially refocus the monitoring program while maintaining/reducing the existing level of effort. The following topics might initially be considered.

- Maintain the close monthly timing between the Shell Creek and Peace River HBMP programs to allow potential future analyses using data from both programs.

- Coordinate methods between the two monitoring programs in order to maintain/increase the ease of future analyses.

- Delete some of the background Shell Creek HBMP lower Peace River monitoring sites that are similar to those being monitored by the Authority.

- Assess the cost effectiveness of continuous recorders to provide greater levels of information towards directly assessing the potential magnitude of freshwater withdrawals.

- Reduce some of the water quality parameters being monitored downstream of the Dam to more closely match those currently being monitored by the Peace River HBMP.

- Assess whether the parameters being monitored above of the Dam are providing the City with sufficient data relative to seasonal changes in upstream water quality.

As future projected interconnections between water supplies are implemented, the need to focus and coordinate HBMP efforts will increase to protect water supplies and assure that sufficient information is provided that the Shell Creek/lower Peace River estuarine system has and will not be significantly adversely impacted as a result of permitted freshwater withdrawals.

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HBMP Report Tables

This section contains tables not included directly in the text for each section

- **Chapter 2 – Description of the Existing Monitoring Program**

Table 2.1
Descriptions of Sampling Site Locations

Station	Station Description
1	Prairie Creek at the CR 764 bridge crossing
2	Shell Creek at the CR 764 bridge crossing
3	Shell Creek Reservoir - off the dock that extends from Hendrickson Dam
4	Shell Creek at the confluence of the split channels and Myrtle Slough, approximately 3/4 mile downstream of Hendrickson Dam
5	Main Shell Creek channel at the US 17 crossing
6	Main Shell Creek channel approximately 1/2 mile upstream of railroad trestle
7	Shell Creek channel approximately 1/3 mile downstream of power line crossing
8	Peace River, upstream of Shell Creek confluence just off Shell Point
9	Shell Creek/Peace River (Marker 17) just upstream of its confluence with the Peace River Centerline
10	North channel of Shell Creek 200-300 feet downstream of Hendrickson Dam
11	South channel of Shell Creek 200-300 feet downstream of Hendrickson Dam
12	Shell Creek at power line crossing downstream of Station 4
13	Shell Creek 1/4 mile upstream of US 17 bridge crossing
14	Shell Creek at a channel split 1/4 mile downstream of Lazy Lagoon Mobile Home Park
15	Shell Creek at railroad trestle
16	Shell Creek channel 1/3 to 1/2 mile downstream from Station 7 and on a level with the northern end of Long Island
17	Shell Creek/Peace River just to the north of Palms and Pines Mobile Home Park
18	Peace River channel across from Harbour Heights area and upstream of Shell Creek confluence
19	Peace River channel (Marker 15) in the area of Coon Key downstream of its confluence with the Shell Creek Centerline

Table 2.2
Relative Spatial Relation Of Sampling Sites Along Shell Creek Transect (in River Kilometers)

Station Location	Latitude	Longitude	Distance (km) Downstream of Shell Creek Dam (Used In 1991-2001)	Distance Upstream From The Mouth of the Peace River (Based On 2001 Centerline and used since)
Station 3	N 26° 59.046'	W 81° 56.140'	0.00	10.0
Station 11	N 26° 59.087'	W 81° 56:178'	0.09	9.9
Station 4	N 26° 59.101'	W 81° 56.624'	1.12	8.74
Station 12	N 26° 59.063'	W 81° 56.972'	1.73	8.09
Station 13	N 26° 58.921'	W 81° 57.214'	2.35	7.4
Station 5	N 26° 58.781'	W 81° 57.515'	2.89	6.72
Station 14	N 26° 58.653'	W 81° 58.026'	3.69	5.73
Station 6	N 26° 58.318'	W 81° 58.219'	4.72	4.61
Station 15	N 26° 58.718'	W 81° 58.394'	5.69	3.66
Station 7	N 26° 58.807'	W 81° 59.051'	6.79	2.35
Station 16	N 26° 58.340'	W 81° 59.562'	7.48	1.26
Station 17	N 26° 58.053'	W 81° 59.582'	8.64	0.43
Station 9	N 26° 57.919'	W 81° 59.789'	9.89	-0.37
Station 19			10.69	-1.24
Station 1	N 26° 59.441'	W 81° 53.682'	NA	NA
Station 2	N 26° 58.501'	W 81° 53.251'	NA	NA
Station 8	N 26° 58.962'	W 81° 59.797'	NA	NA
Station 18	N 26° 59.274'	N 26° 59.274'	NA	NA
Note 1: Stations 1 & 2 are located on Prairie Creek and Shell Creek approximately 2 miles upstream of the reservoir.				
Note 2: Stations 8 & 18 are located along the Peace River, upstream of its confluence with Shell Creek				

Table 3.8

Lowest Average Flow (cfs)
for Indicated Recurrence Intervals (years)
(Estimated Shell Creek Flow Without Withdrawals)

Consecutive Days	Variable	2 Years	3 Years	5 Years	10 Years	25 Years
1	pu	3.4	0.7	0.2	0.0	0.0
1	pl	0.9	0.2	0.0	0.0	0.0
1	p_flow	1.8	0.4	0.1	0.0	0.0
3	pu	3.7	0.8	0.2	0.0	0.0
3	pl	1.0	0.2	0.0	0.0	0.0
3	p_flow	1.9	0.4	0.1	0.0	0.0
10	pu	6.5	1.4	0.3	0.1	0.0
10	pl	1.9	0.4	0.1	0.0	0.0
10	p_flow	3.5	0.8	0.2	0.0	0.0
30	pu	19.6	6.2	2.0	0.6	0.2
30	pl	7.7	2.4	0.7	0.2	0.0
30	p_flow	12.2	3.9	1.2	0.3	0.1
60	pu	38.6	21.7	12.5	6.9	3.8
60	pl	24.1	13.4	7.3	3.7	1.8
60	p_flow	30.5	17.2	9.7	5.1	2.7
90	pu	54.7	36.5	25.0	16.8	11.3
90	pl	39.3	25.9	17.1	10.7	6.7
90	p_flow	46.3	31.0	20.9	13.7	8.9
120	pu	75.7	53.0	38.1	27.1	19.5
120	pl	56.3	38.9	27.0	18.2	12.2
120	p_flow	65.3	45.7	32.4	22.6	15.8

PU = Predicted Upper Limit
PL = Predicted Lower Limit
P_FLOW = Predicted Flow

Table 3.9

Lowest Average Flow (cfs)
for Indicated Recurrence Intervals (years)
(USGS Gaged Shell Creek Flow)

Consecutive Days	Variable	2 Years	3 Years	5 Years	10 Years	25 Years
1	pu	1.2	0.2	0.1	0.0	0.0
1	pl	0.3	0.1	0.0	0.0	0.0
1	p_flow	0.6	0.1	0.0	0.0	0.0
3	pu	1.4	0.3	0.1	0.0	0.0
3	pl	0.4	0.1	0.0	0.0	0.0
3	p_flow	0.7	0.1	0.0	0.0	0.0
10	pu	3.3	0.7	0.2	0.0	0.0
10	pl	0.9	0.2	0.0	0.0	0.0
10	p_flow	1.8	0.4	0.1	0.0	0.0
30	pu	13.0	3.6	1.0	0.3	0.1
30	pl	4.6	1.2	0.3	0.1	0.0
30	p_flow	7.7	2.1	0.6	0.1	0.0
60	pu	32.2	15.6	7.8	3.7	1.7
60	pl	17.9	8.6	4.0	1.7	0.7
60	p_flow	23.9	11.7	5.7	2.6	1.1
90	pu	49.4	31.3	20.3	12.9	8.2
90	pl	34.0	21.2	13.2	7.8	4.5
90	p_flow	40.9	25.9	16.6	10.2	6.2
120	pu	70.4	47.8	33.4	23.0	16.0
120	pl	51.1	34.3	23.0	15.0	9.7
120	p_flow	59.9	40.7	28.0	18.9	12.8

PU = Predicted Upper Limit
PL = Predicted Lower Limit
P_FLOW = Predicted Flow

Table 3.10

Lowest Average Flow (cfs)
for Indicated Recurrence Intervals (years)
(Shell Creek Flow after current maximum permitted withdrawals)

Consecutive Days	Variable	2 Years	3 Years	5 Years	10 Years	25 Years
1	pu	0.3	0.1	0.0	0.0	0.0
1	pl	0.1	0.0	0.0	0.0	0.0
1	p_flow	0.1	0.0	0.0	0.0	0.0
3	pu	0.3	0.1	0.0	0.0	0.0
3	pl	0.1	0.0	0.0	0.0	0.0
3	p_flow	0.2	0.0	0.0	0.0	0.0
10	pu	0.6	0.1	0.0	0.0	0.0
10	pl	0.2	0.0	0.0	0.0	0.0
10	p_flow	0.3	0.1	0.0	0.0	0.0
30	pu	3.8	0.8	0.2	0.0	0.0
30	pl	1.1	0.2	0.0	0.0	0.0
30	p_flow	2.0	0.4	0.1	0.0	0.0
60	pu	17.8	5.4	1.7	0.5	0.1
60	pl	6.7	2.0	0.6	0.1	0.0
60	p_flow	10.9	3.3	1.0	0.3	0.1
90	pu	36.8	17.8	8.8	4.1	1.9
90	pl	20.4	9.7	4.4	1.8	0.7
90	p_flow	27.3	13.2	6.4	2.8	1.2
120	pu	56.8	34.2	21.2	12.8	7.8
120	pl	37.4	22.2	13.1	7.3	4.0
120	p_flow	46.1	27.7	16.9	9.9	5.8

PU = Predicted Upper Limit
PL = Predicted Lower Limit
P_FLOW = Predicted Flow

HBMP Report Figures

- **Chapter 3 – Status and Trends in the Shell Creek/Lower Peace River Estuary**
- **Chapter 4 – Influences of Withdrawals on Flow Characteristics**

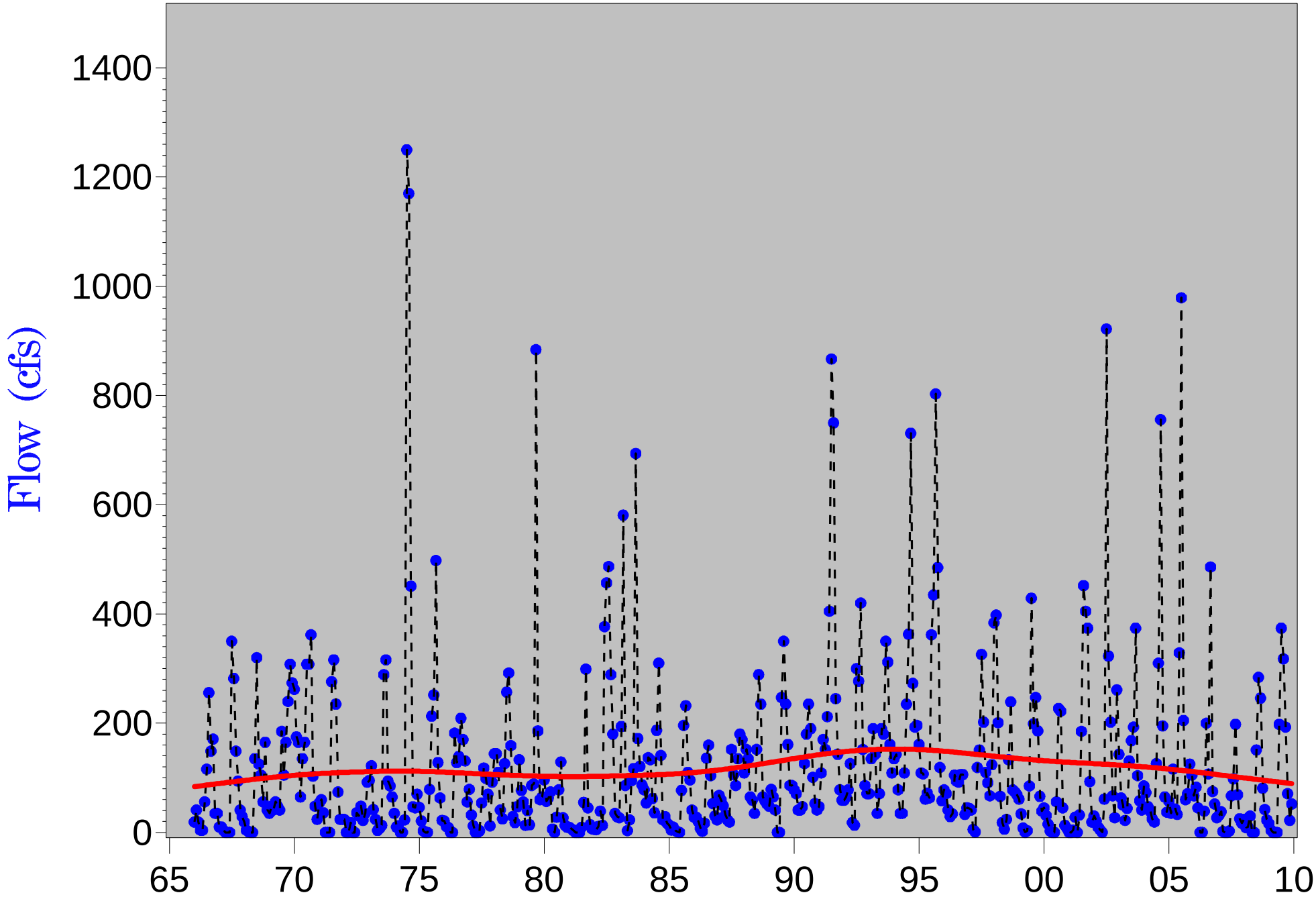


Figure 3.1a Monthly minimum long-term flow at the USGS Shell Creek gage (1965-2009)

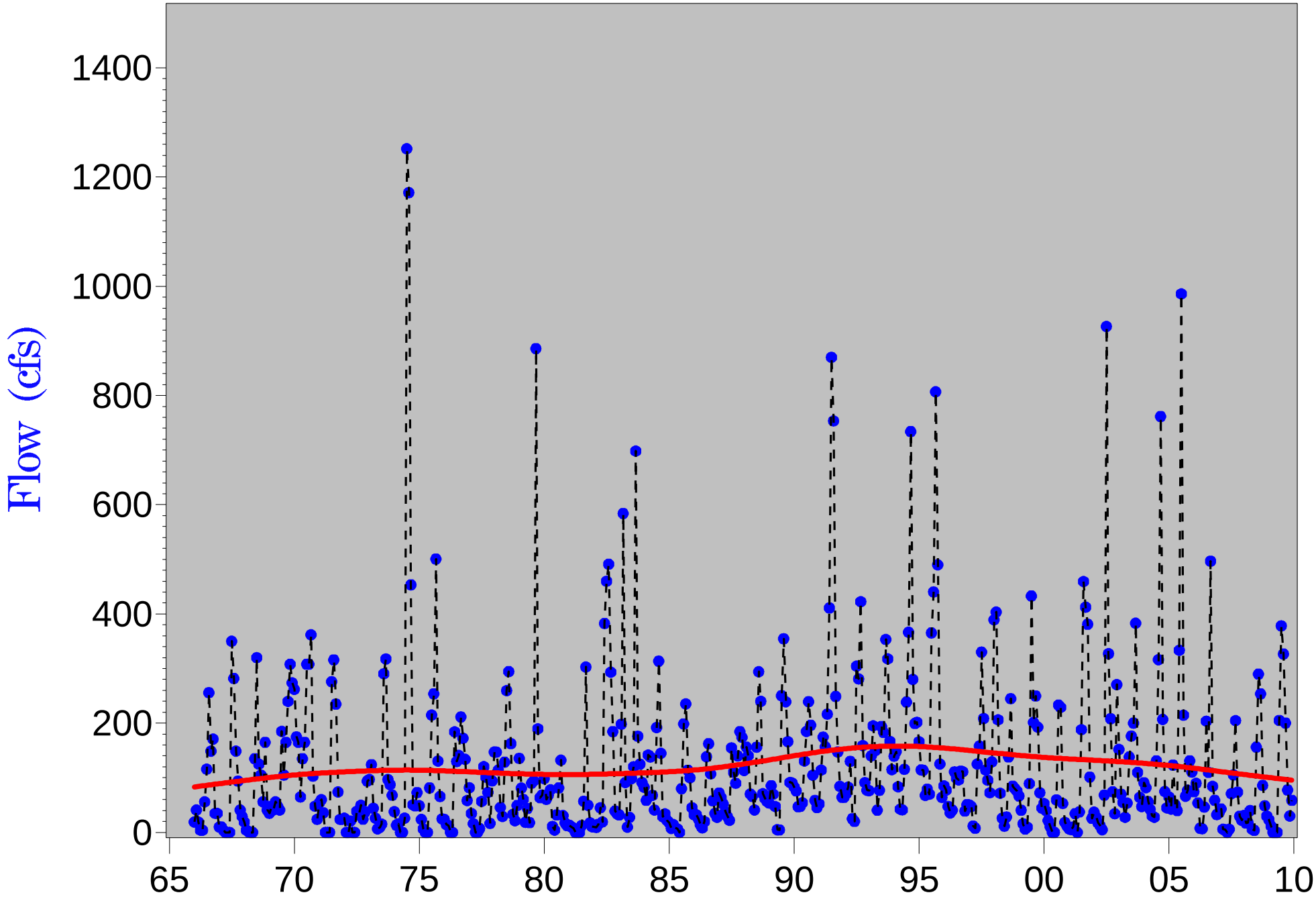


Figure 3.1b Estimated monthly minimum flow without Facility withdrawals (1965-2009)

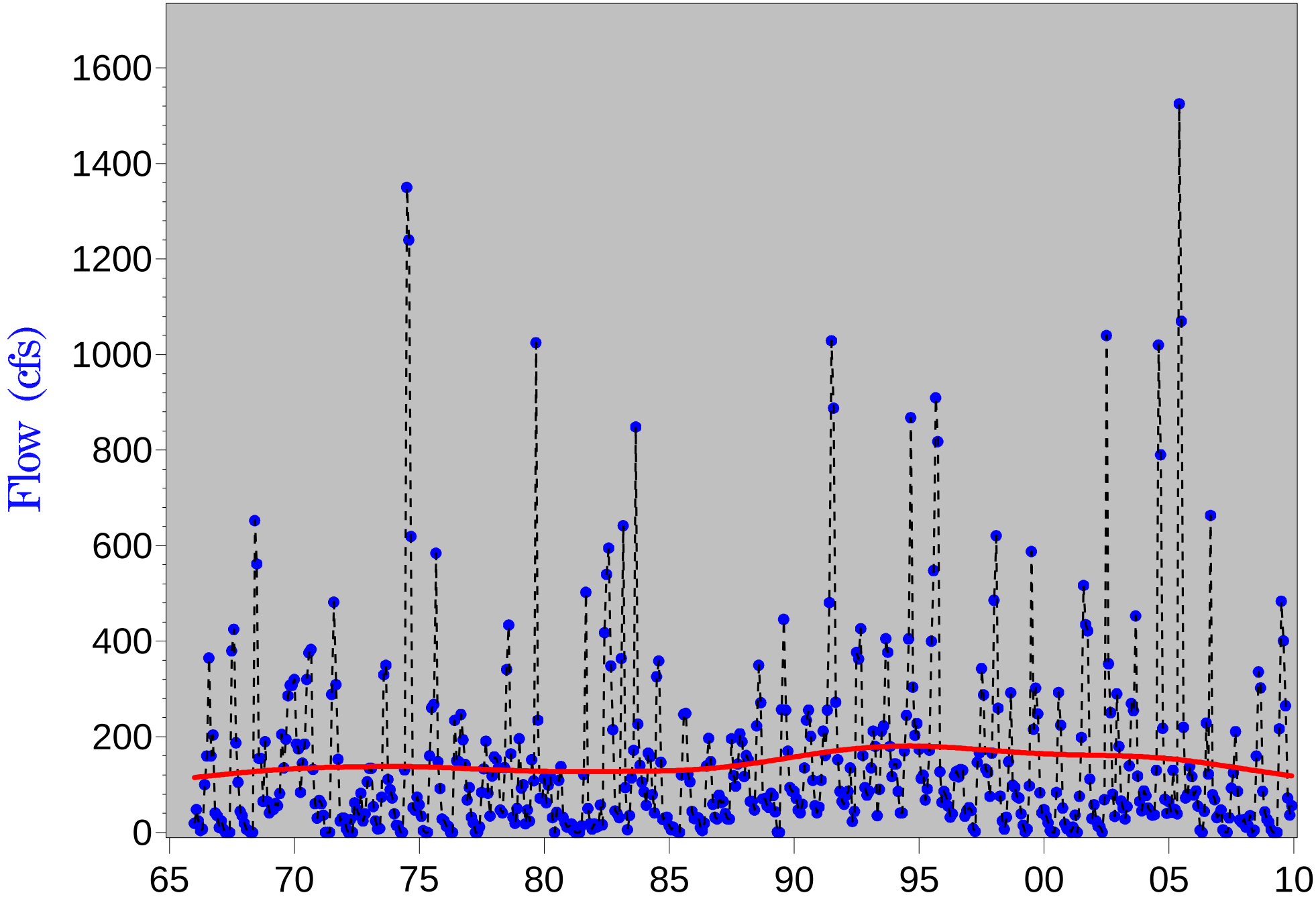


Figure 3.2a Monthly P10 long-term flow at the USGS Shell Creek gage (1965-2009)

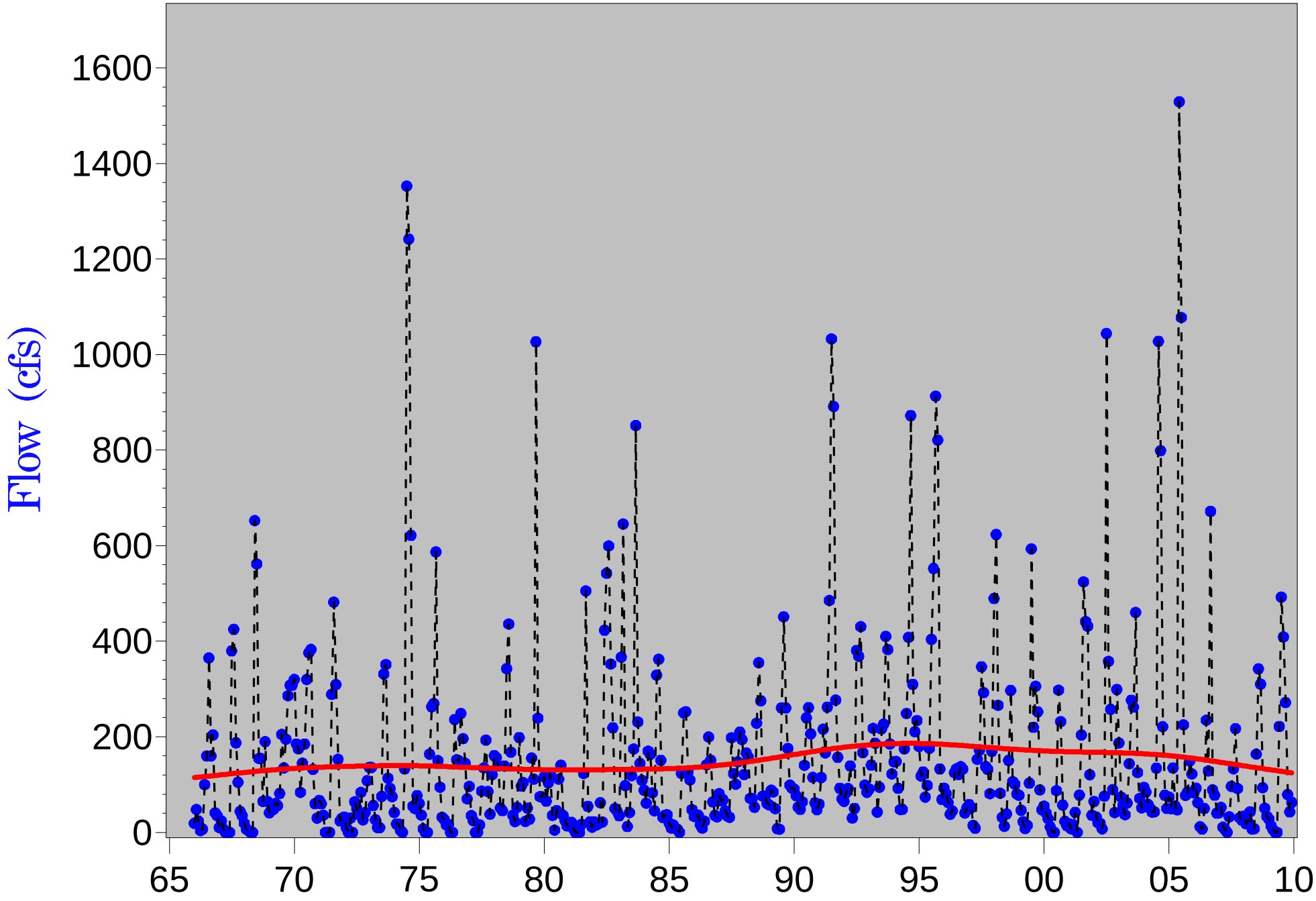
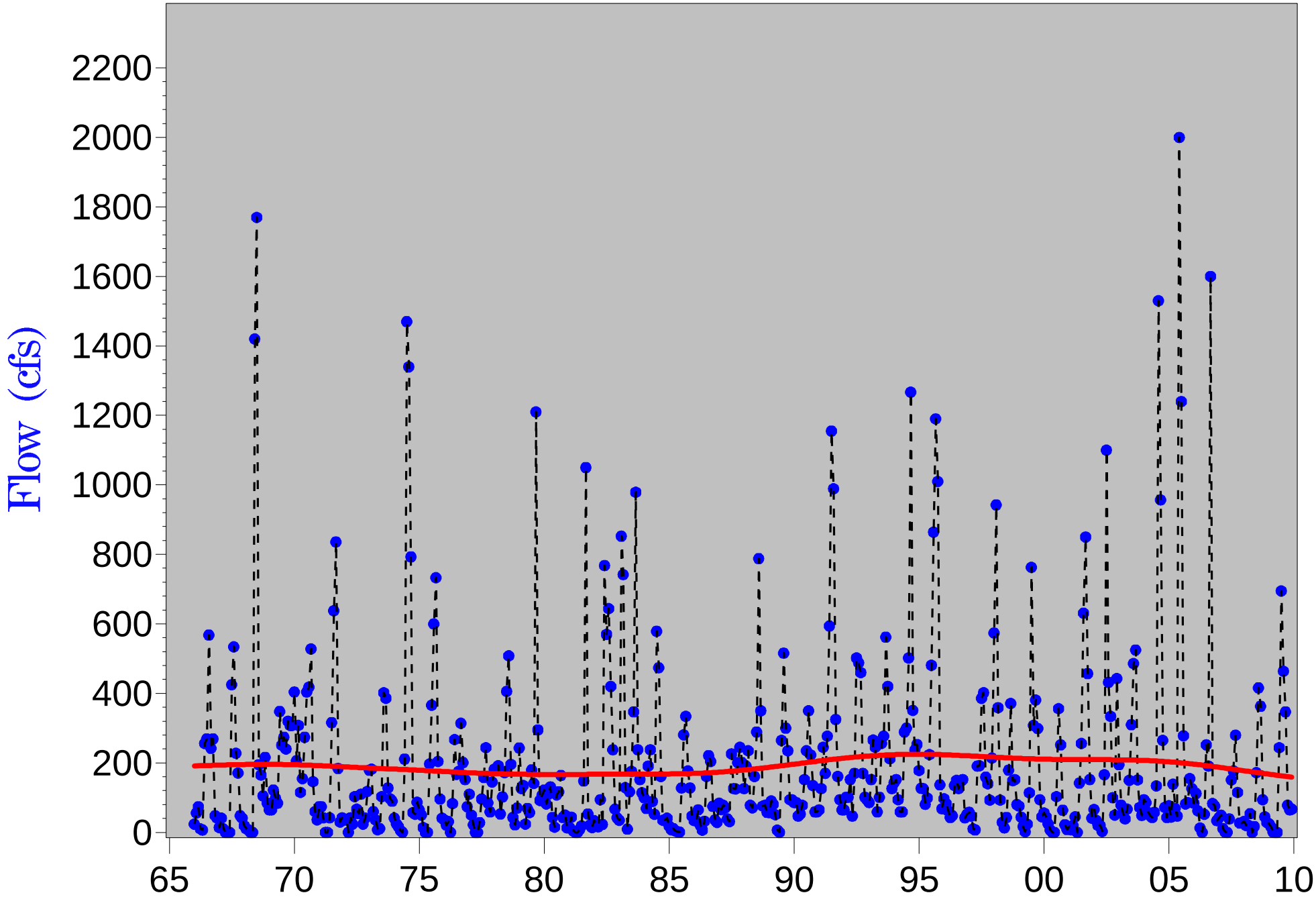
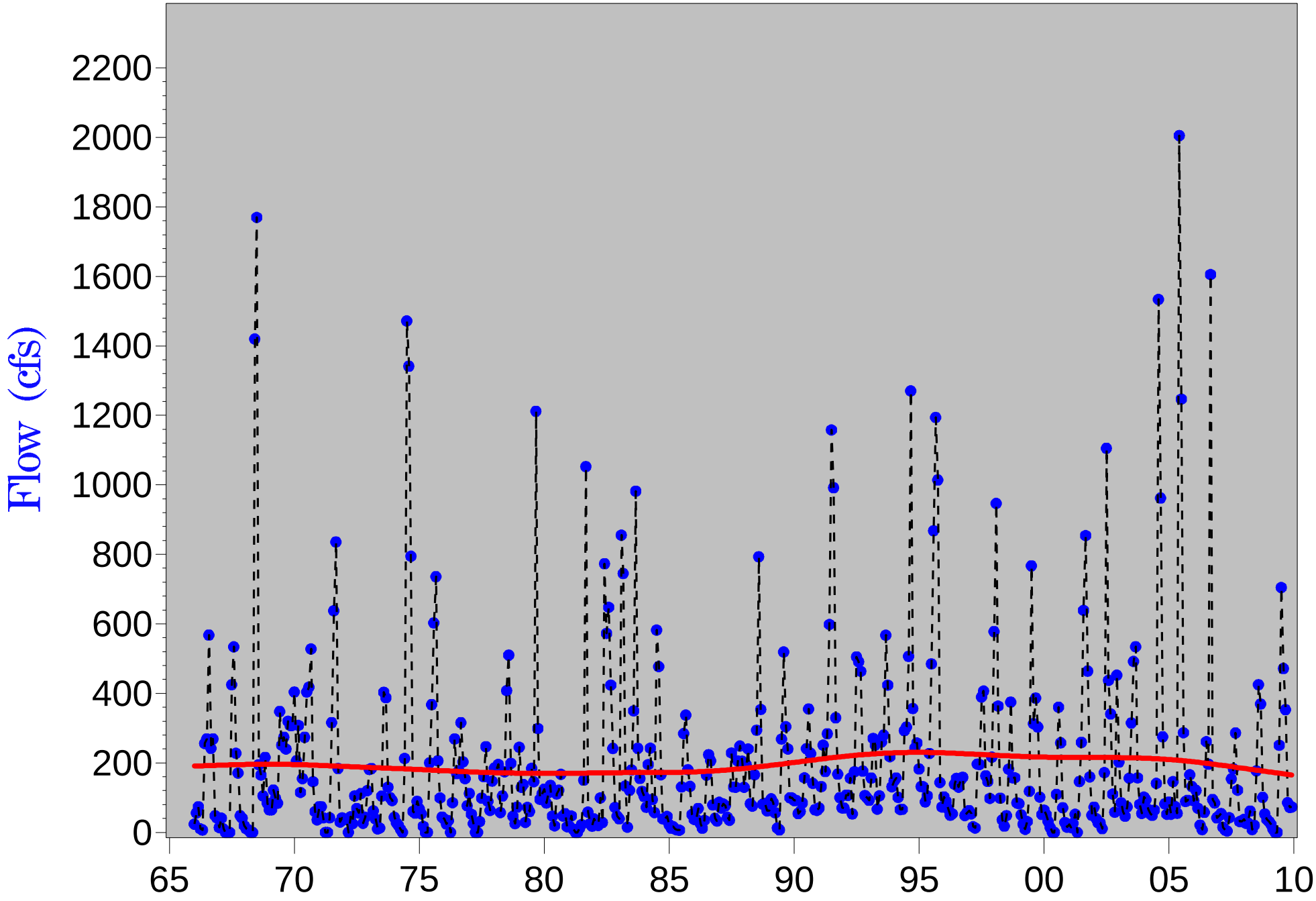


Figure 3.2b Estimated monthly P10 flow without Facility withdrawals (1965-2009)



. Figure 3.3a Monthly P25 long-term flow at the USGS Shell Creek gage (1965-2009)



. Figure 3.3b Estimated monthly P25 flow without Facility withdrawals (1965-2009)

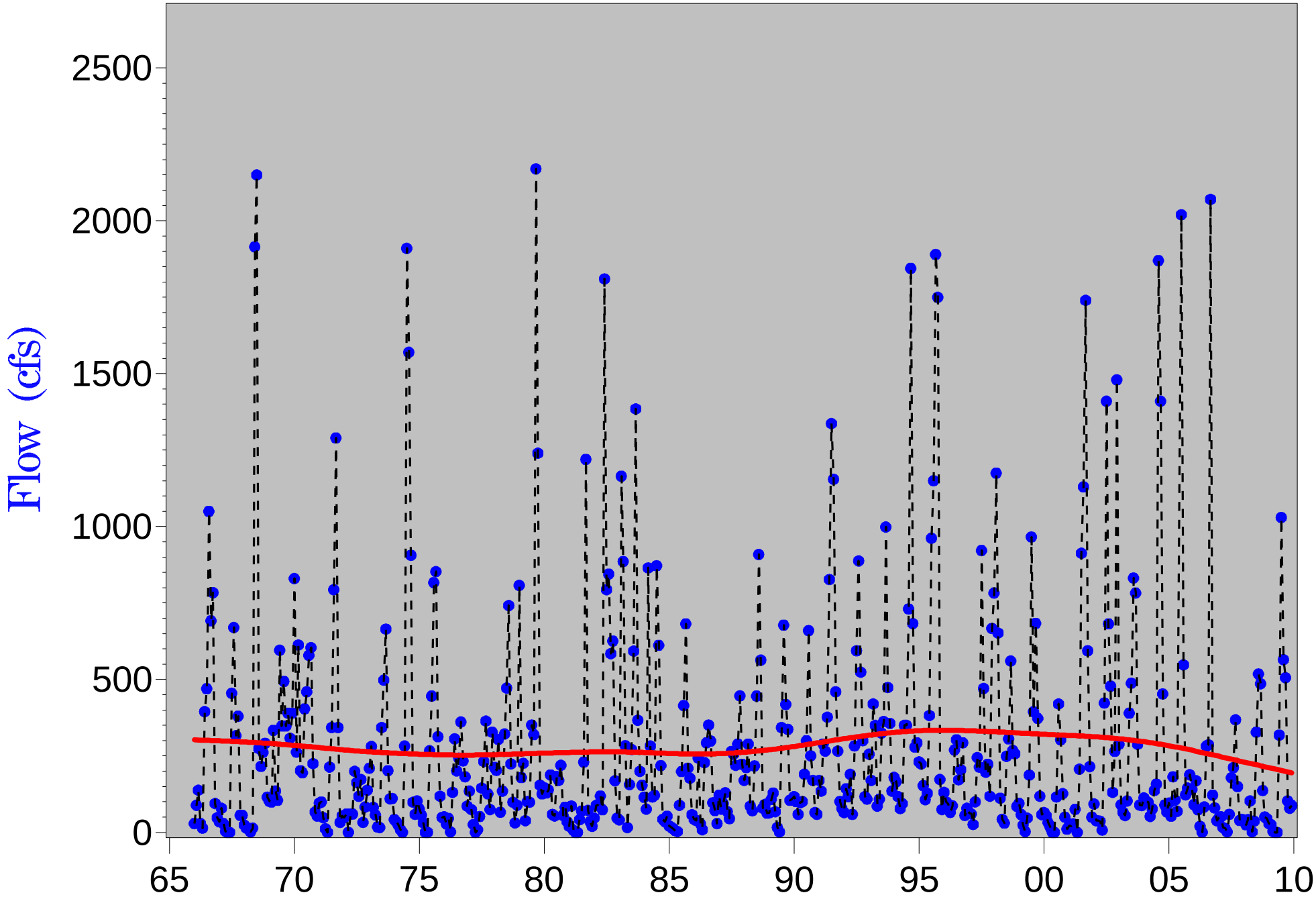


Figure 3.4a Monthly P50 (median) long-term flow at the USGS Shell Creek gage (1965-2009)

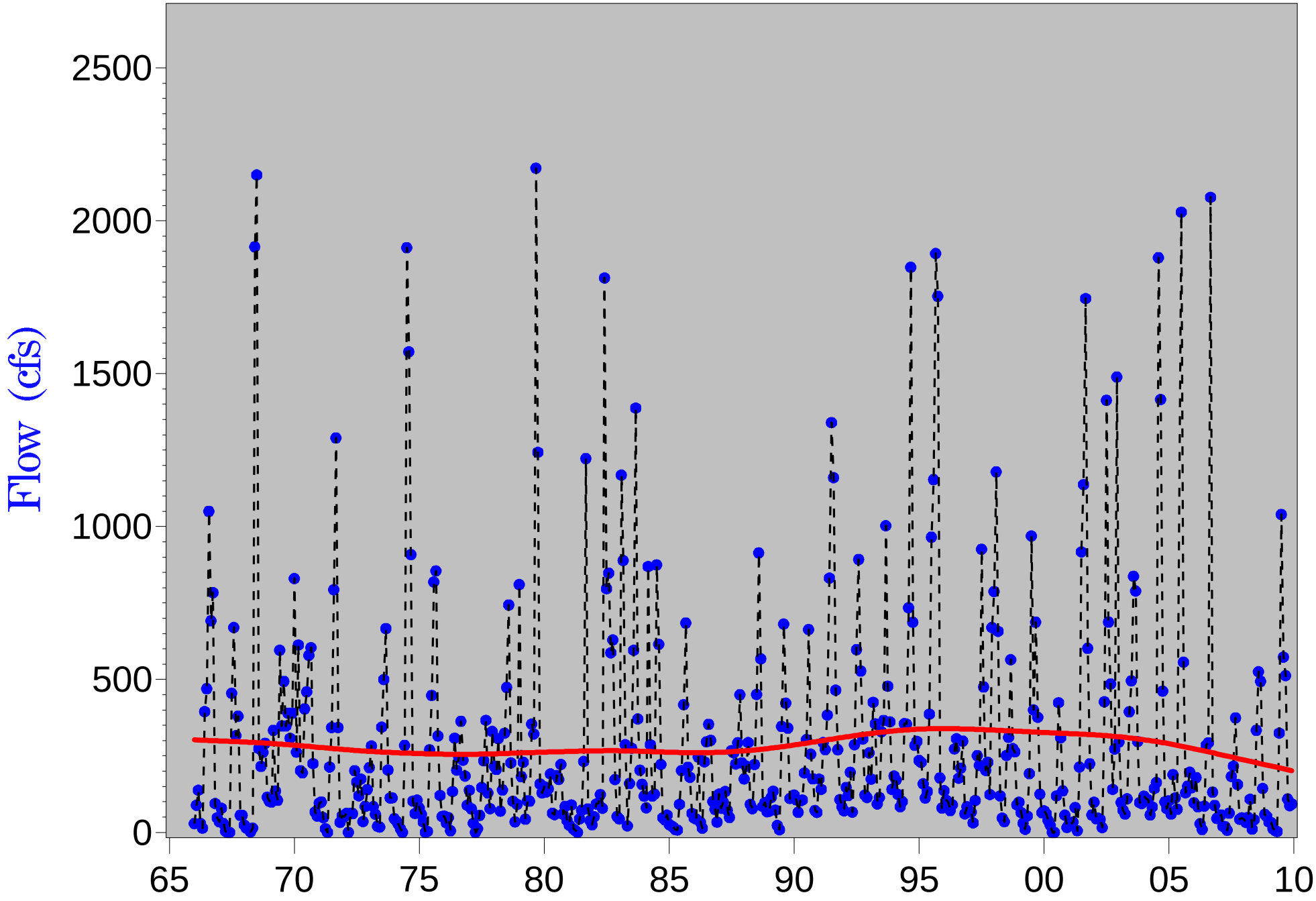


Figure 3.4b Estimated monthly P50 (median) flow without Facility withdrawals (1965-2009)

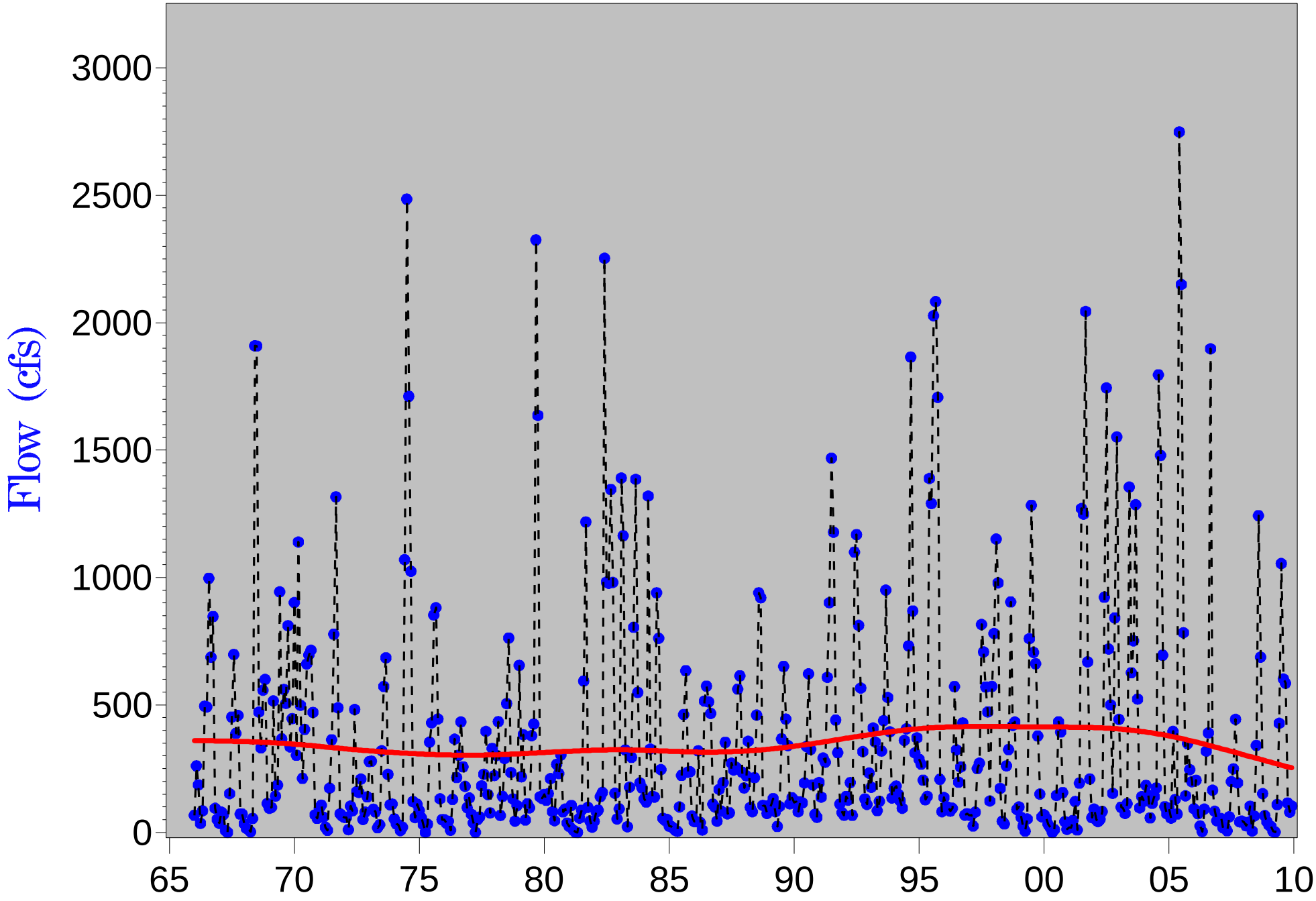


Figure 3.5a Monthly mean long-term flow at the USGS Shell Creek gage (1965-2009)

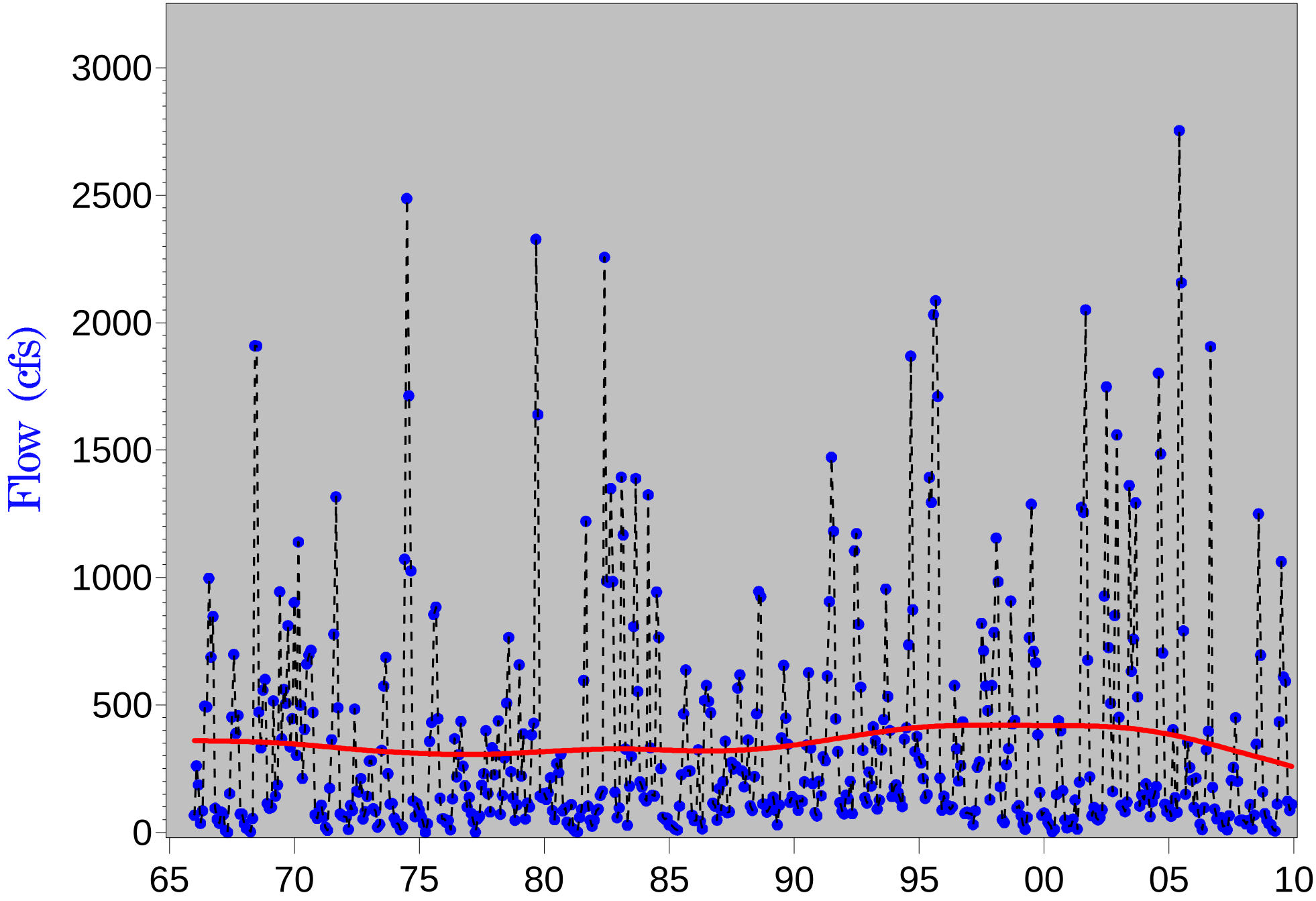


Figure 3.5b Estimated monthly mean flow without Facility withdrawals (1965-2009)

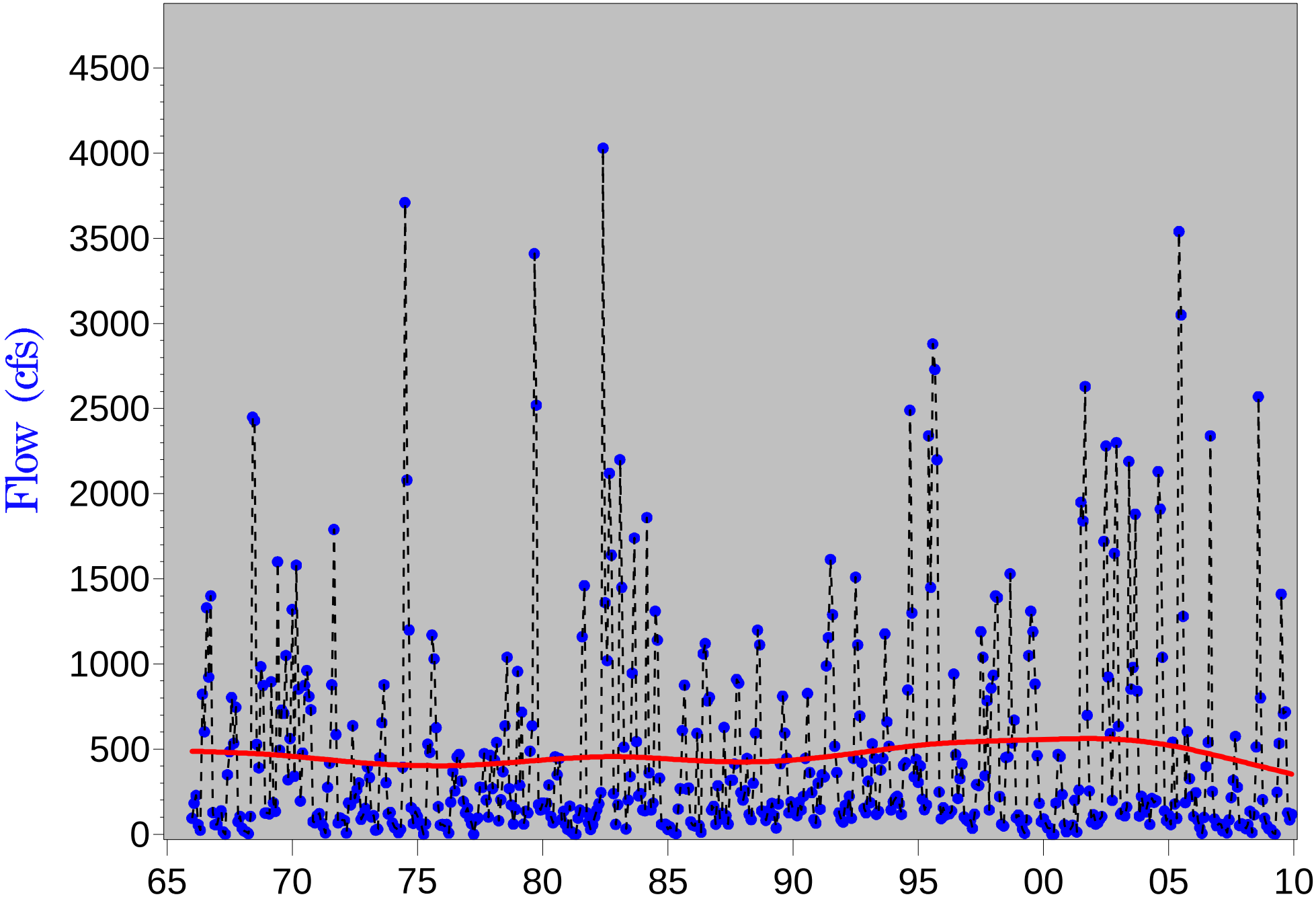


Figure 3.6a Monthly P75 long-term flow at the USGS Shell Creek gage (1965-2009)

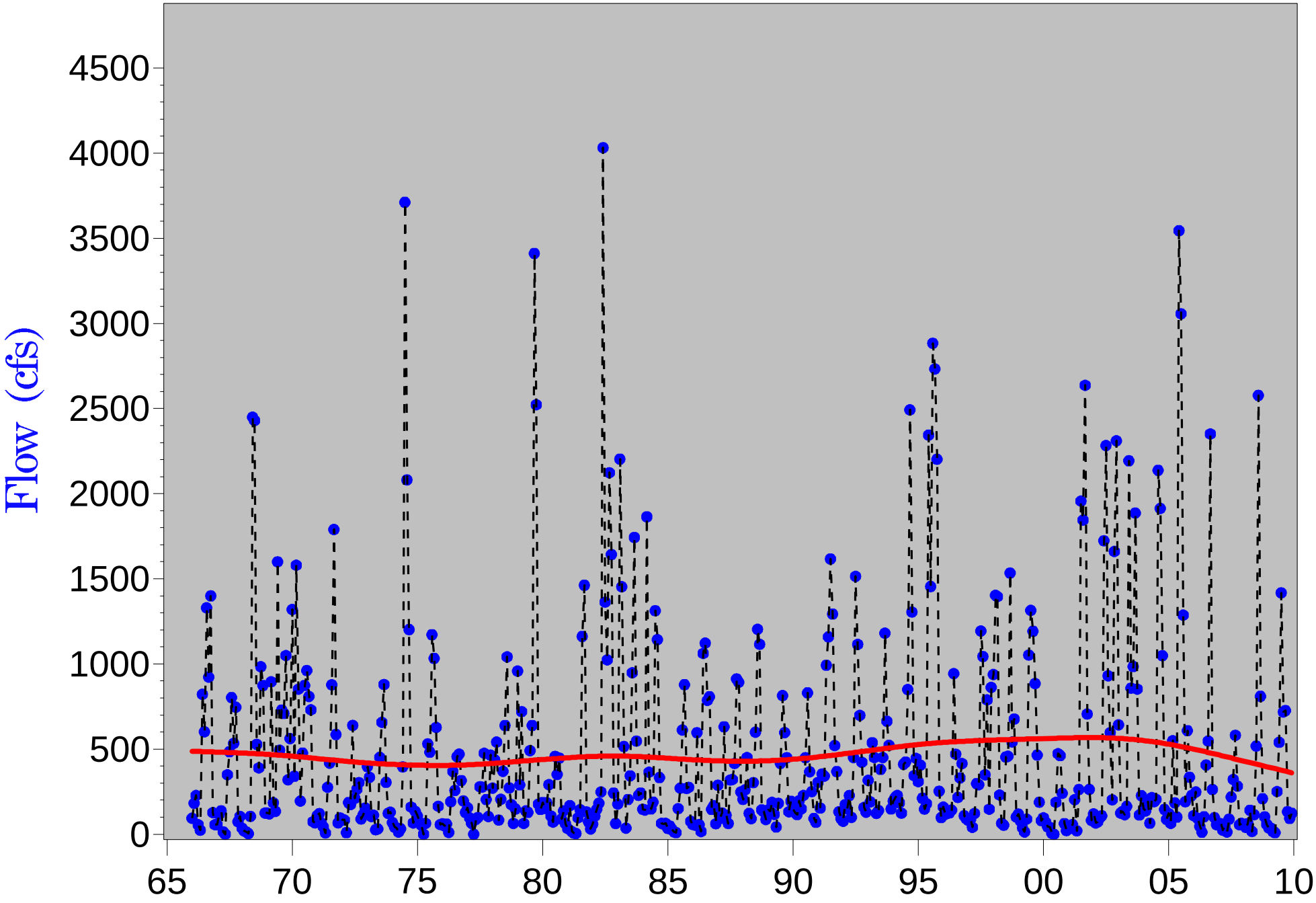


Figure 3.6b Estimated monthly P75 flow without Facility withdrawals (1965-2009)

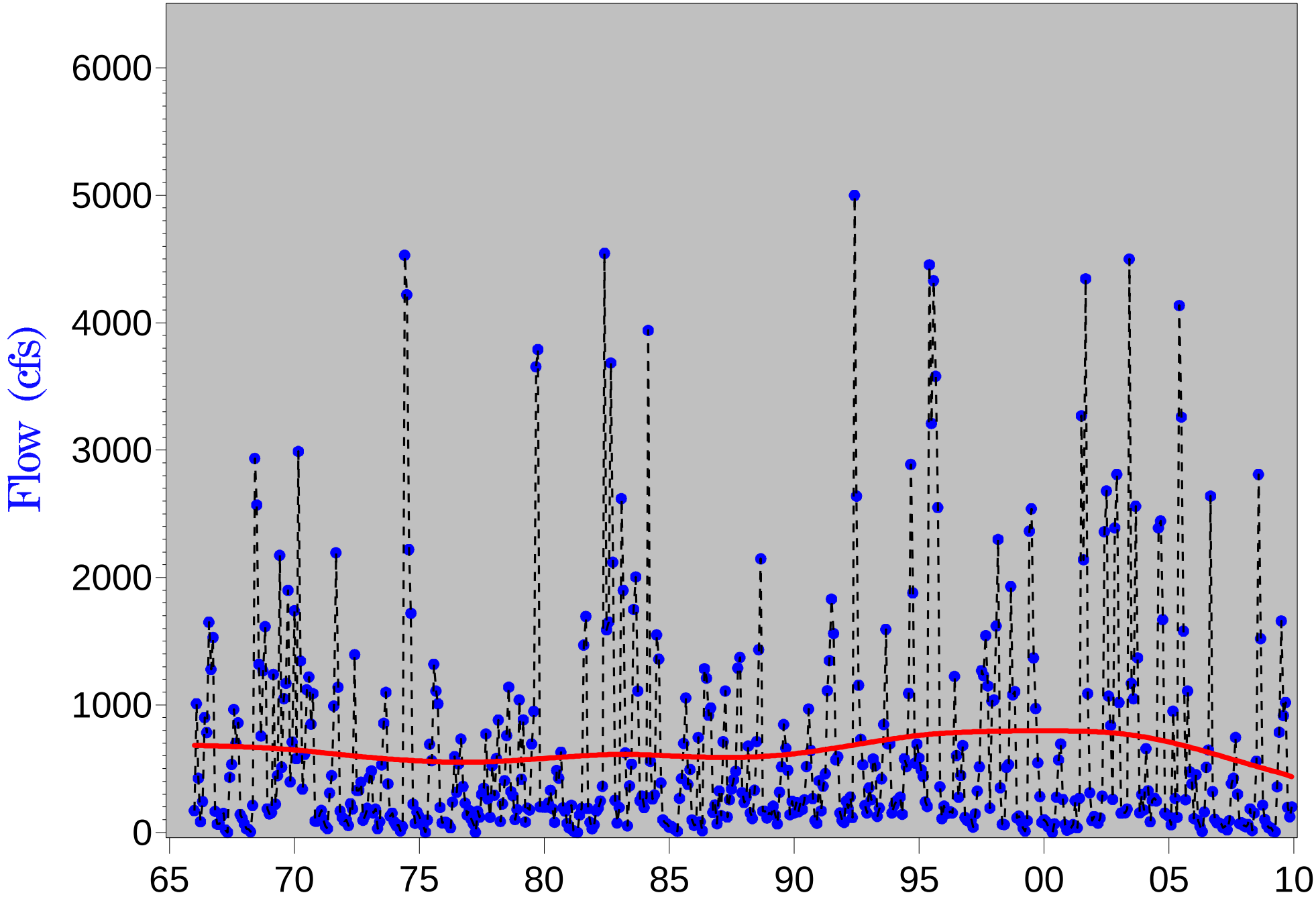


Figure 3.7a Monthly P90 long-term flow at the USGS Shell Creek gage (1965-2009)

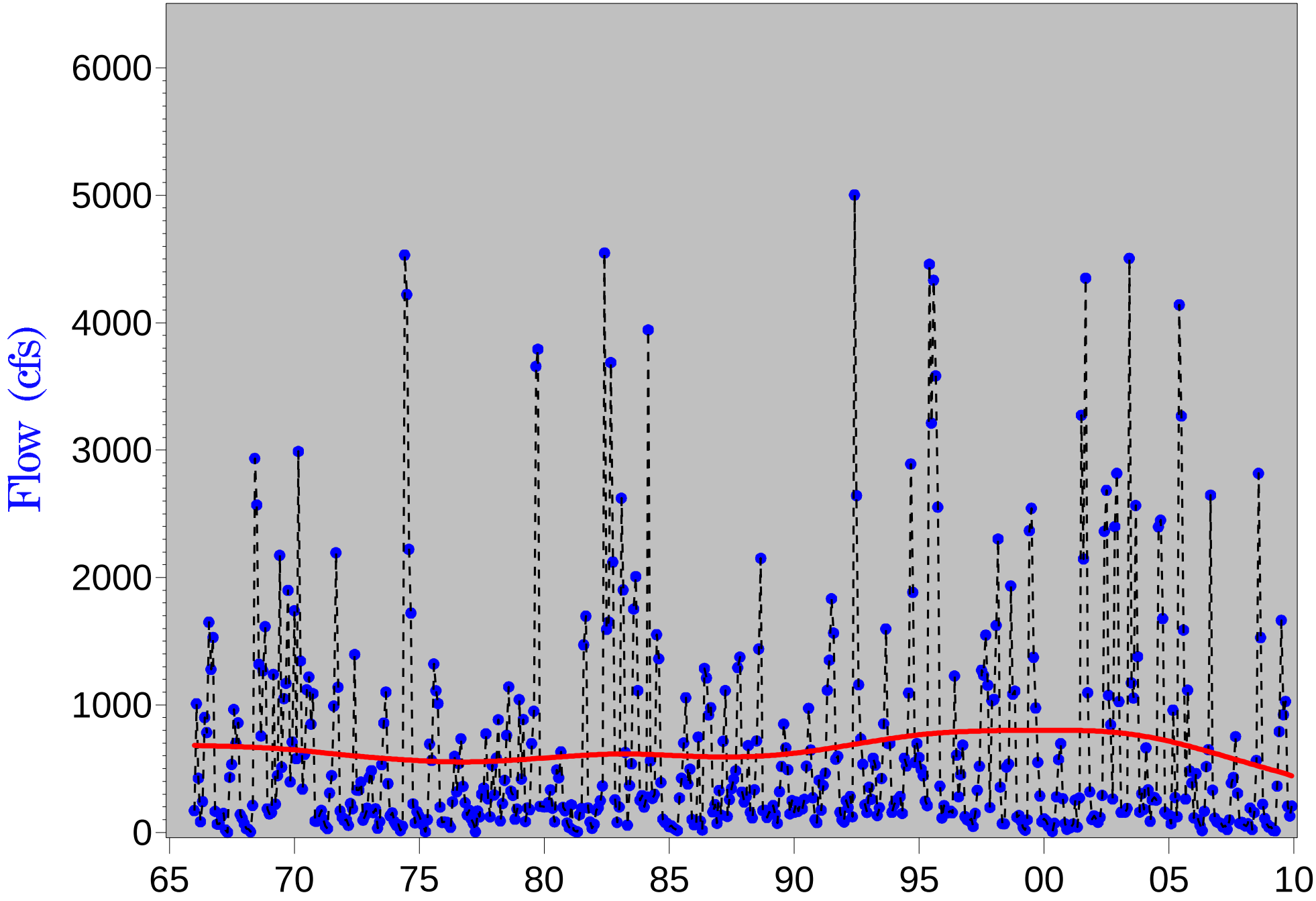


Figure 3.7b Estimated monthly P90 flow without Facility withdrawals (1965-2009)

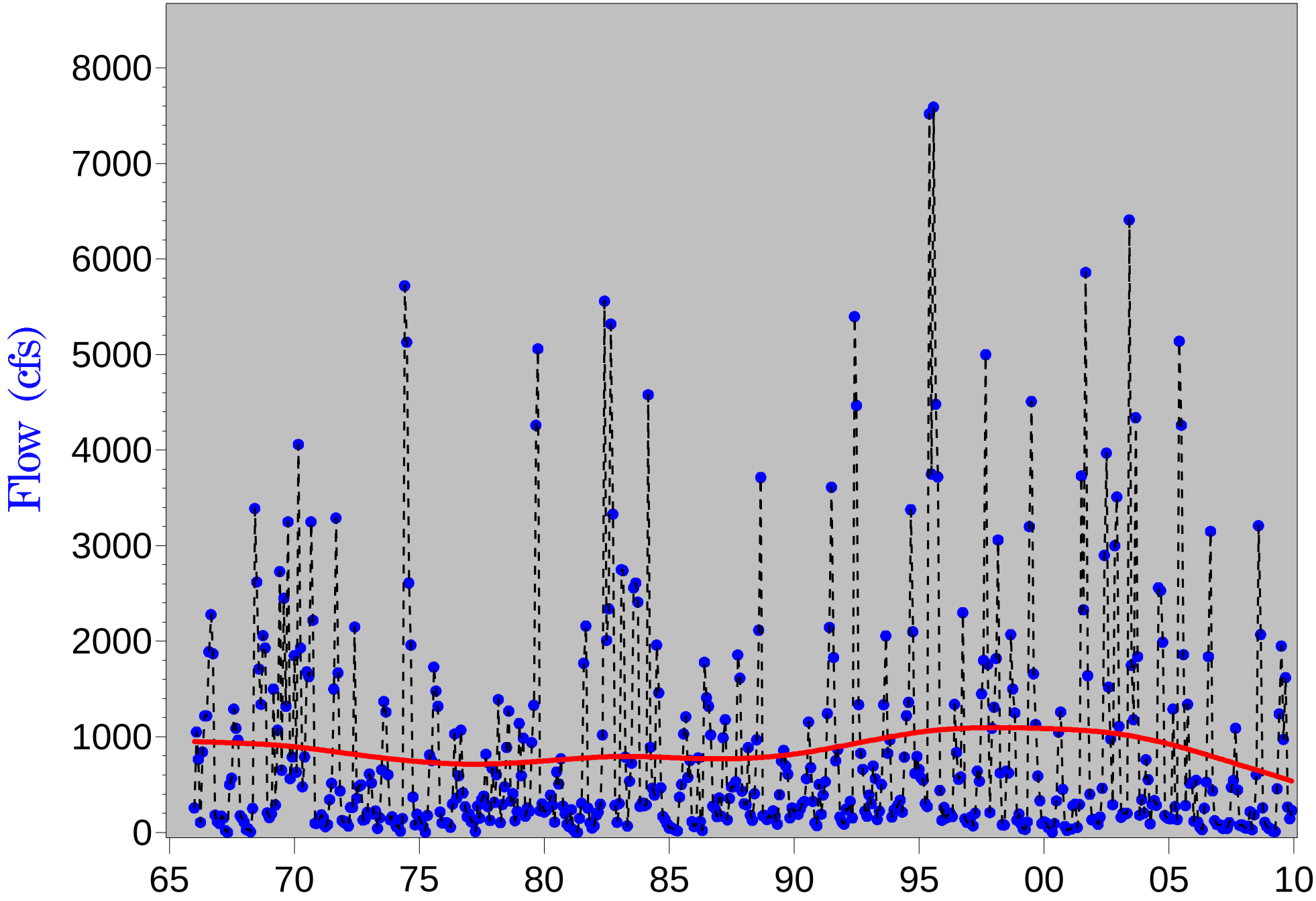


Figure 3.8a Monthly maximum long-term flow at the USGS Shell Creek gage (1965-2009)

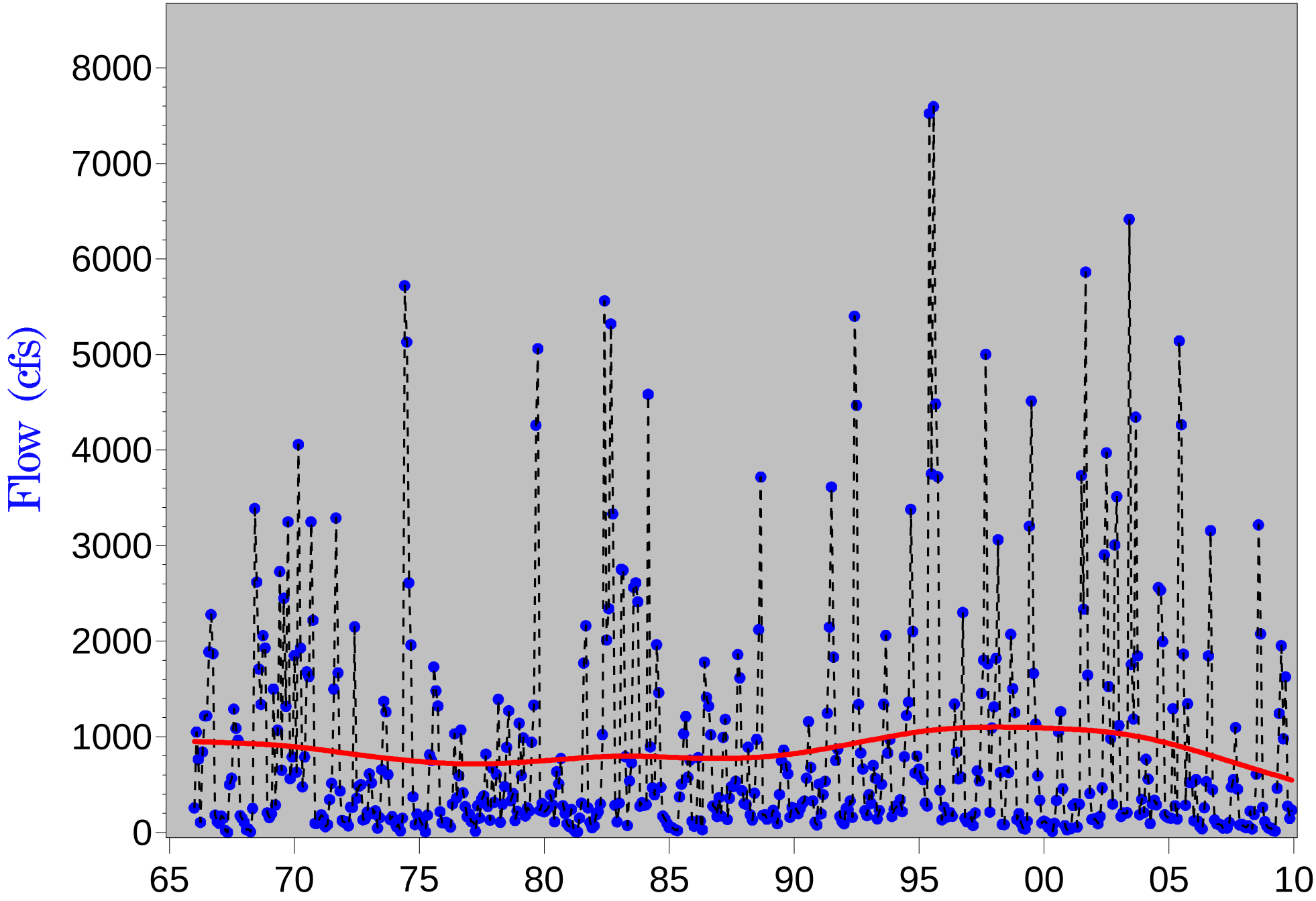


Figure 3.8b Estimated monthly maximum flow without Facility withdrawals (1965-2009)

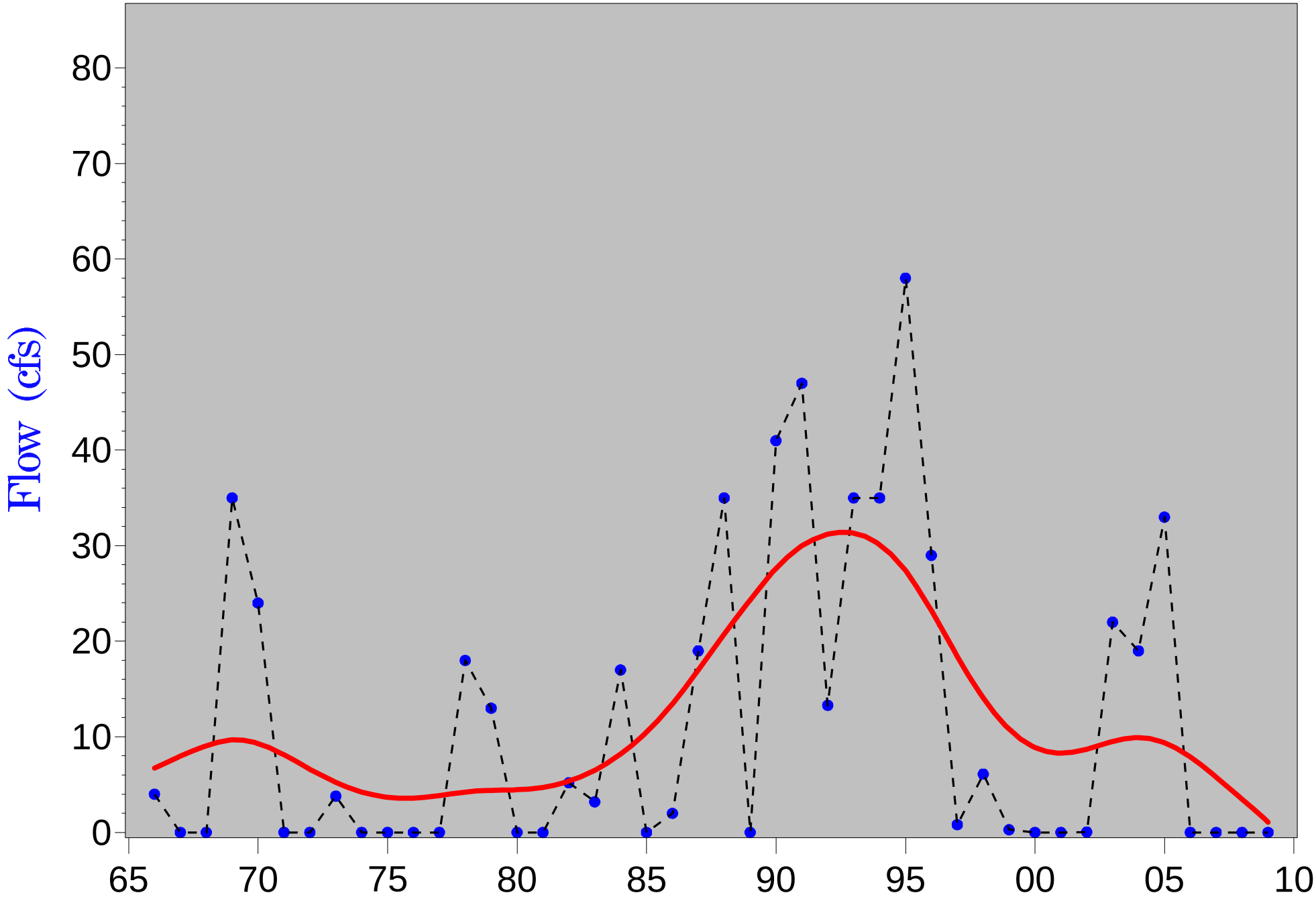


Figure 3.9a Yearly minimum long-term flow at the USGS Shell Creek gage (1965-2009)

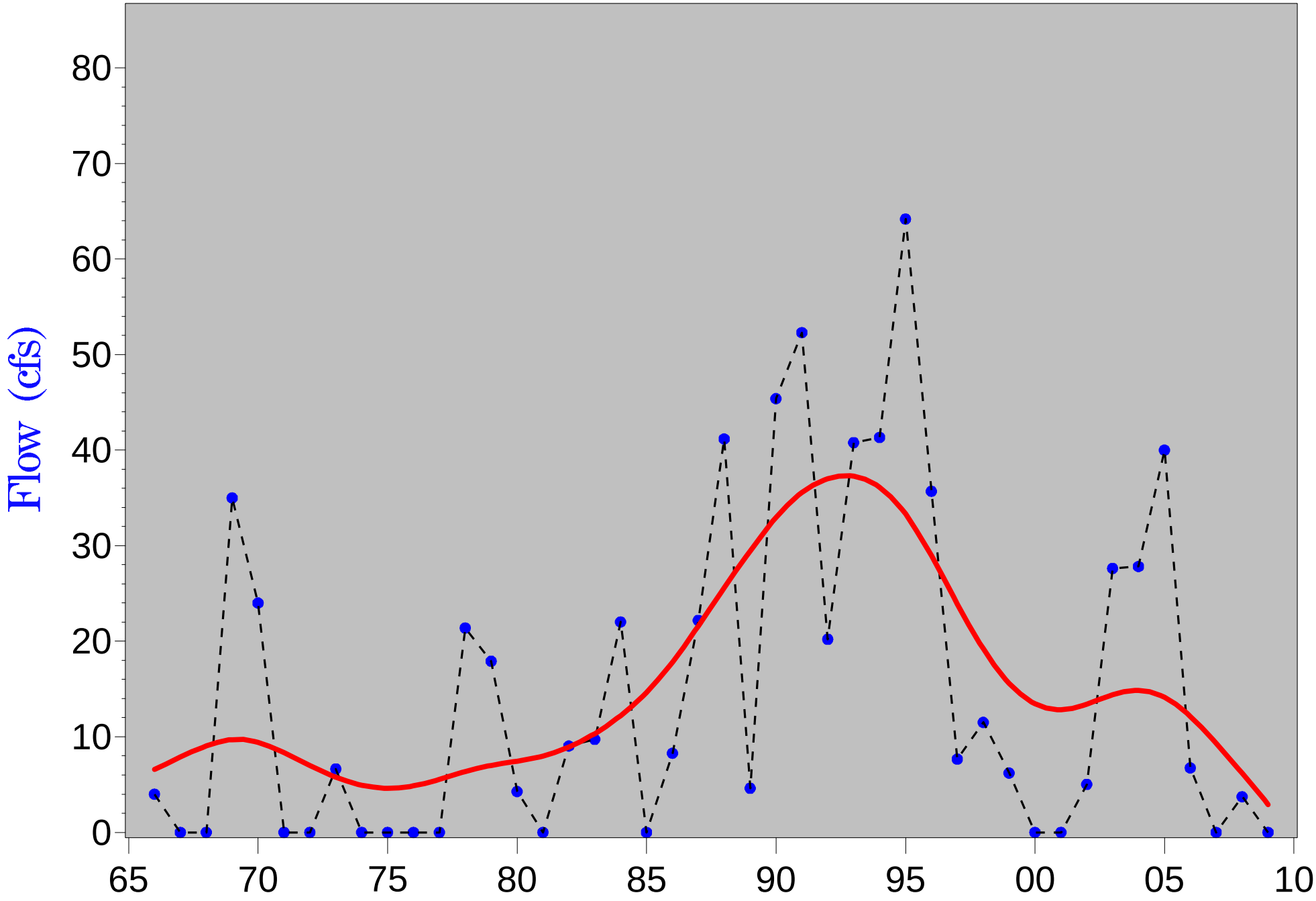


Figure 3.9b Estimated yearly minimum flow without Facility withdrawals (1965-2009)

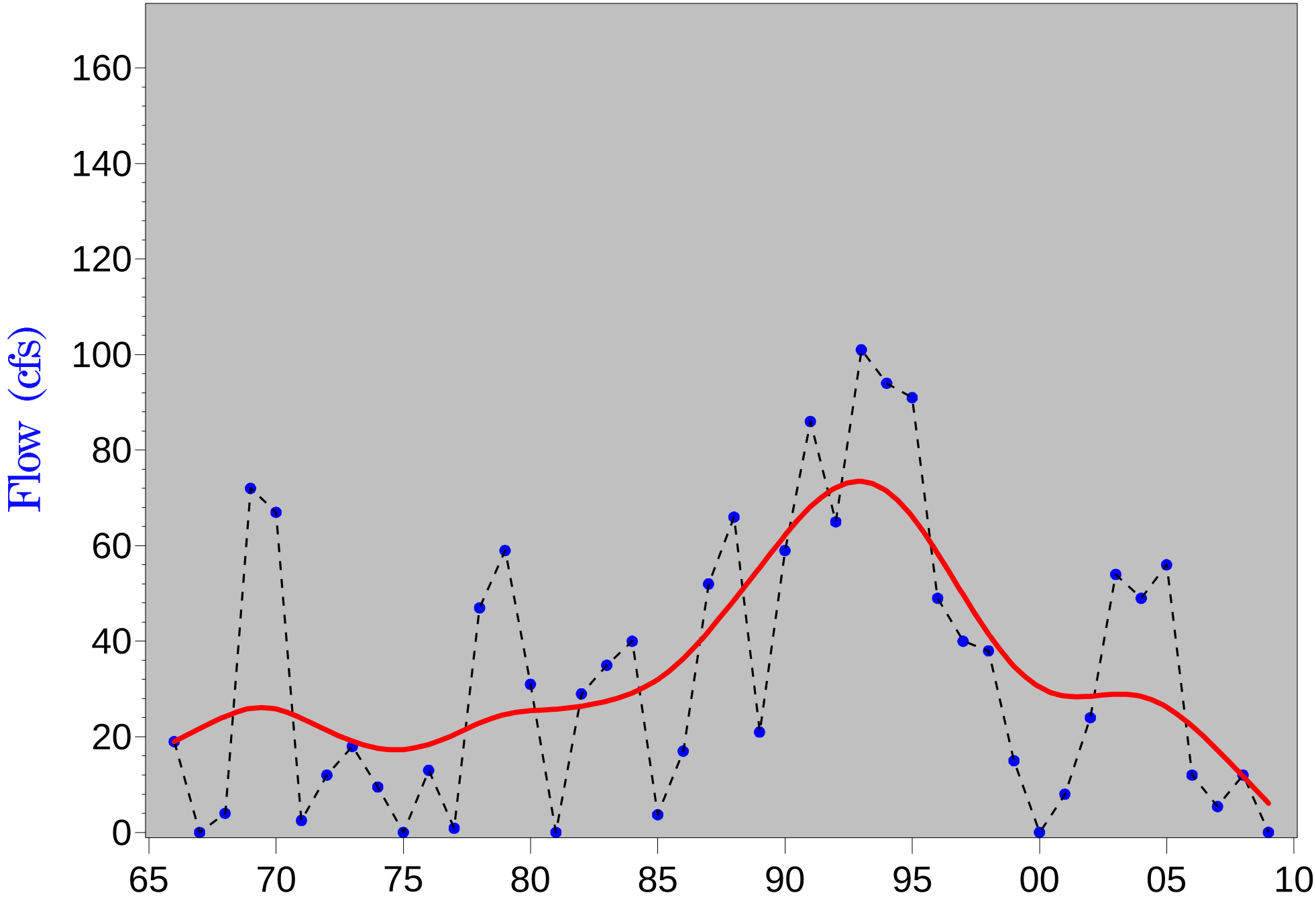


Figure 3.10a Yearly P10 long-term flow at the USGS Shell Creek gage (1965-2009)

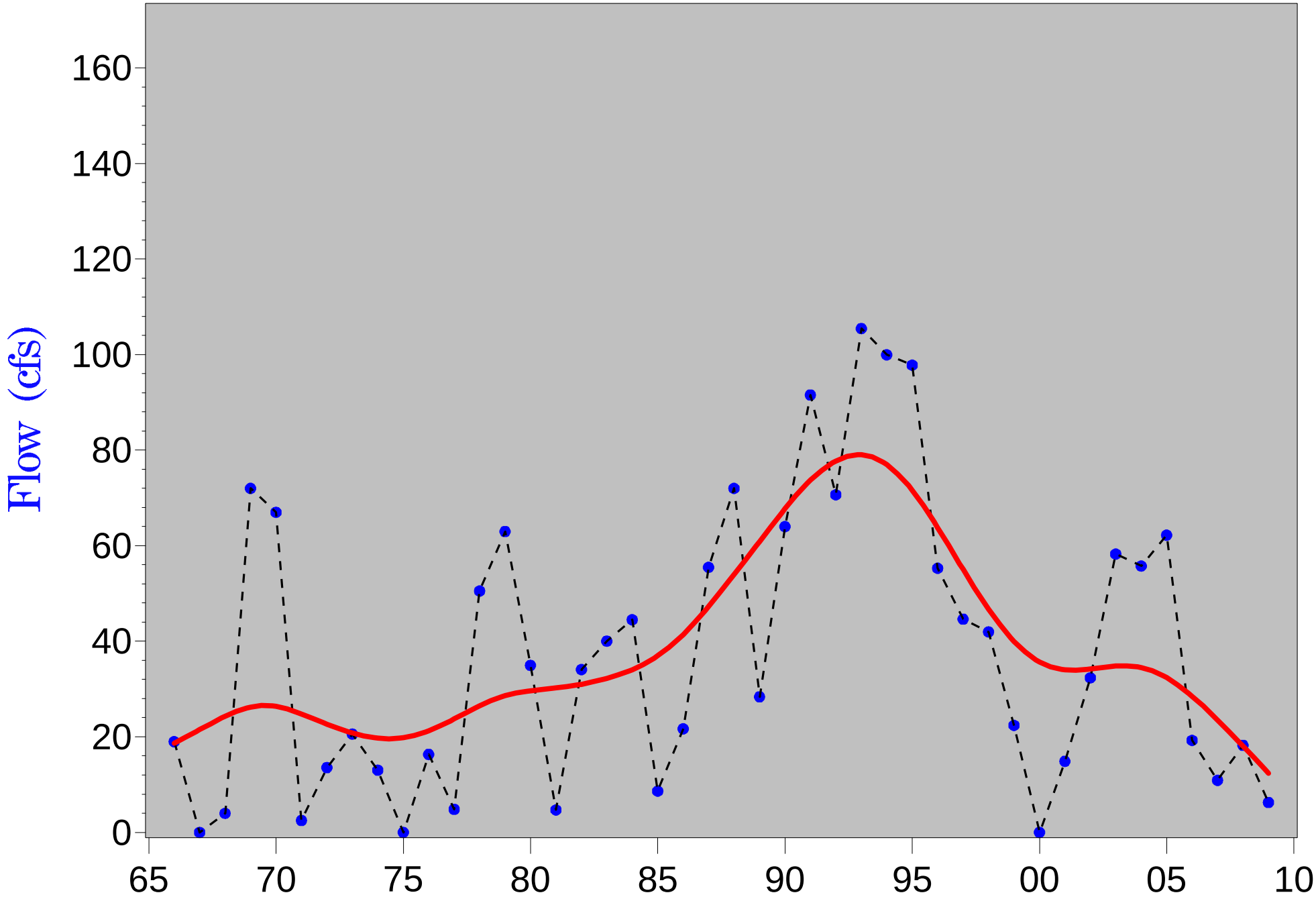
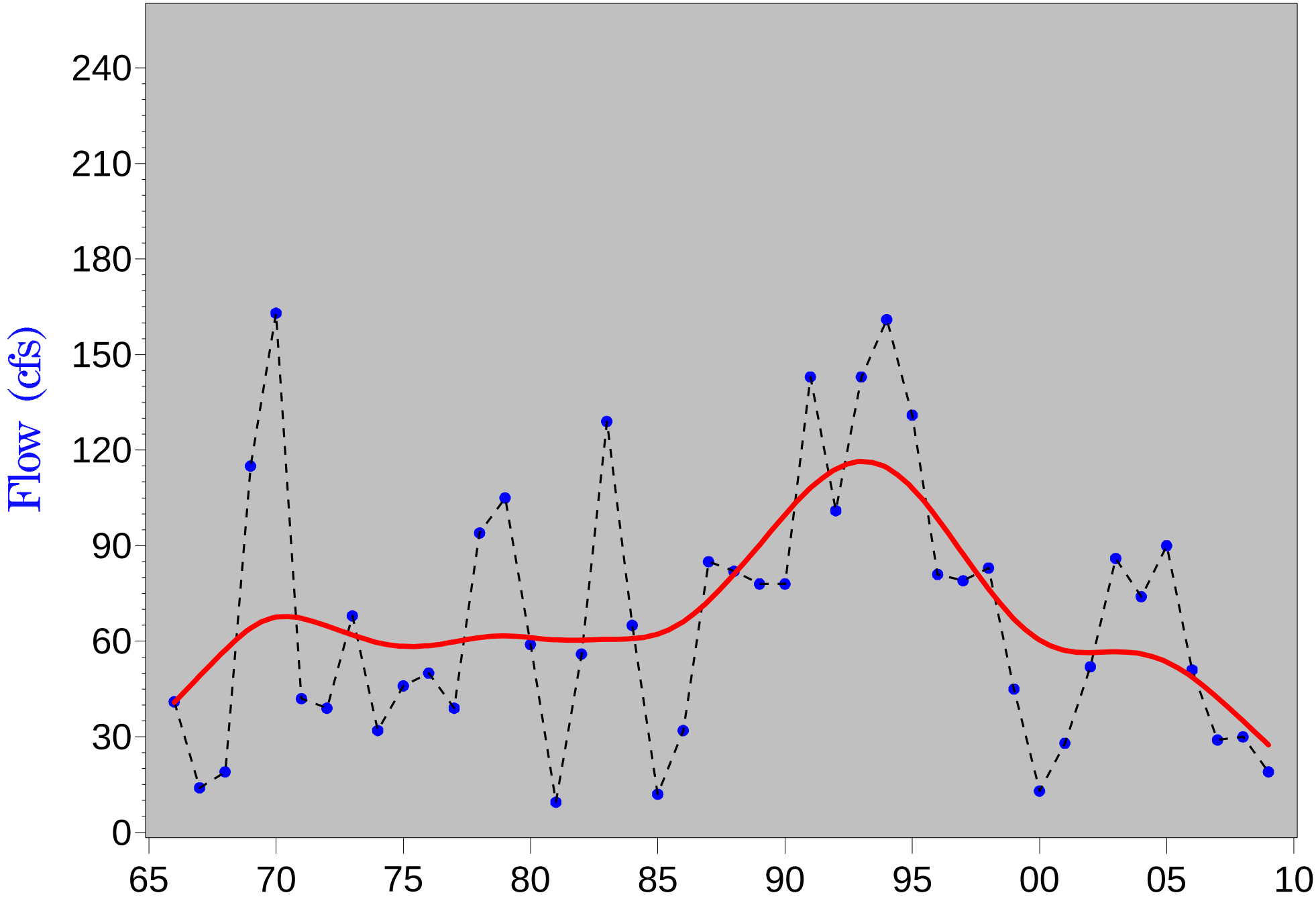
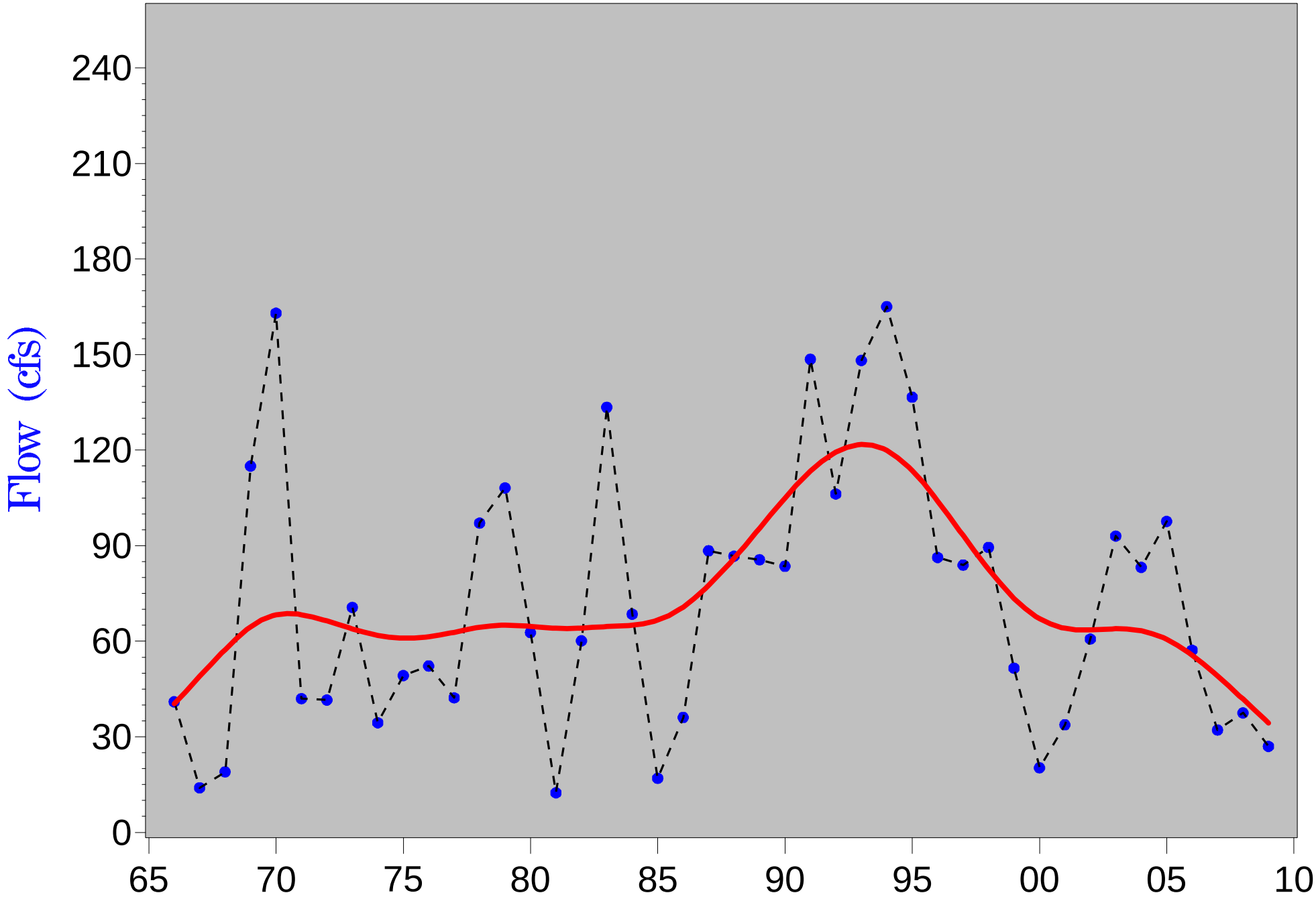


Figure 3.10b Estimated yearly P10 flow without Facility withdrawals (1965-2009)



. Figure 3.11a Yearly P25 long-term flow at the USGS Shell Creek gage (1965-2009)



. Figure 3.11b Estimated yearly P25 flow without Facility withdrawals (1965-2009)

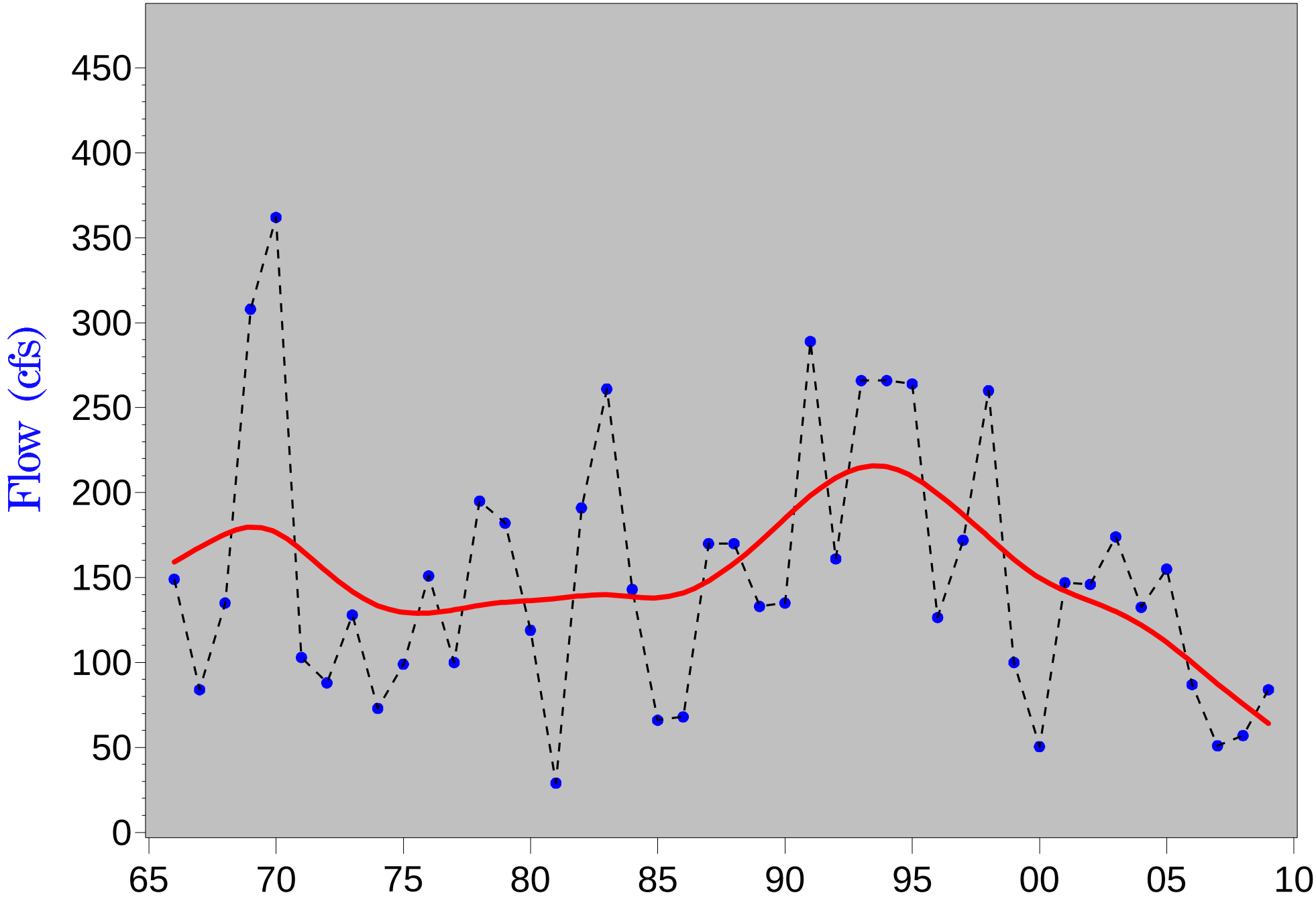


Figure 3.12a Yearly P50 (median) long-term flow at the USGS Shell Creek gage (1965-2009)

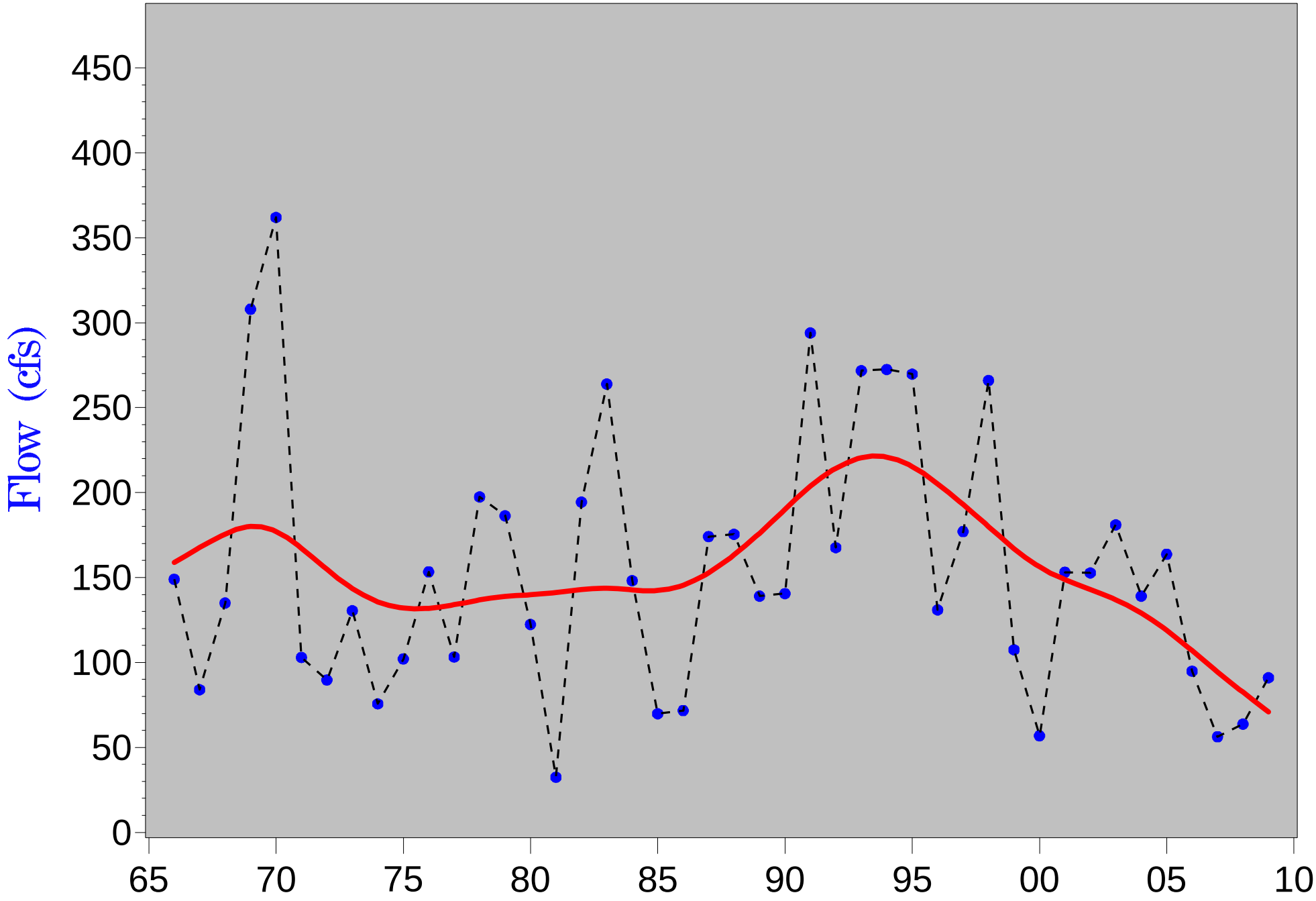


Figure 3.12b Estimated yearly P50 (median) flow without Facility withdrawals (1965-2009)

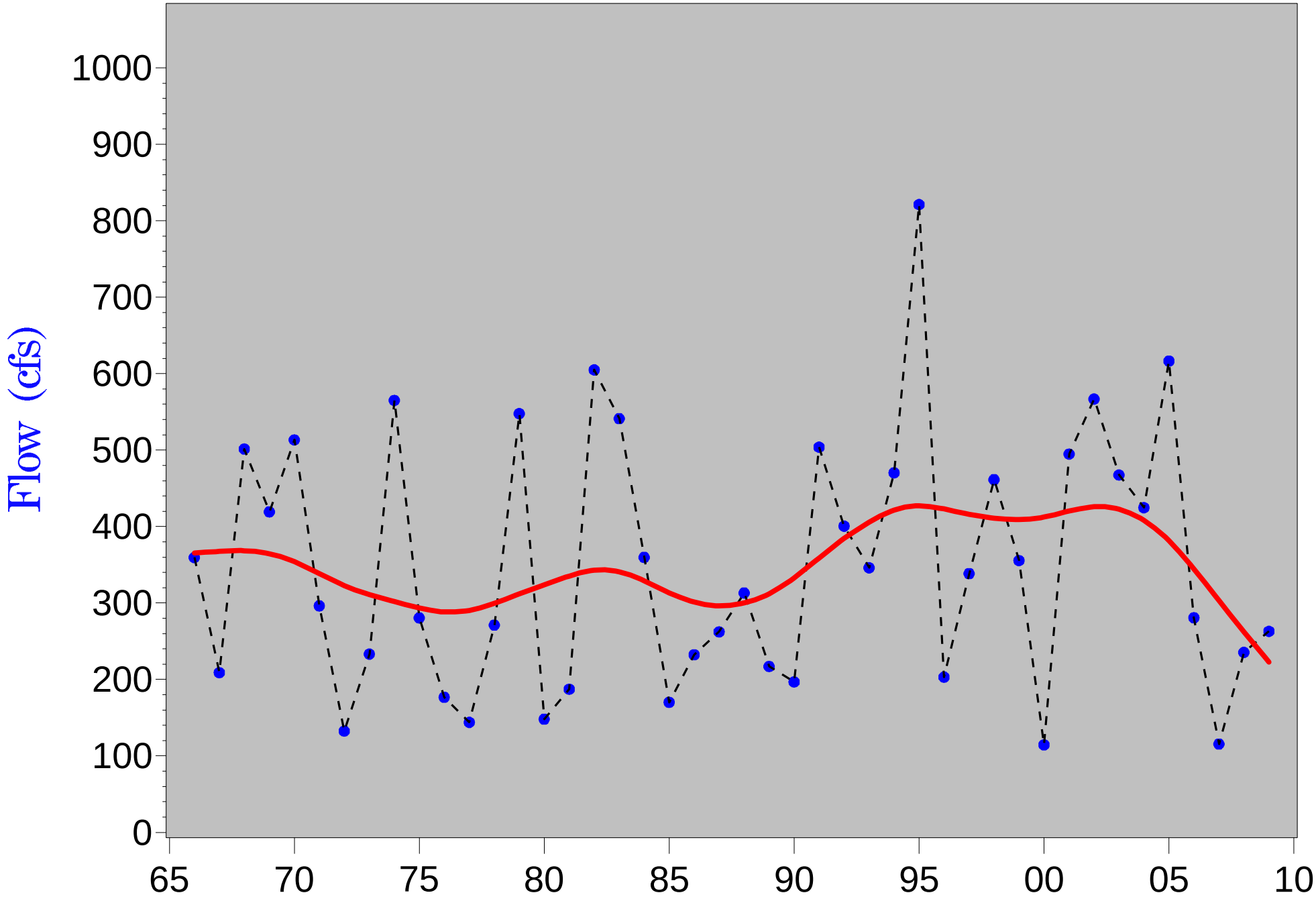


Figure 3.13a Yearly mean long-term flow at the USGS Shell Creek gage (1965-2009)

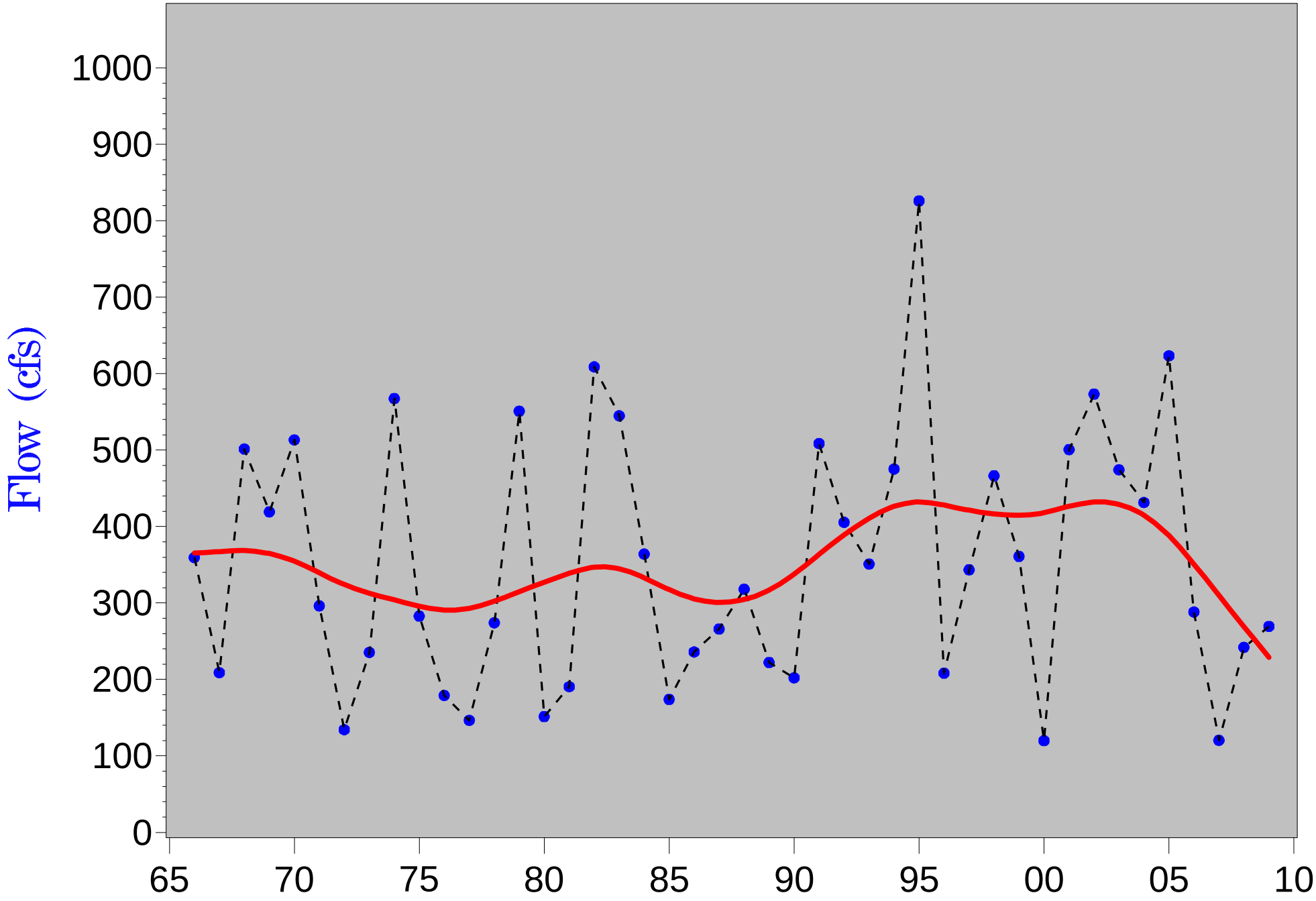


Figure 3.13b Estimated yearly mean flow without Facility withdrawals (1965-2009)

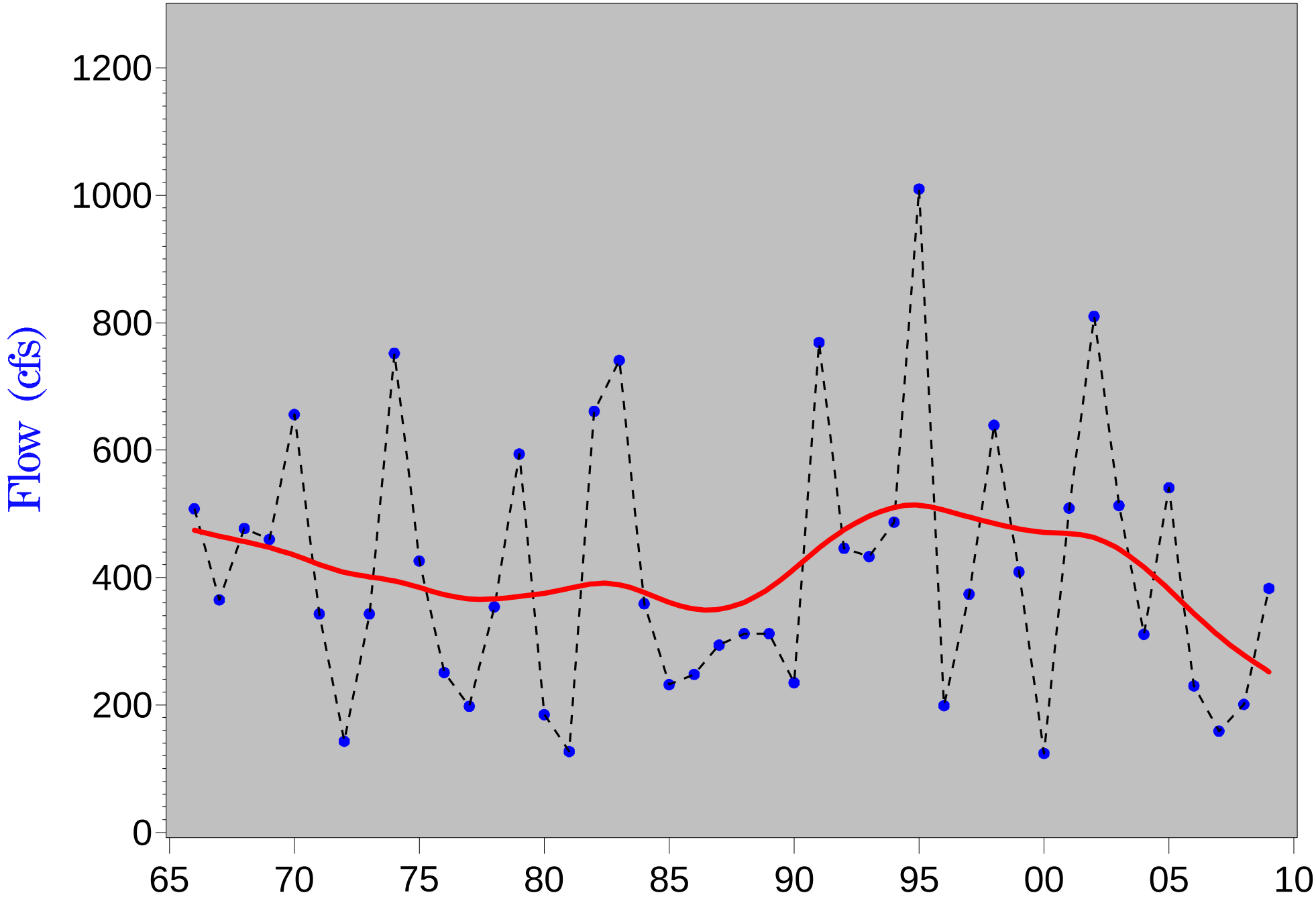


Figure 3.14a Yearly P75 long-term flow at the USGS Shell Creek gage (1965-2009)

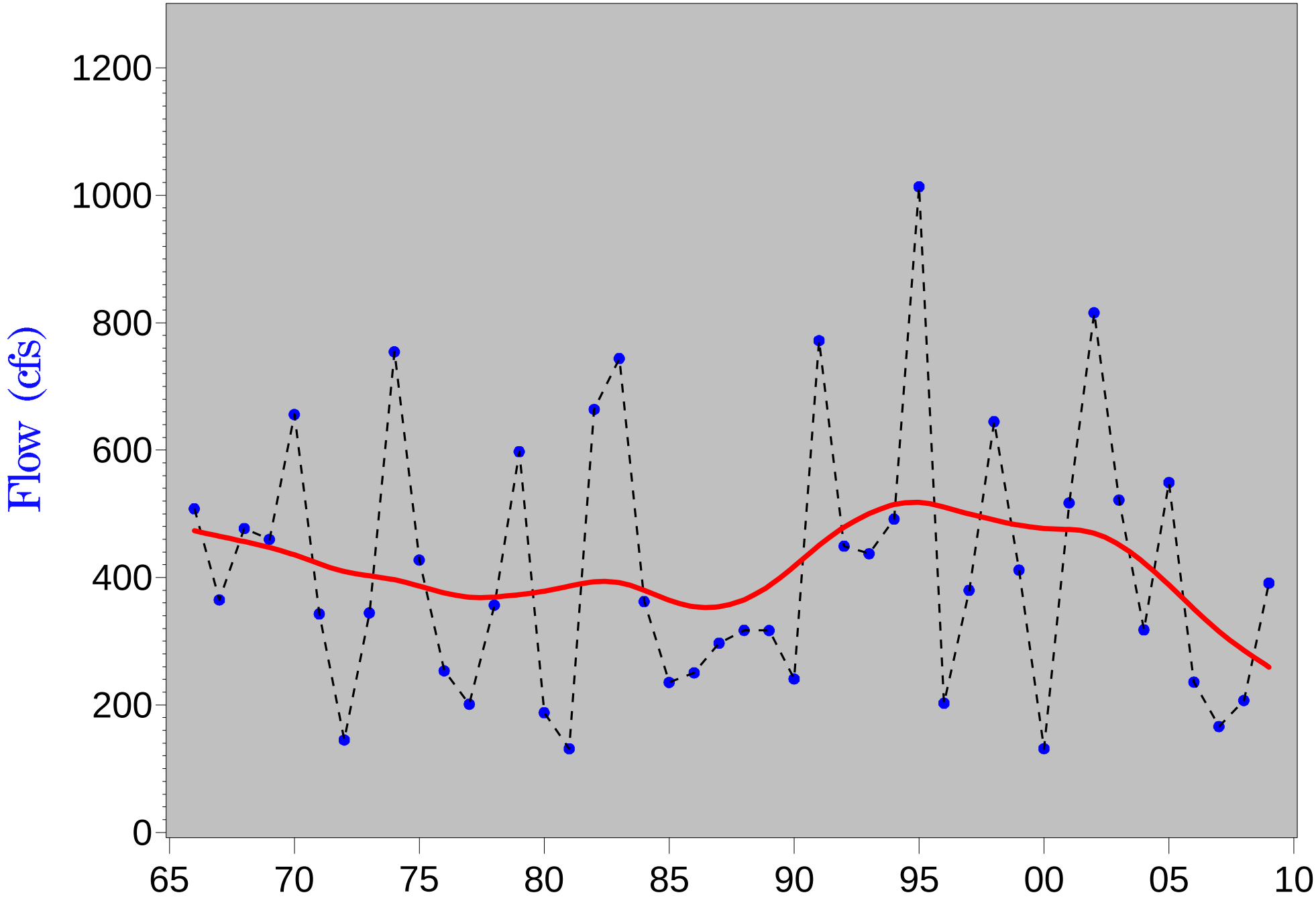


Figure 3.14b Estimated yearly P75 flow without Facility withdrawals (1965-2009)

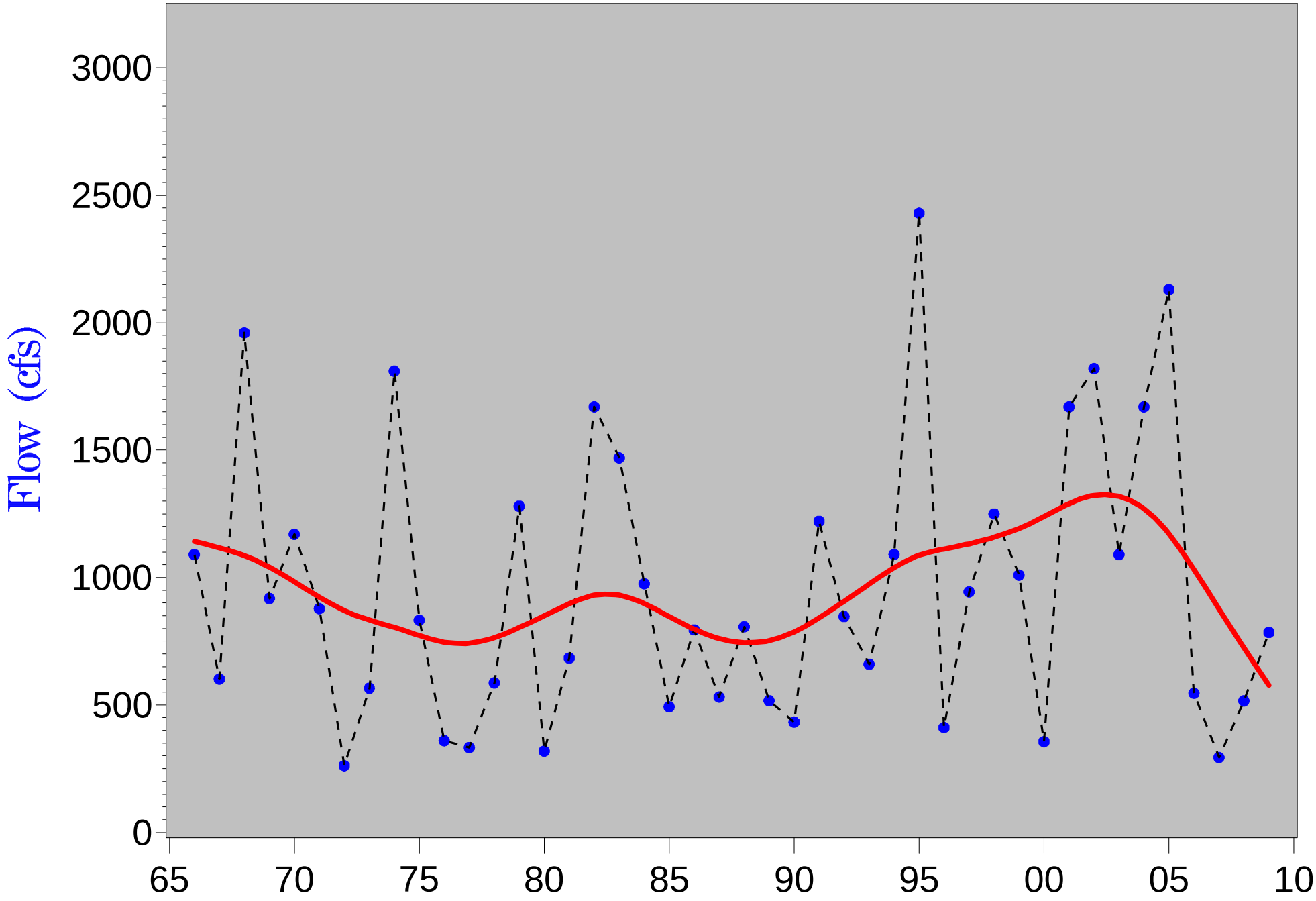


Figure 3.15a Yearly P90 long-term flow at the USGS Shell Creek gage (1965-2009)

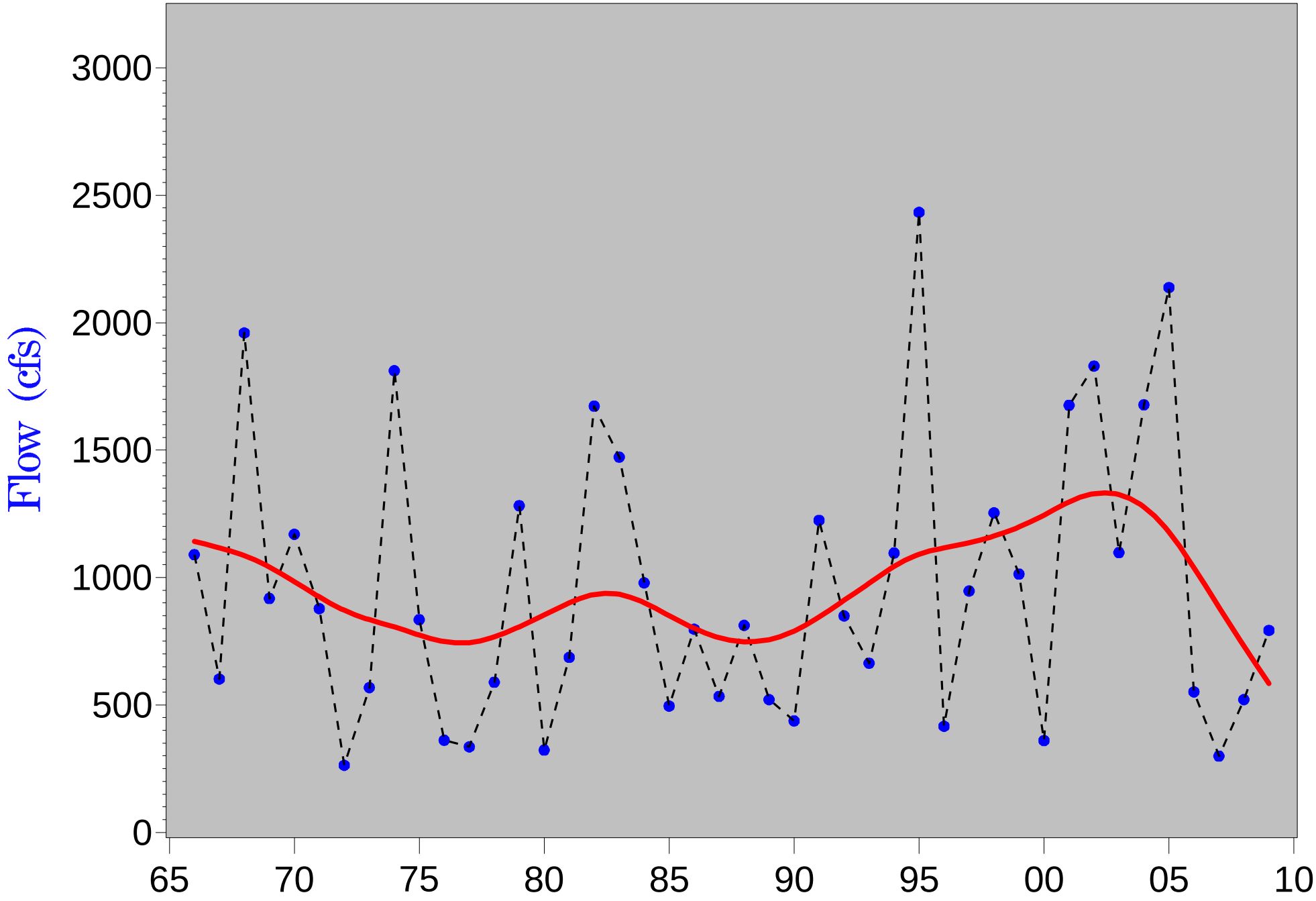


Figure 3.15b Estimated yearly P90 flow without Facility withdrawals (1965-2009)

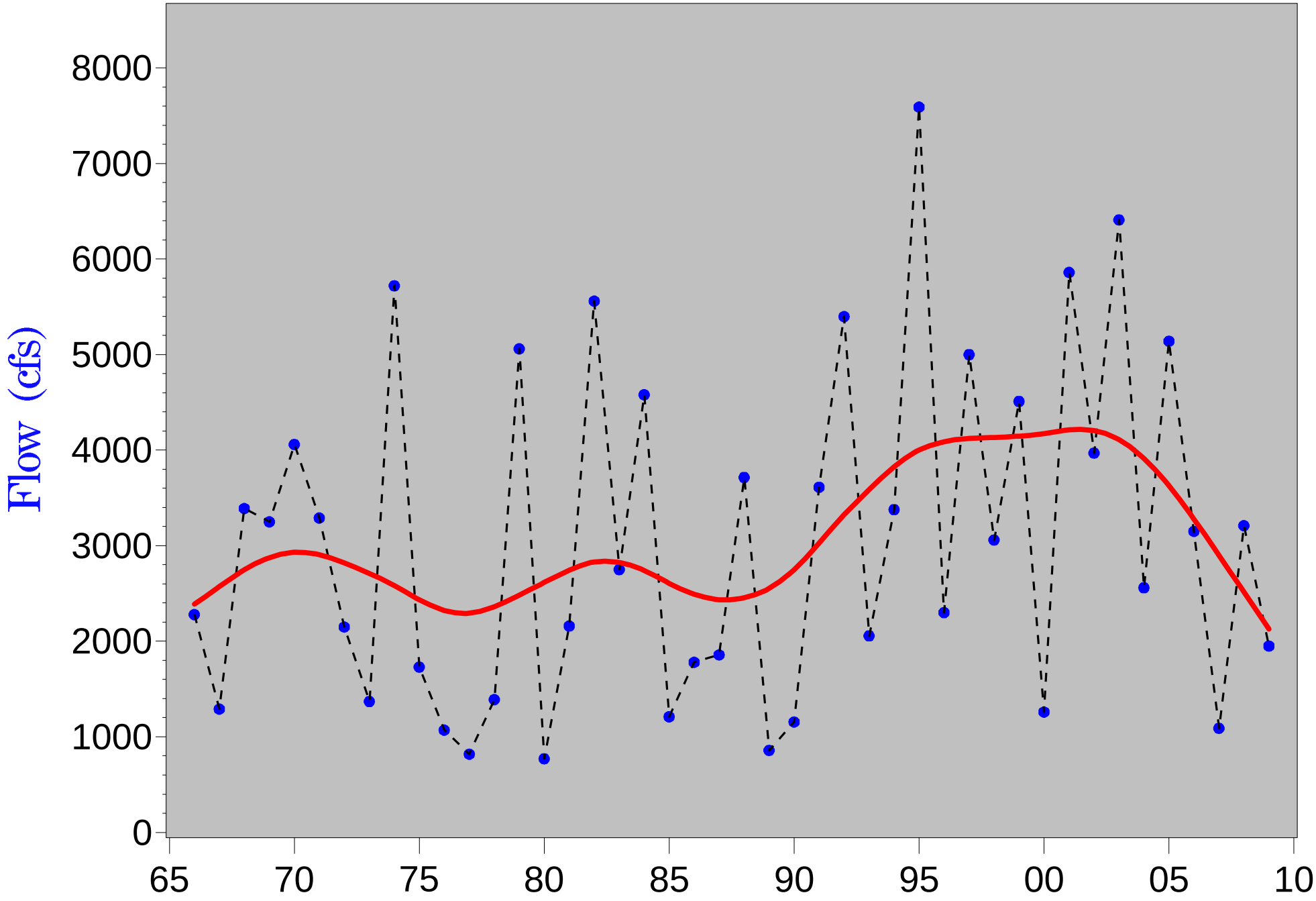


Figure 3.16a Yearly maximum long-term flow at the USGS Shell Creek gage (1965-2009)

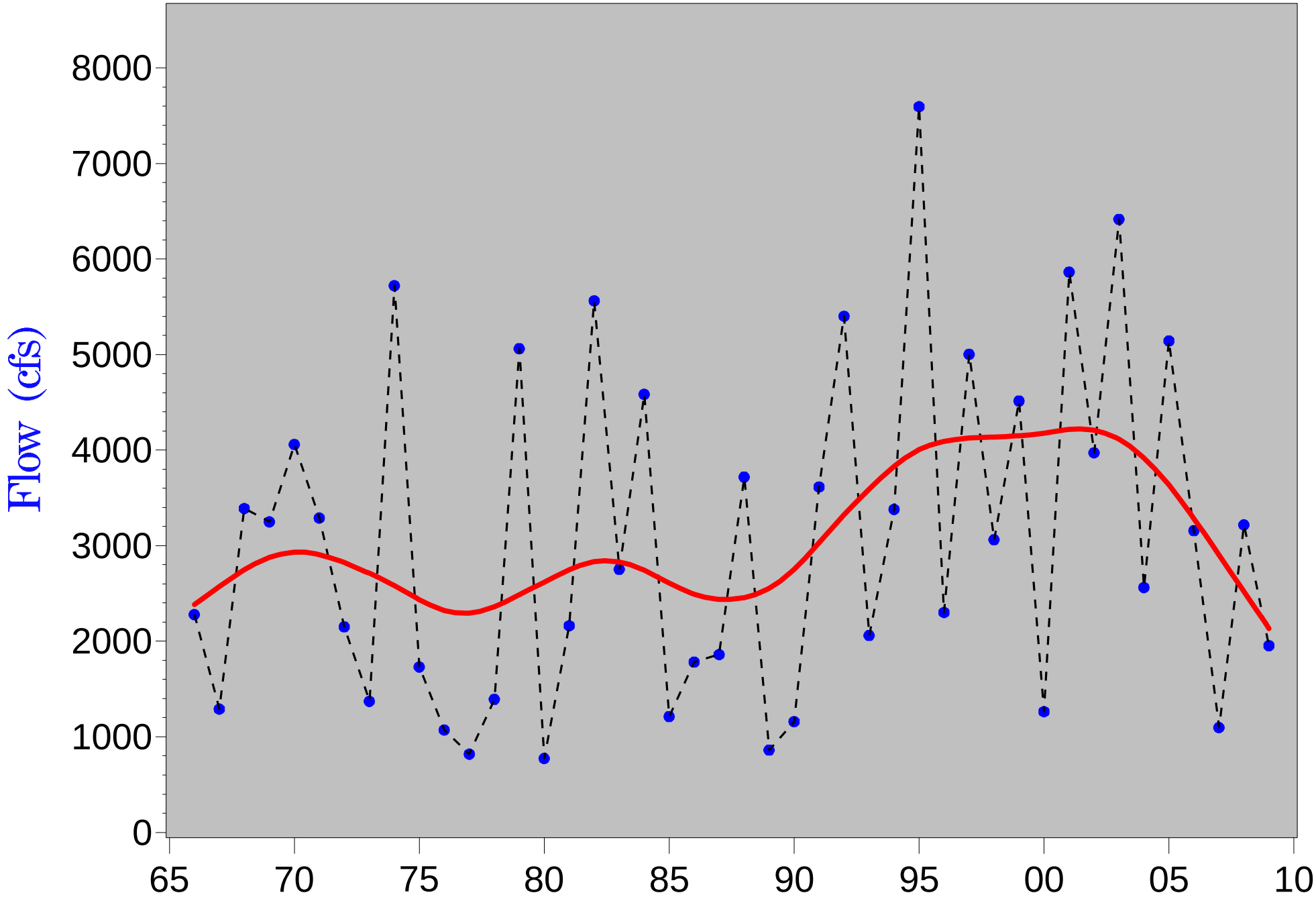


Figure 3.16b Estimated yearly maximum flow without Facility withdrawals (1965-2009)

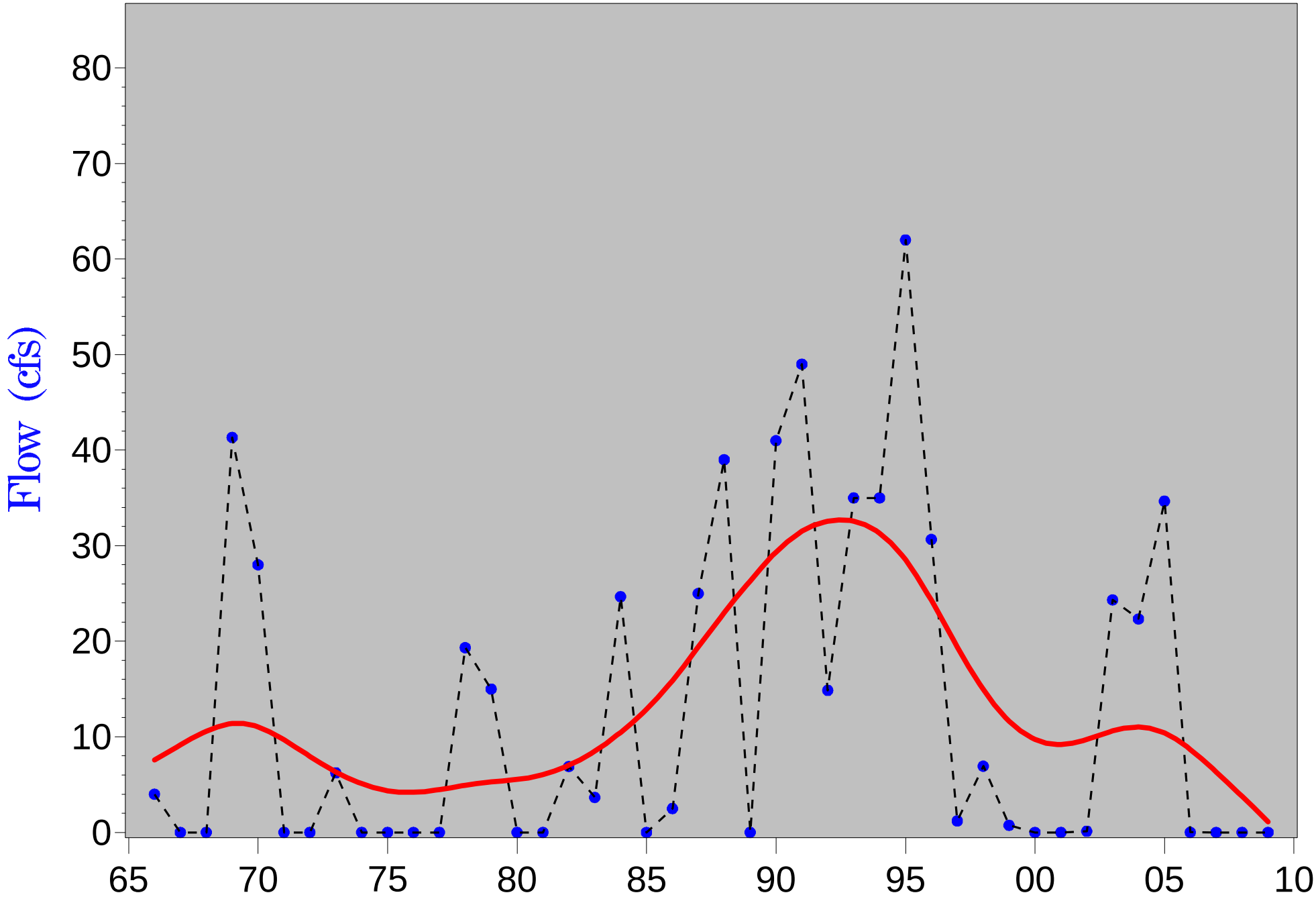


Figure 3.17a Yearly minimum 3-day flow at the USGS Shell Creek gage (1965-2009)

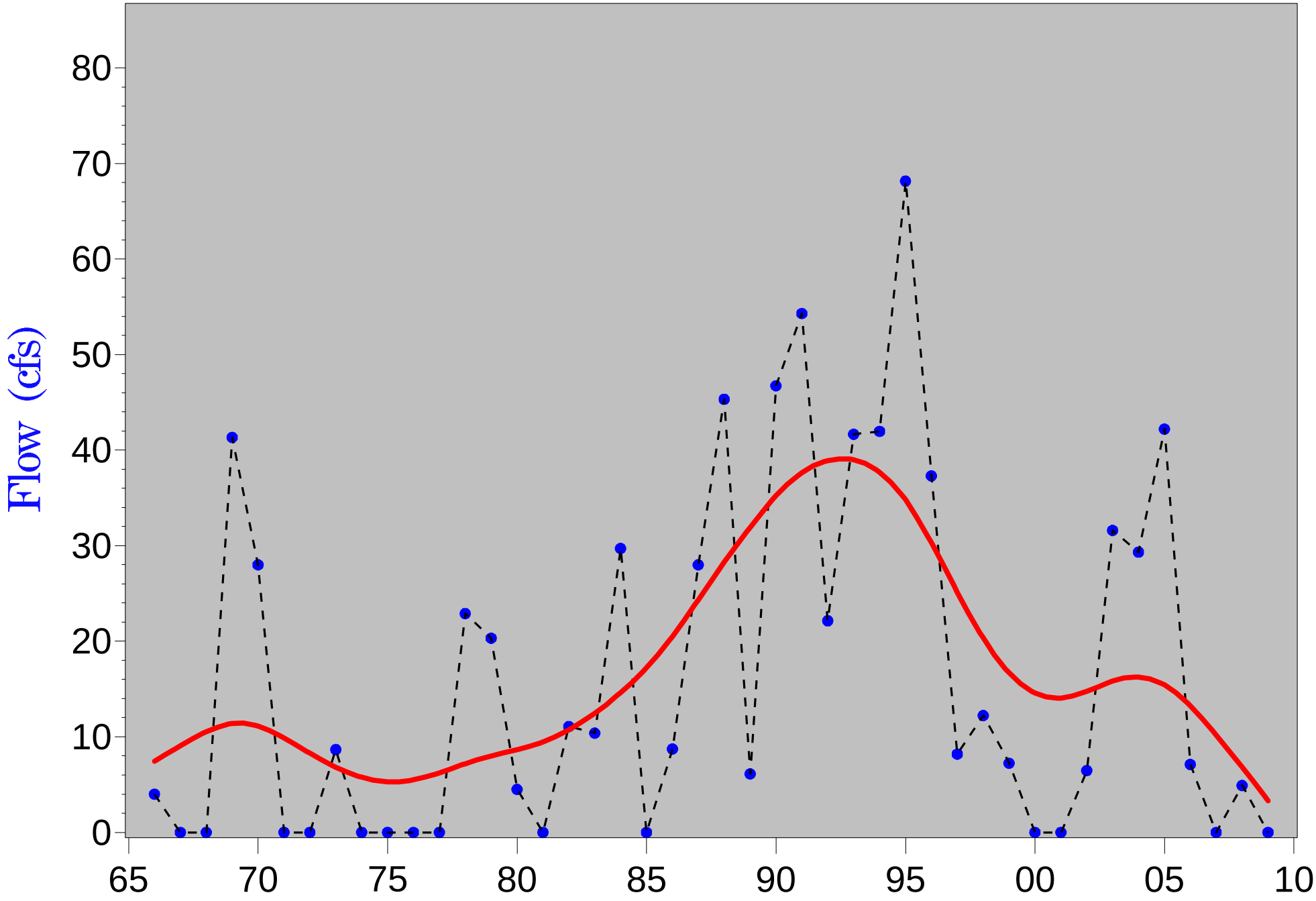


Figure 3.17b Estimated yearly minimum 3-day flow without Facility withdrawals (1965-2009)

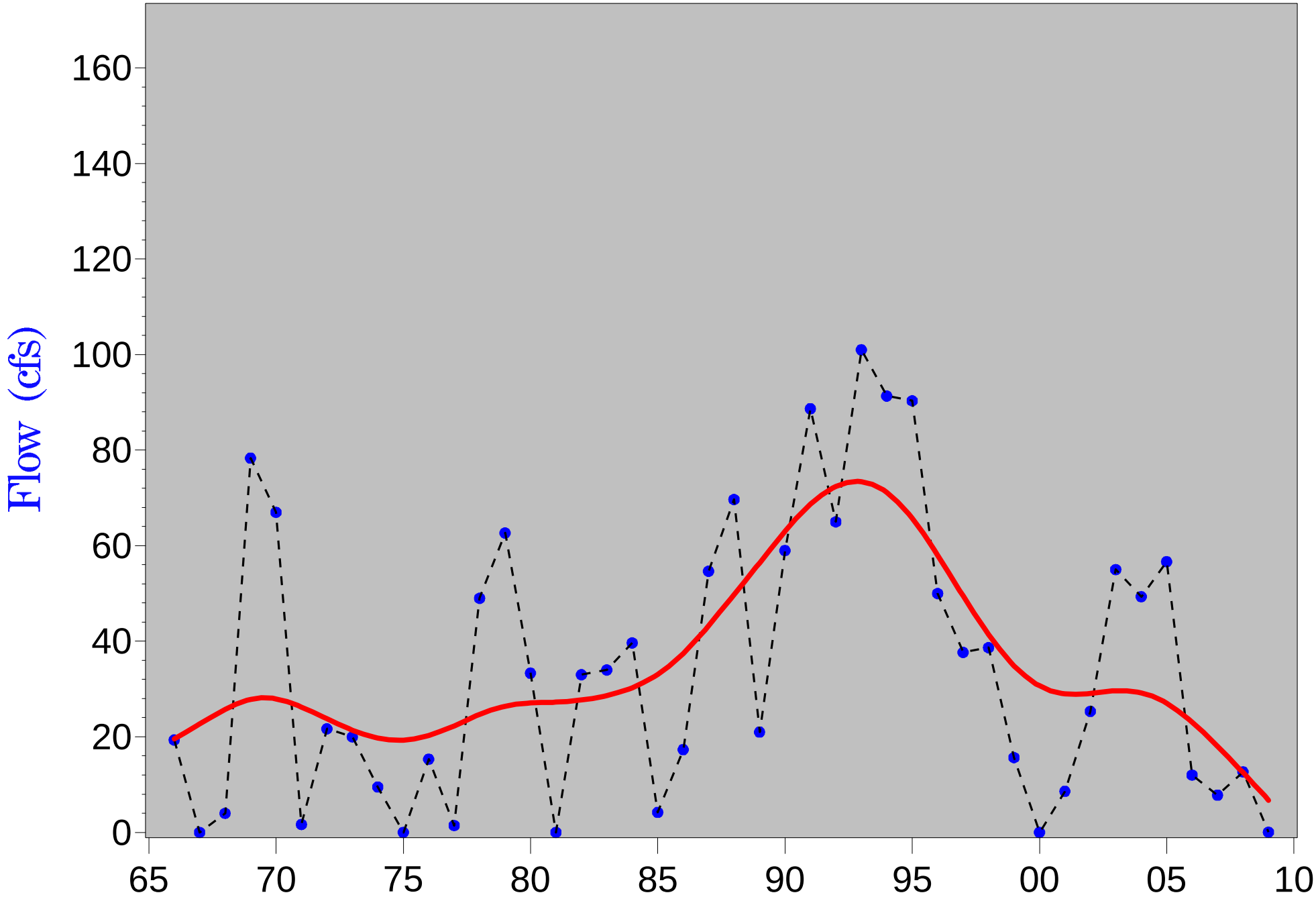


Figure 3.18a Yearly P10 3-day flow at the USGS Shell Creek gage (1965-2009)

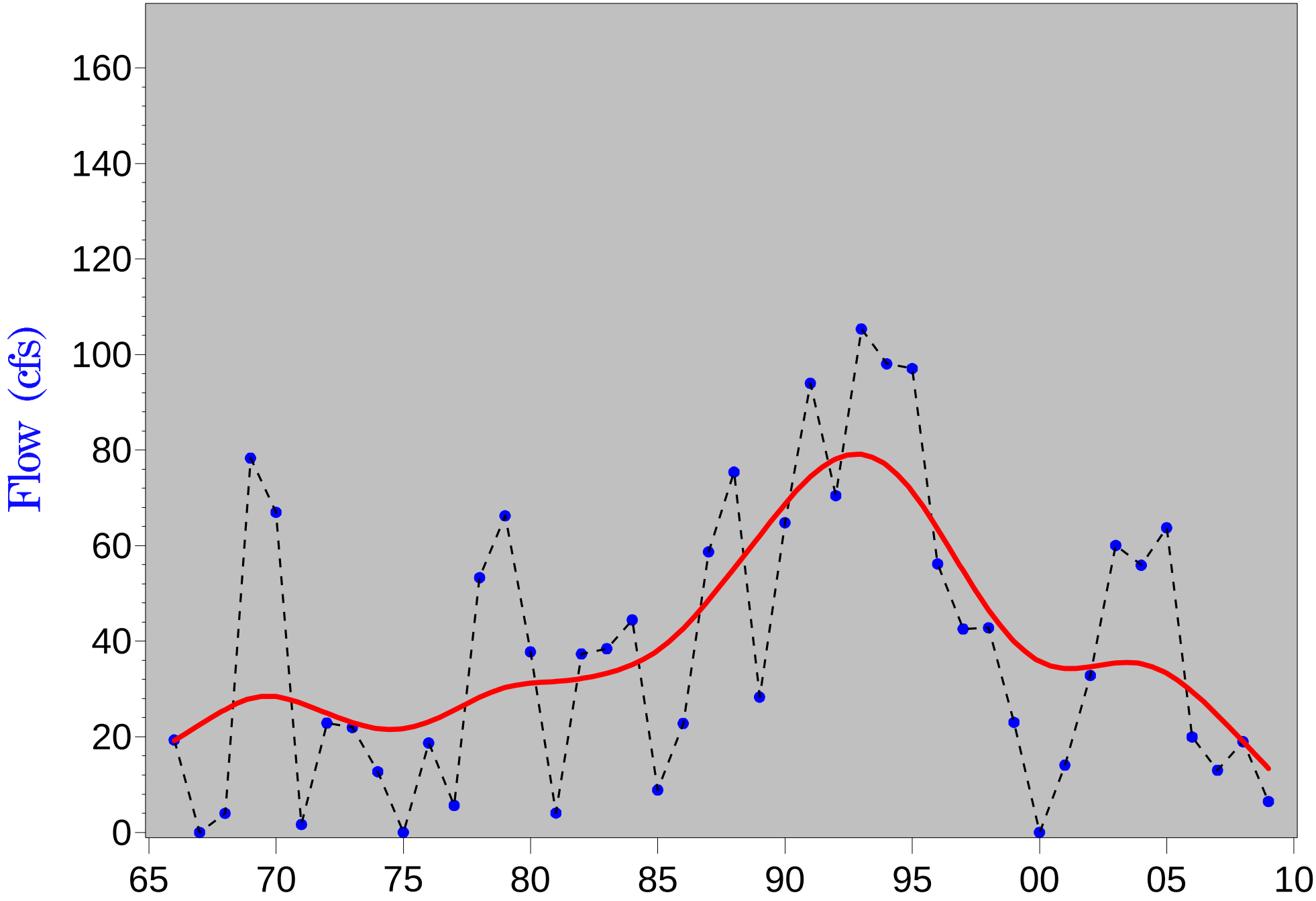
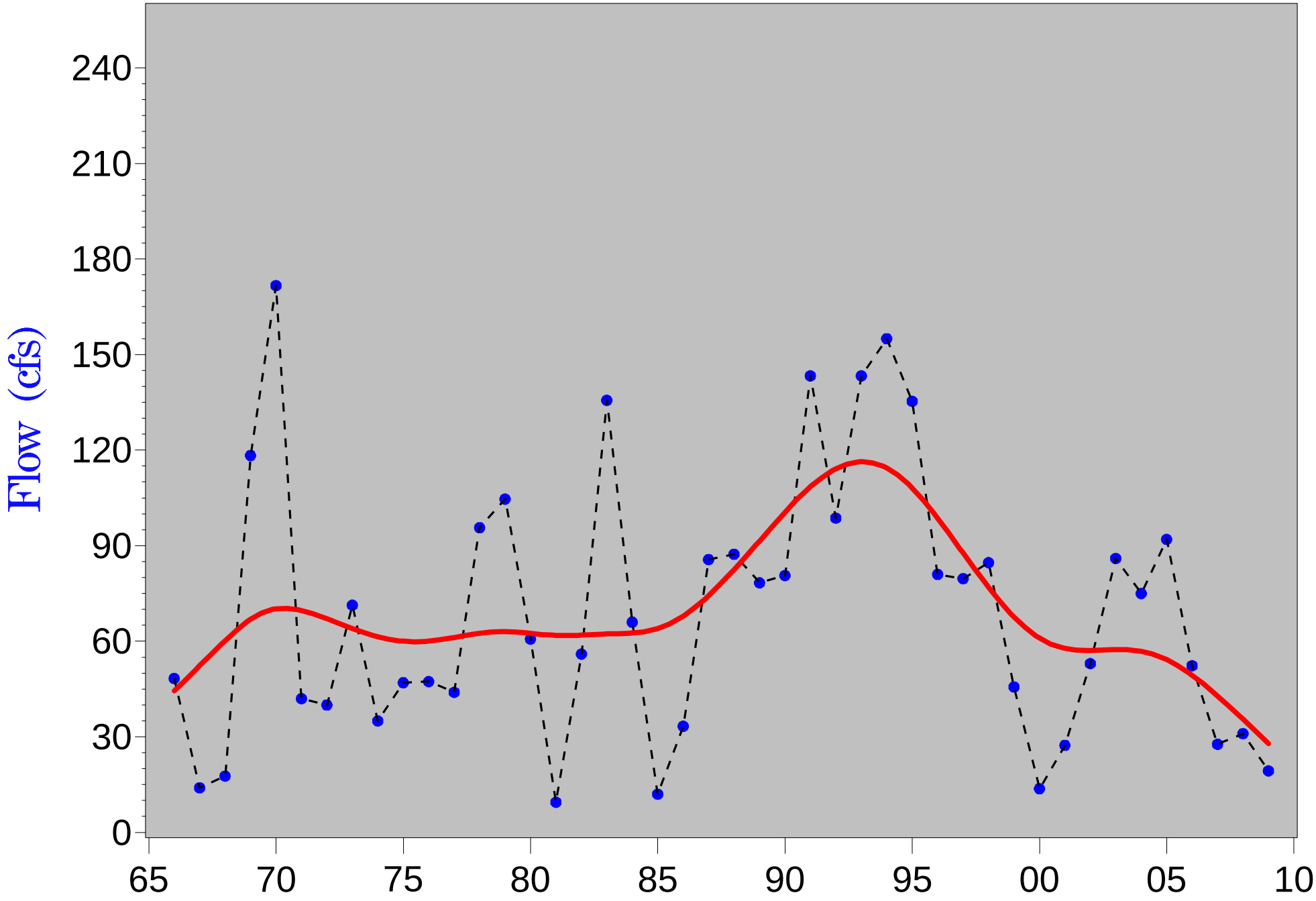
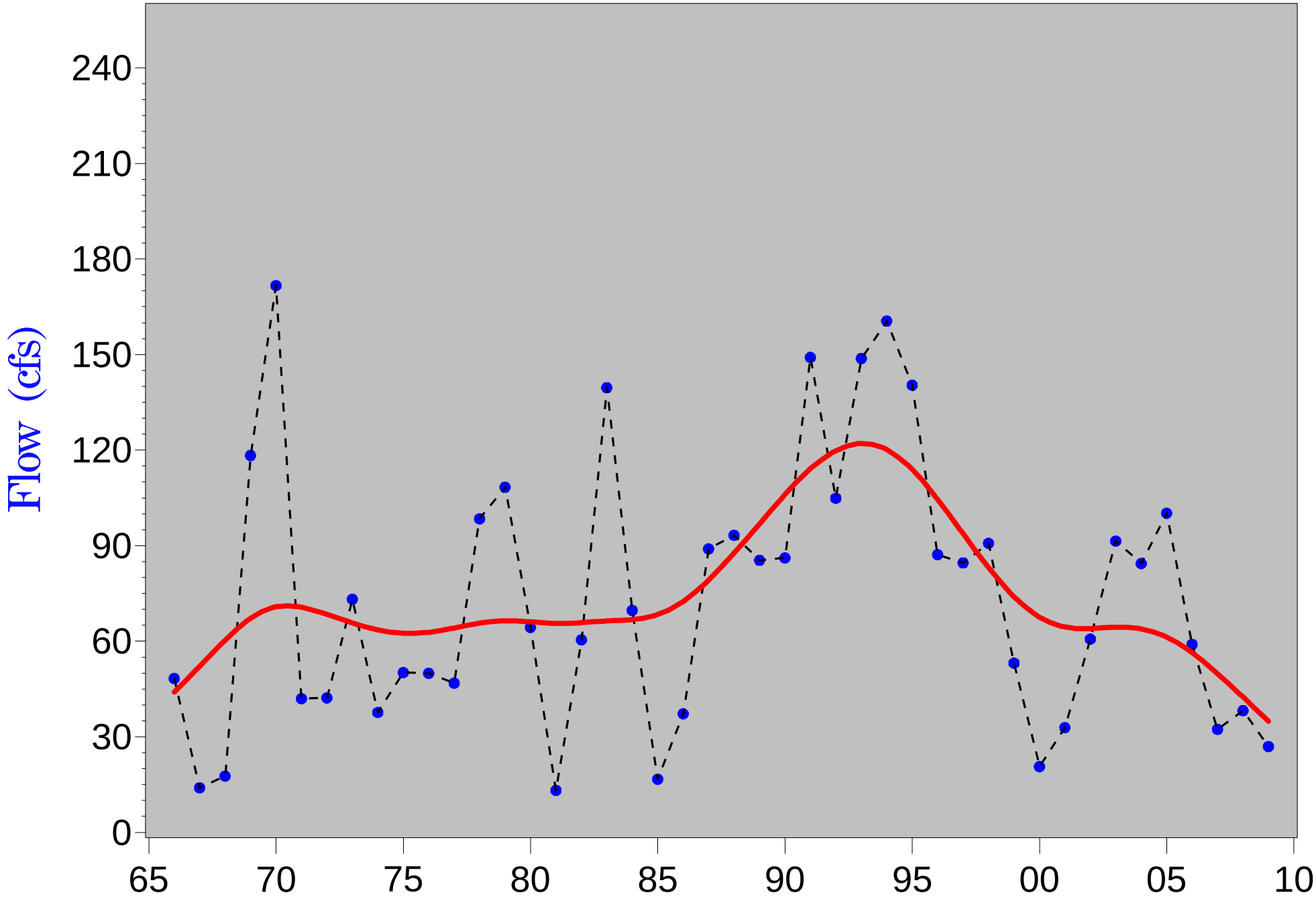


Figure 3.18b Estimated yearly P10 3-day flow without Facility withdrawals (1965-2009)



. Figure 3.19a Yearly P25 3-day flow at the USGS Shell Creek gage (1965-2009)



. Figure 3.19b Estimated yearly P25 3-day flow without Facility withdrawals (1965-2009)

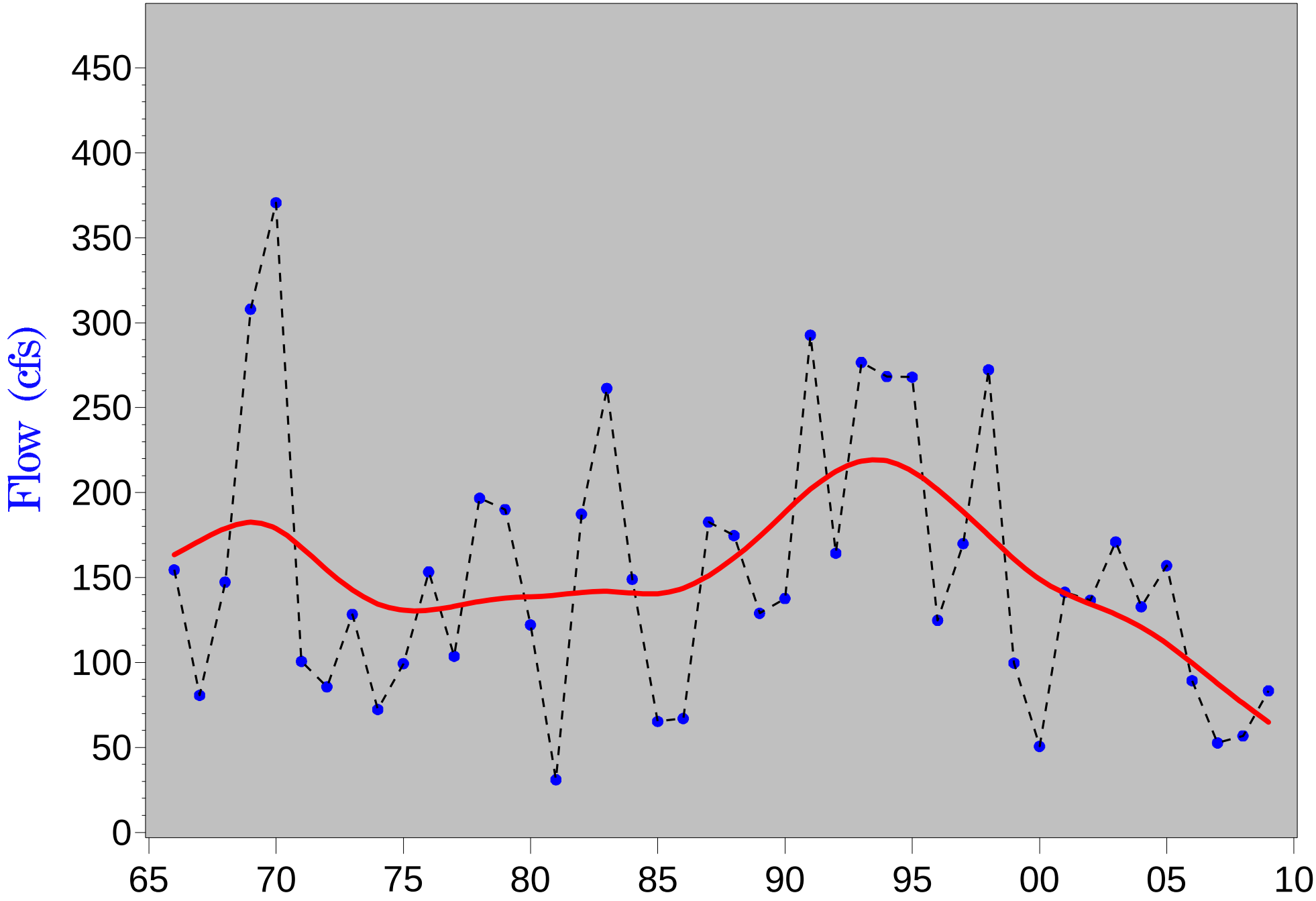


Figure 3.20a Yearly P50 (median) 3-day flow at the USGS Shell Creek gage (1965-2009)

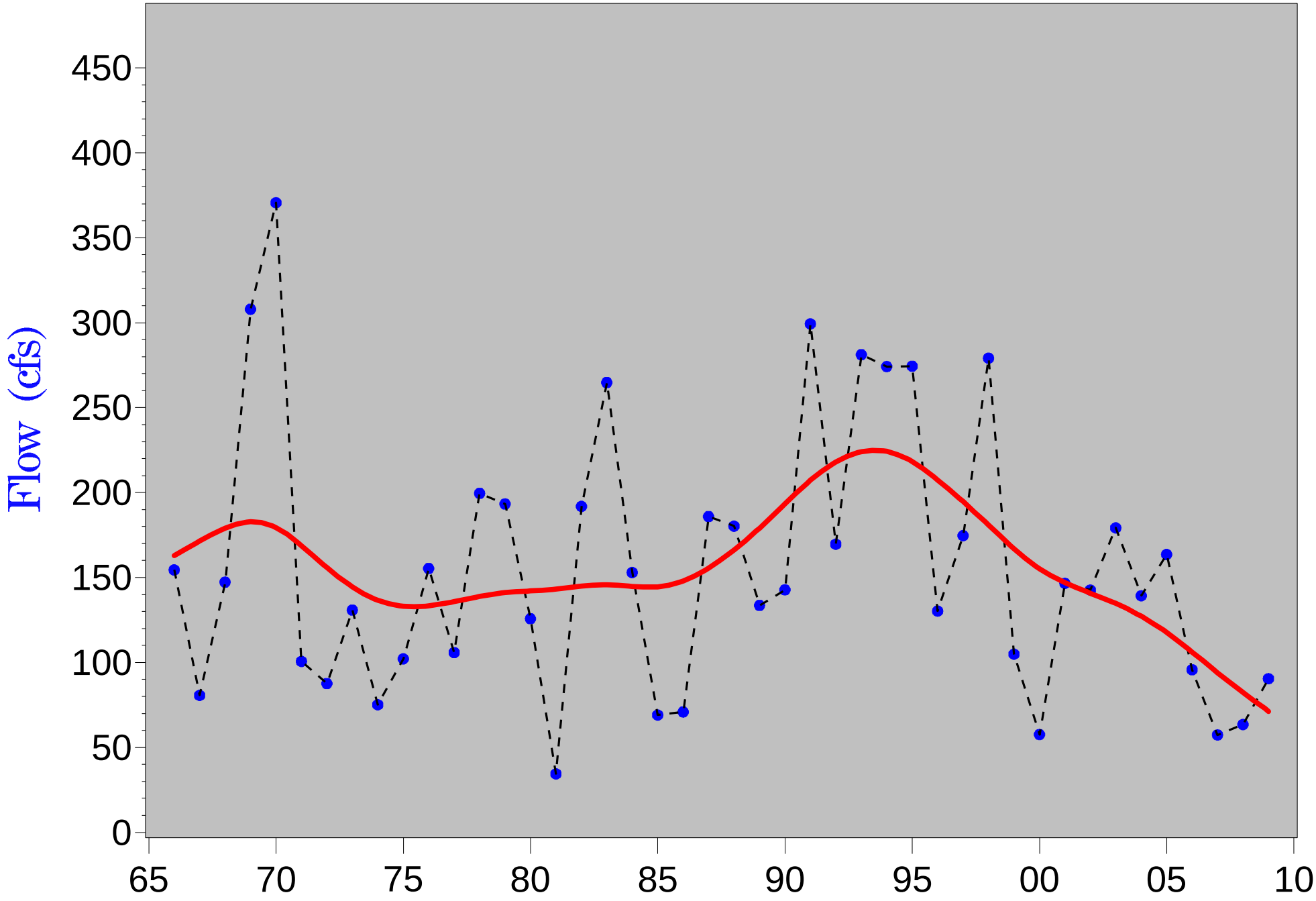


Figure 3.20b Estimated yearly P50 (median) 3-day flow without Facility withdrawals (1965-2009)

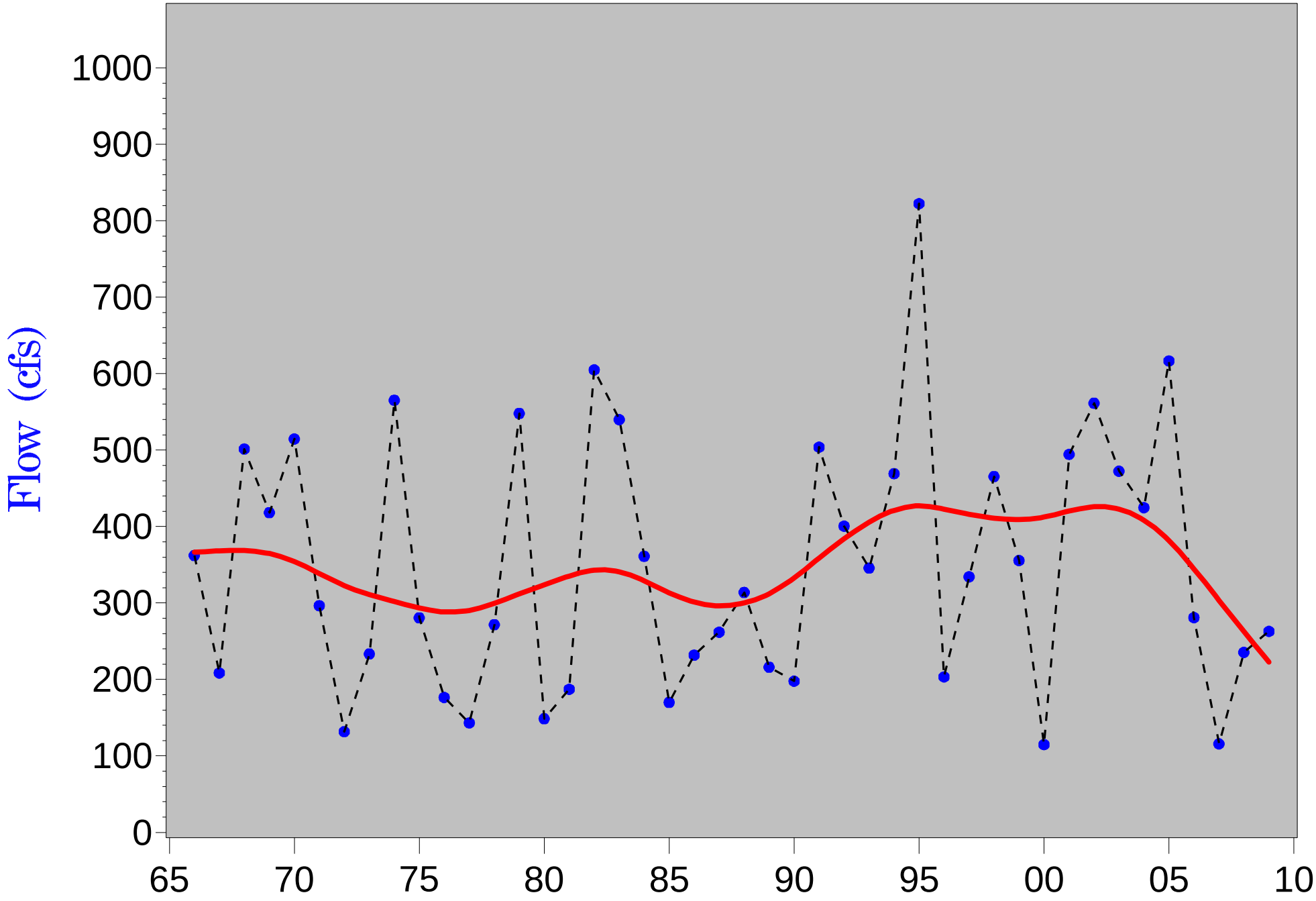


Figure 3.21a Yearly mean 3-day flow at the USGS Shell Creek gage (1965-2009)

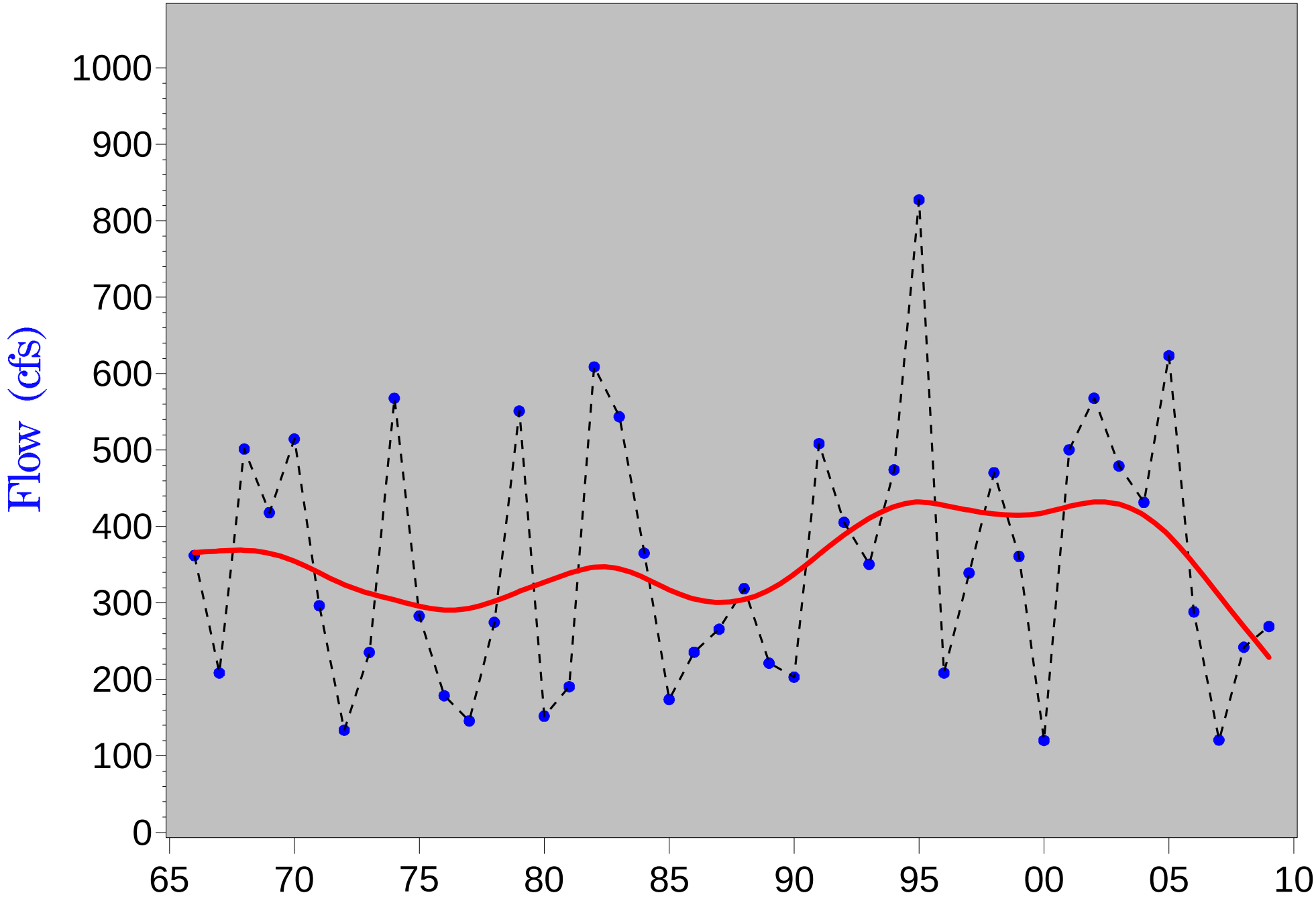


Figure 3.21b Estimated yearly mean 3-day flow without Facility withdrawals (1965-2009)

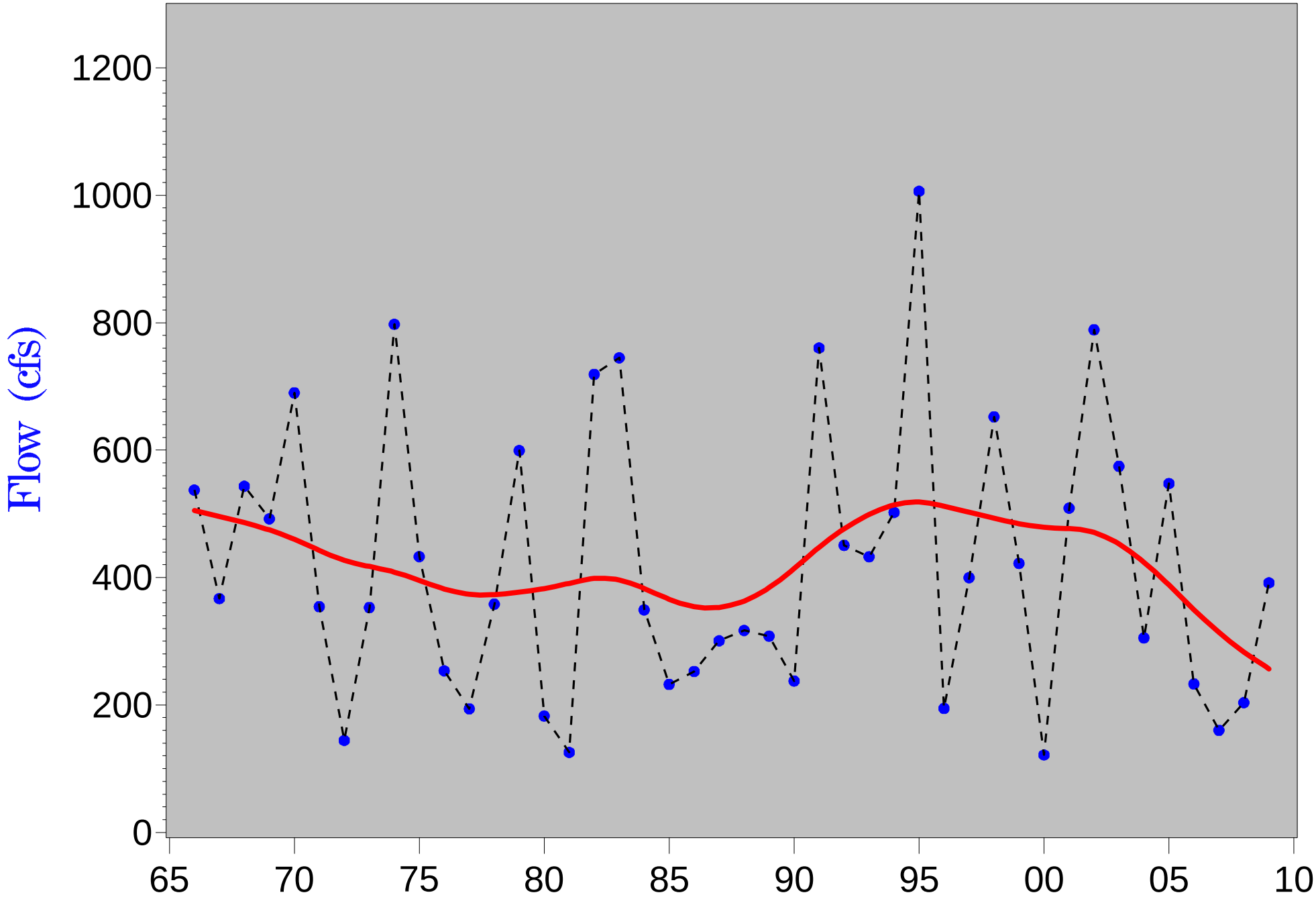


Figure 3.22a Yearly P75 3-day flow at the USGS Shell Creek gage (1965-2009)

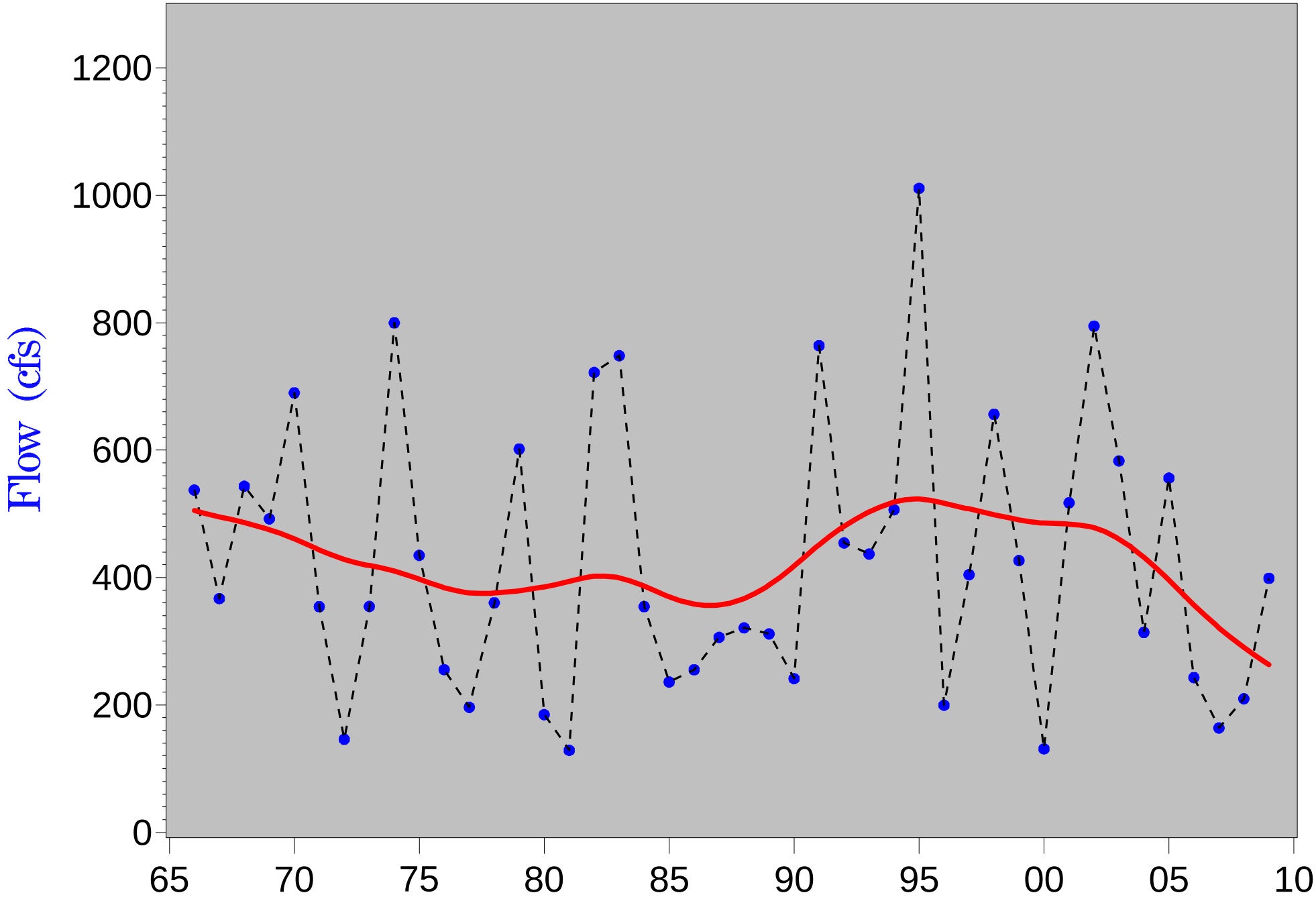


Figure 3.22b Estimated yearly P75 3-day flow without Facility withdrawals (1965-2009)

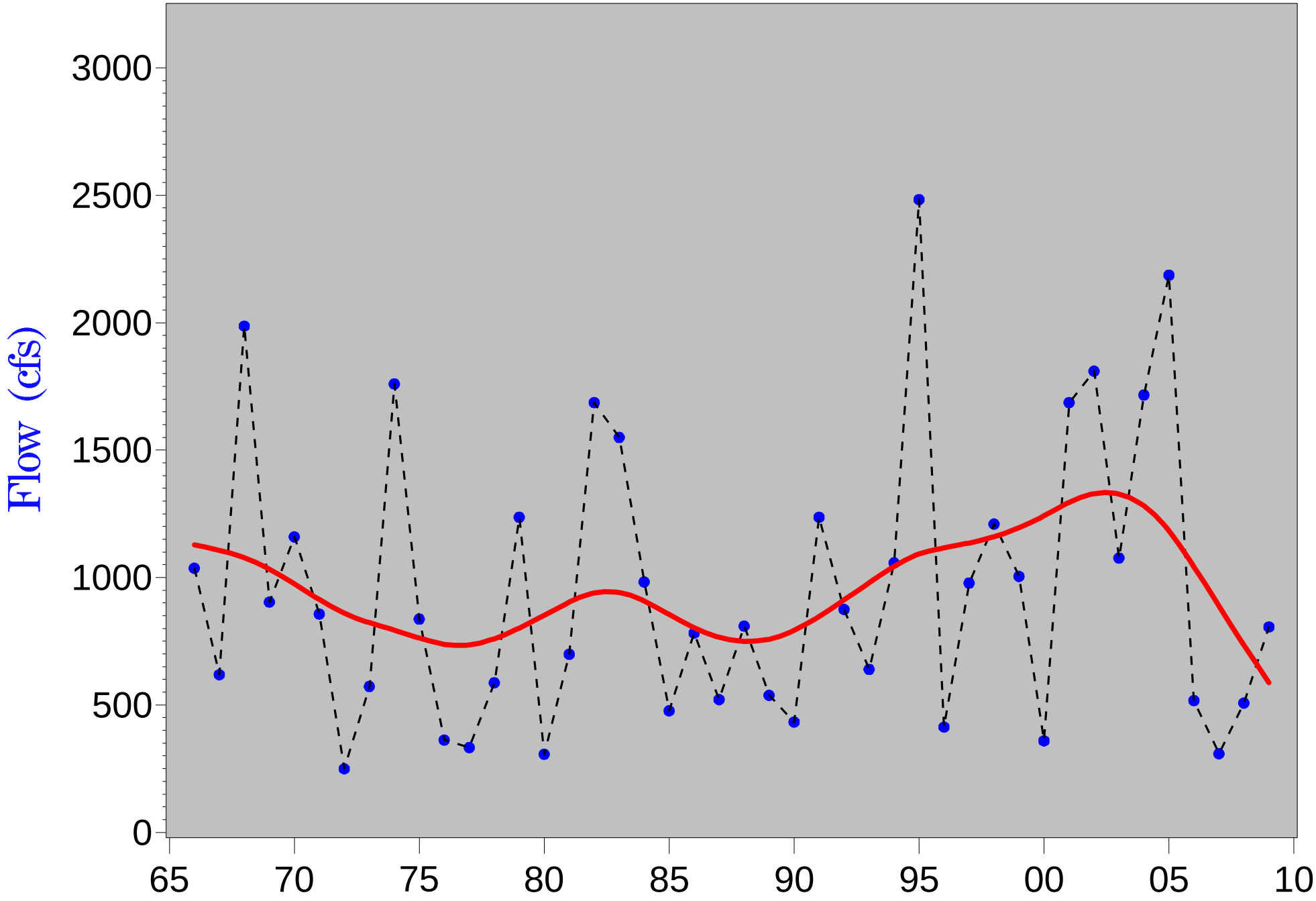


Figure 3.23a Yearly P90 3-day flow at the USGS Shell Creek gage (1965-2009)

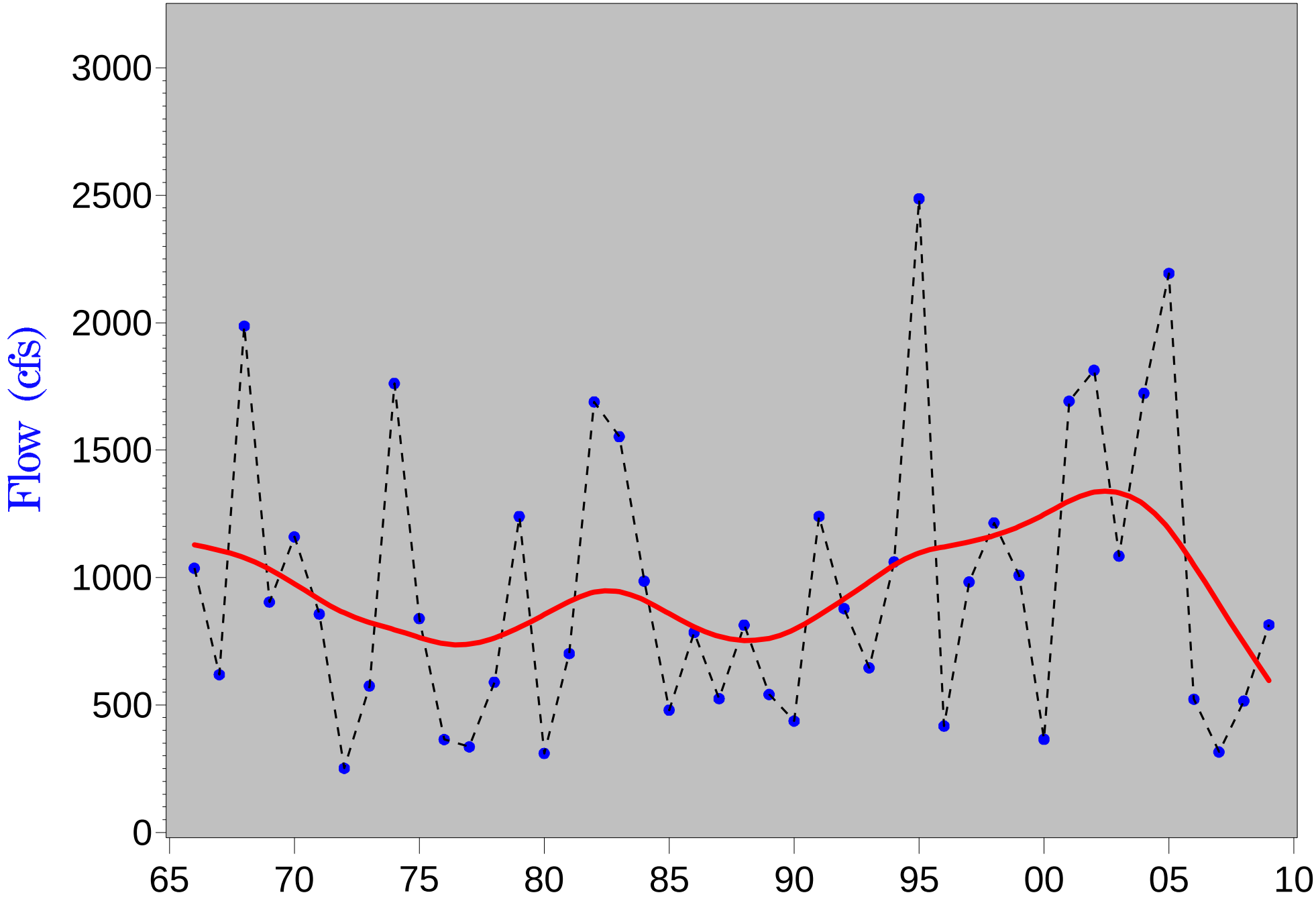


Figure 3.23b Estimated yearly P90 3-day flow without Facility withdrawals (1965-2009)

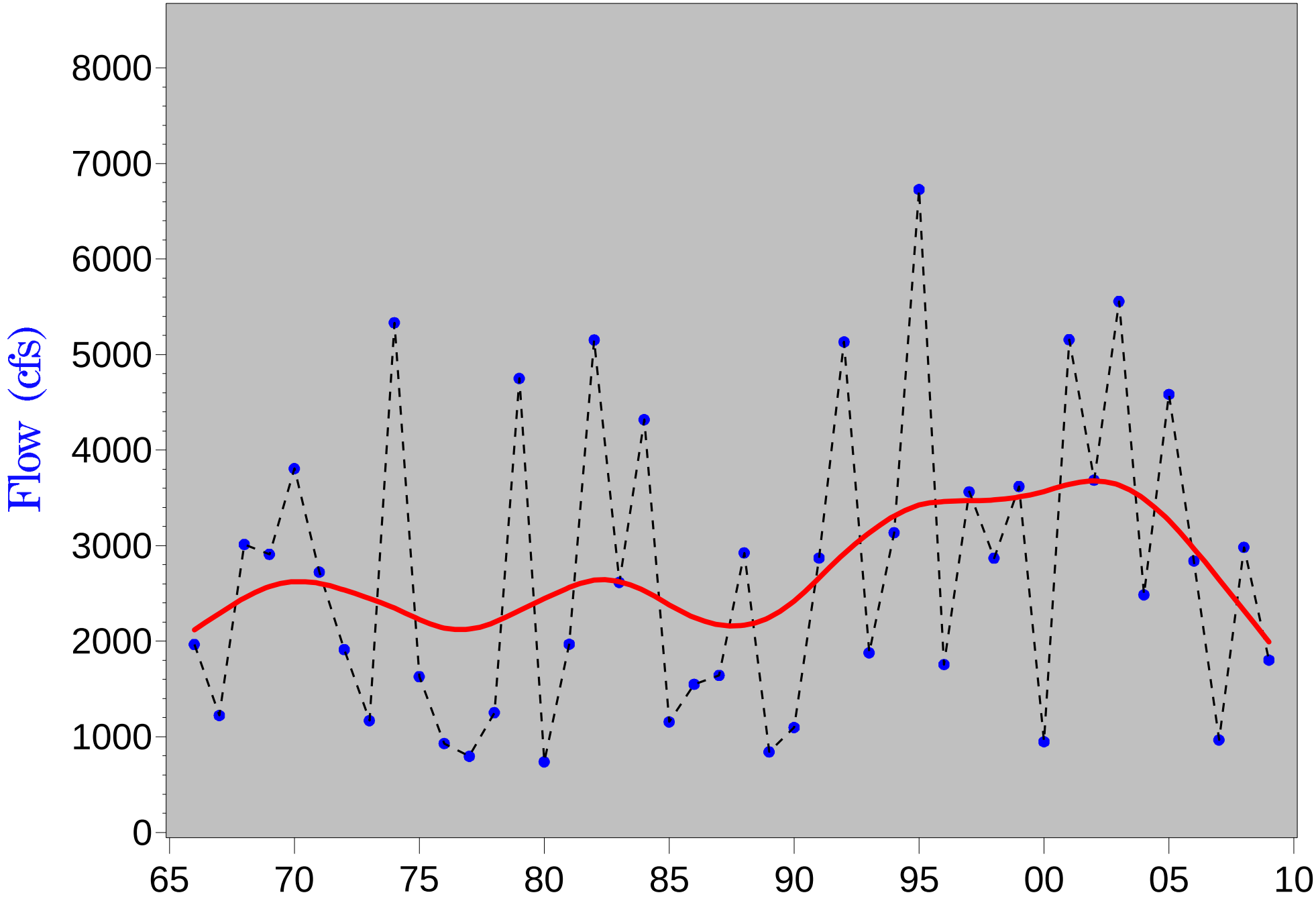


Figure 3.24a Yearly maximum 3-day flow at the USGS Shell Creek gage (1965-2009)

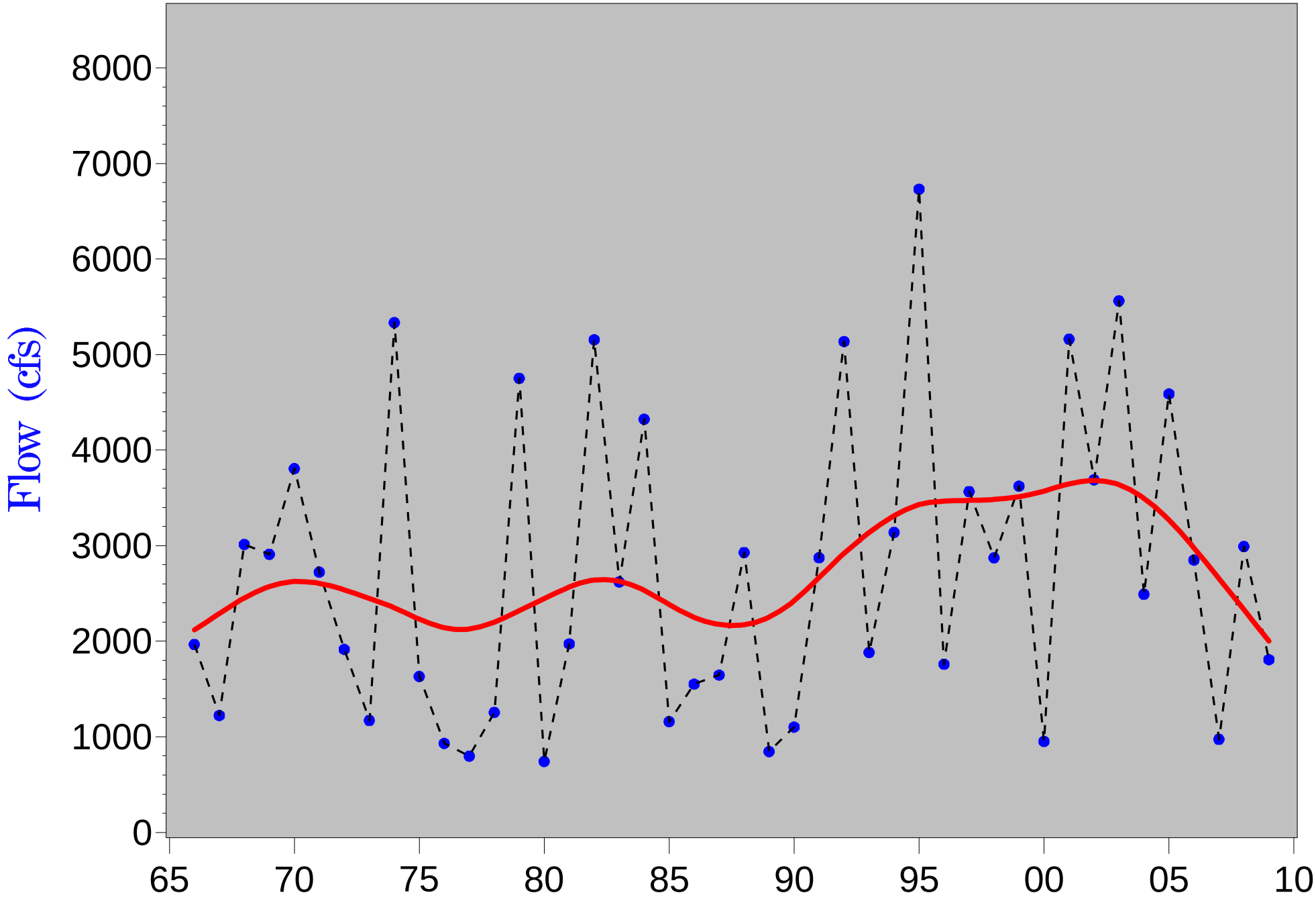


Figure 3.24b Estimated yearly maximum 3-day flow without Facility withdrawals (1965-2009)

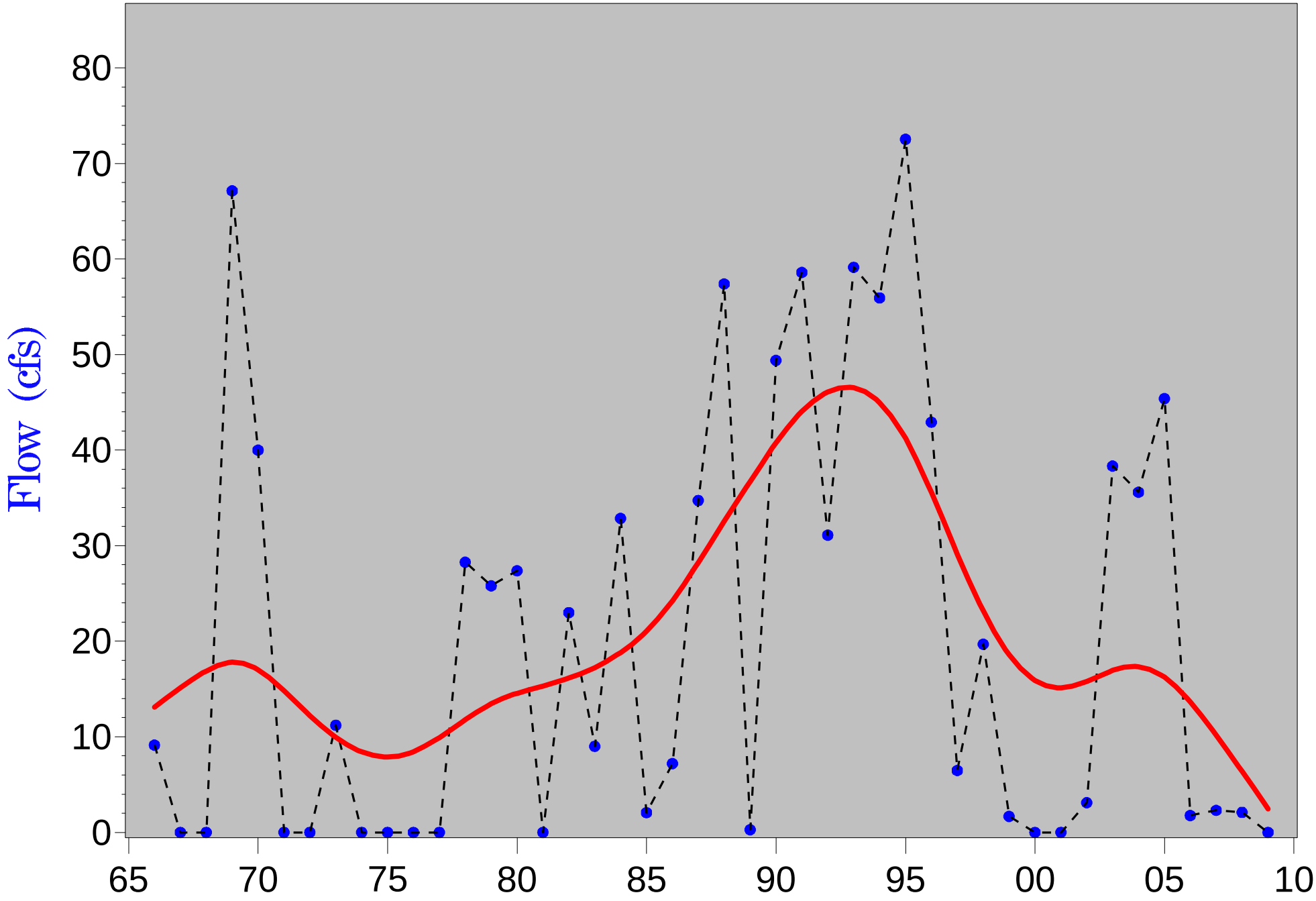


Figure 3.25a Yearly minimum 15-day flow at the USGS Shell Creek gage (1965-2009)

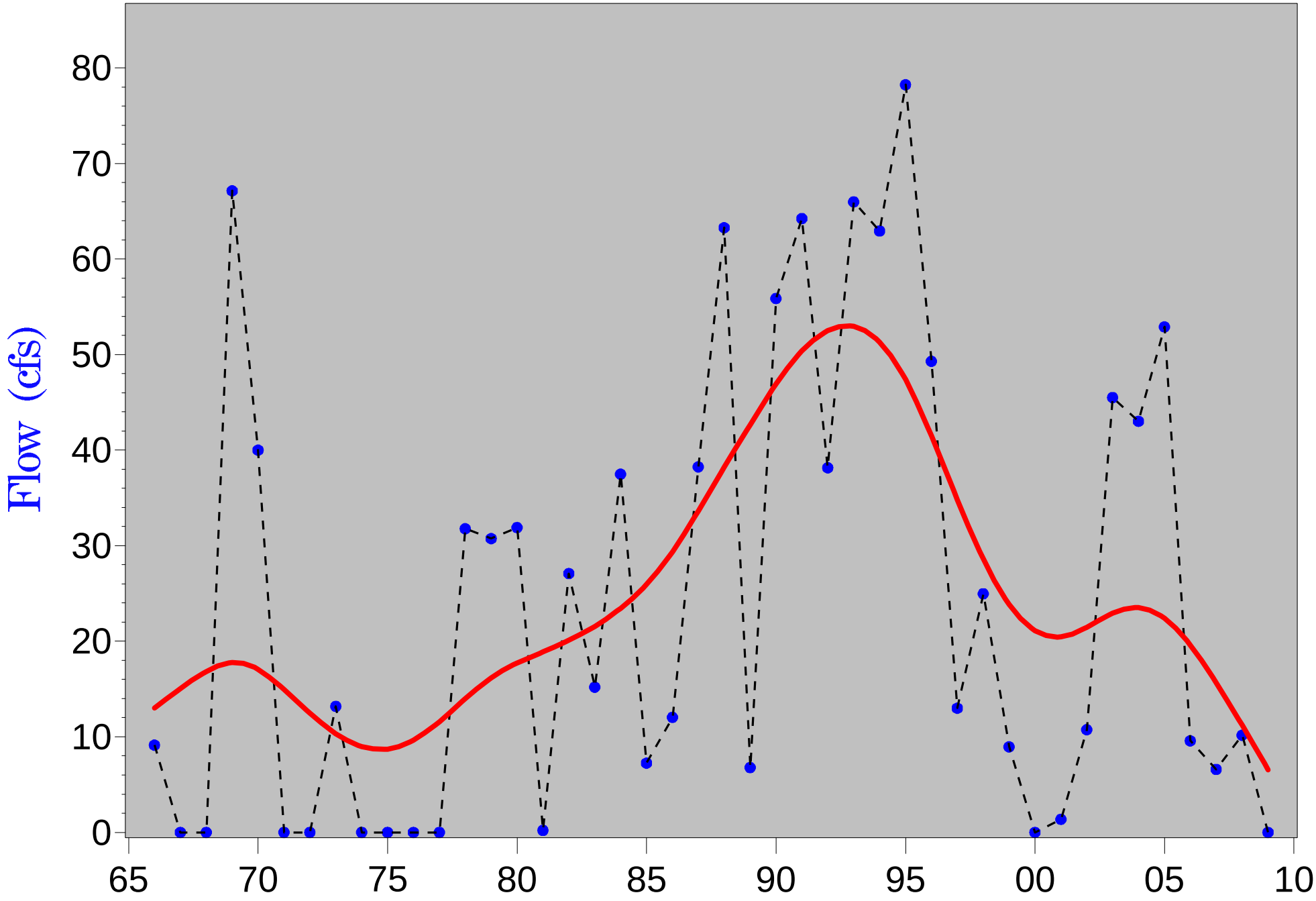


Figure 3.25b Estimated yearly minimum 15-day flow without Facility withdrawals (1965-2009)

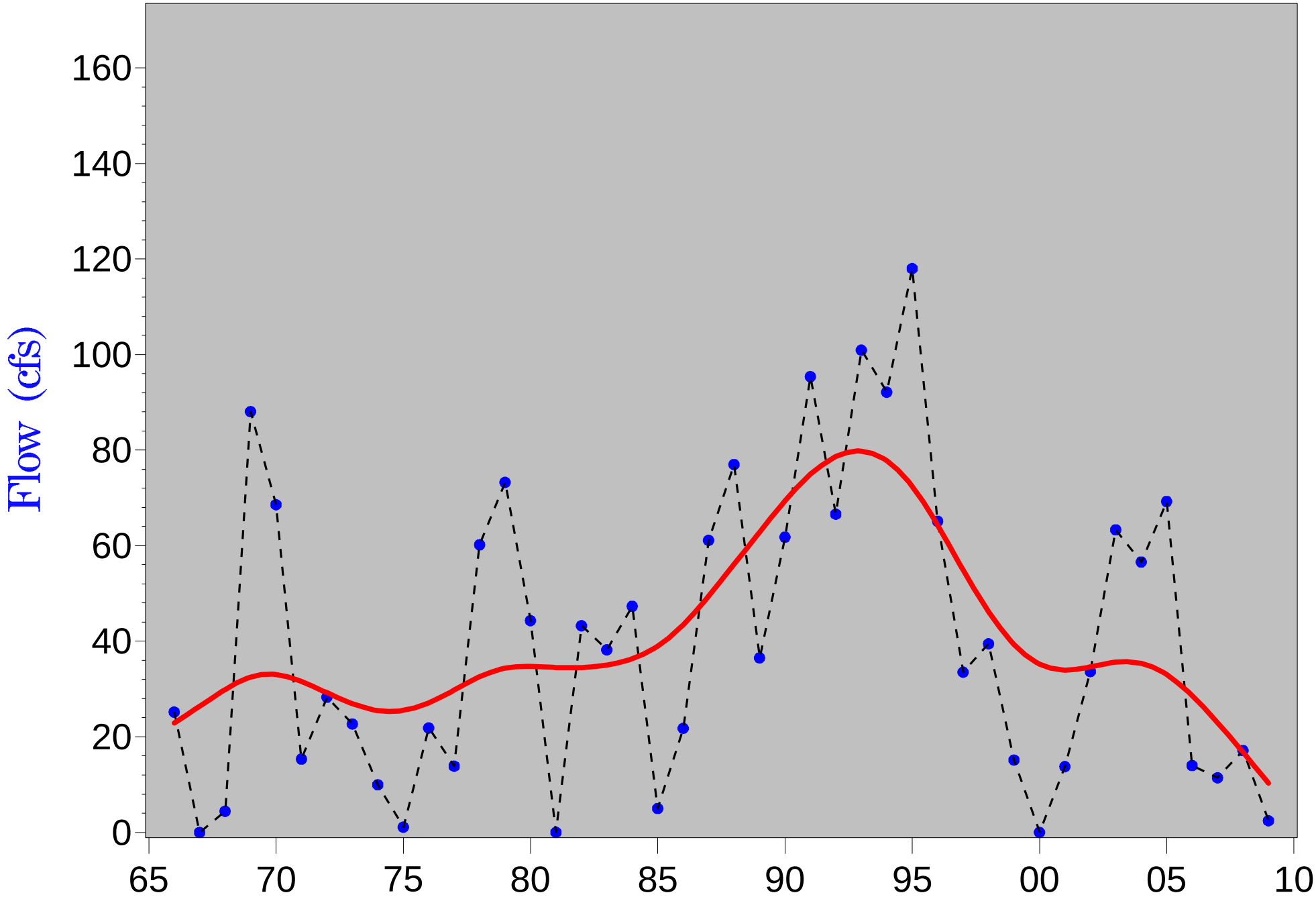


Figure 3.26a Yearly P10 15-day flow at the USGS Shell Creek gage (1965-2009)

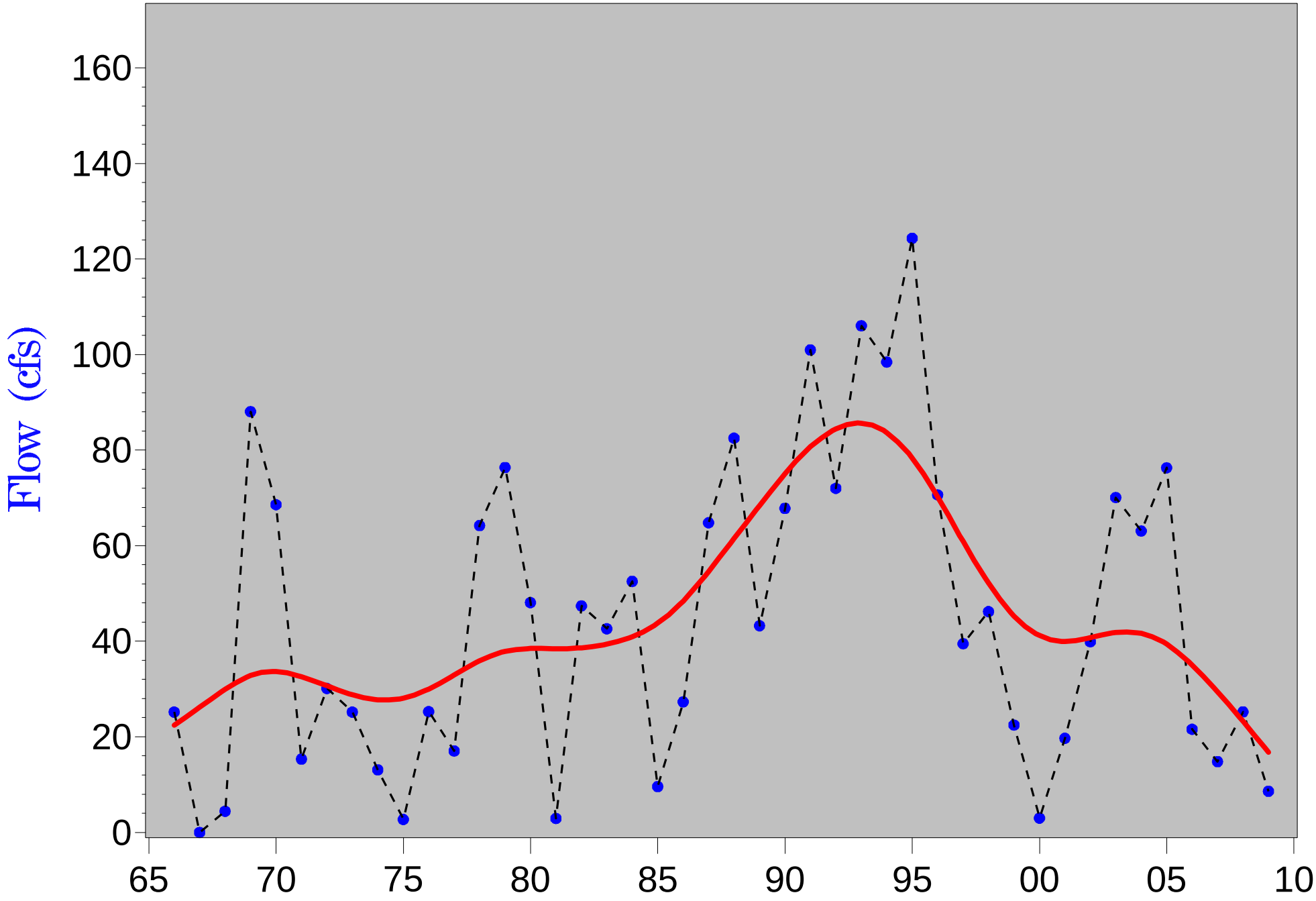
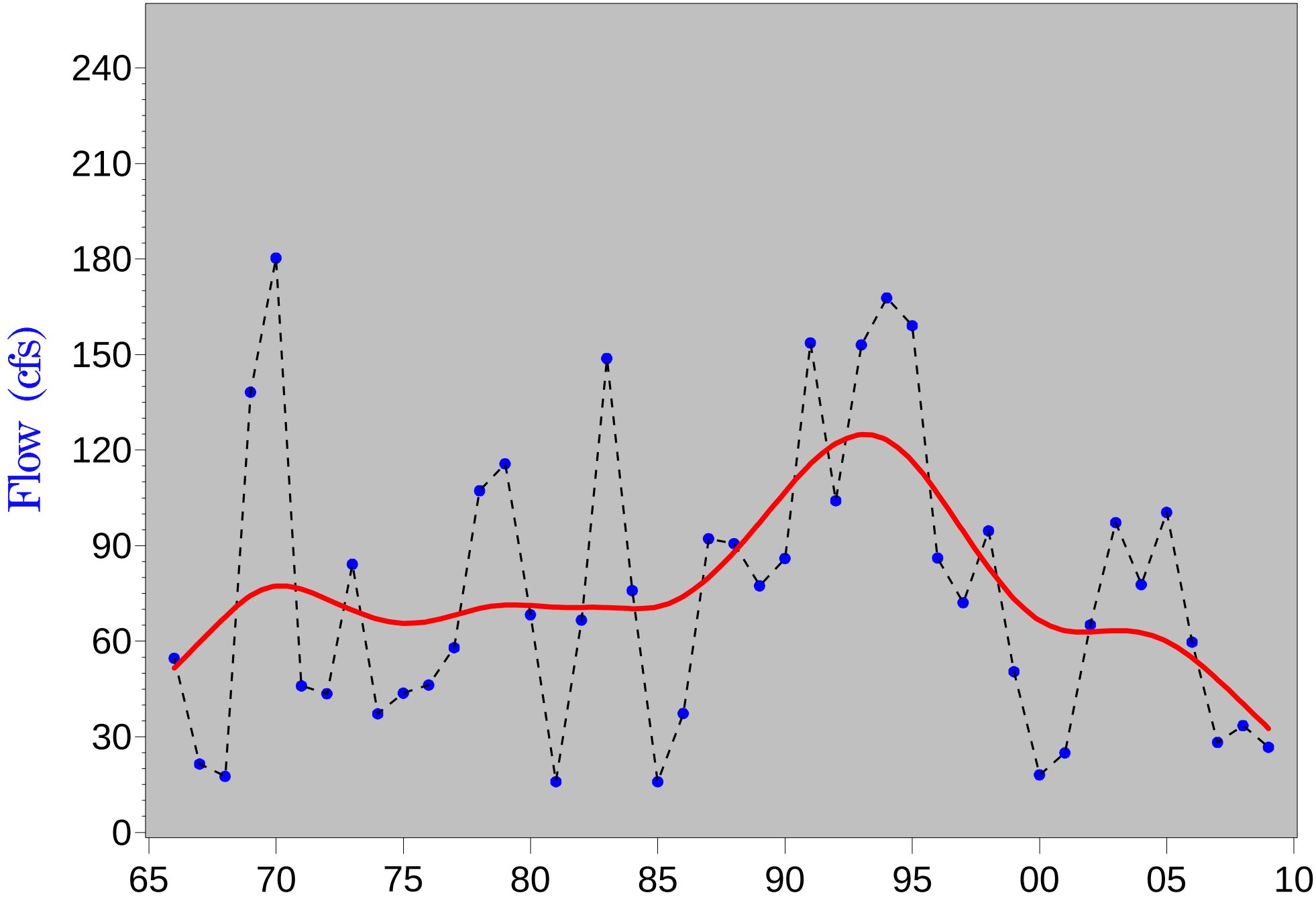
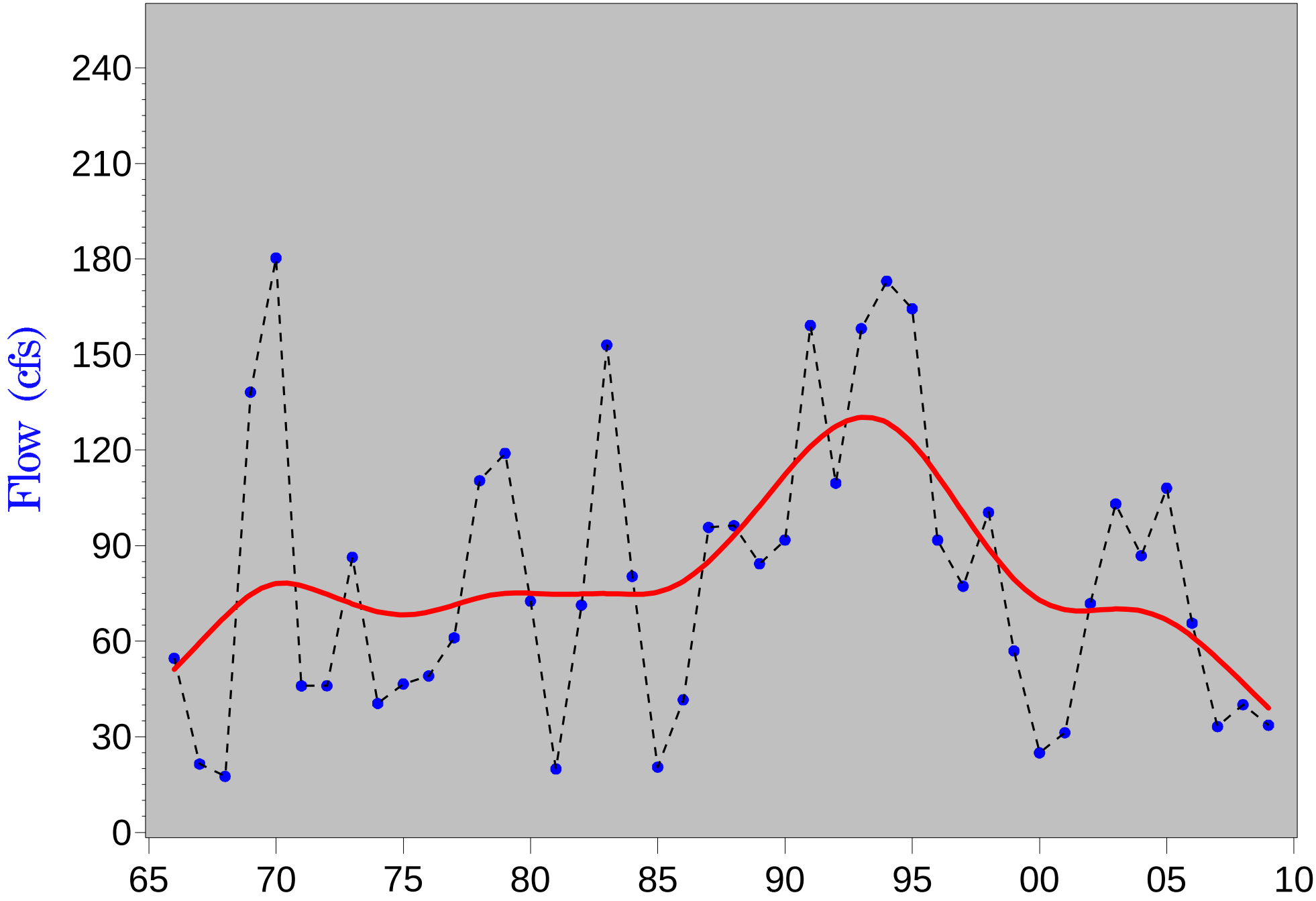


Figure 3.26b Estimated yearly P10 15-day flow without Facility withdrawals (1965-2009)



. Figure 3.27a Yearly P25 15-day flow at the USGS Shell Creek gage (1965-2009)



. Figure 3.27b Estimated yearly P25 15-day flow without Facility withdrawals (1965-2009)

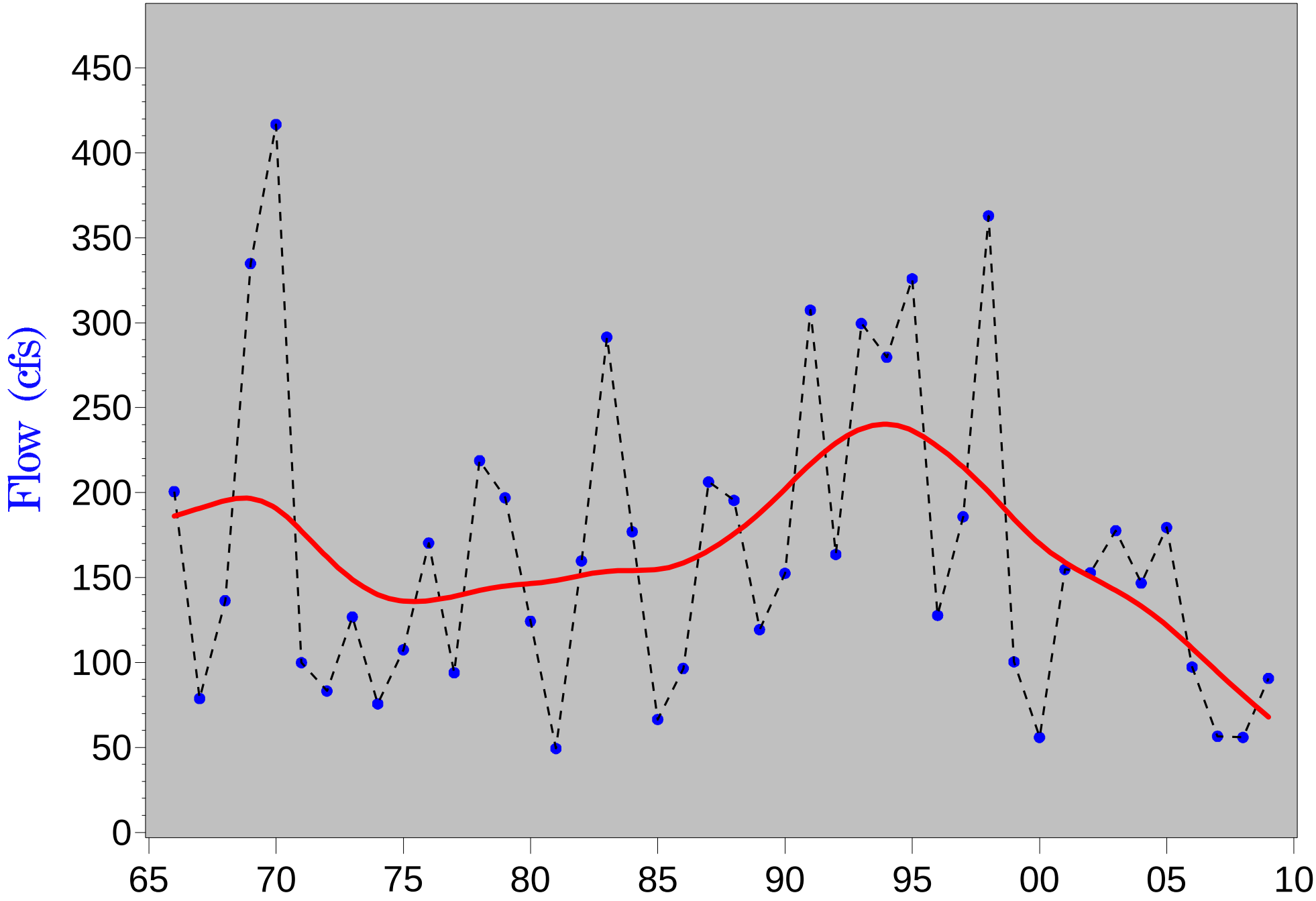


Figure 3.28a Yearly P50 (median) 15-day flow at the USGS Shell Creek gage (1965-2009)

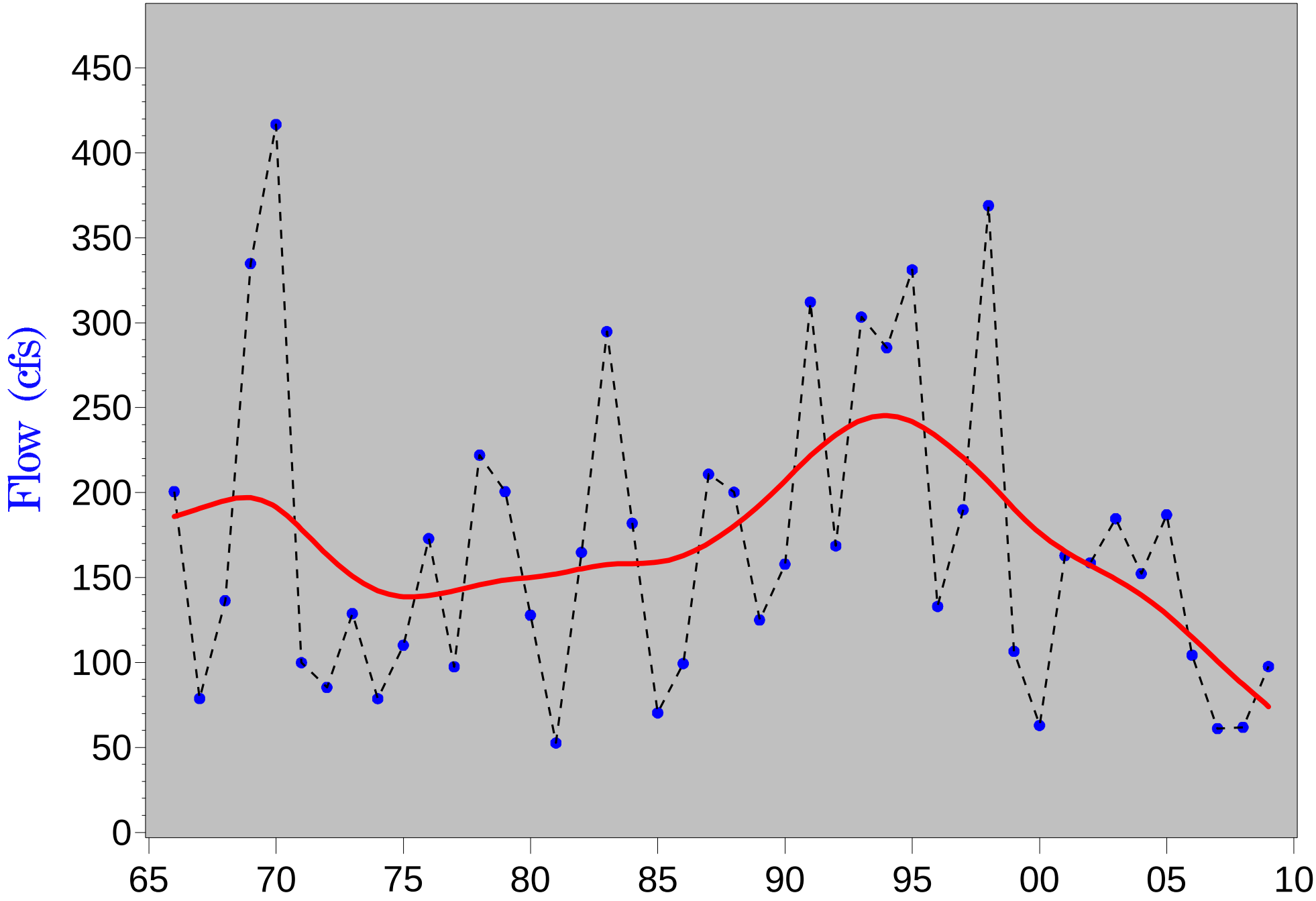


Figure 3.28b Estimated yearly P50 (median) 15-day flow without Facility withdrawals (1965-2009)

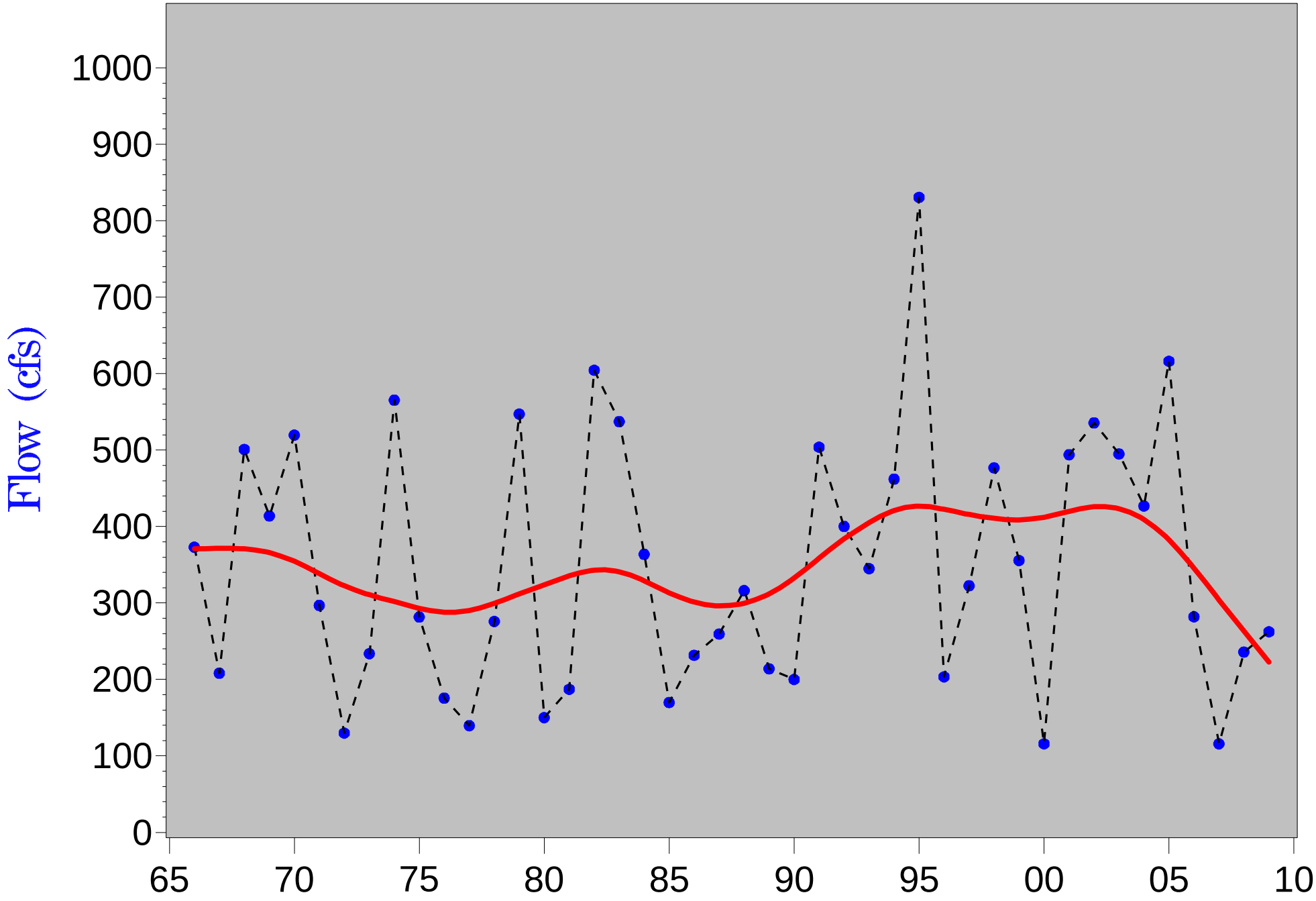


Figure 3.29a Yearly mean 15-day flow at the USGS Shell Creek gage (1965-2009)

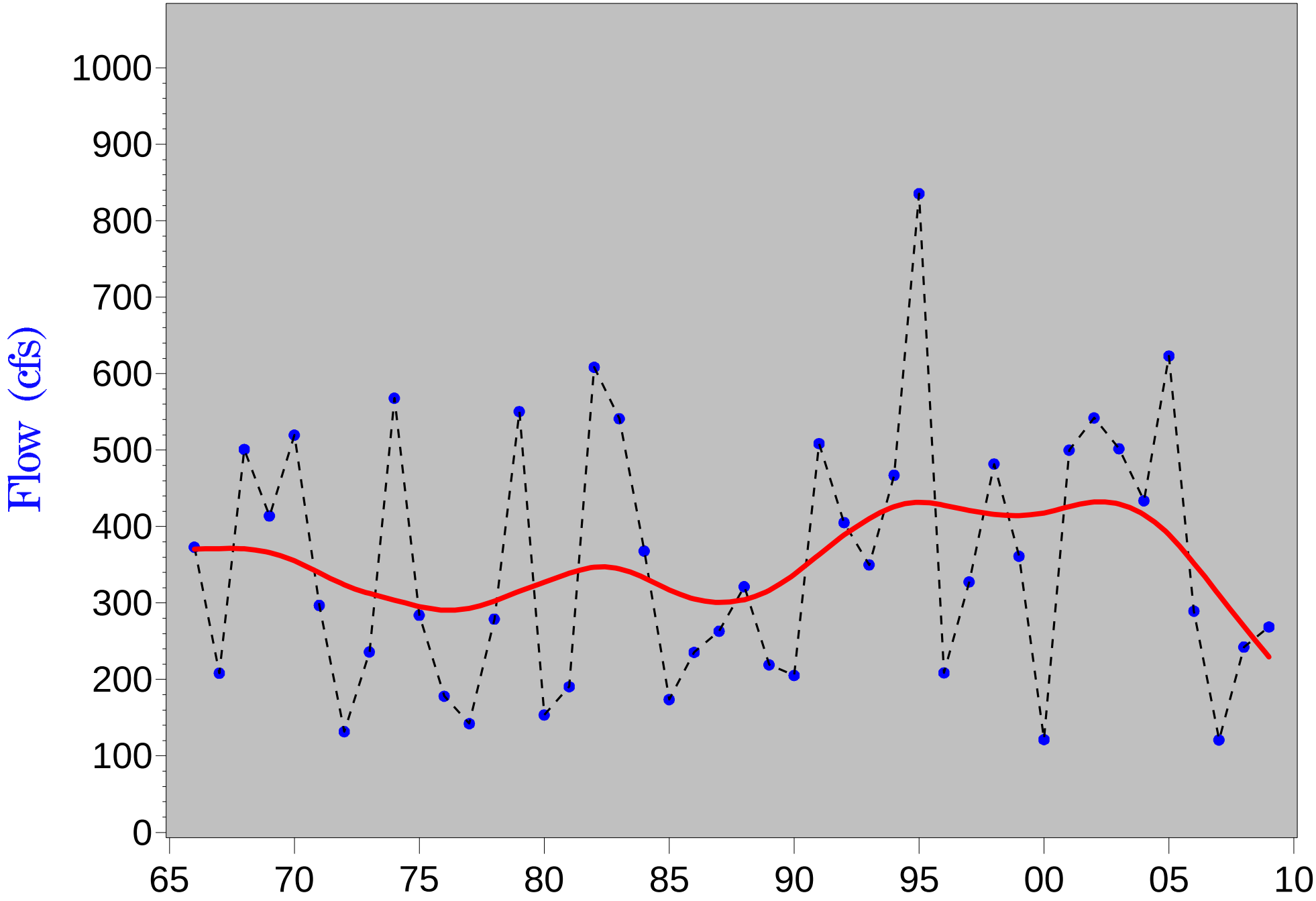


Figure 3.29b Estimated yearly mean 15-day flow without Facility withdrawals (1965-2009)

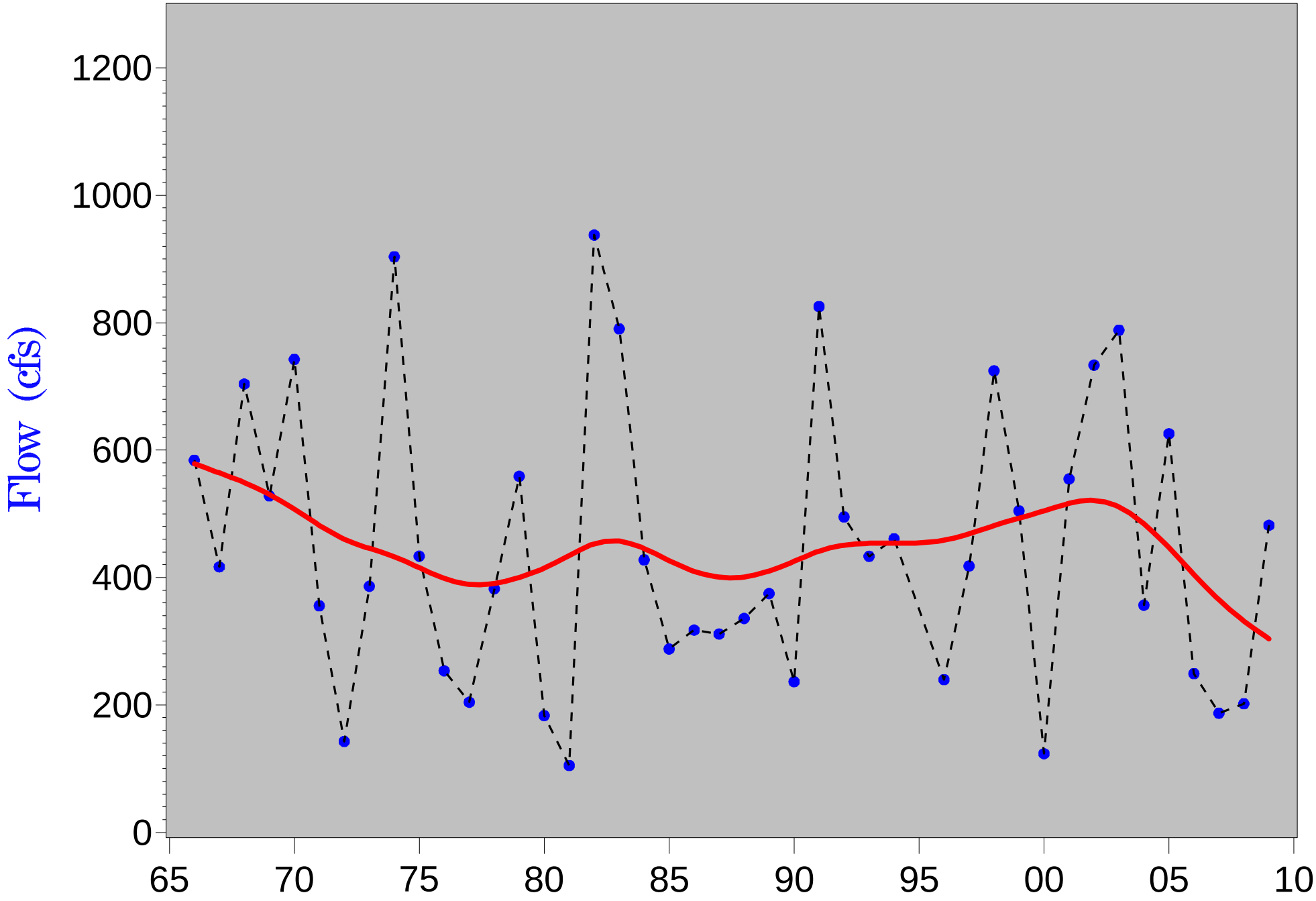


Figure 3.30a Yearly P75 15-day flow at the USGS Shell Creek gage (1965-2009)

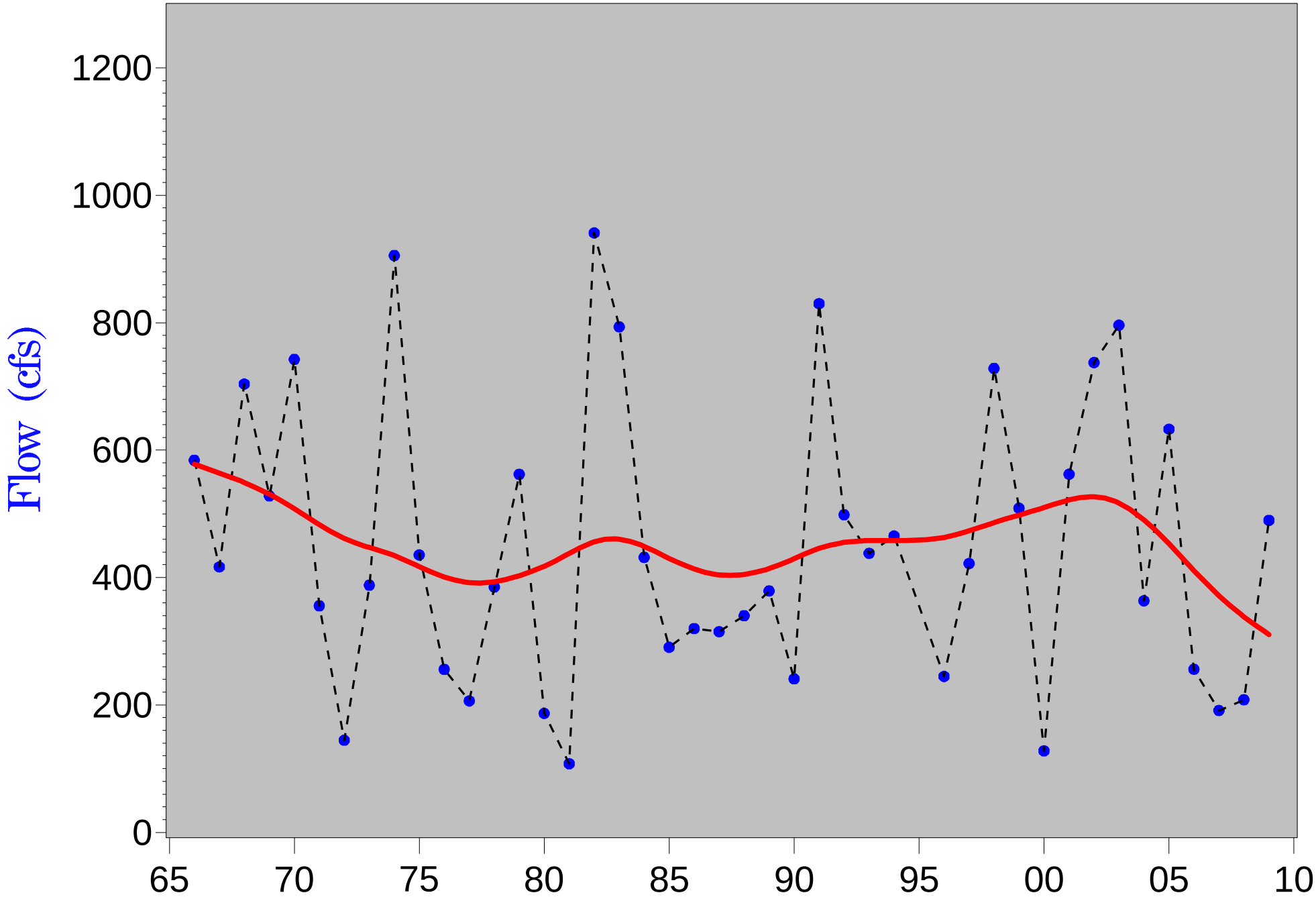


Figure 3.30b Estimated yearly P75 15-day flow without Facility withdrawals (1965-2009)

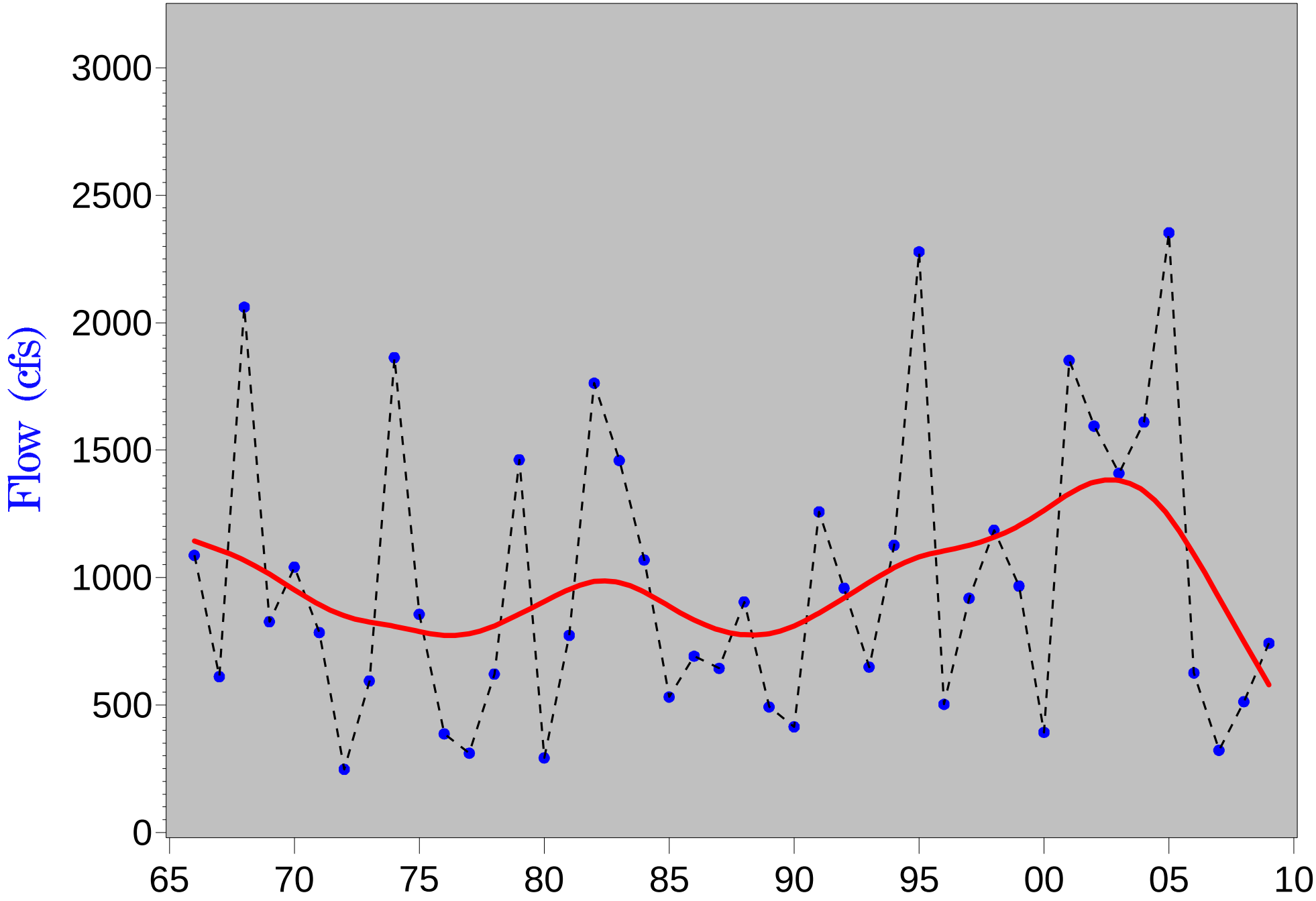


Figure 3.31a Yearly P90 15-day flow at the USGS Shell Creek gage (1965-2009)

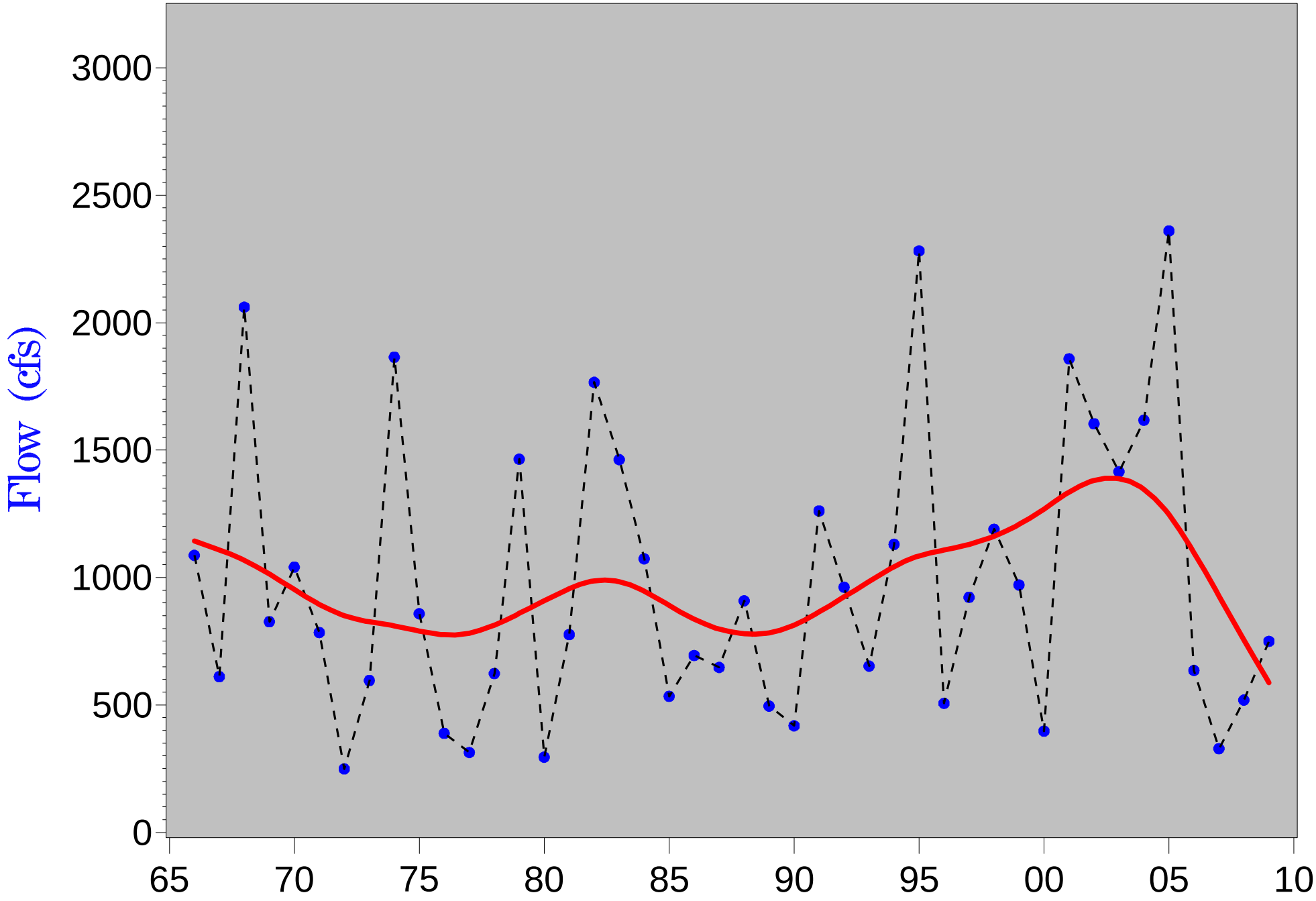


Figure 3.31b Estimated yearly P90 15-day flow without Facility withdrawals (1965-2009)

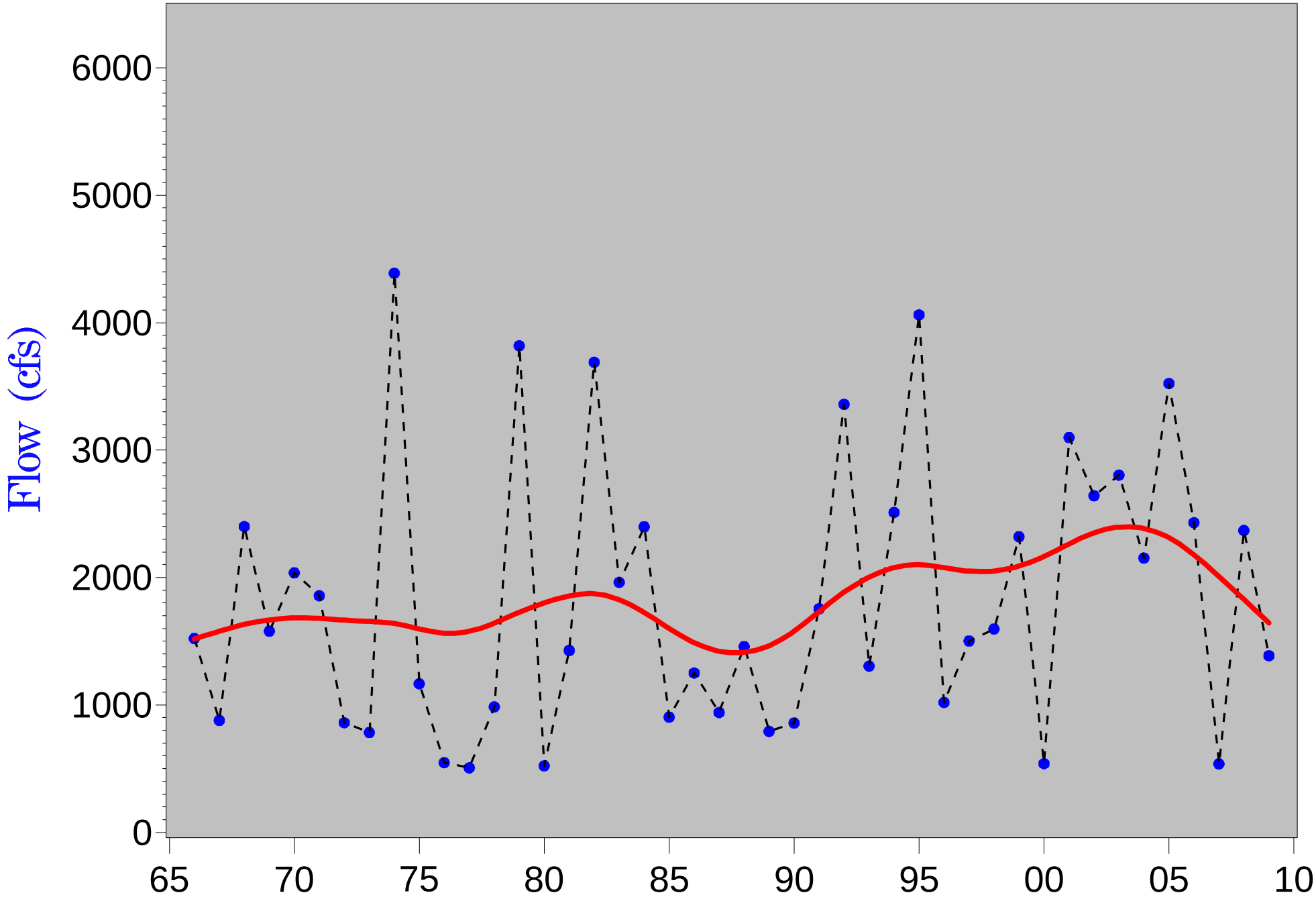


Figure 3.32a Yearly maximum 15-day flow at the USGS Shell Creek gage (1965-2009)

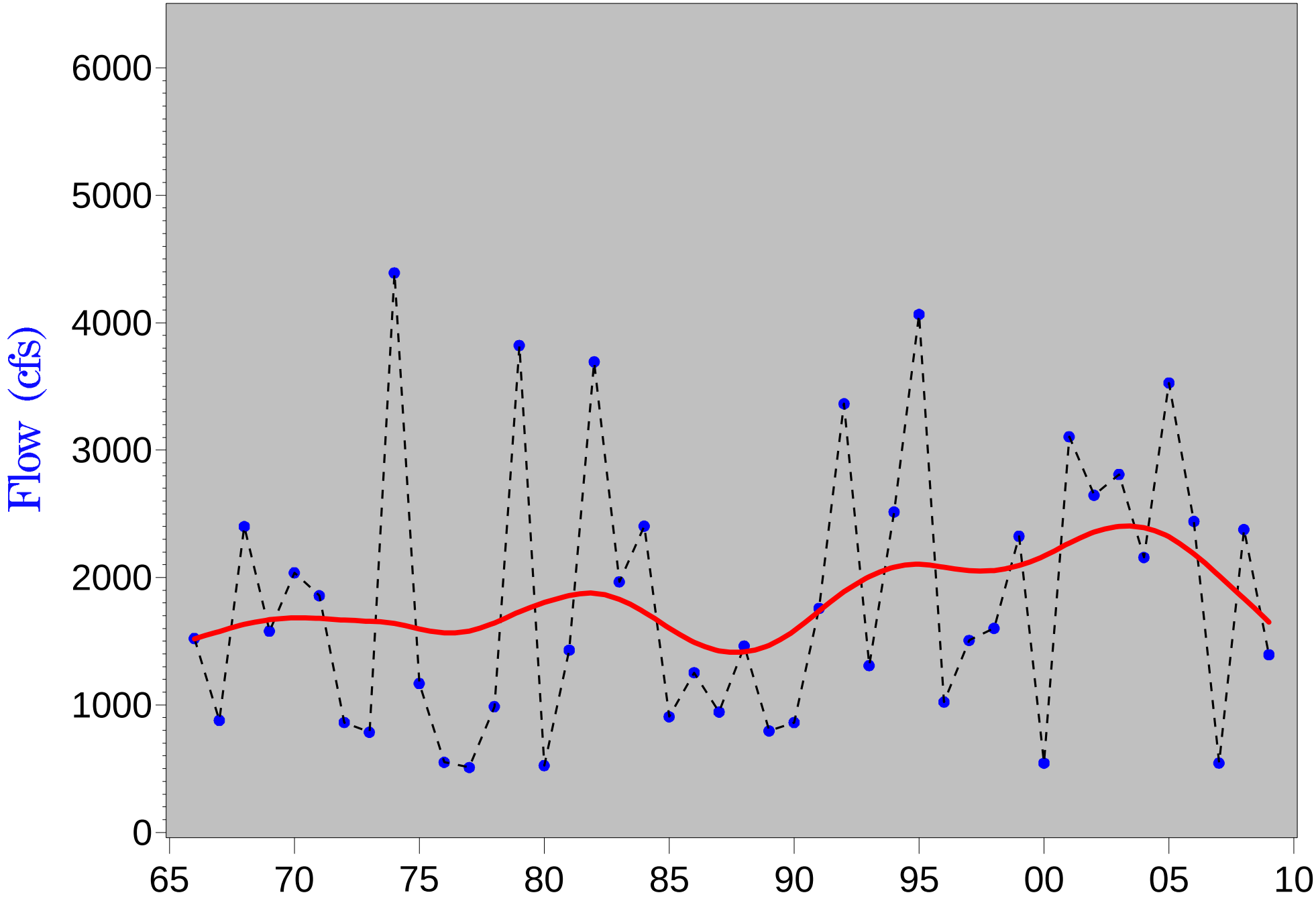


Figure 3.32b Estimated yearly maximum 15-day flow without Facility withdrawals (1965-2009)

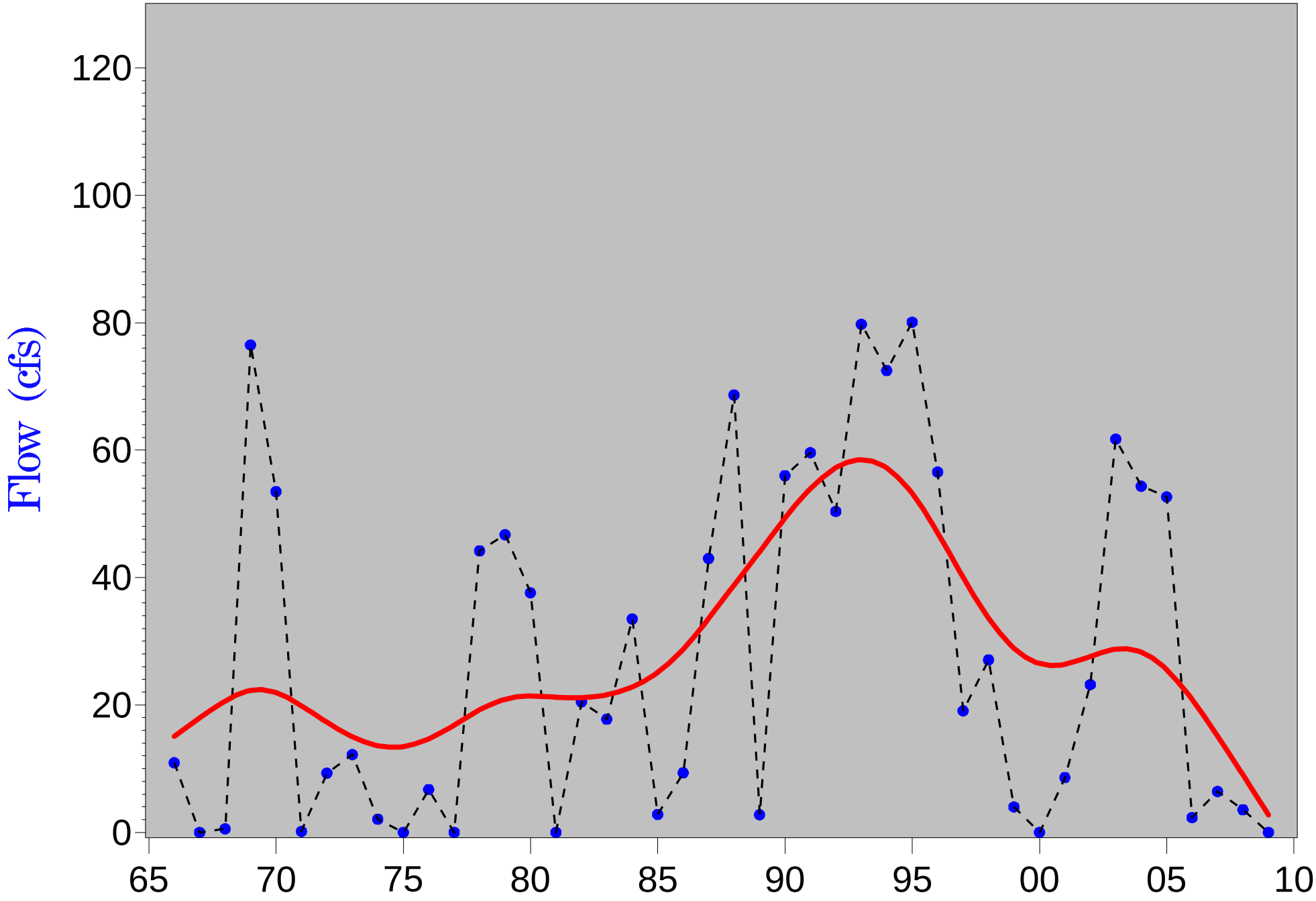


Figure 3.33a Yearly minimum 30-day flow at the USGS Shell Creek gage (1965-2009)

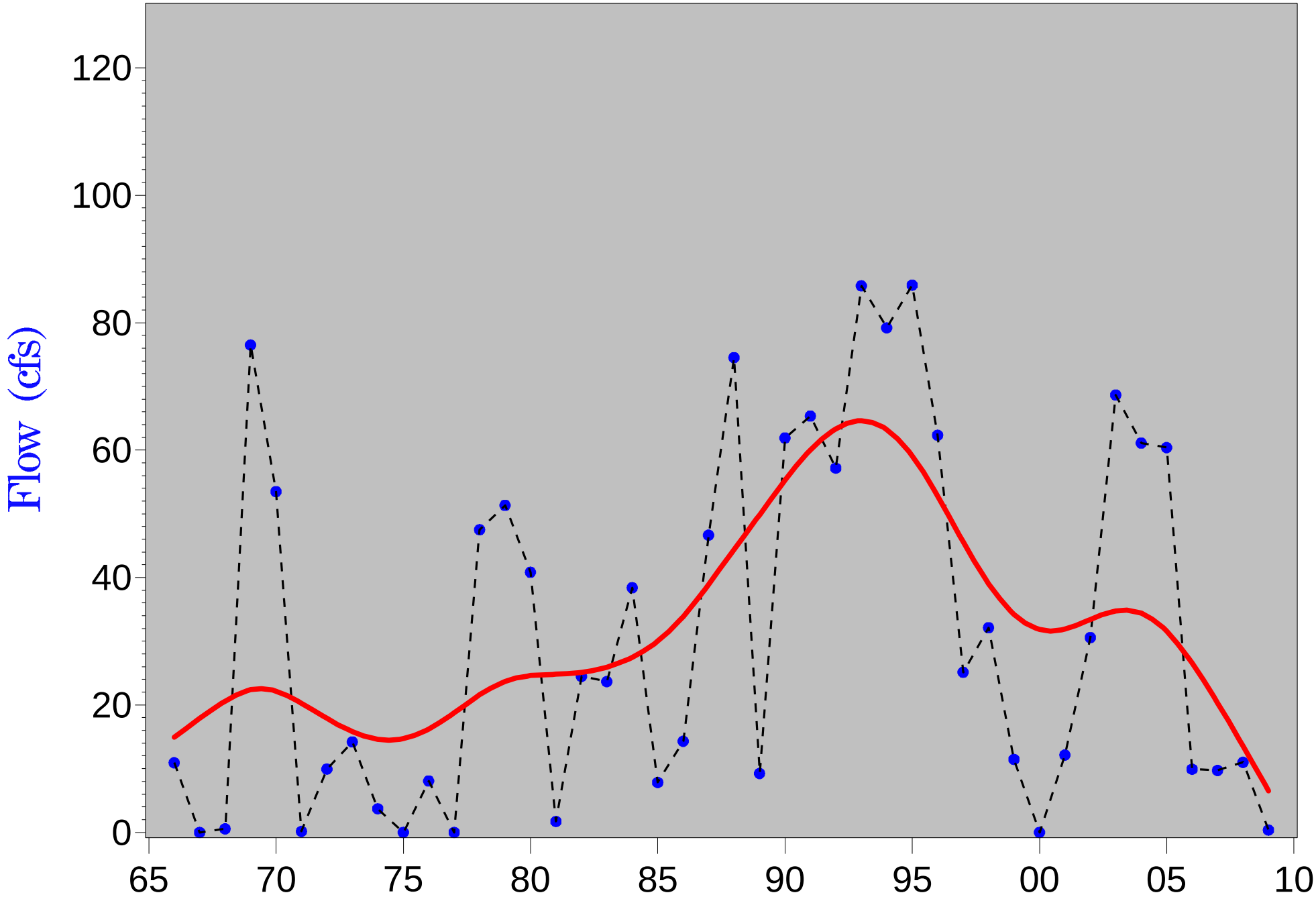


Figure 3.33b Estimated yearly minimum 30-day flow without Facility withdrawals (1965-2009)

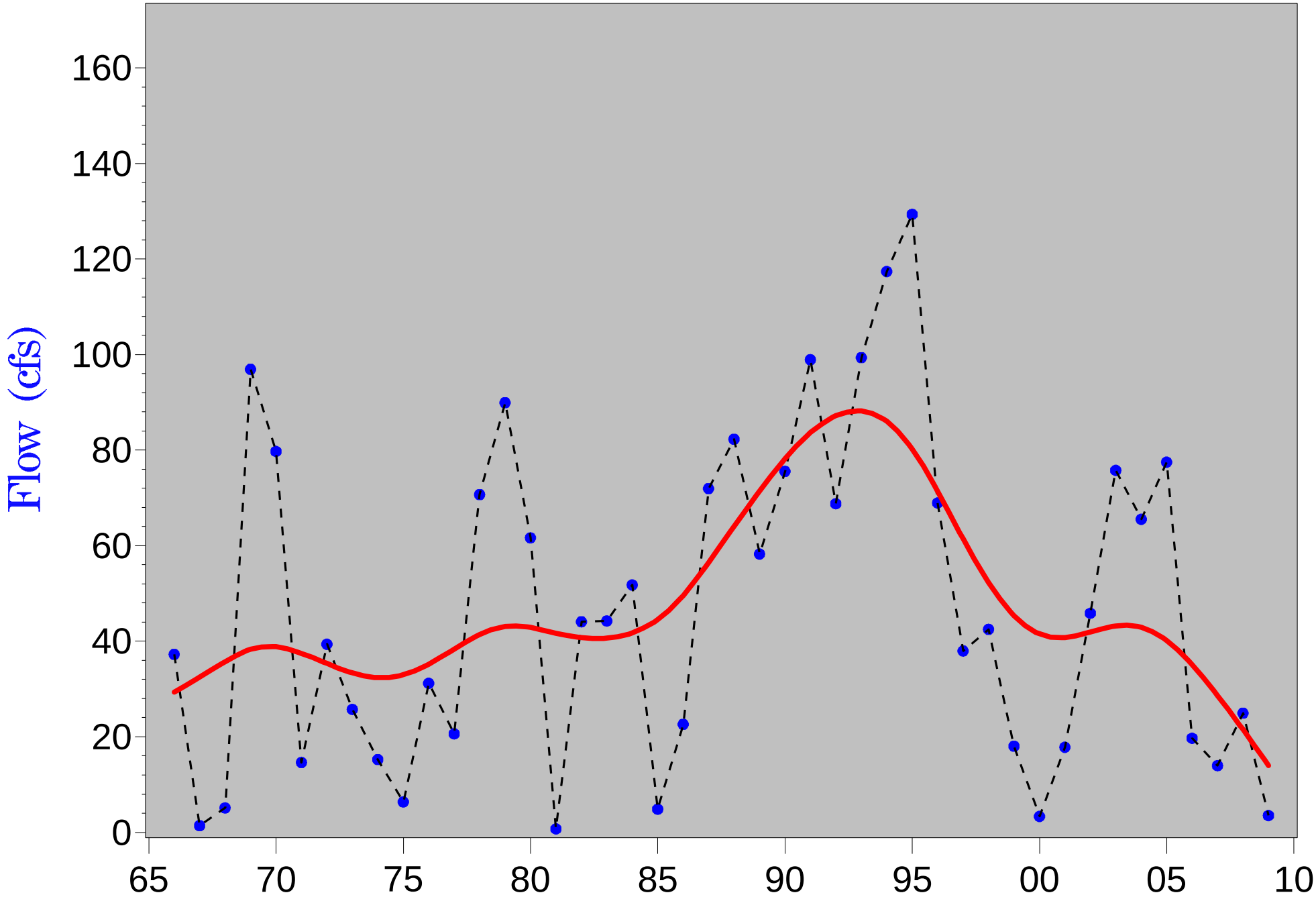


Figure 3.34a Yearly P10 30-day flow at the USGS Shell Creek gage (1965-2009)

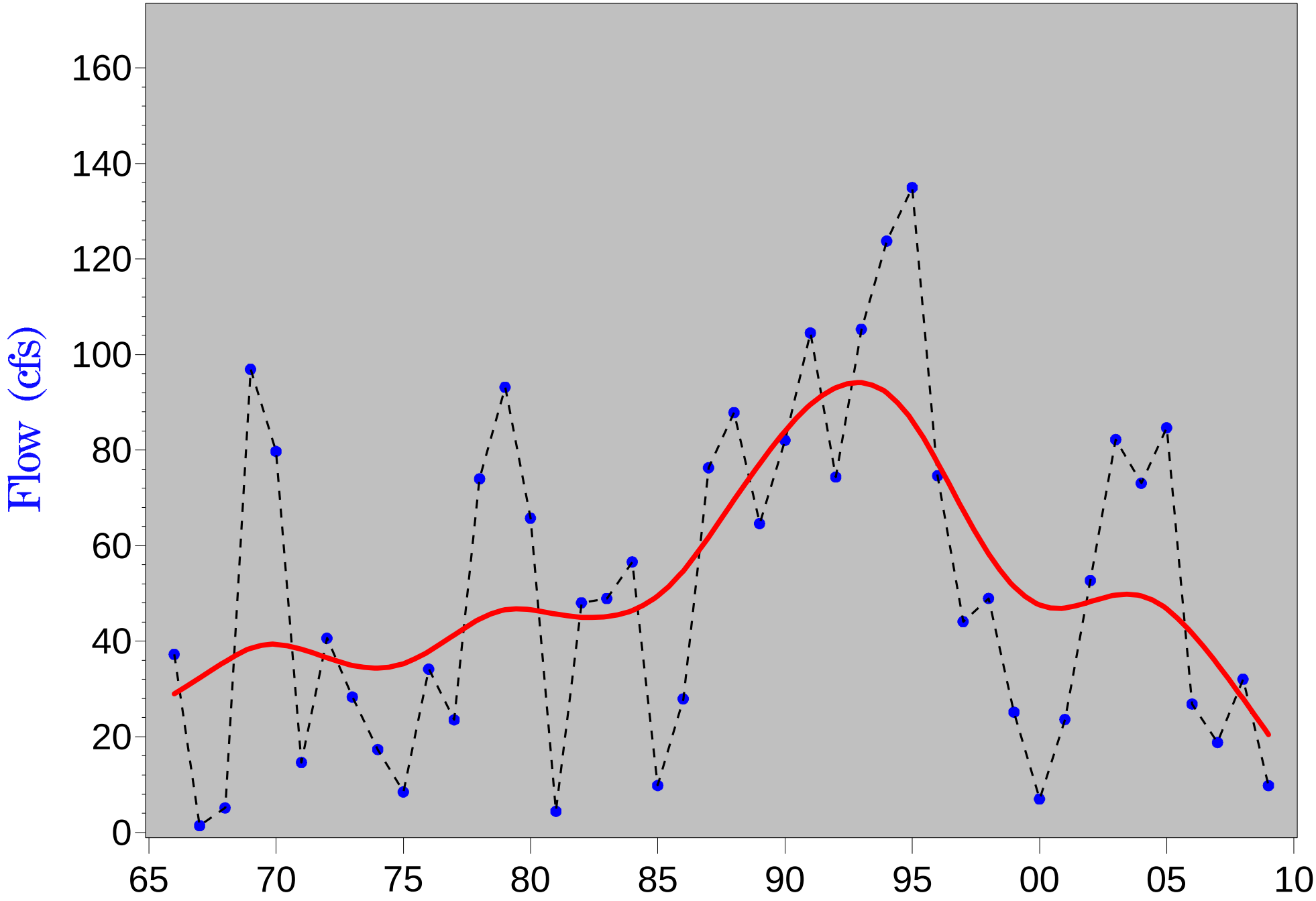
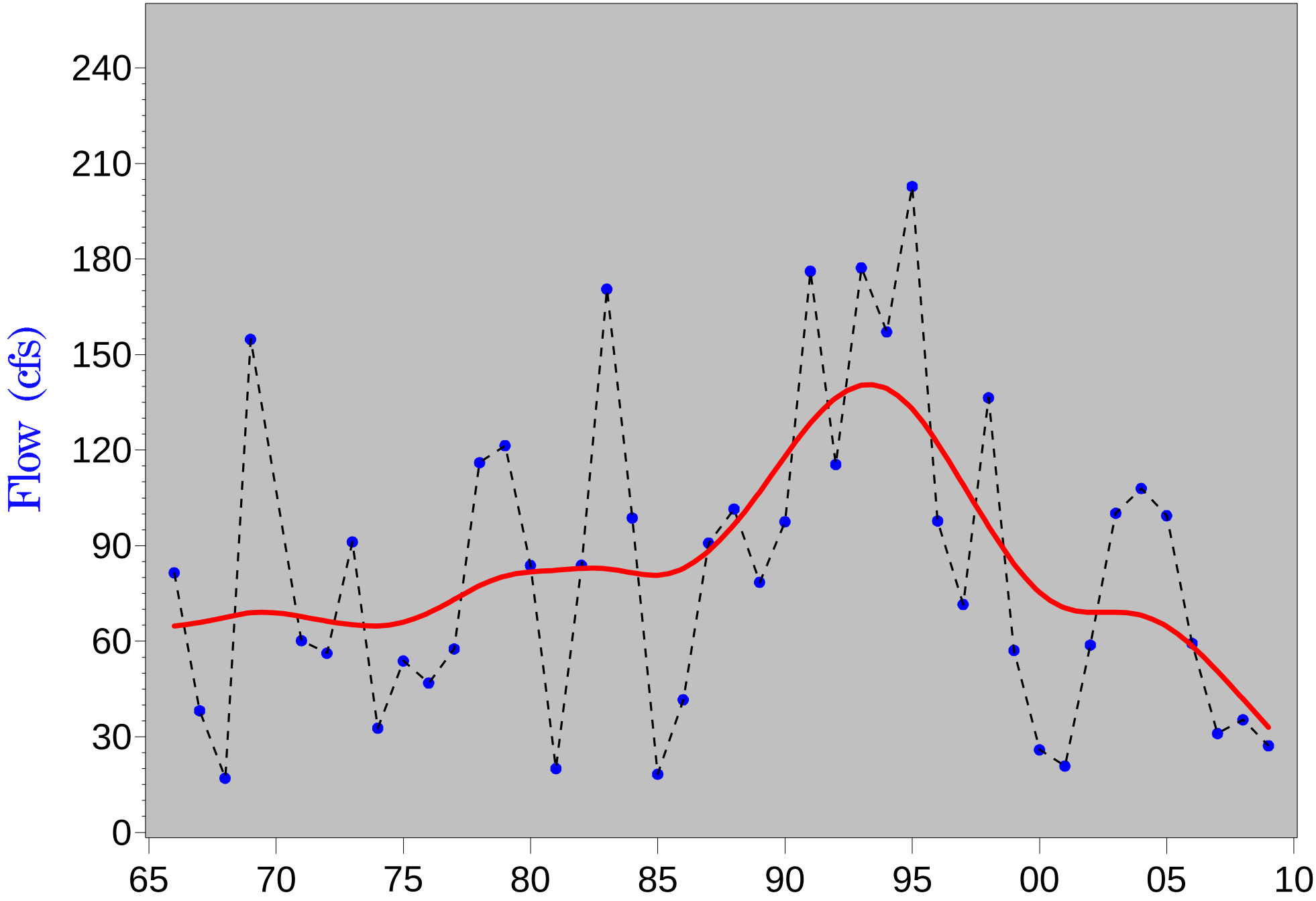
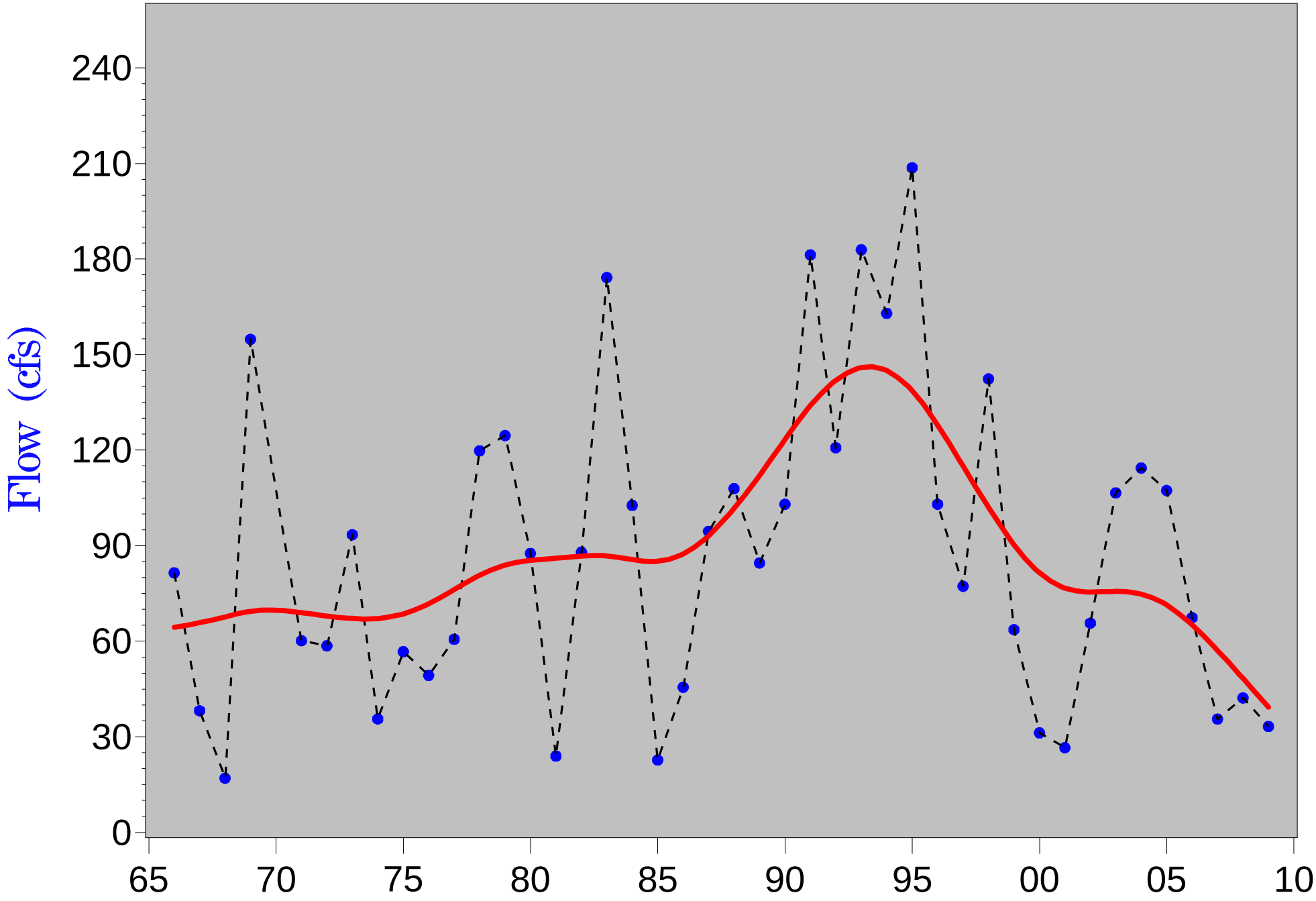


Figure 3.34b Estimated yearly P10 30-day flow without Facility withdrawals (1965-2009)



. Figure 3.35a Yearly P25 30-day flow at the USGS Shell Creek gage (1965-2009)



. Figure 3.35b Estimated yearly P25 30-day flow without Facility withdrawals (1965-2009)

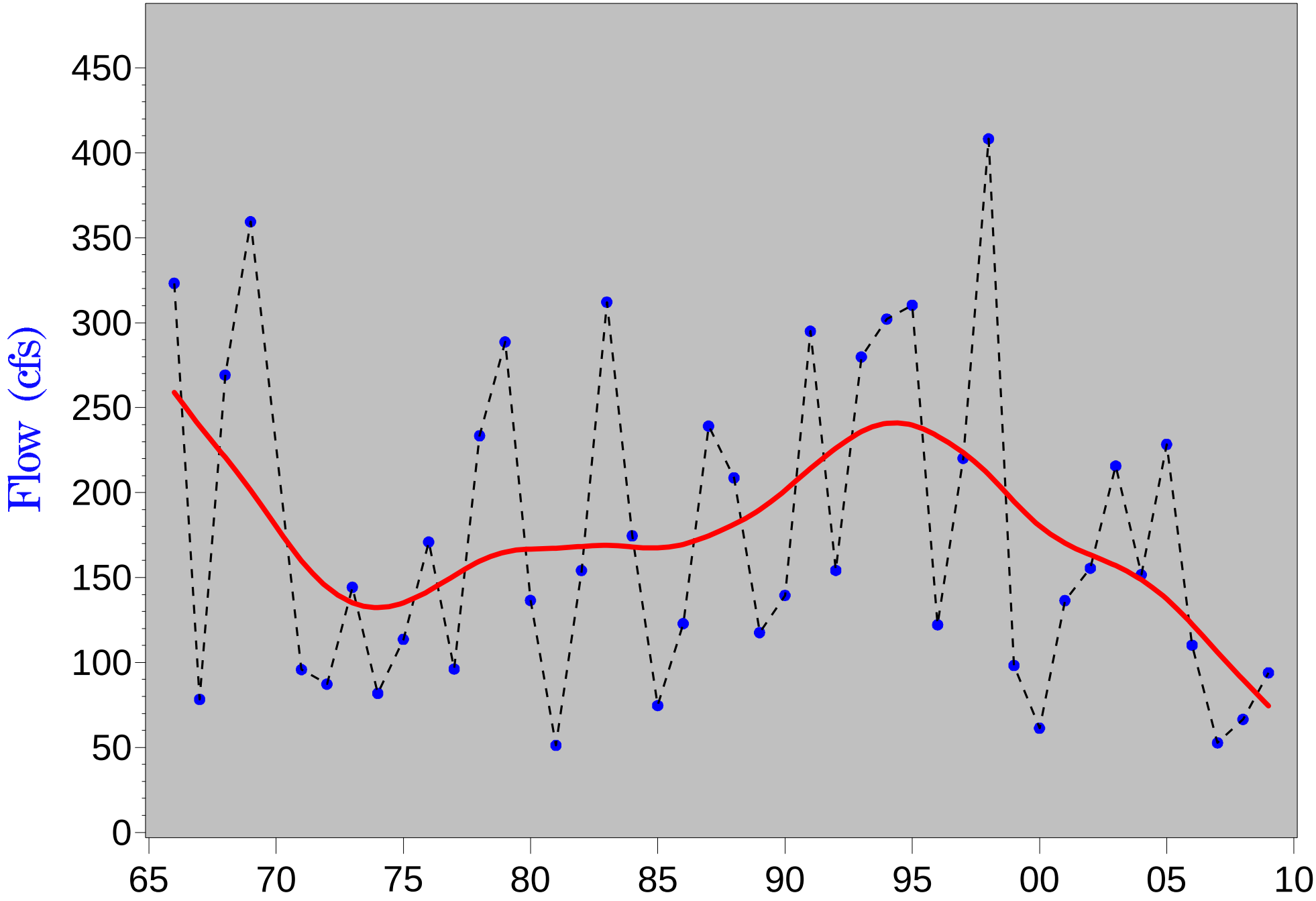


Figure 3.36a Yearly P50 (median) 30-day flow at the USGS Shell Creek gage (1965-2009)

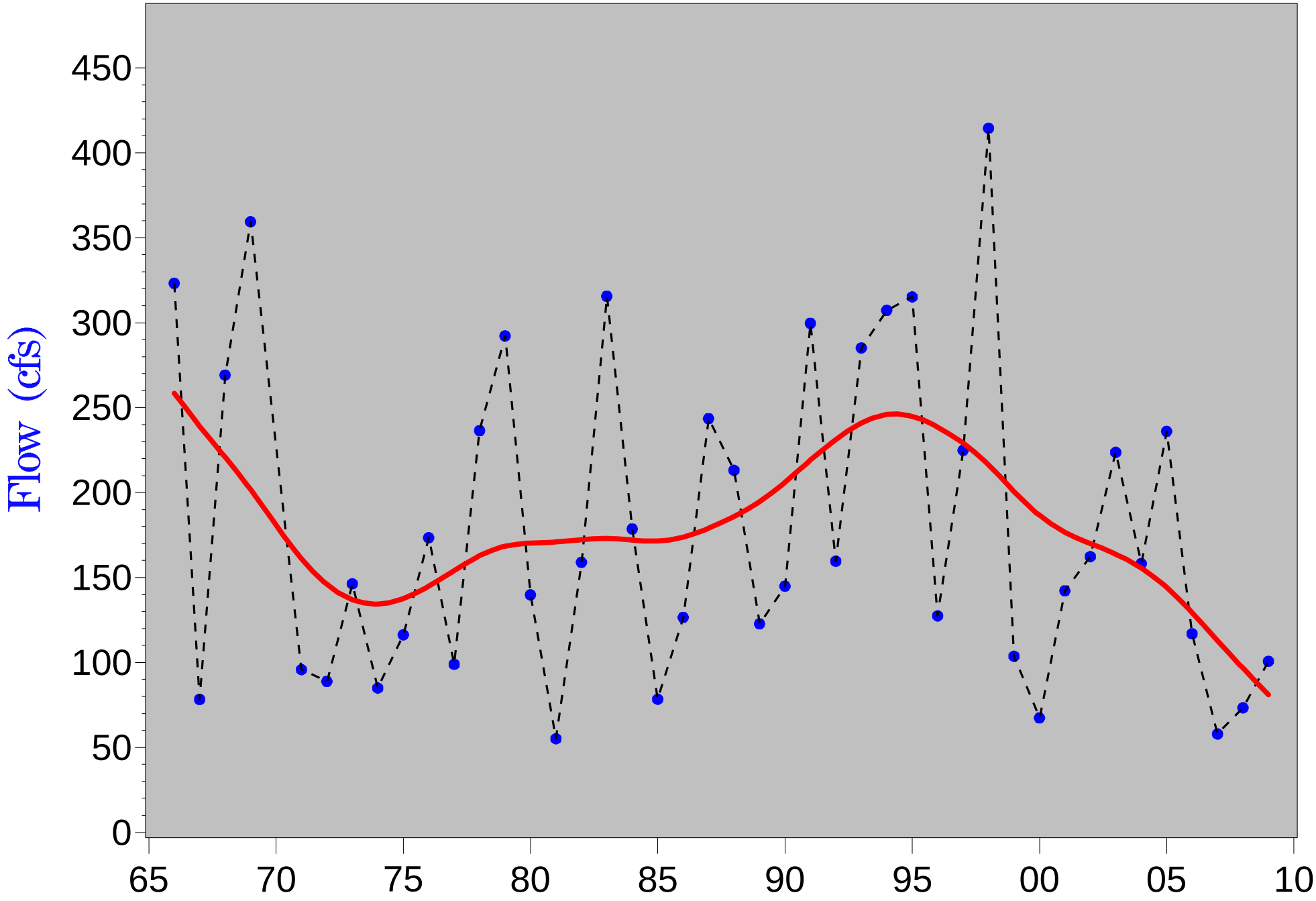


Figure 3.36b Estimated yearly P50 (median) 30-day flow without Facility withdrawals (1965-2009)

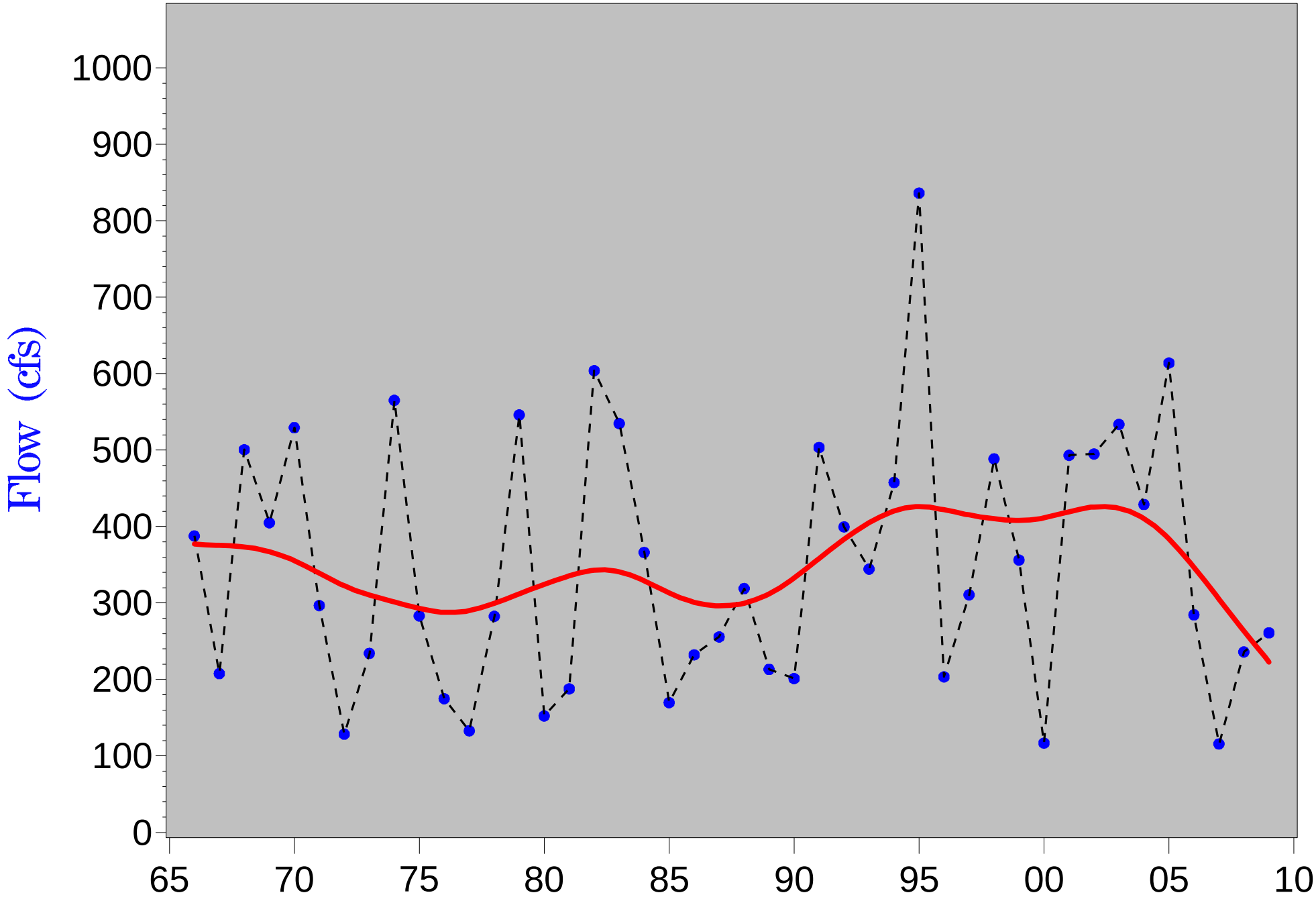


Figure 3.37a Yearly mean 30-day flow at the USGS Shell Creek gage (1965-2009)

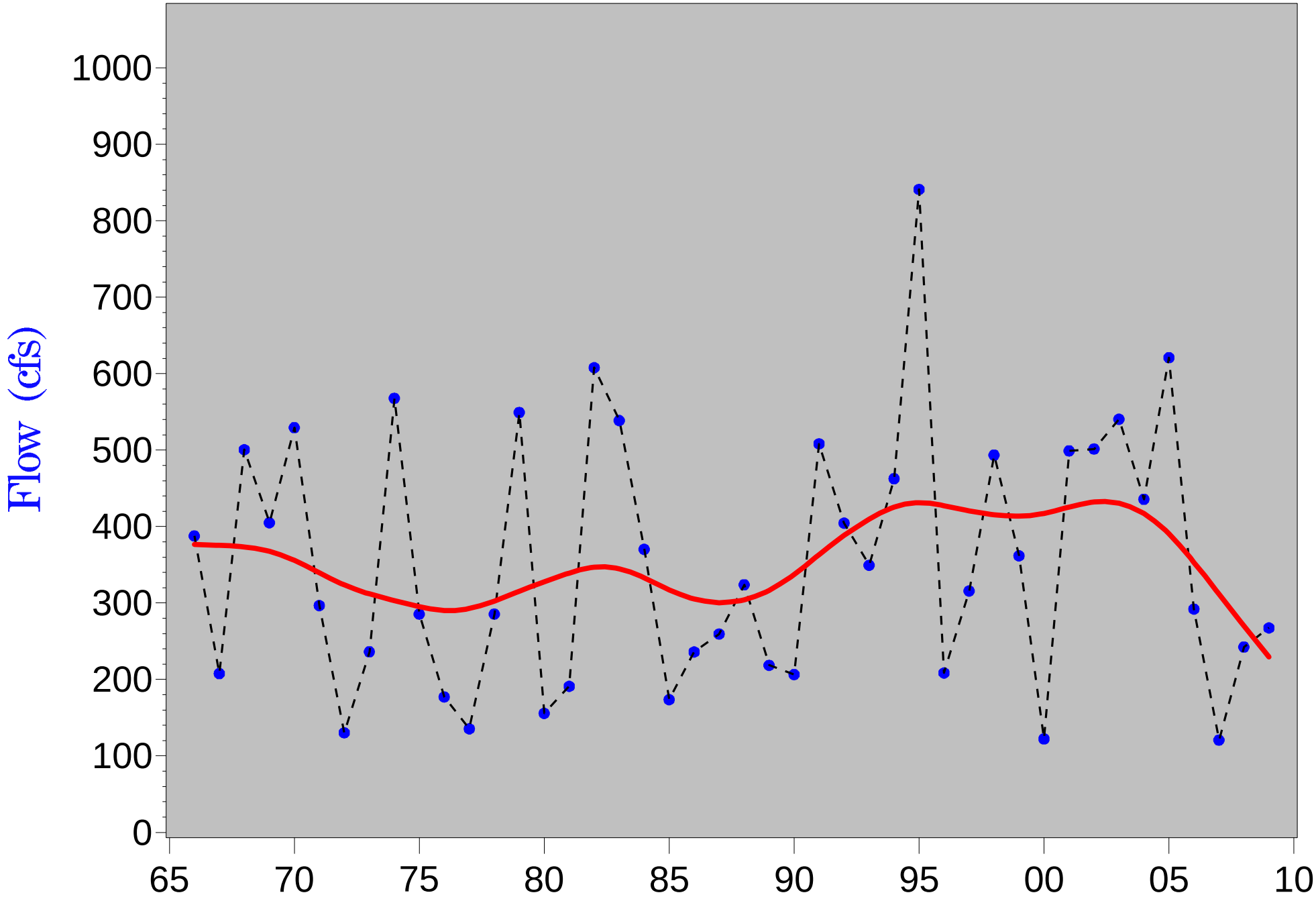


Figure 3.37b Estimated yearly mean 30-day flow without Facility withdrawals (1965-2009)

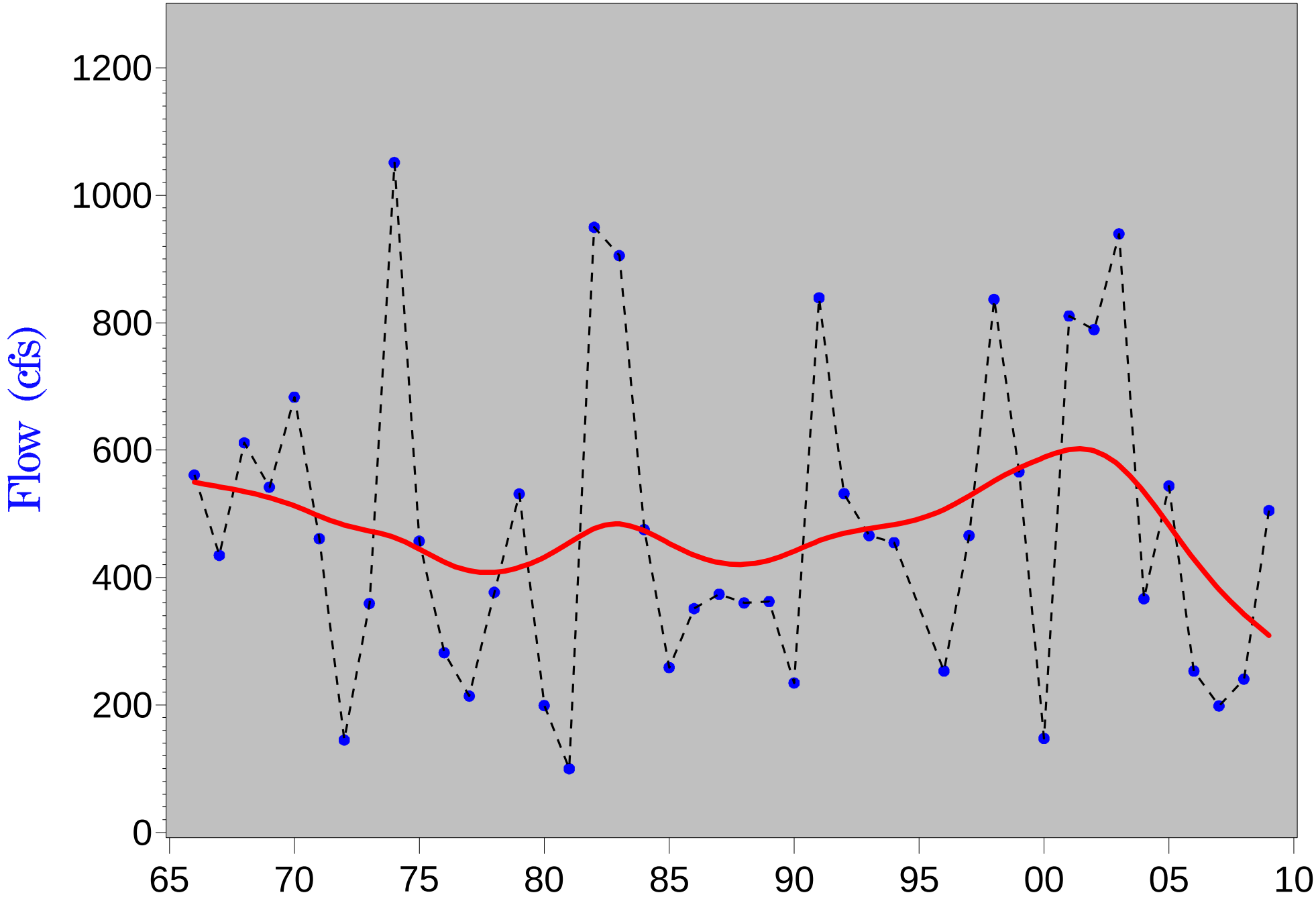


Figure 3.38a Yearly P75 30-day flow at the USGS Shell Creek gage (1965-2009)

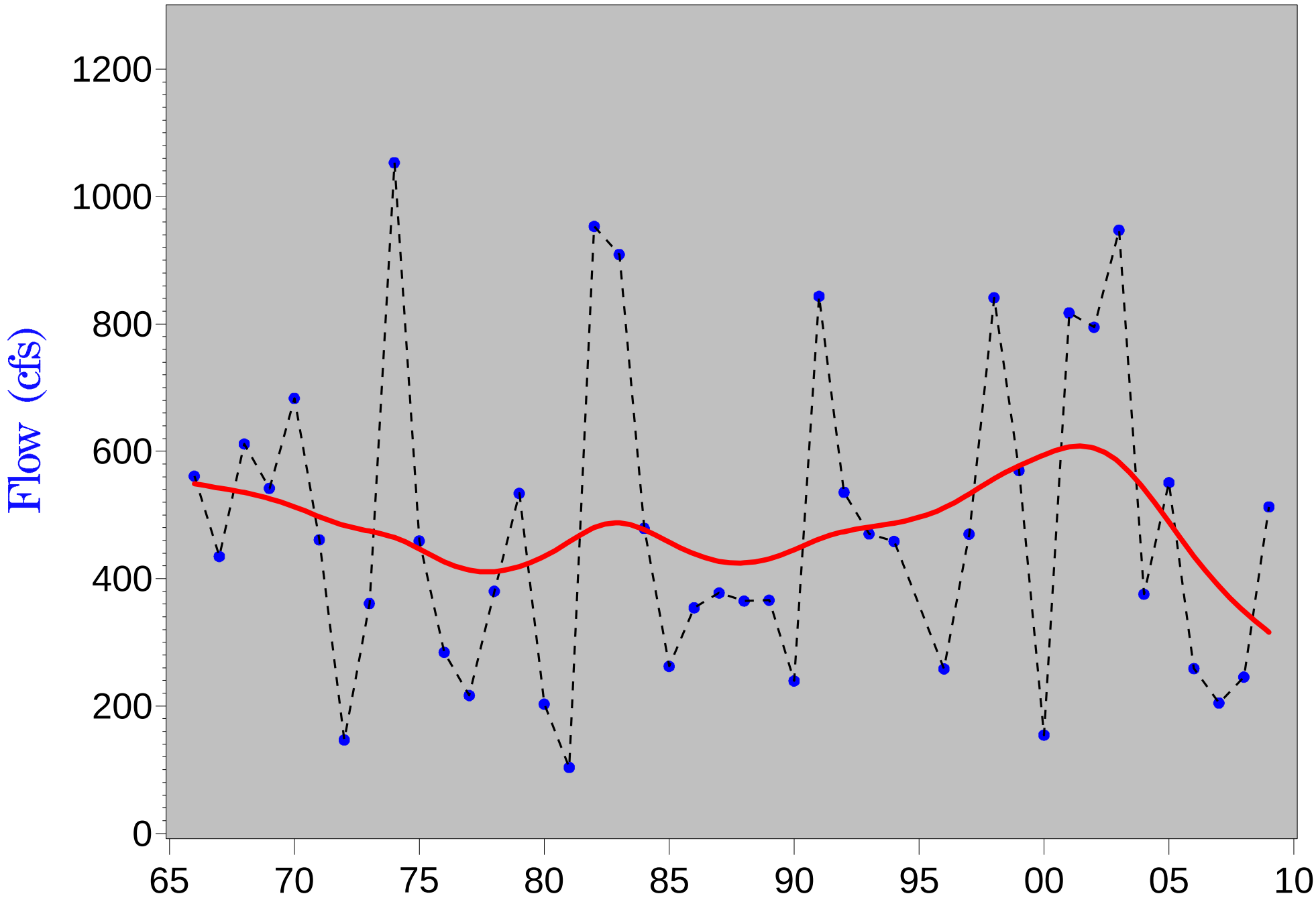


Figure 3.38b Estimated yearly P75 30-day flow without Facility withdrawals (1965-2009)

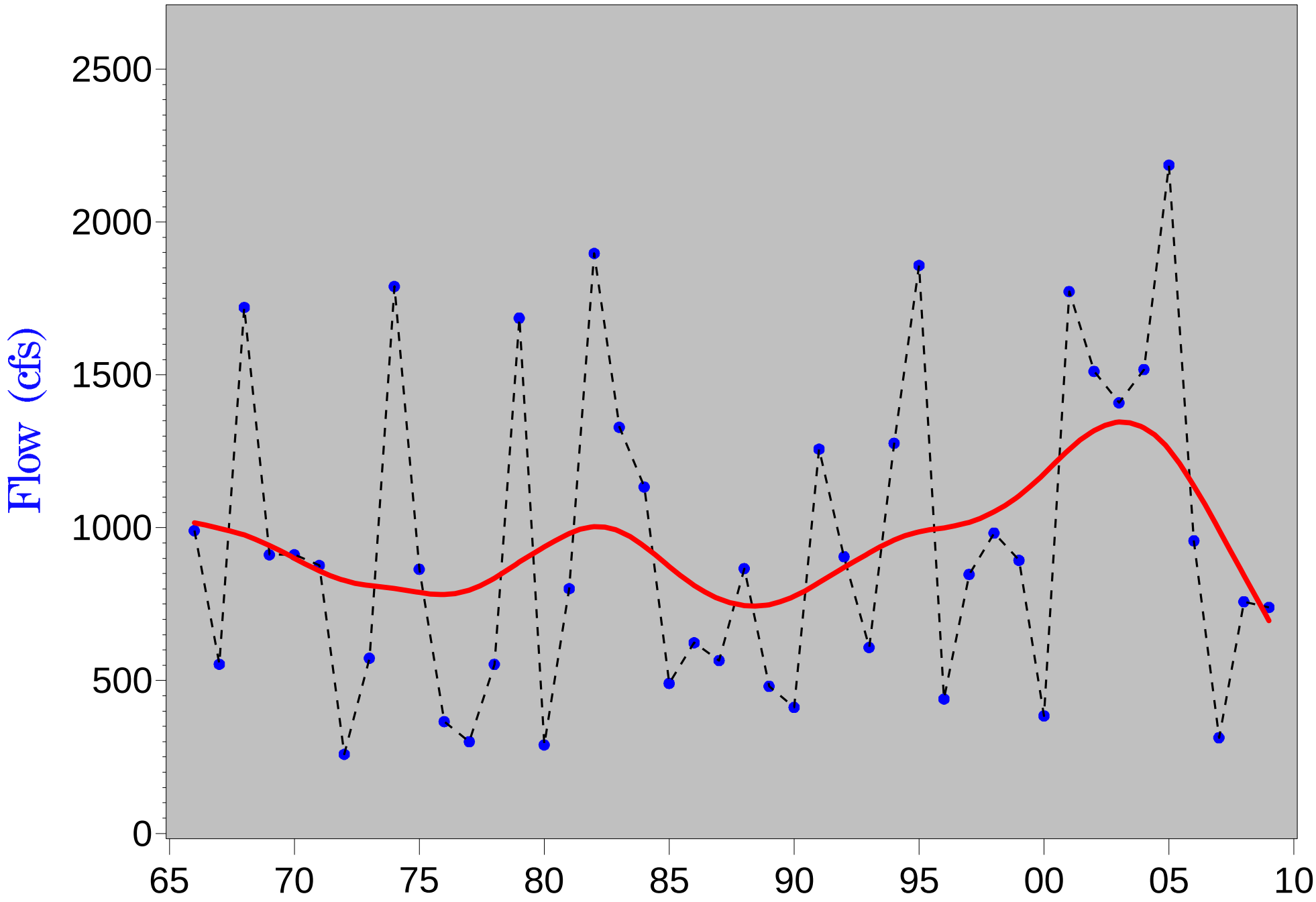


Figure 3.39a Yearly P90 30-day flow at the USGS Shell Creek gage (1965-2009)

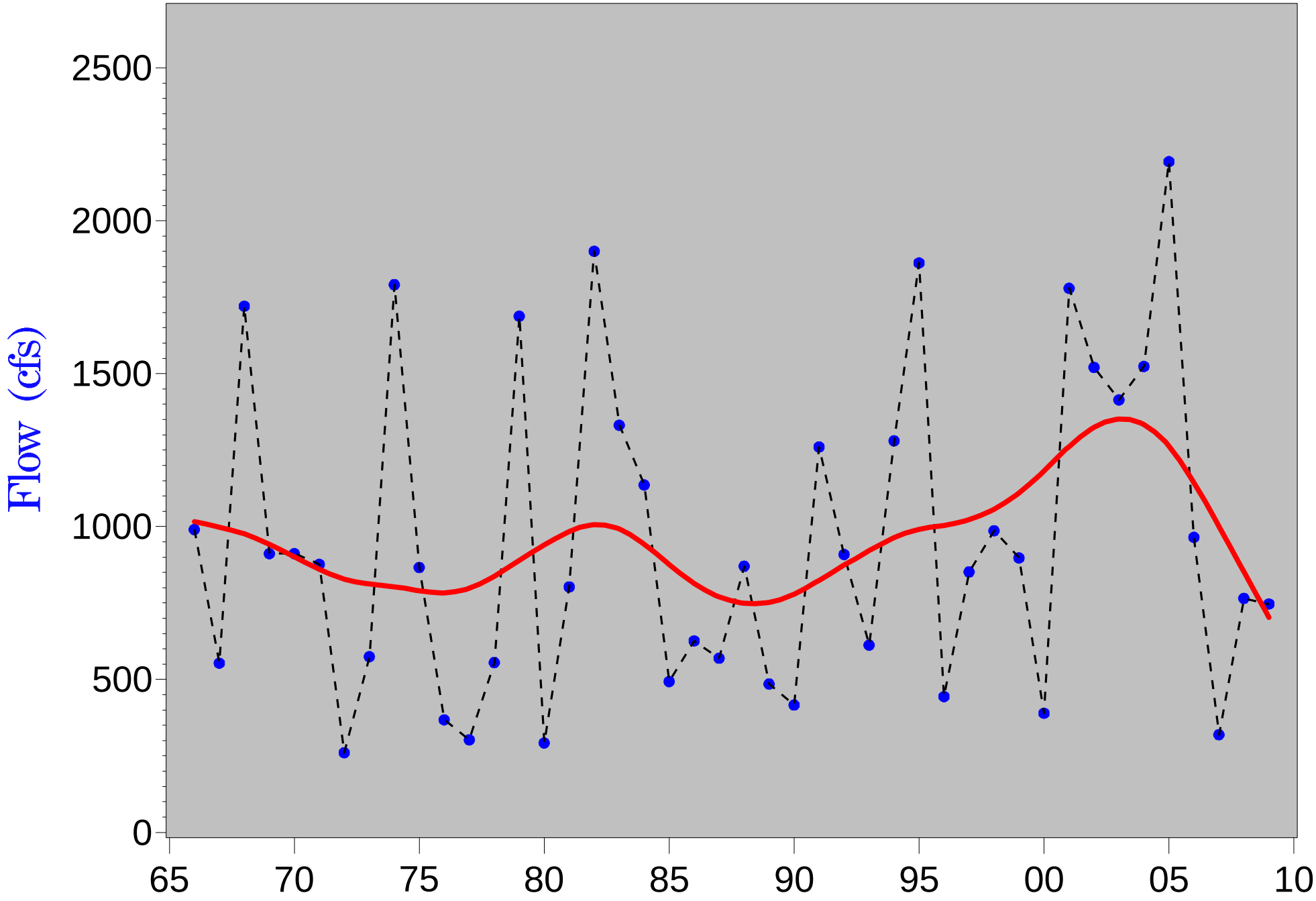


Figure 3.39b Estimated yearly P90 30-day flow without Facility withdrawals (1965-2009)

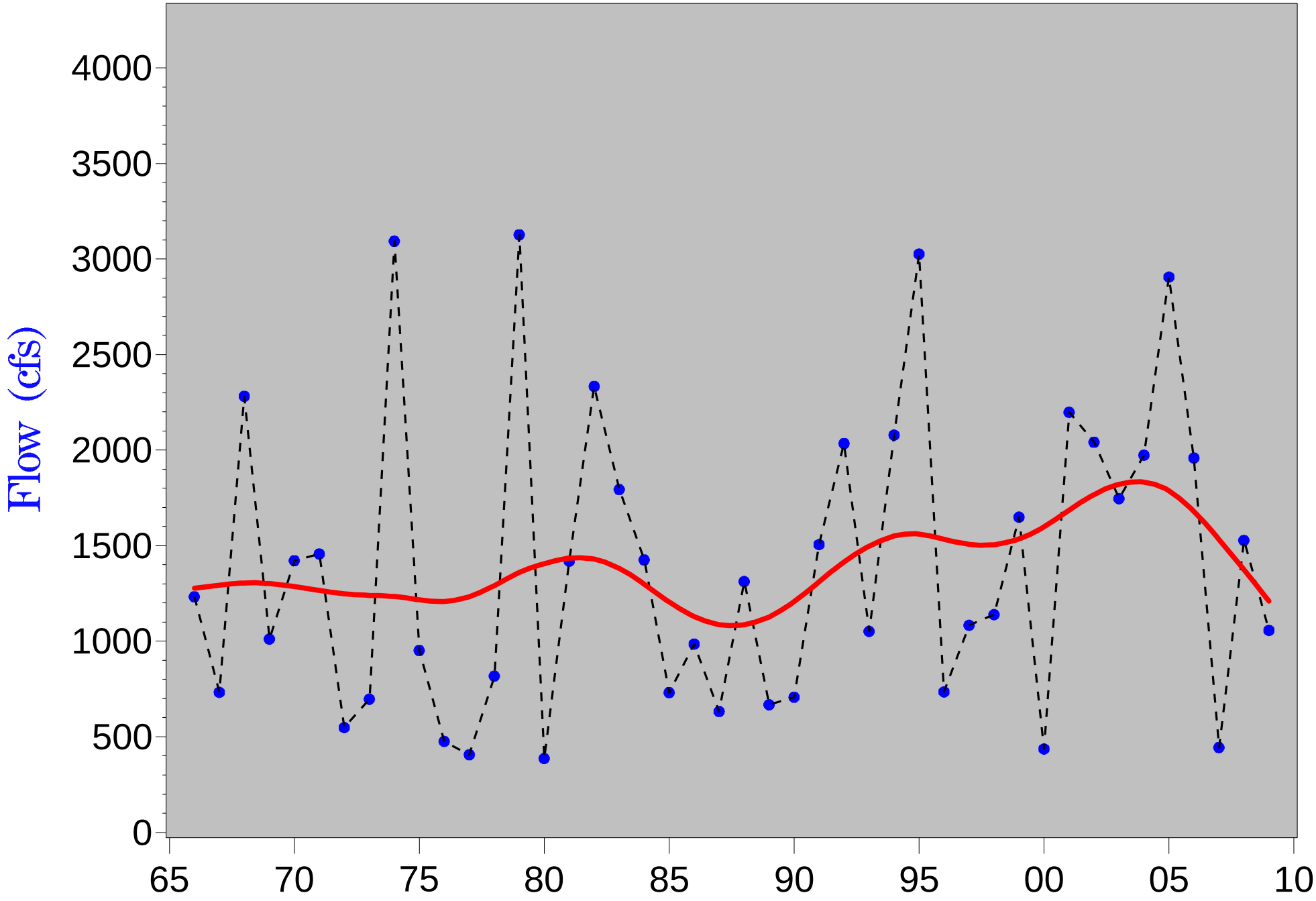


Figure 3.40a Yearly maximum 30-day flow at the USGS Shell Creek gage (1965-2009)

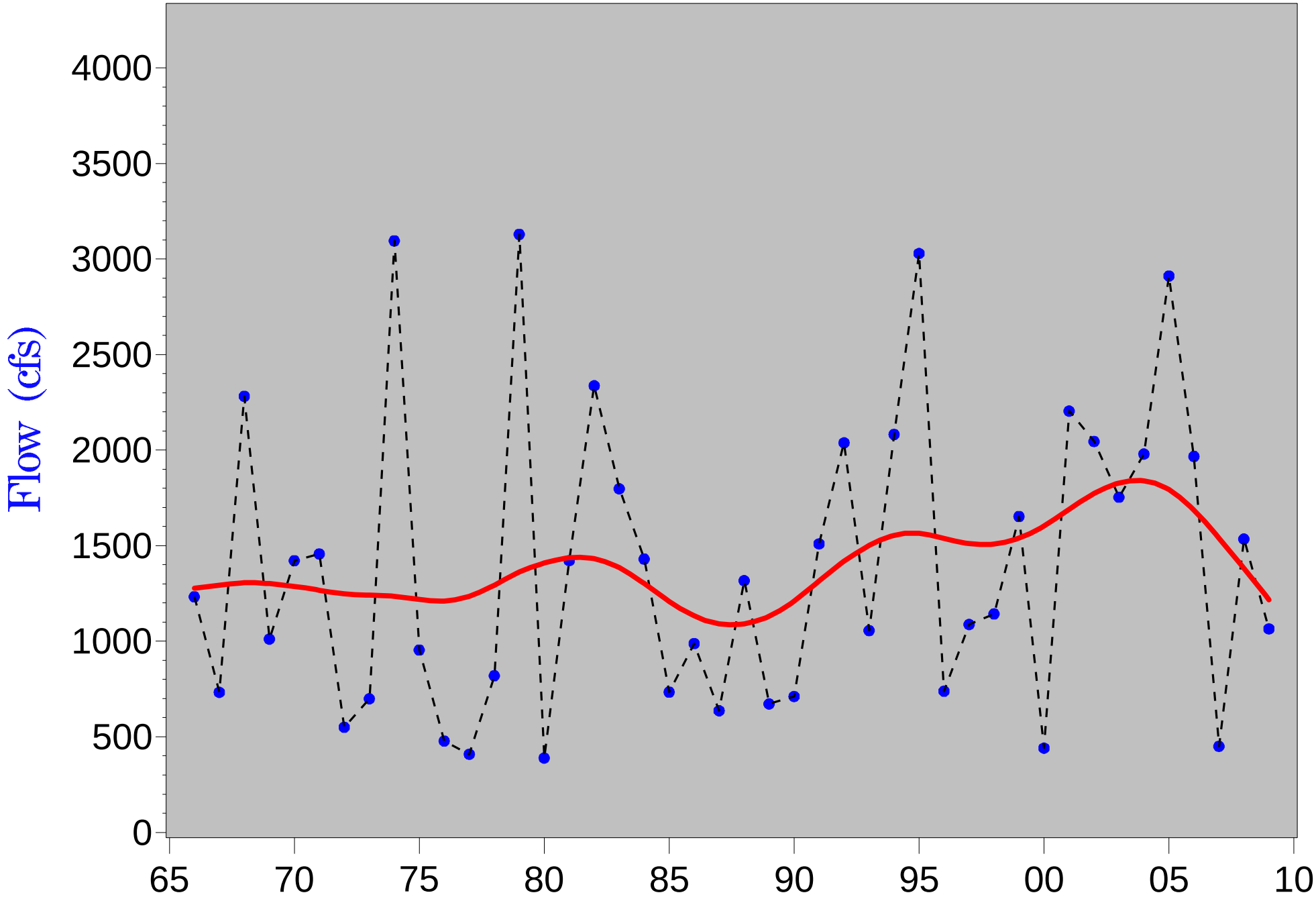


Figure 3.40b Estimated yearly maximum 30-day flow without Facility withdrawals (1965-2009)

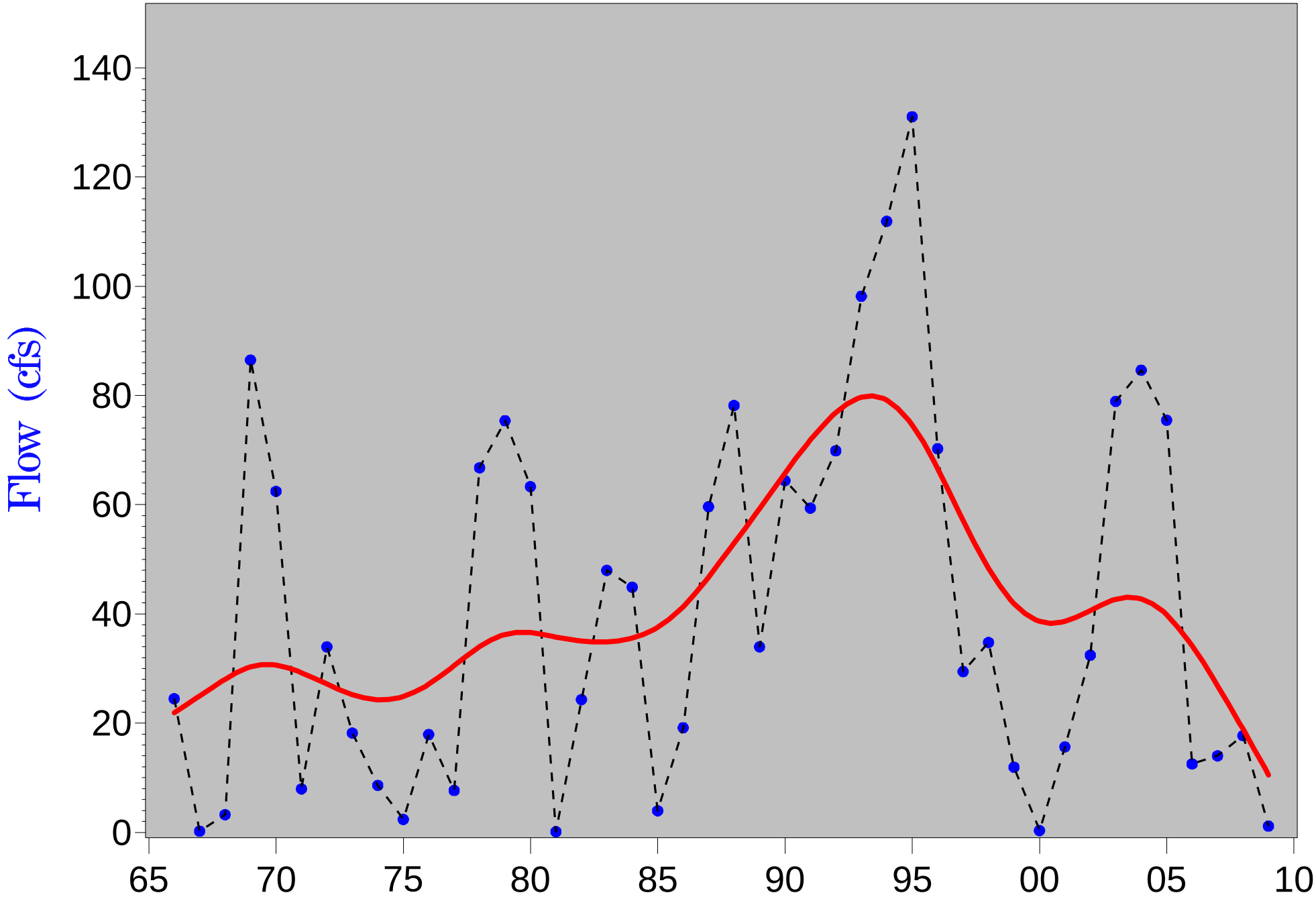


Figure 3.41a Yearly minimum 60-day flow at the USGS Shell Creek gage (1965-2009)

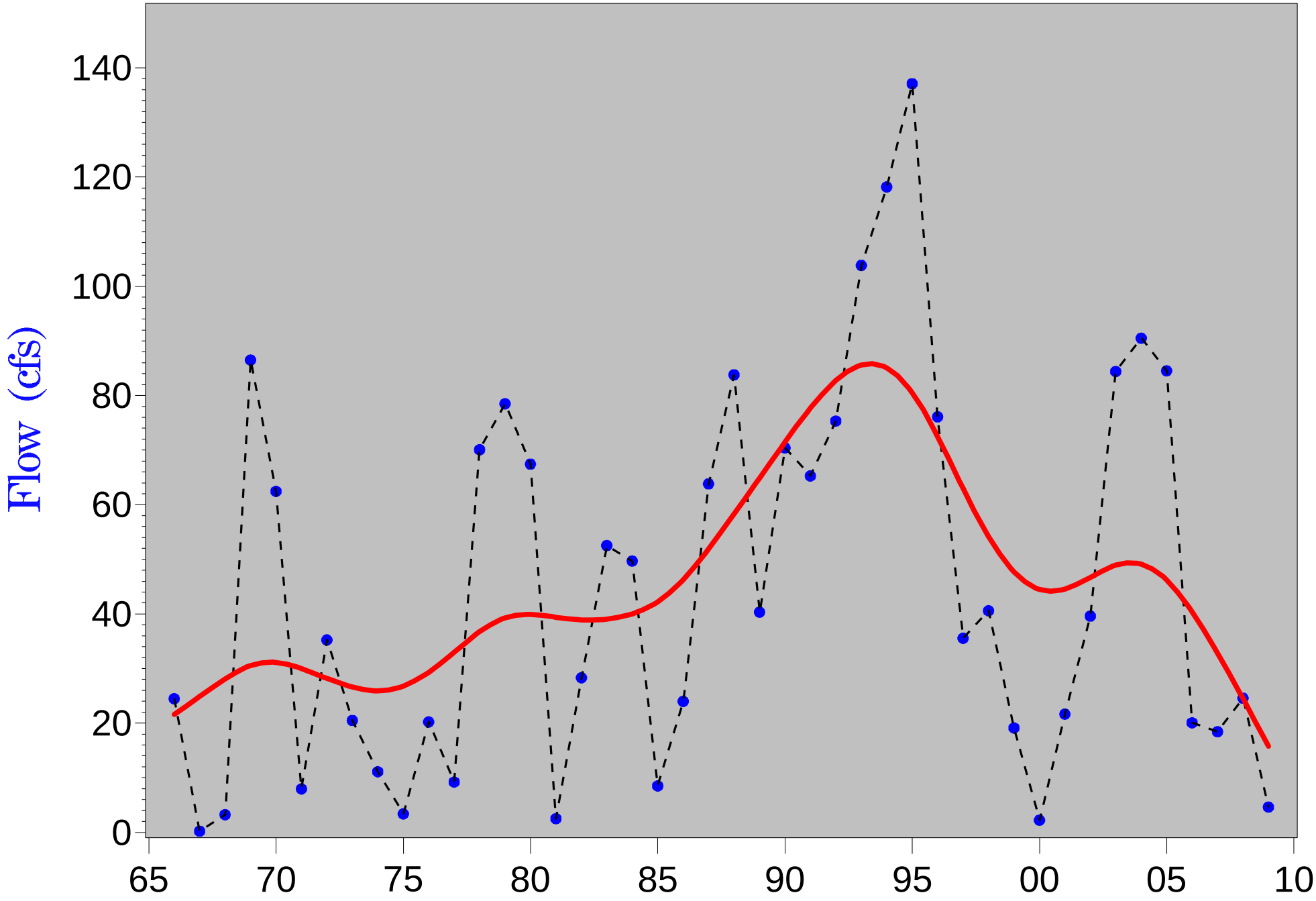


Figure 3.41b Estimated yearly minimum 60-day flow without Facility withdrawals (1965-2009)

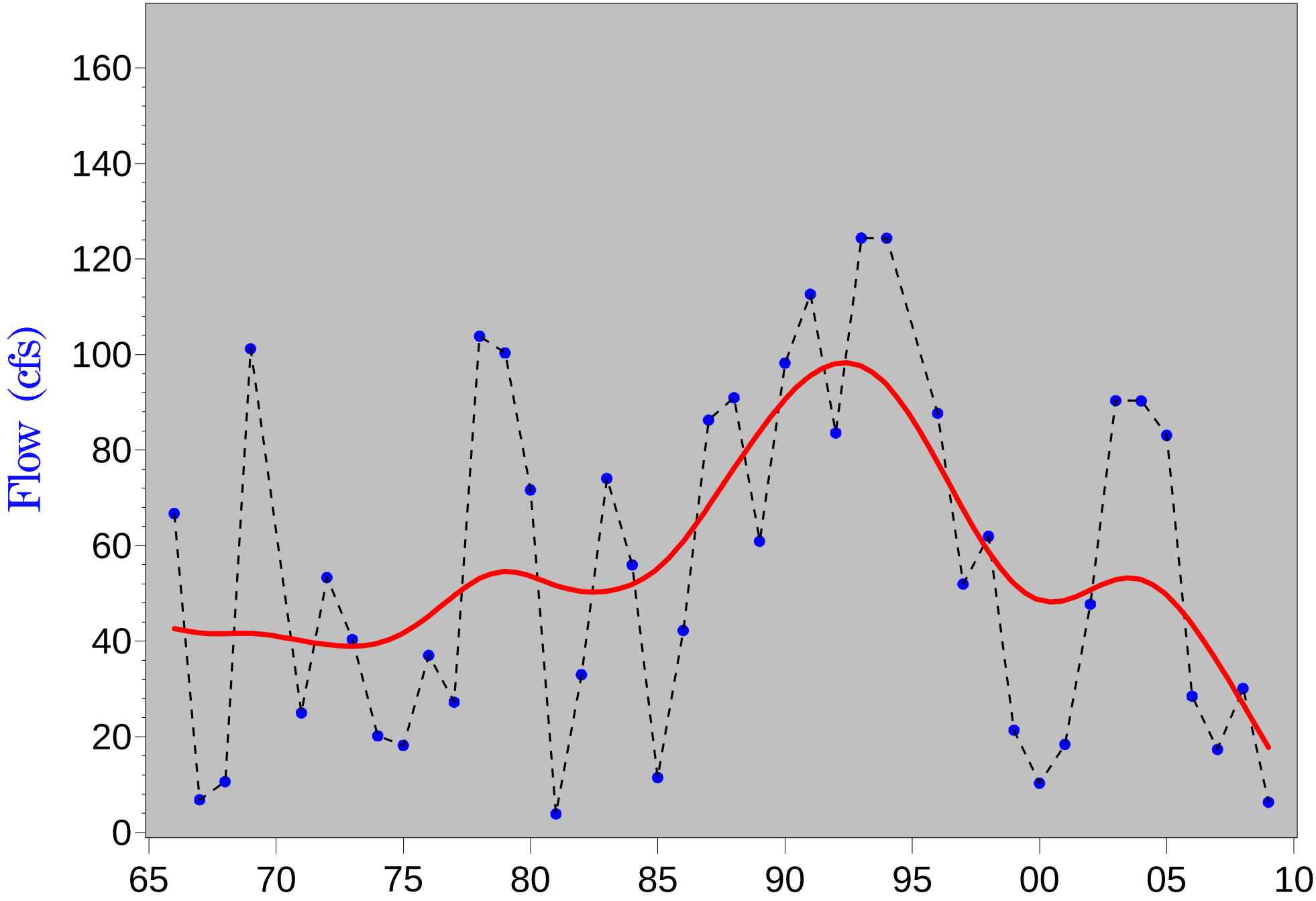


Figure 3.42a Yearly P10 60-day flow at the USGS Shell Creek gage (1965-2009)

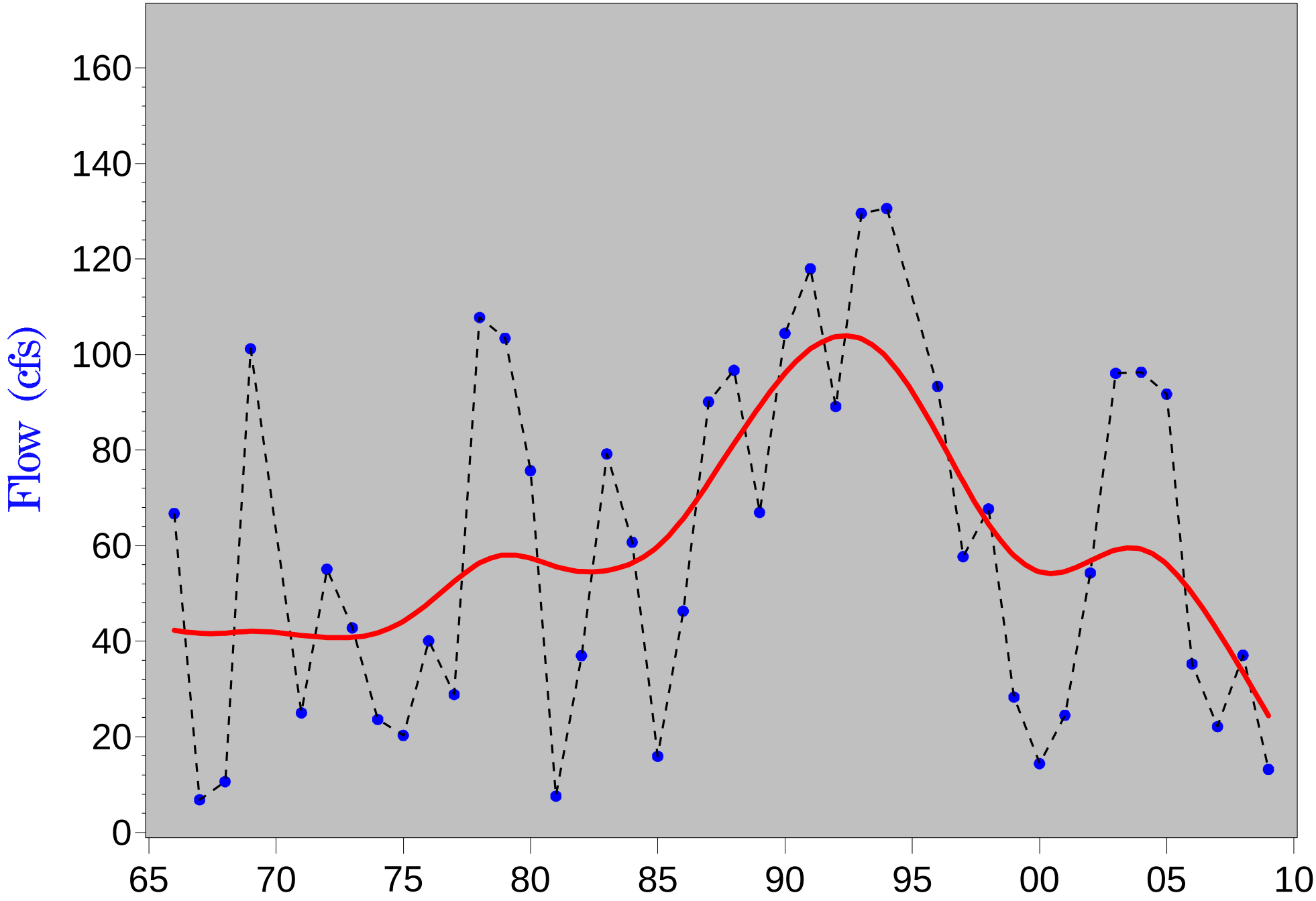
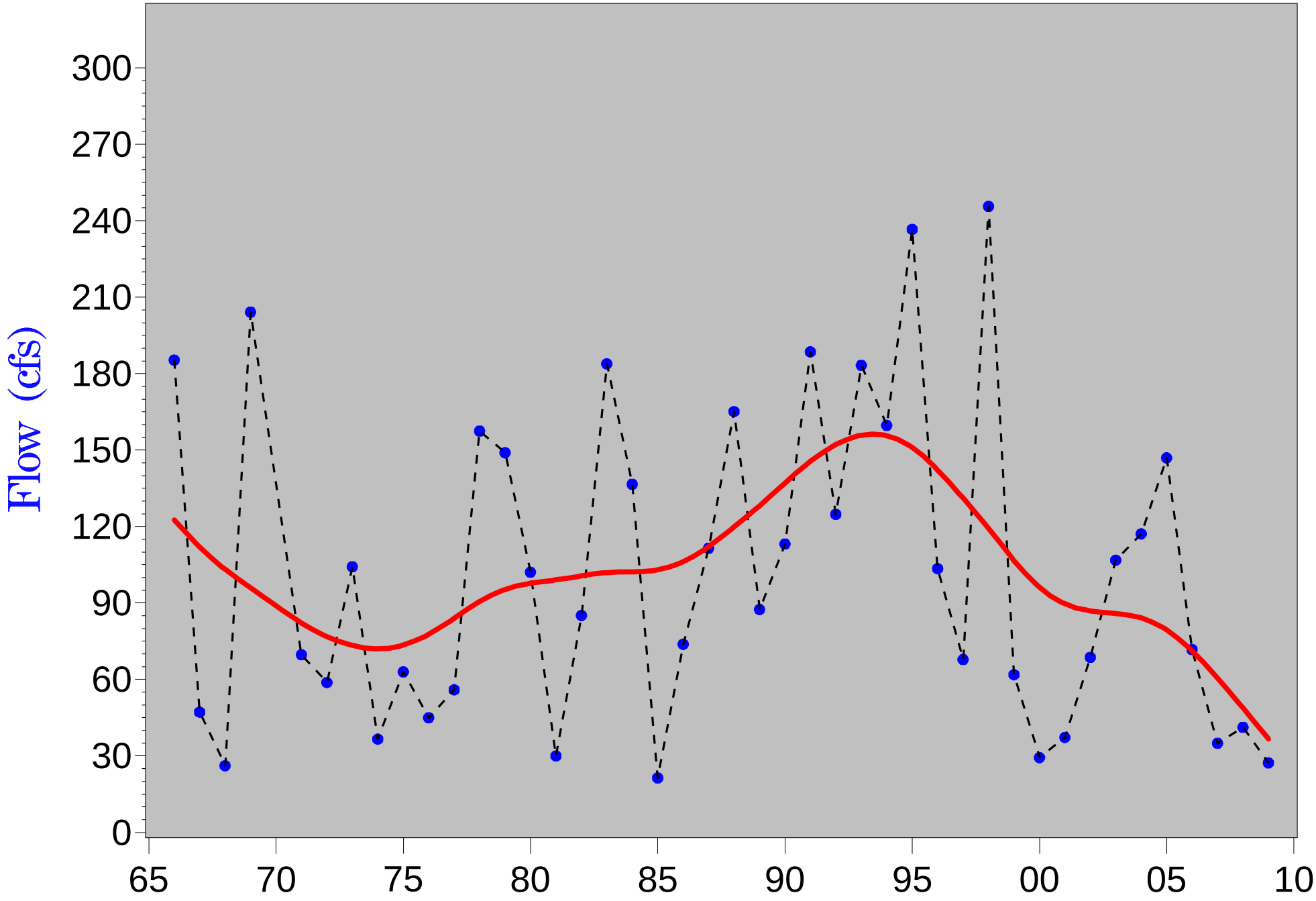
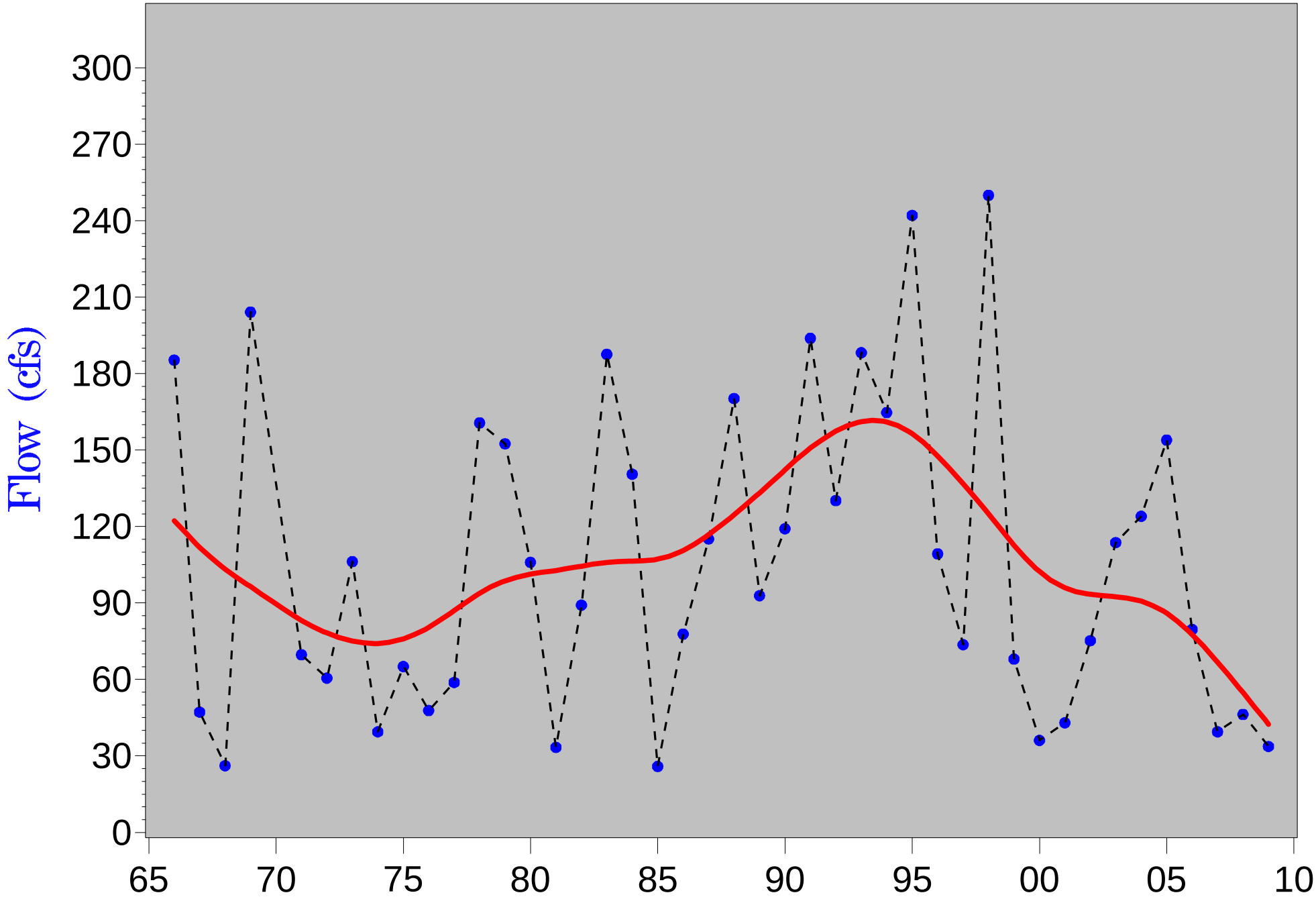


Figure 3.42b Estimated yearly P10 60-day flow without Facility withdrawals (1965-2009)



. Figure 3.43a Yearly P25 60-day flow at the USGS Shell Creek gage (1965-2009)



. Figure 3.43b Estimated yearly P25 60-day flow without Facility withdrawals (1965-2009)

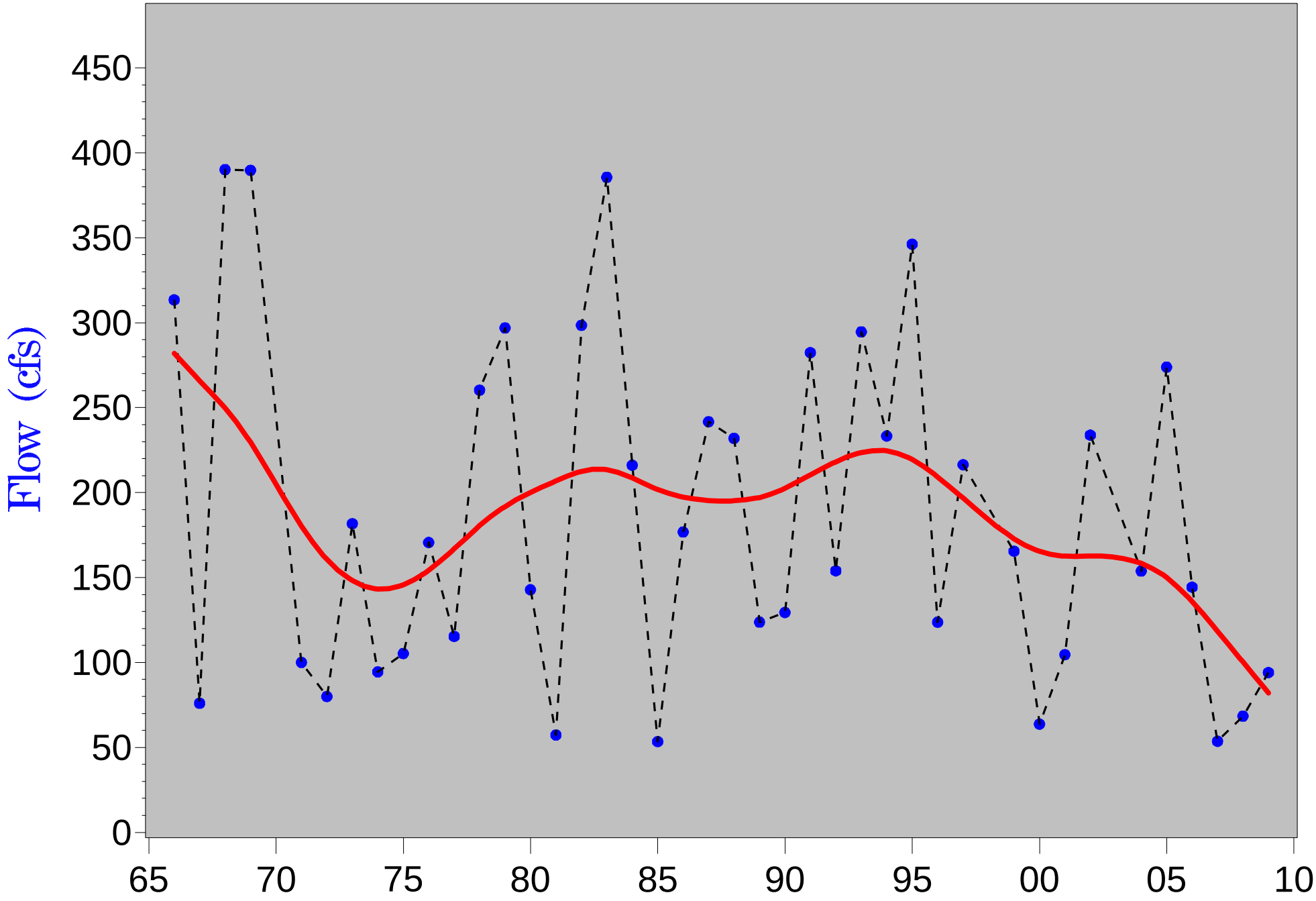


Figure 3.44a Yearly P50 (median) 60-day flow at the USGS Shell Creek gage (1965-2009)

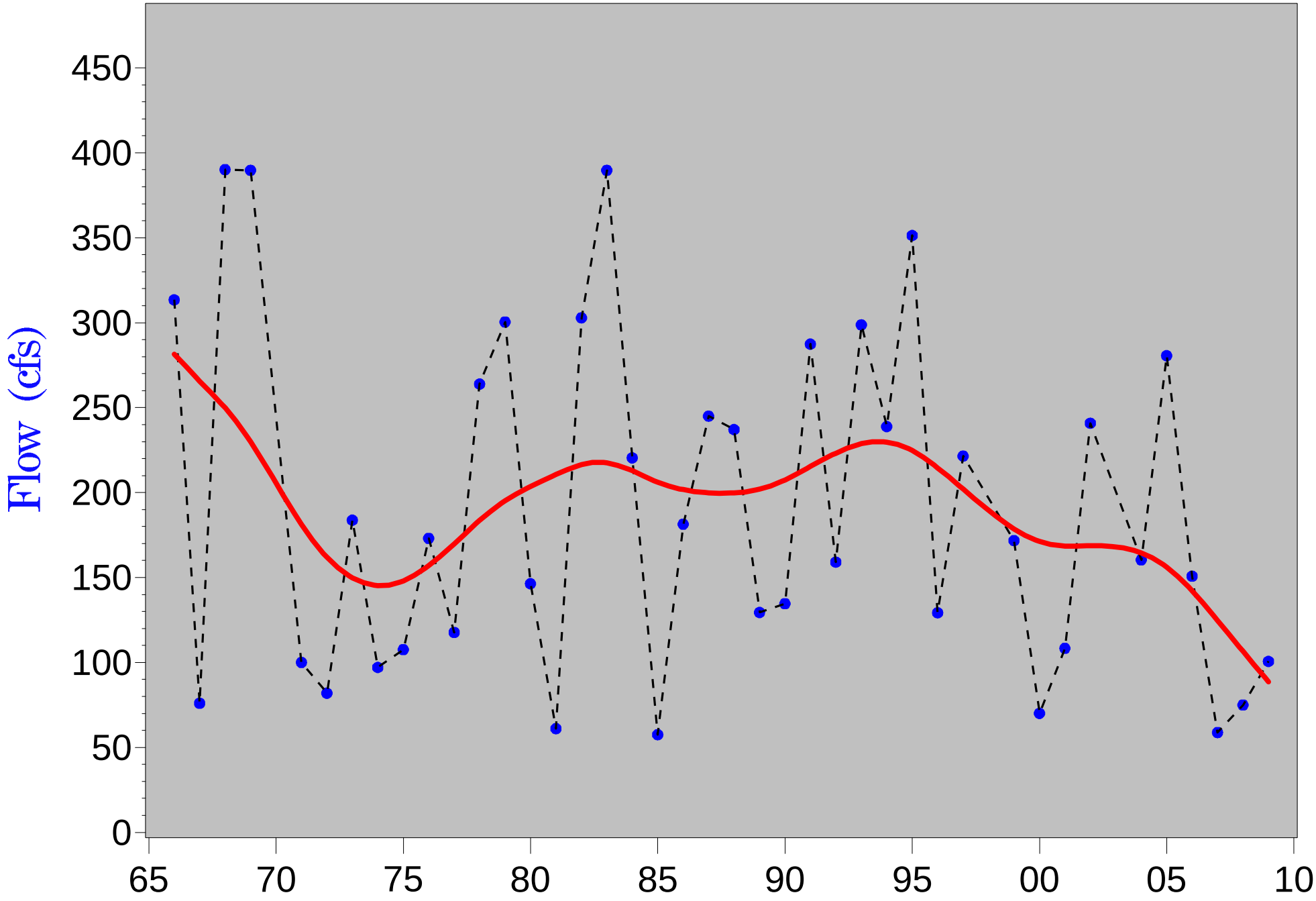


Figure 3.44b Estimated yearly P50 (median) 60-day flow without Facility withdrawals (1965-2009)

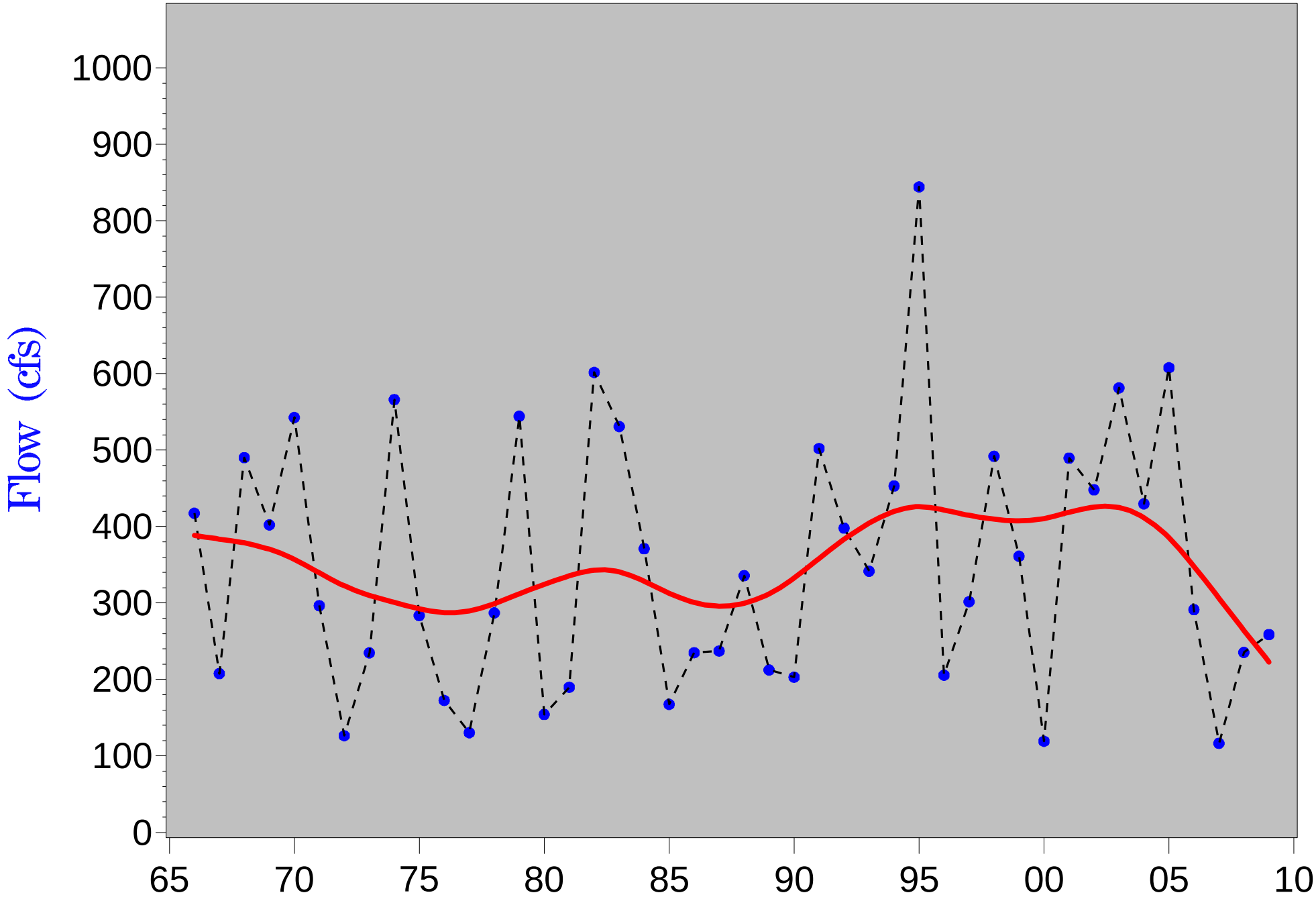


Figure 3.45a Yearly mean 60-day flow at the USGS Shell Creek gage (1965-2009)

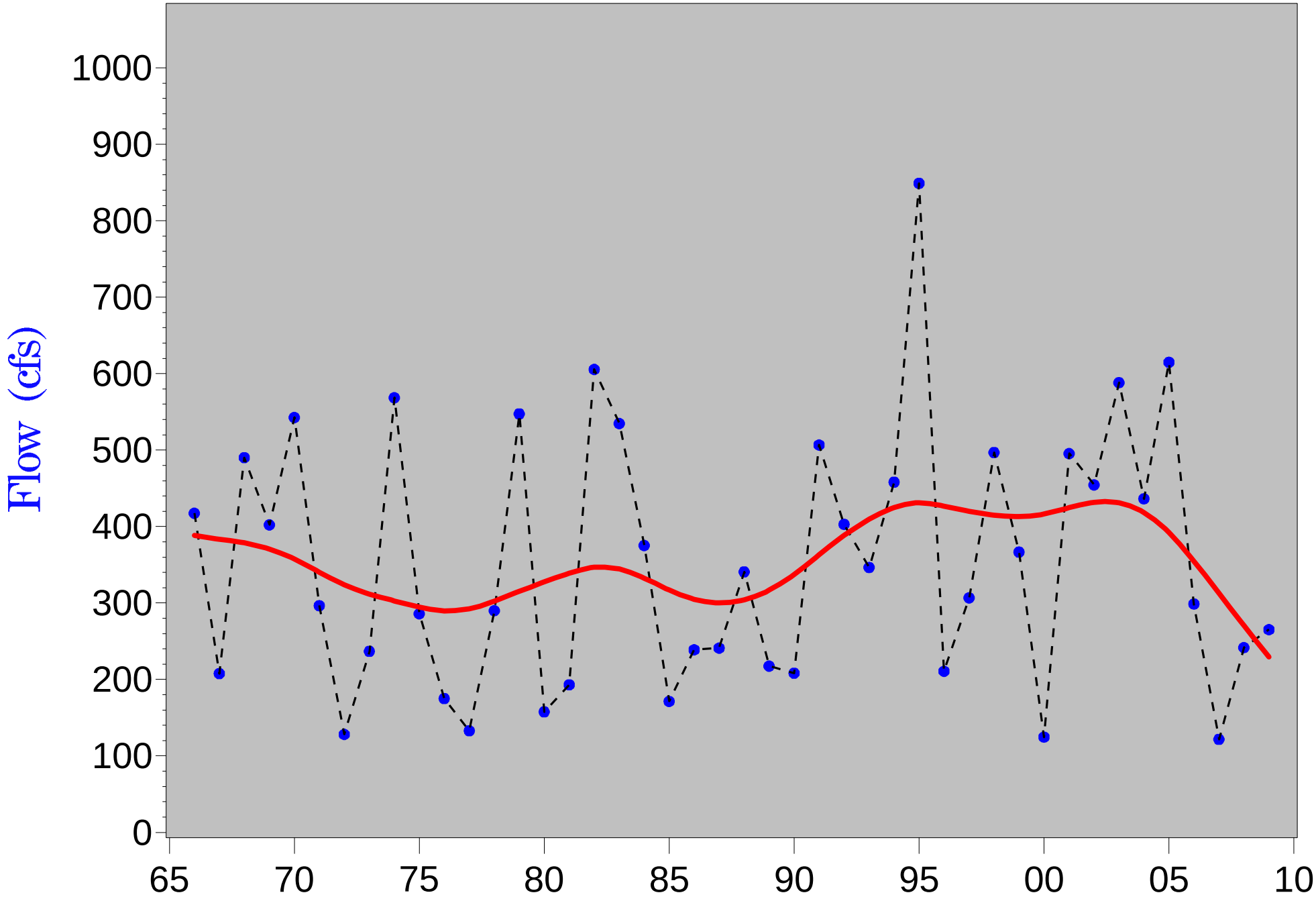


Figure 3.45b Estimated yearly mean 60-day flow without Facility withdrawals (1965-2009)

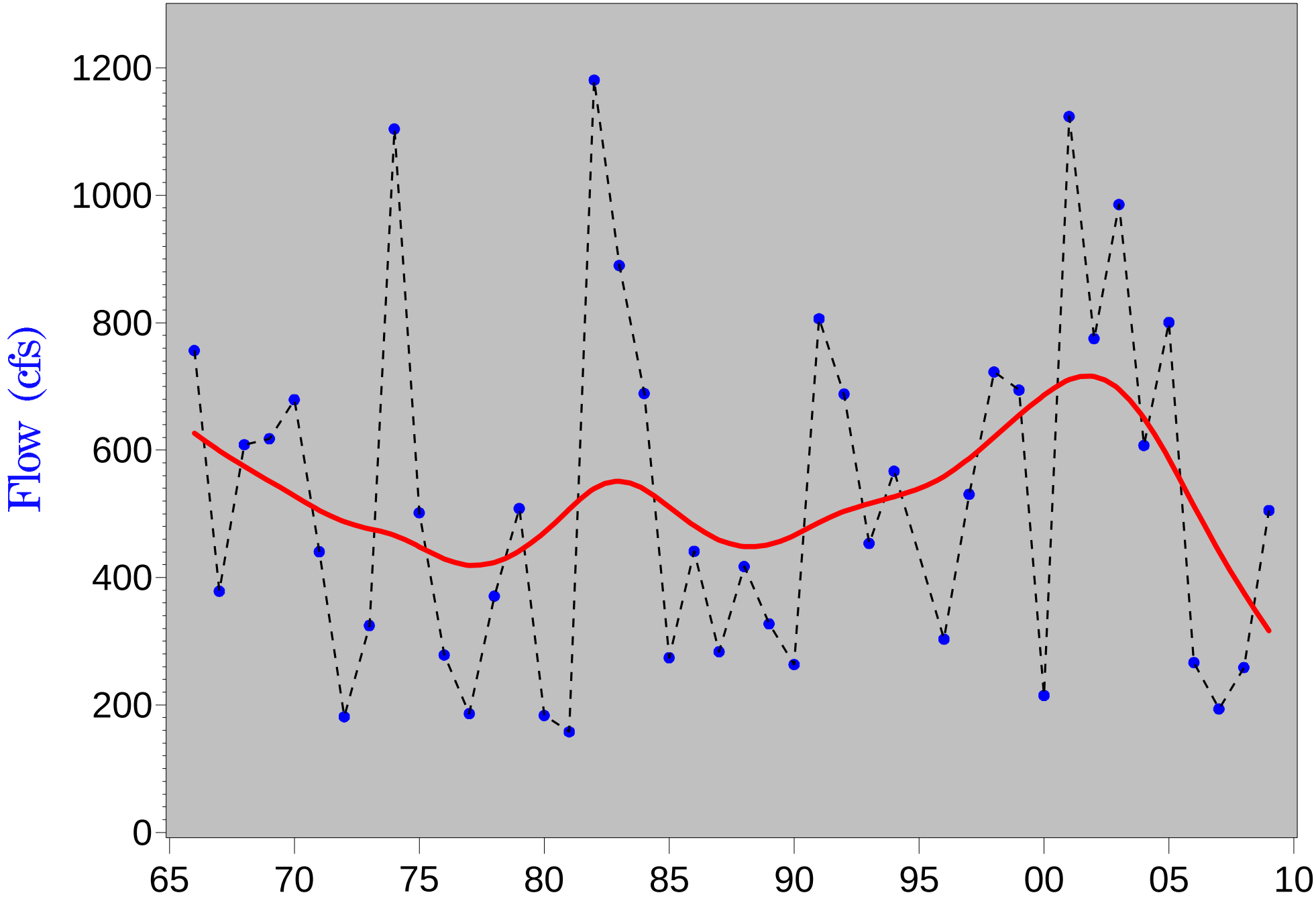


Figure 3.46a Yearly P75 60-day flow at the USGS Shell Creek gage (1965-2009)

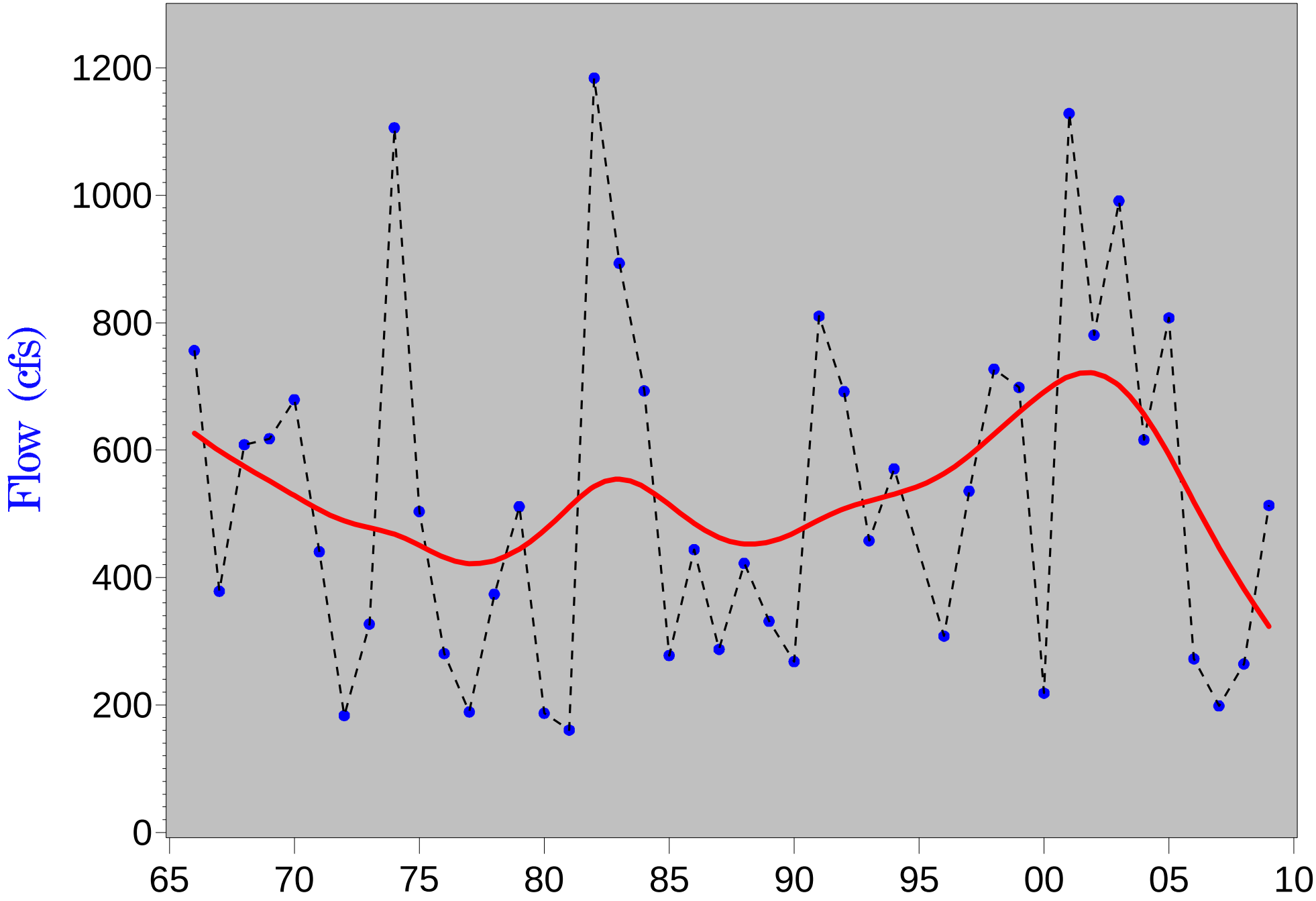


Figure 3.46b Estimated yearly P75 60-day flow without Facility withdrawals (1965-2009)

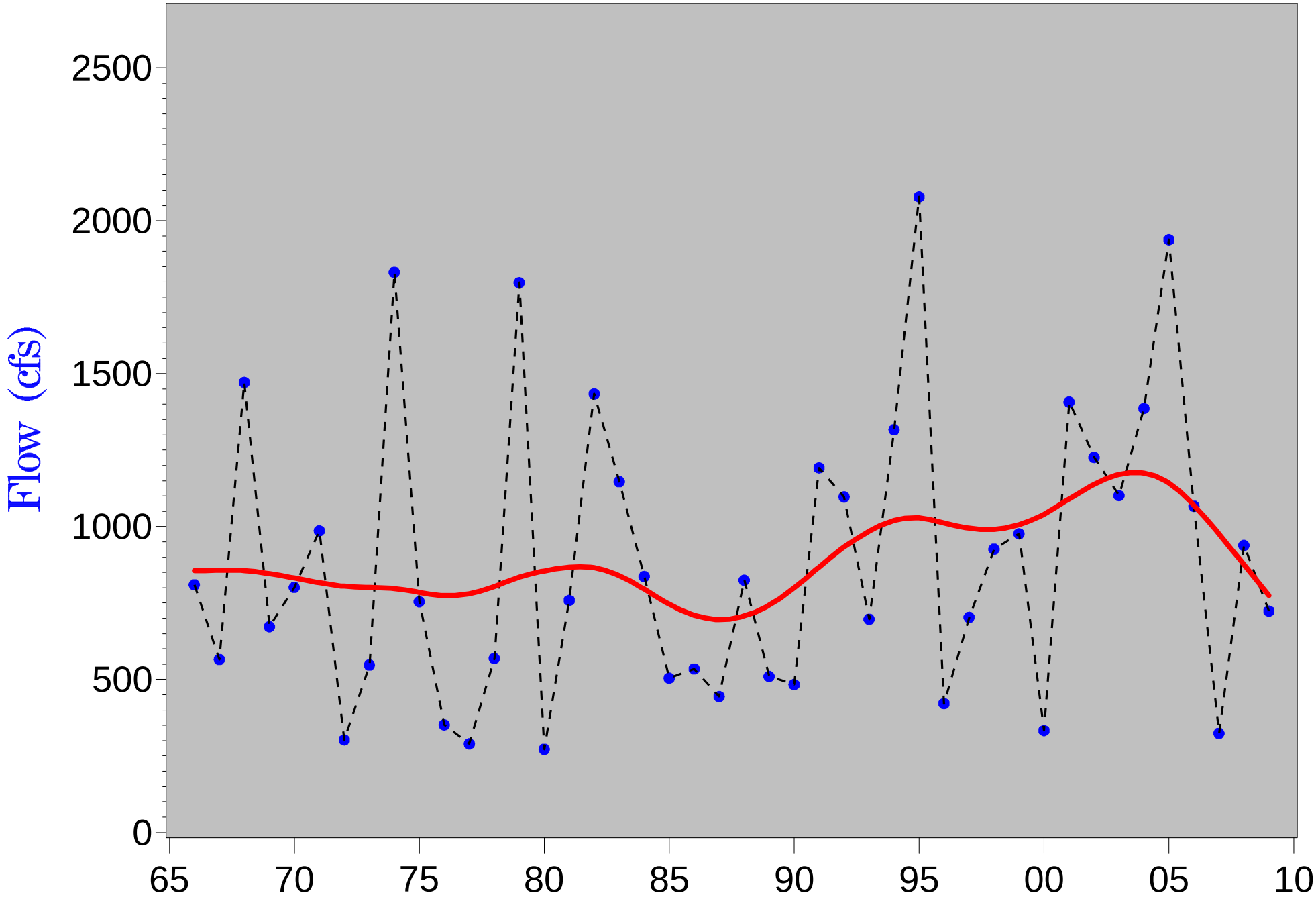


Figure 3.47a Yearly P90 60-day flow at the USGS Shell Creek gage (1965-2009)

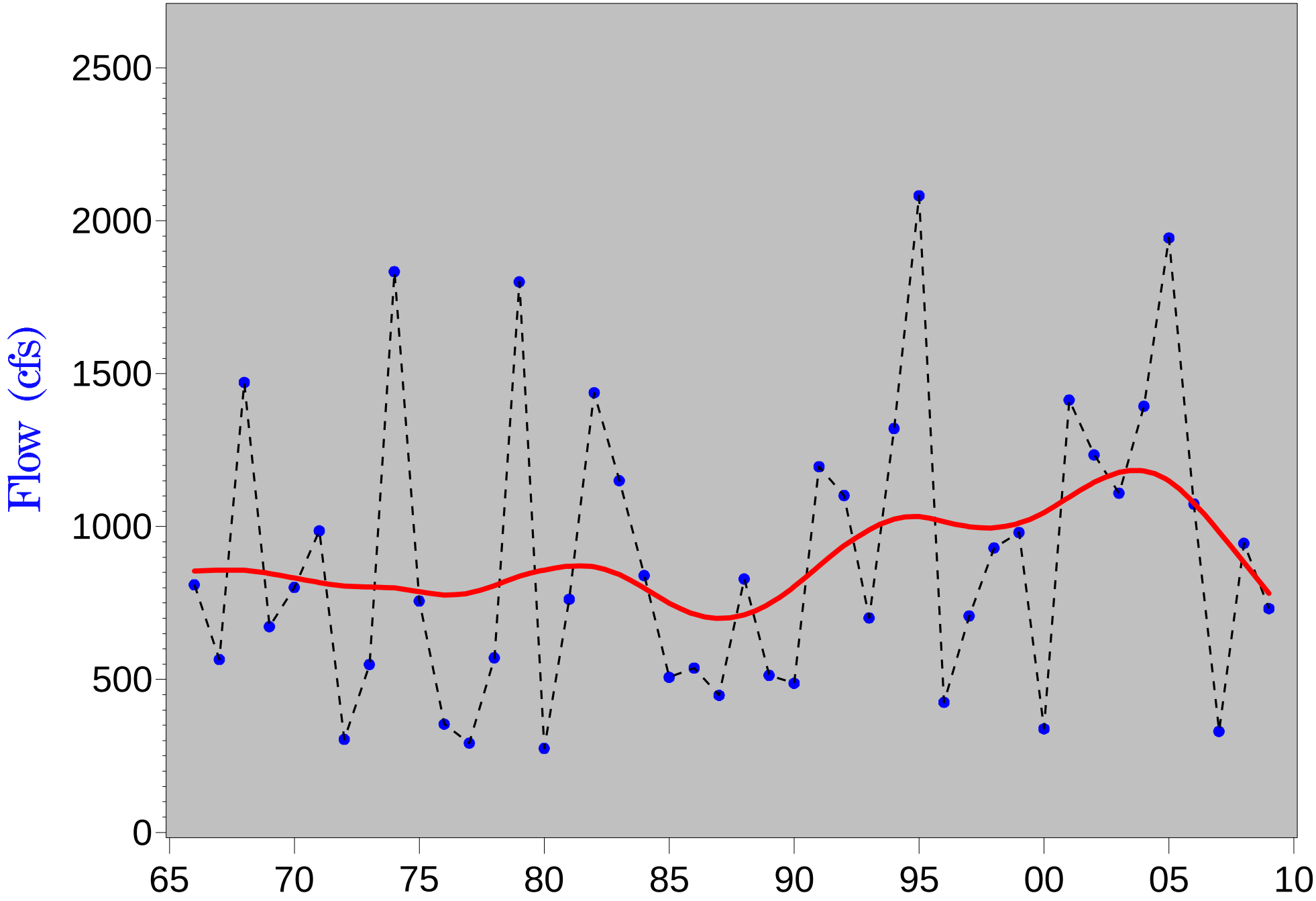


Figure 3.47b Estimated yearly P90 60-day flow without Facility withdrawals (1965-2009)

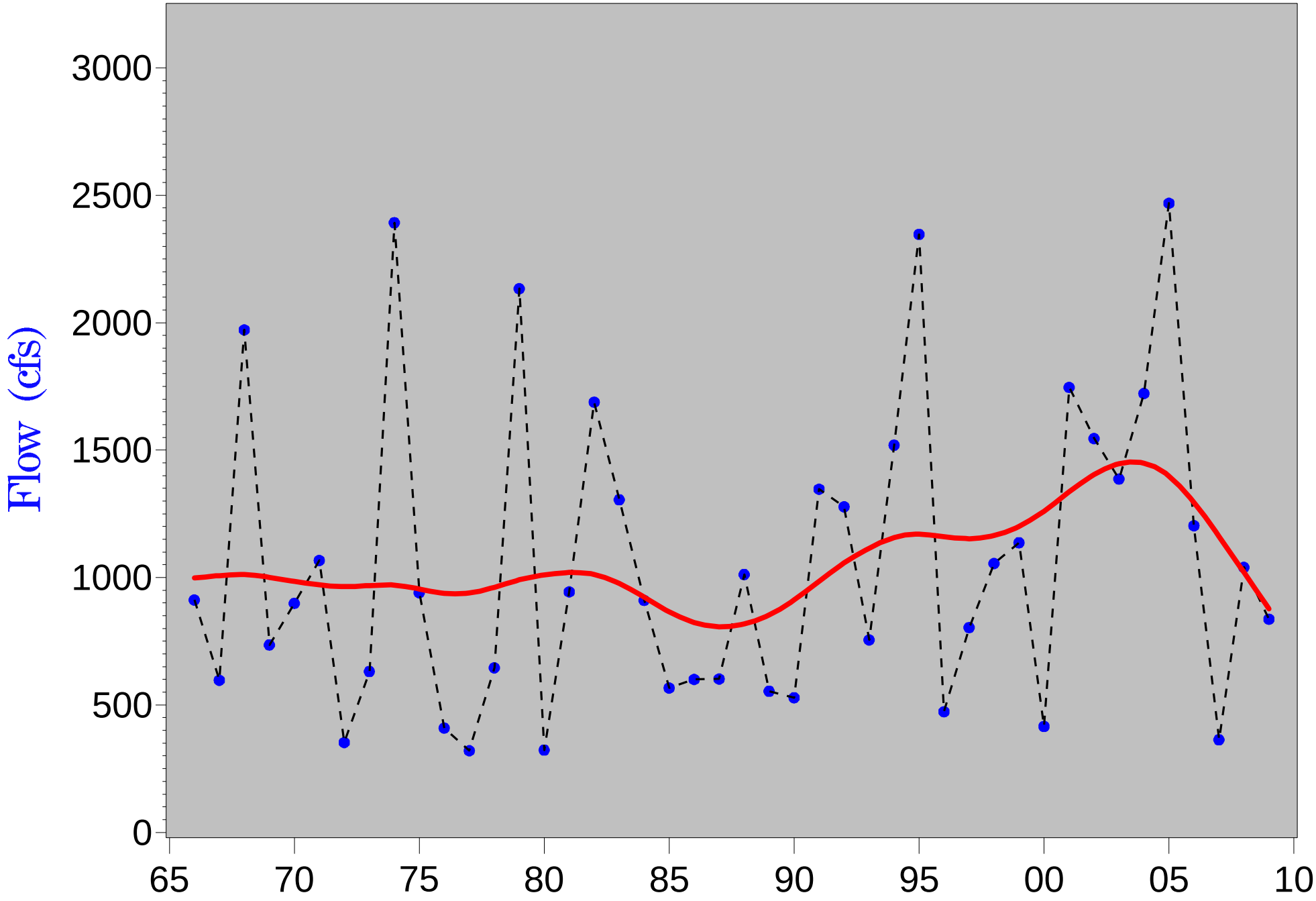


Figure 3.48a Yearly maximum 60-day flow at the USGS Shell Creek gage (1965-2009)

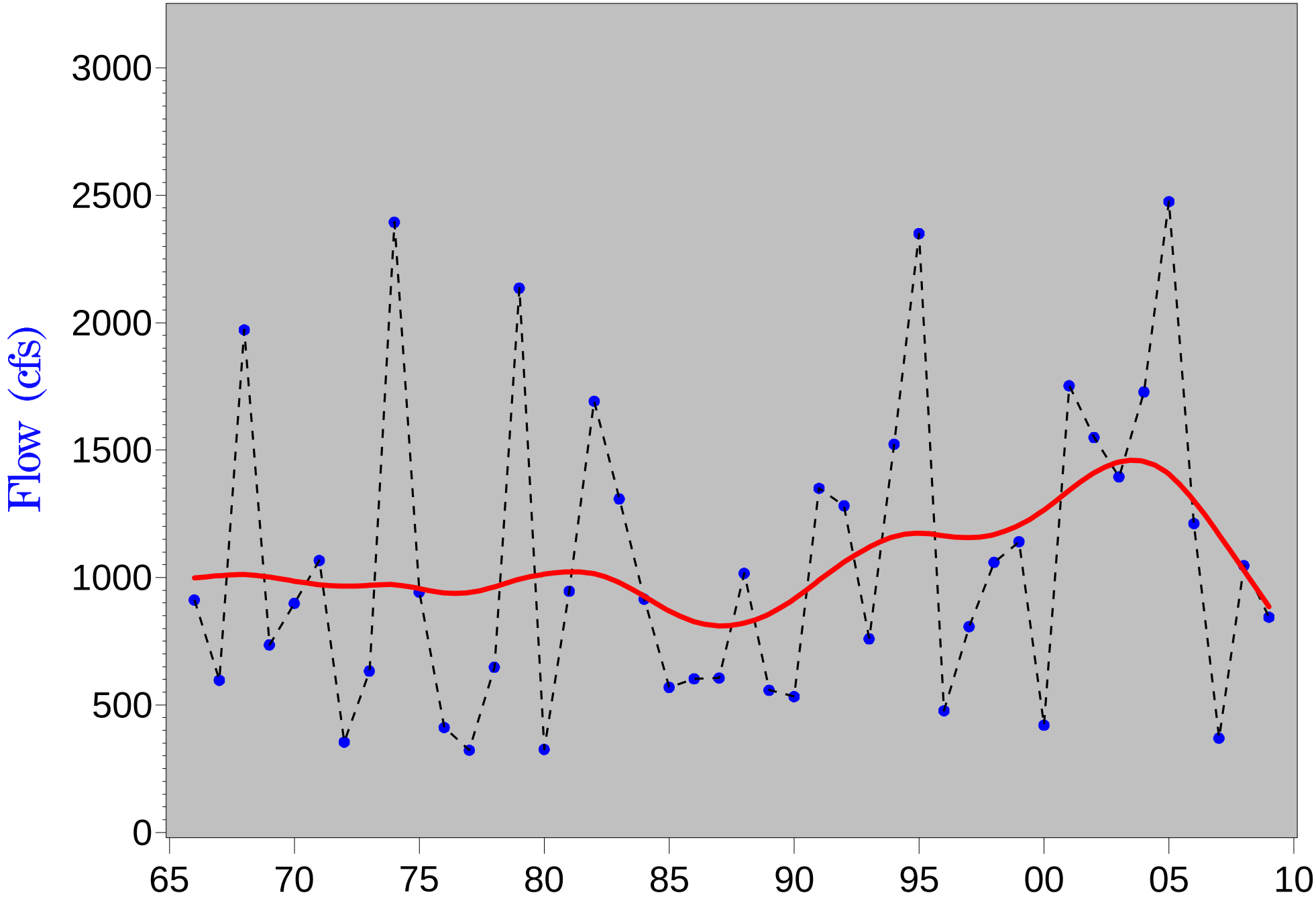


Figure 3.48b Estimated yearly maximum 60-day flow without Facility withdrawals (1965-2009)

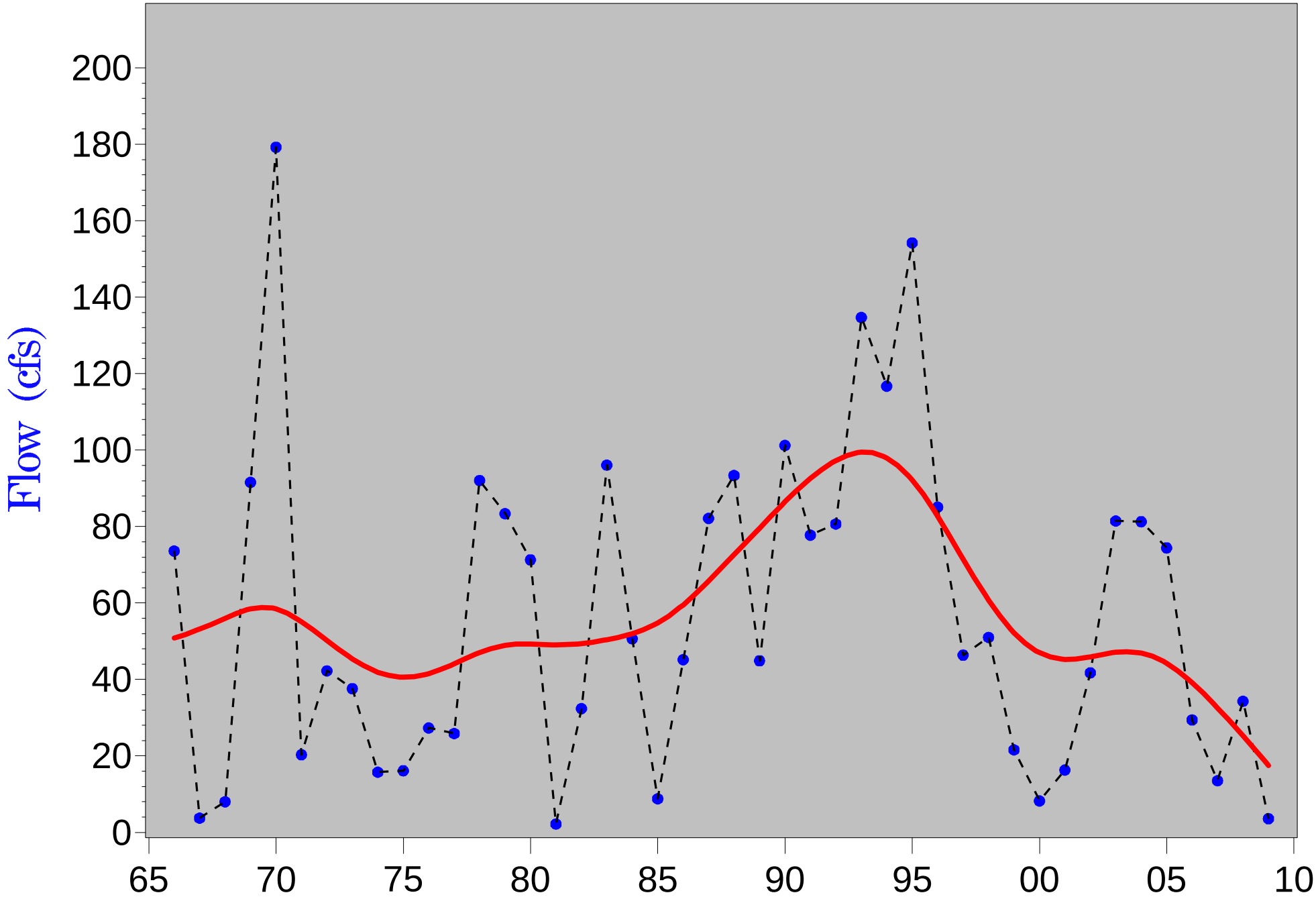


Figure 3.49a Yearly minimum 90-day flow at the USGS Shell Creek gage (1965-2009)

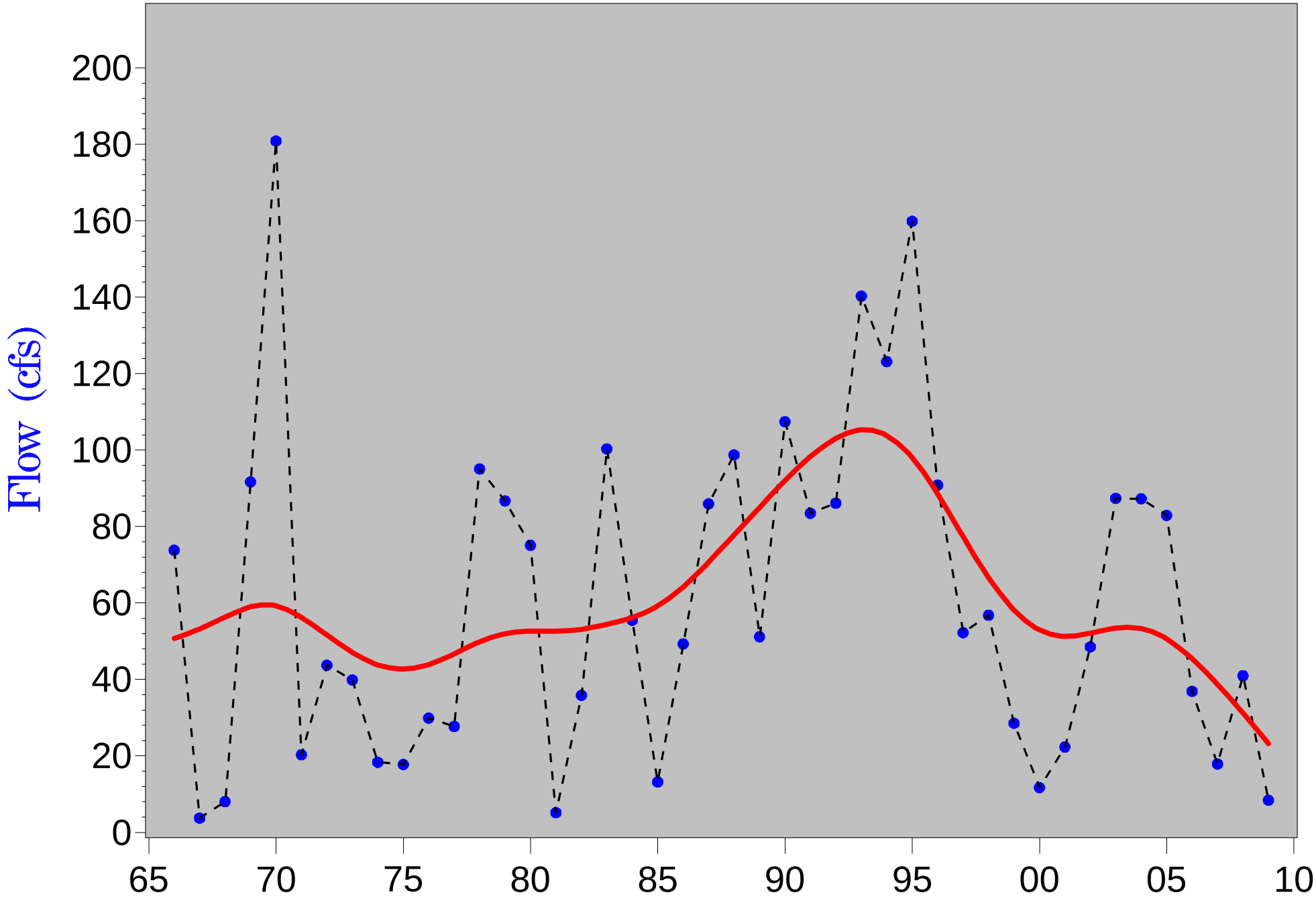


Figure 3.49b Estimated yearly minimum 90-day flow without Facility withdrawals (1965-2009)

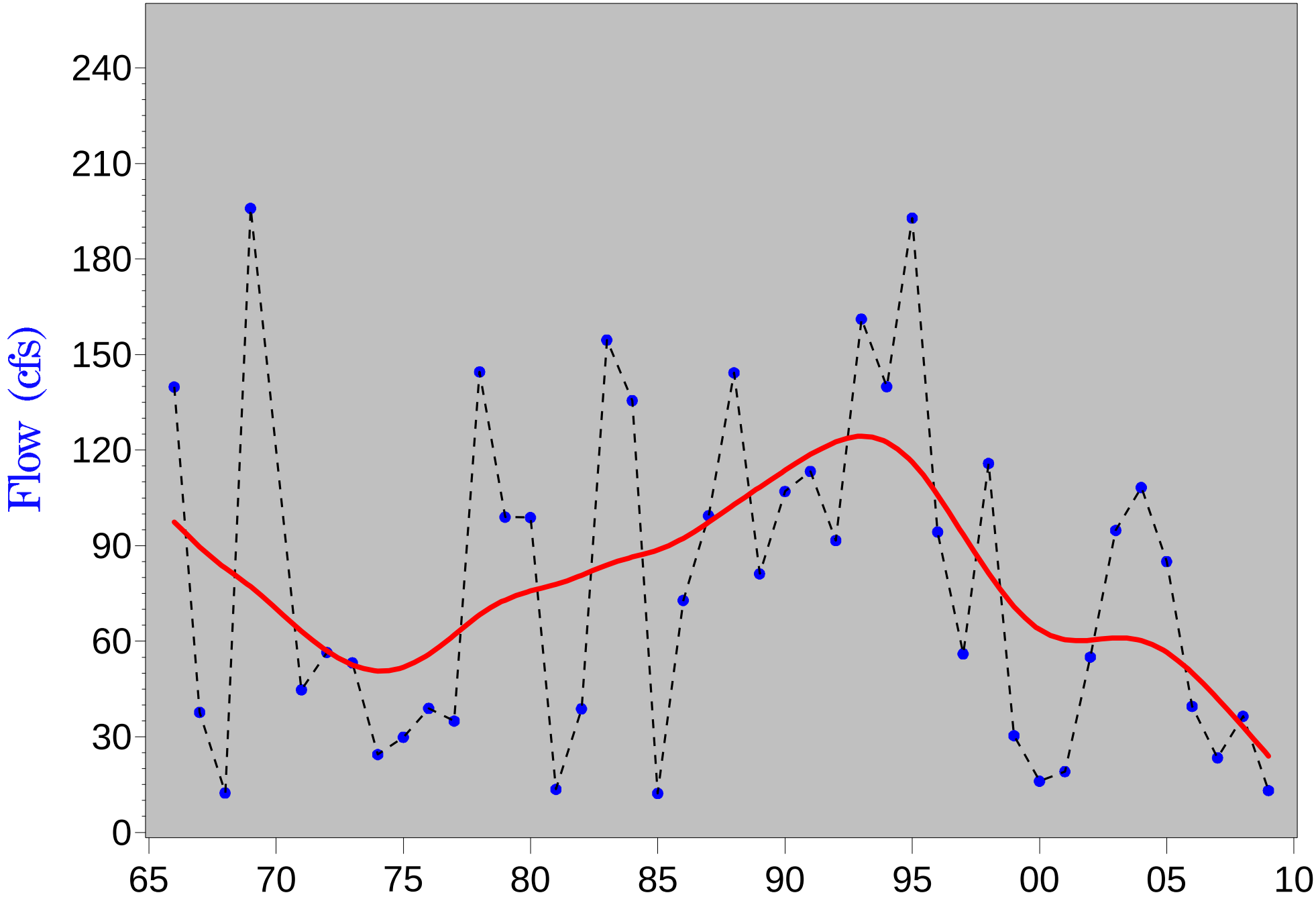


Figure 3.50a Yearly P10 90-day flow at the USGS Shell Creek gage (1965-2009)

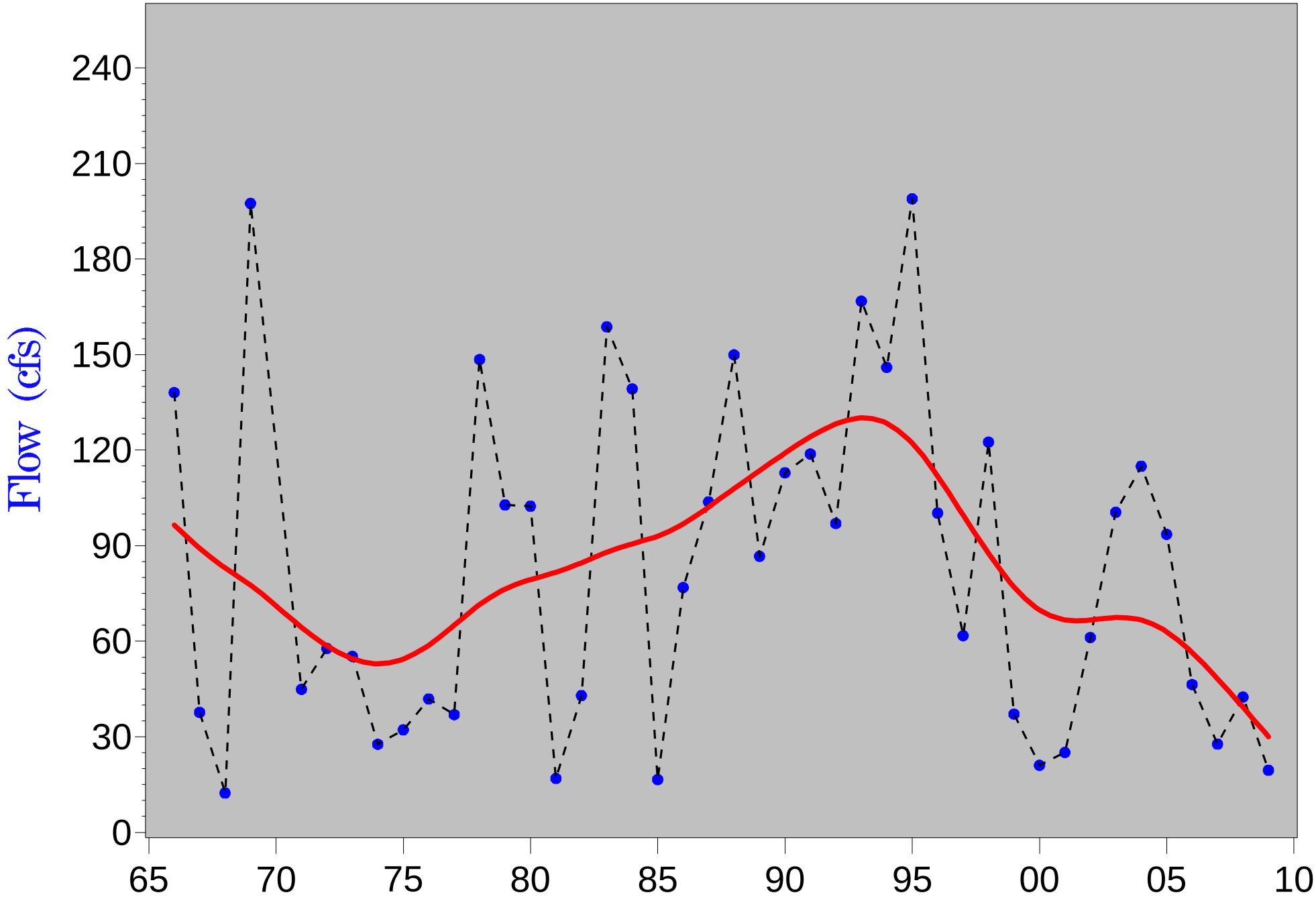


Figure 3.50b Estimated yearly P10 90-day flow without Facility withdrawals (1965-2009)

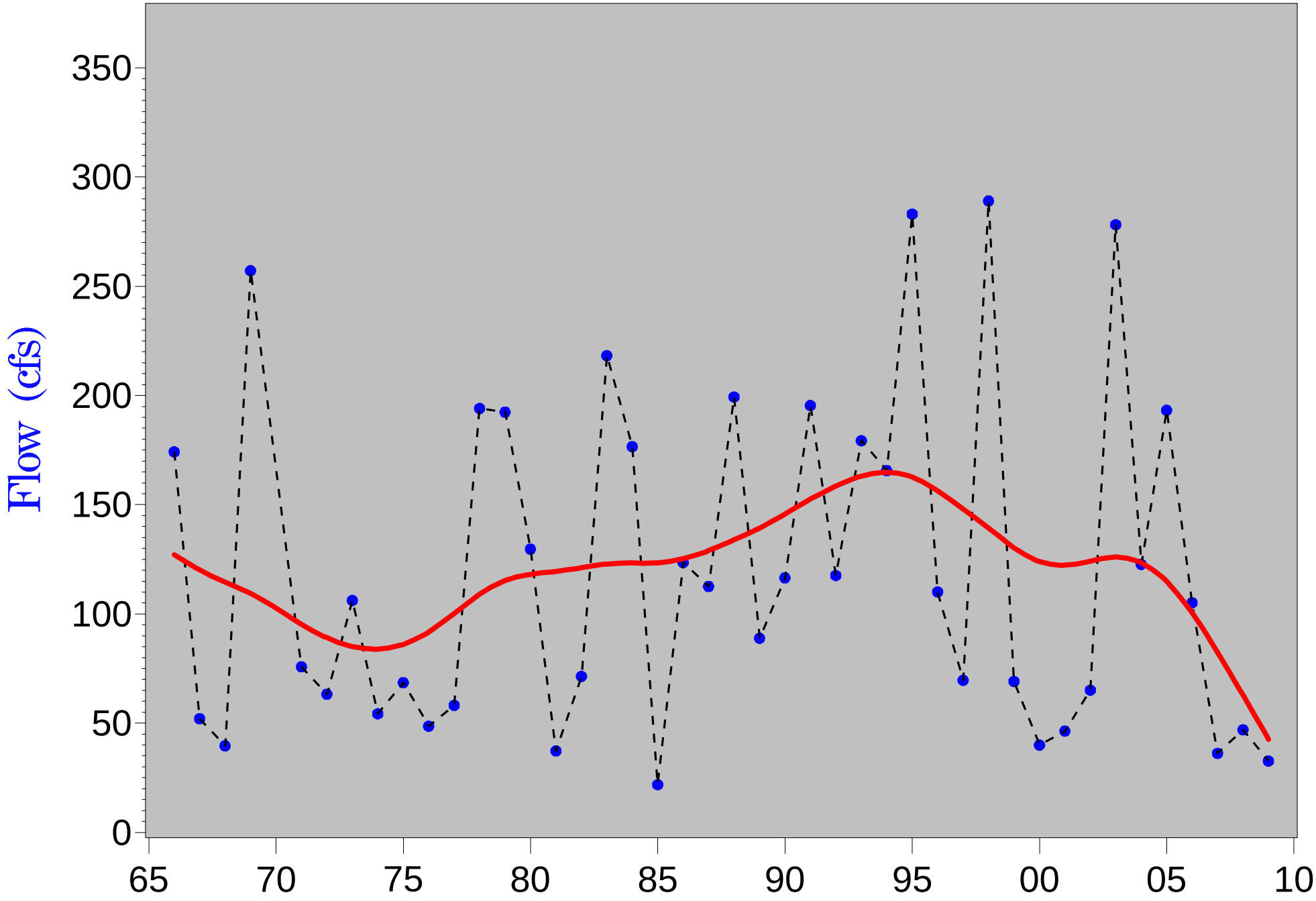


Figure 3.51a Yearly P25 90-day flow at the USGS Shell Creek gage (1965-2009)

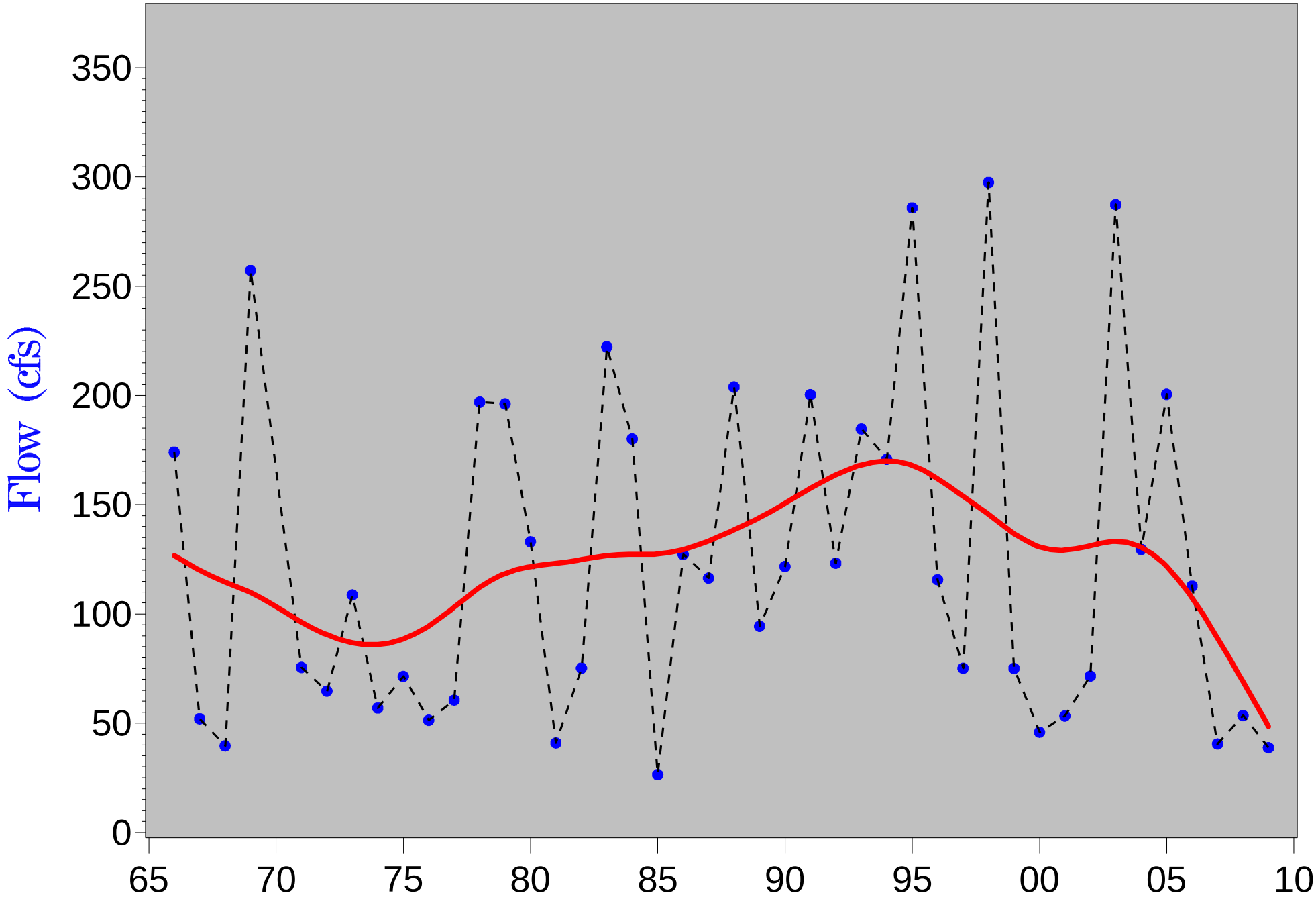


Figure 3.51b Estimated yearly P25 90-day flow without Facility withdrawals (1965-2009)

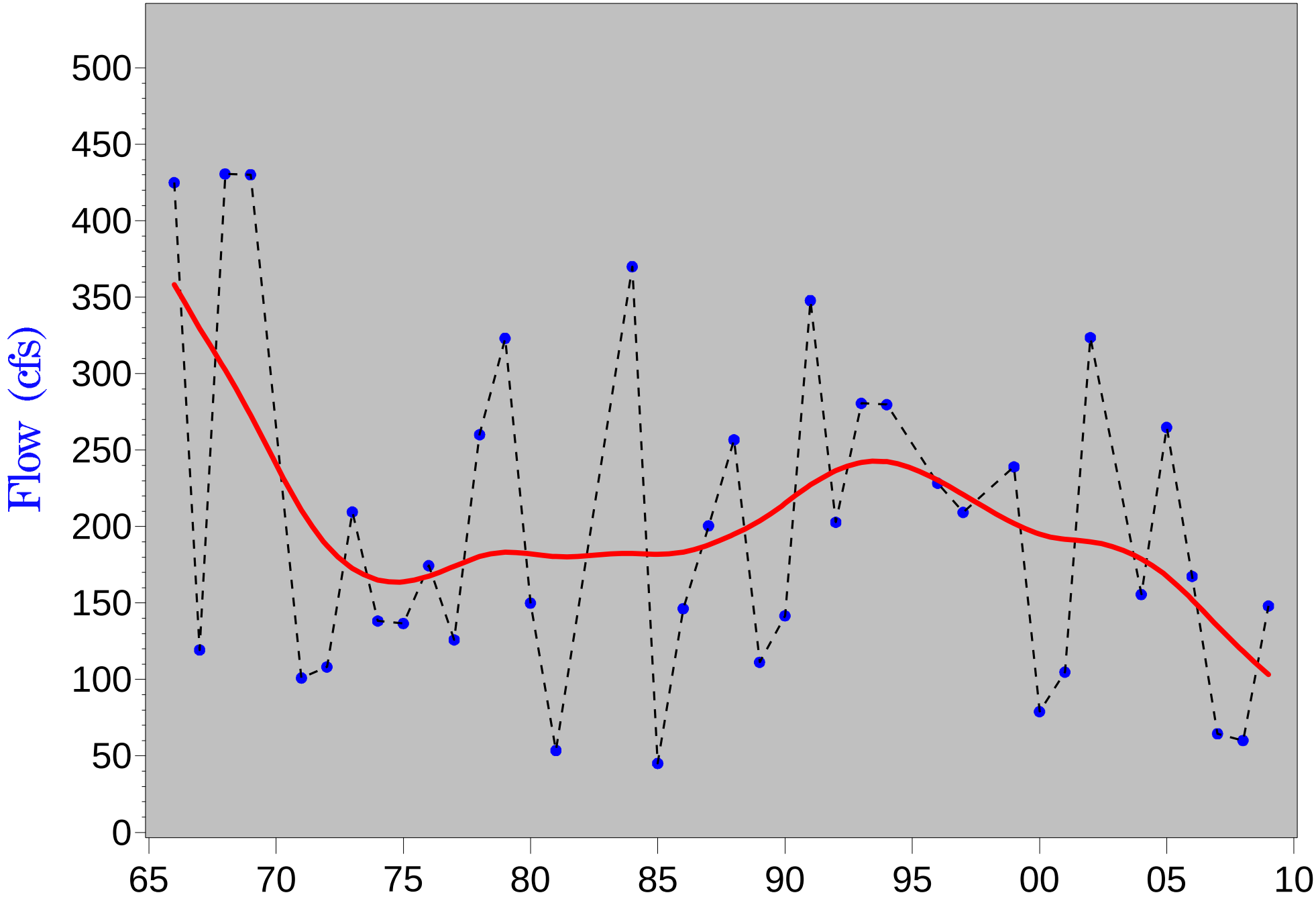


Figure 3.52a Yearly P50 (median) 90-day flow at the USGS Shell Creek gage (1965-2009)

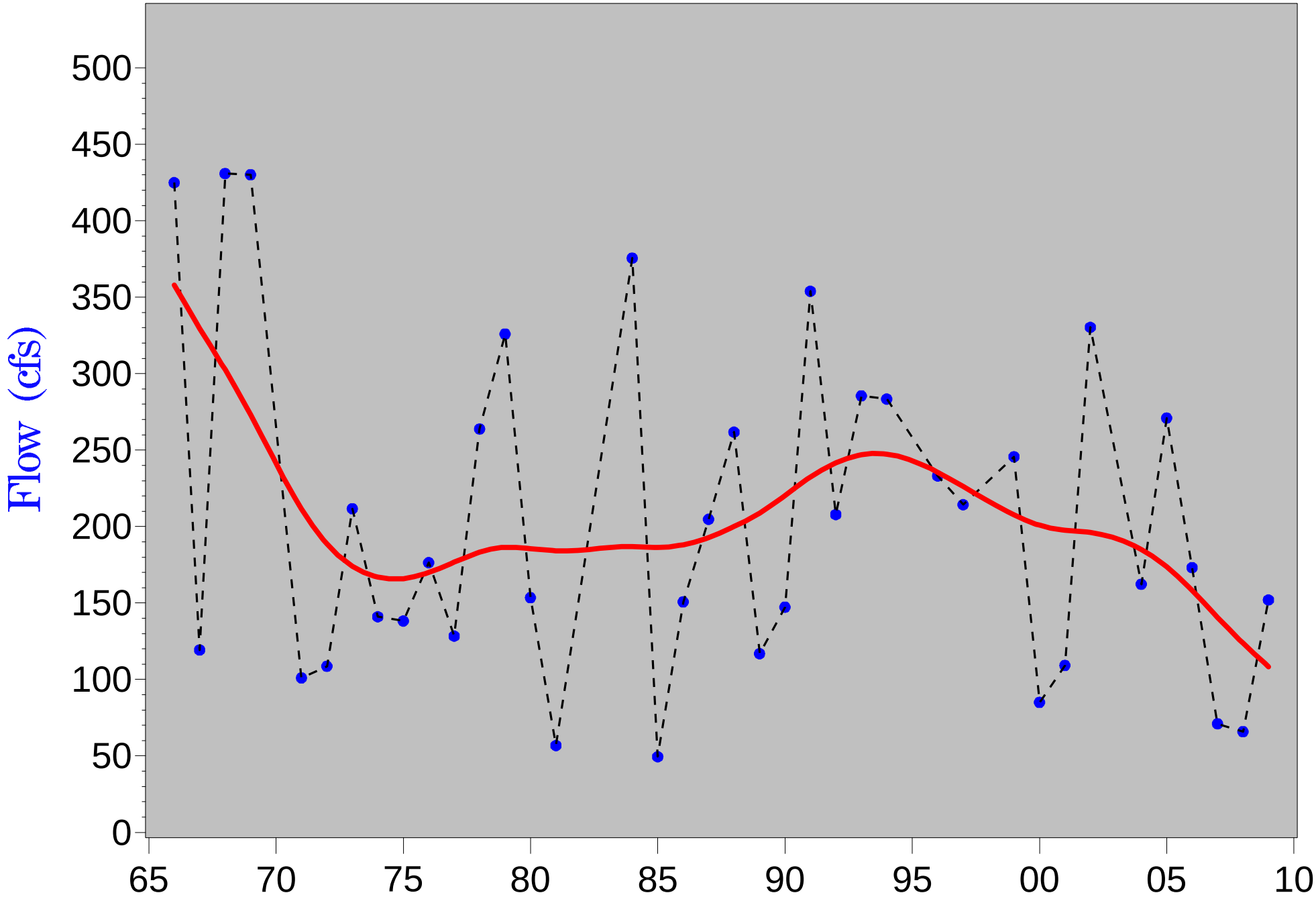


Figure 3.52b Estimated yearly P50 (median) 90-day flow without Facility withdrawals (1965-2009)

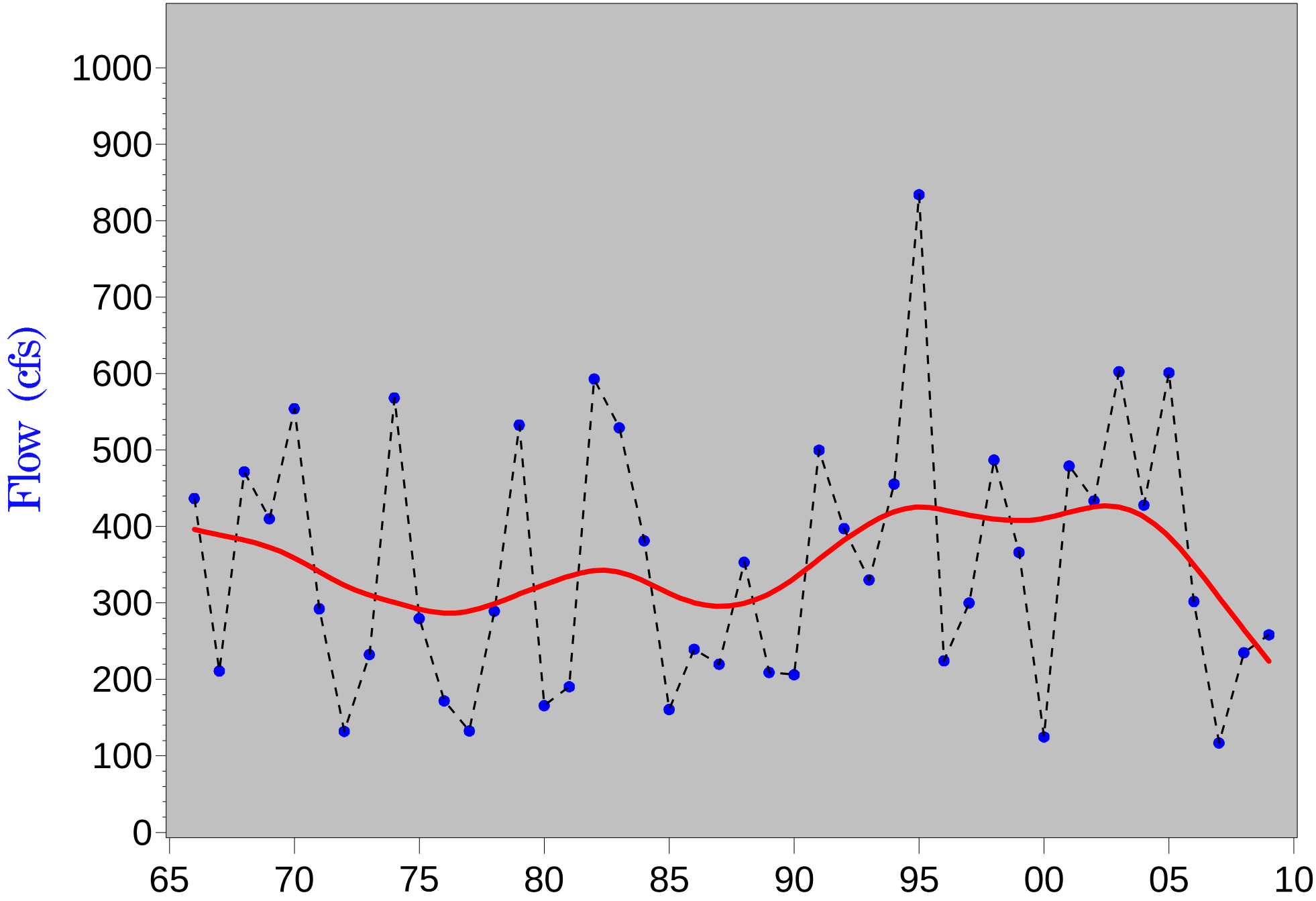


Figure 3.53a Yearly mean 90-day flow at the USGS Shell Creek gage (1965-2009)

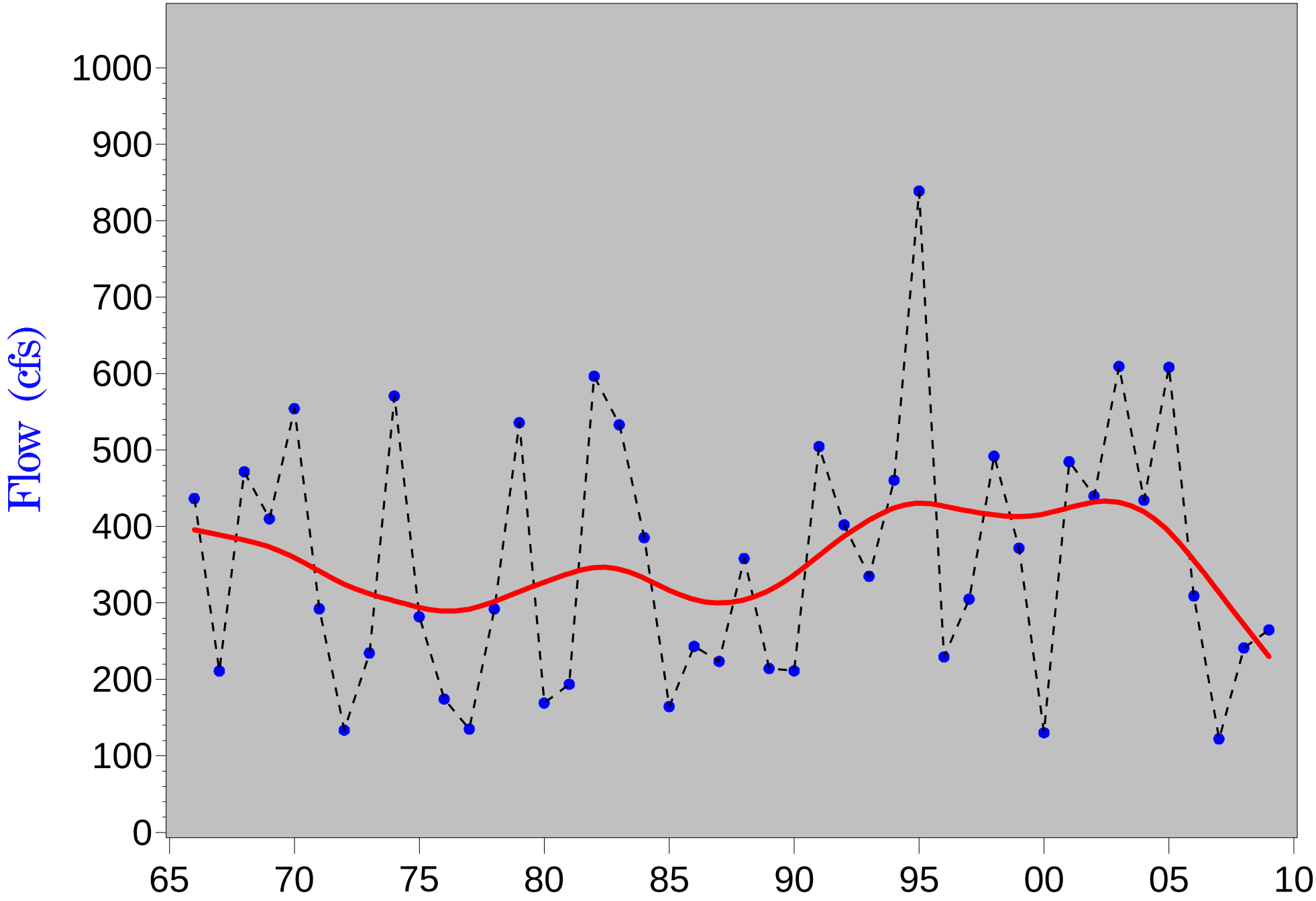


Figure 3.53b Estimated yearly mean 90-day flow without Facility withdrawals (1965-2009)

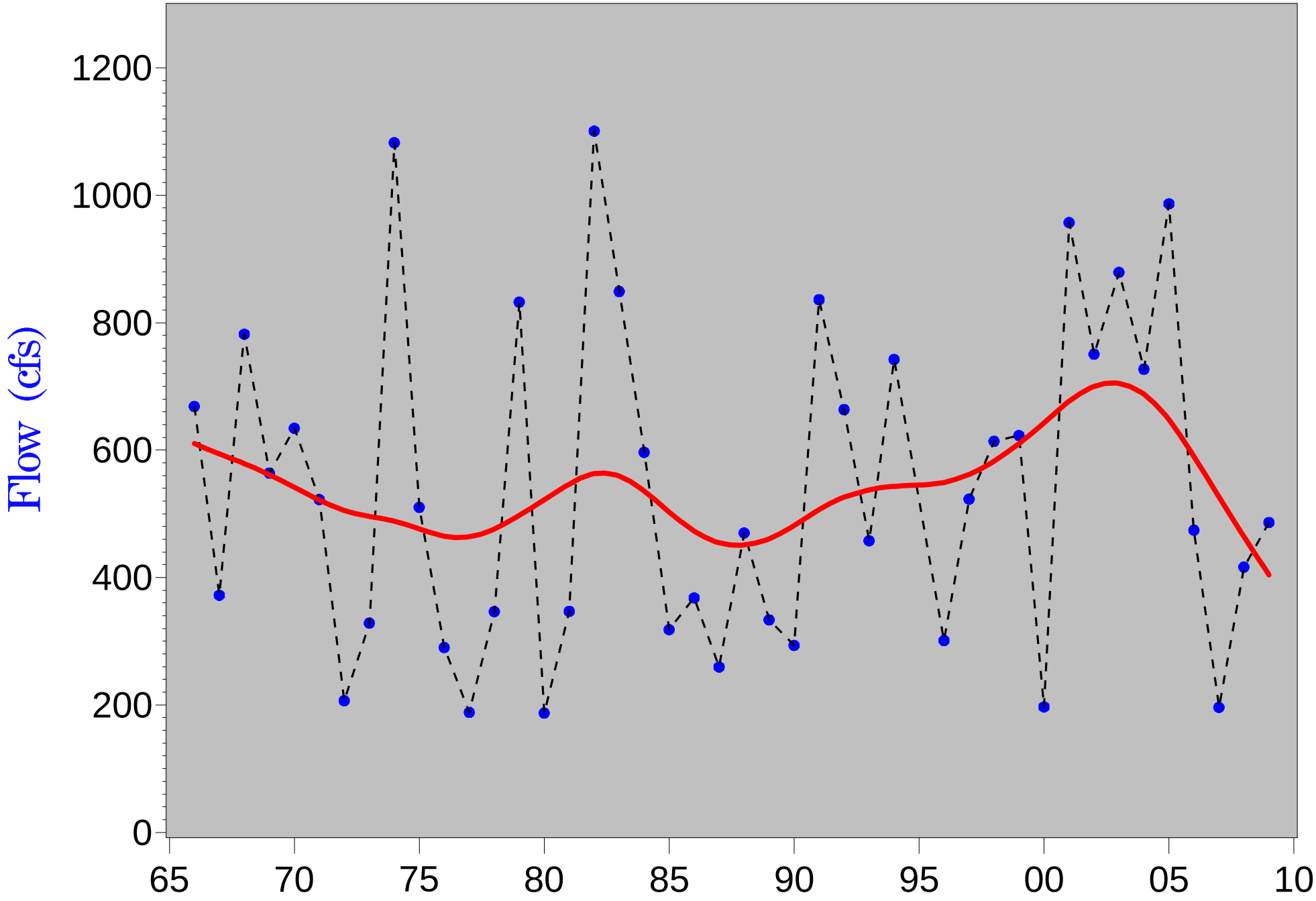


Figure 3.54a Yearly P75 90-day flow at the USGS Shell Creek gage (1965-2009)

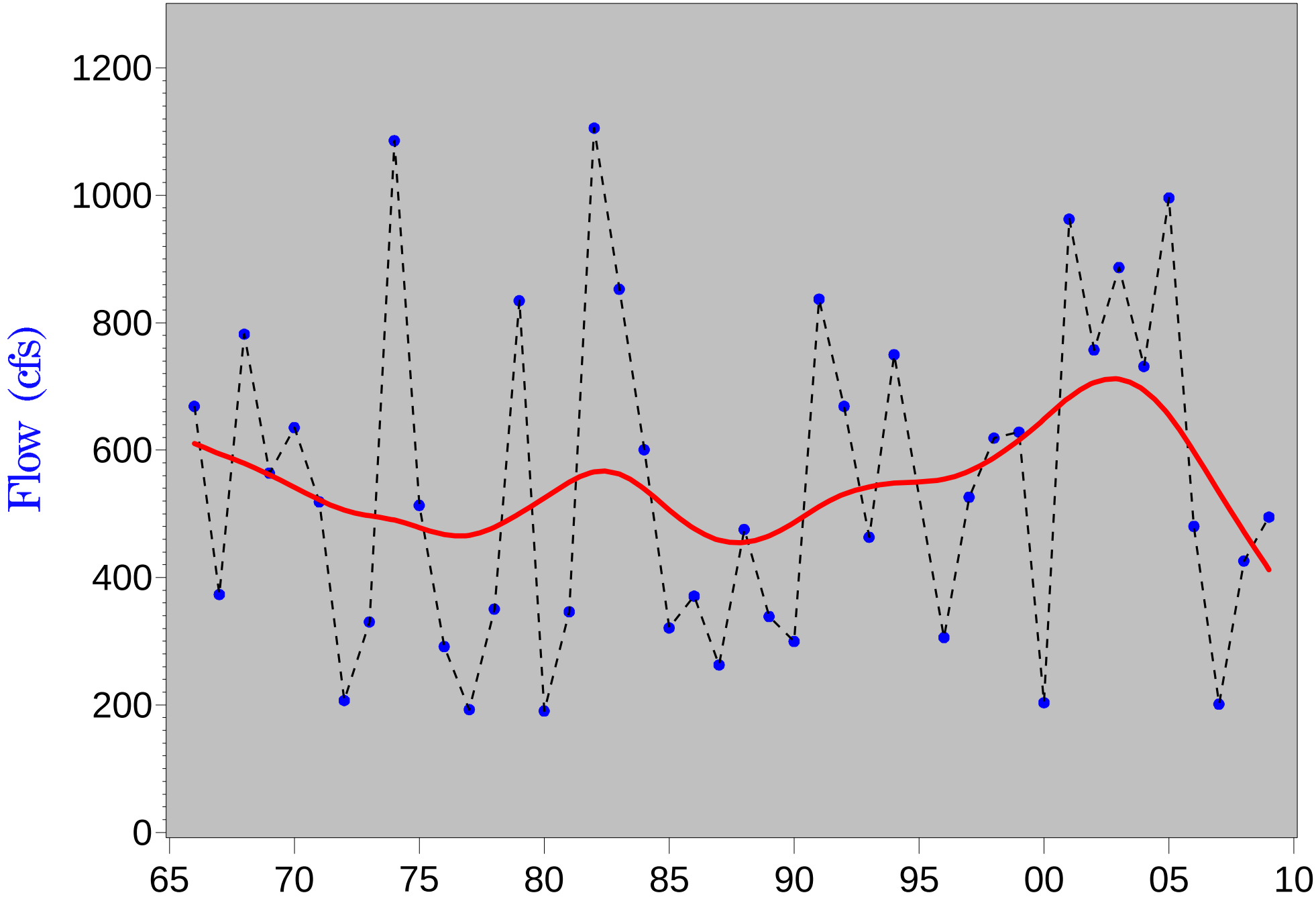


Figure 3.54b Estimated yearly P75 90-day flow without Facility withdrawals (1965-2009)

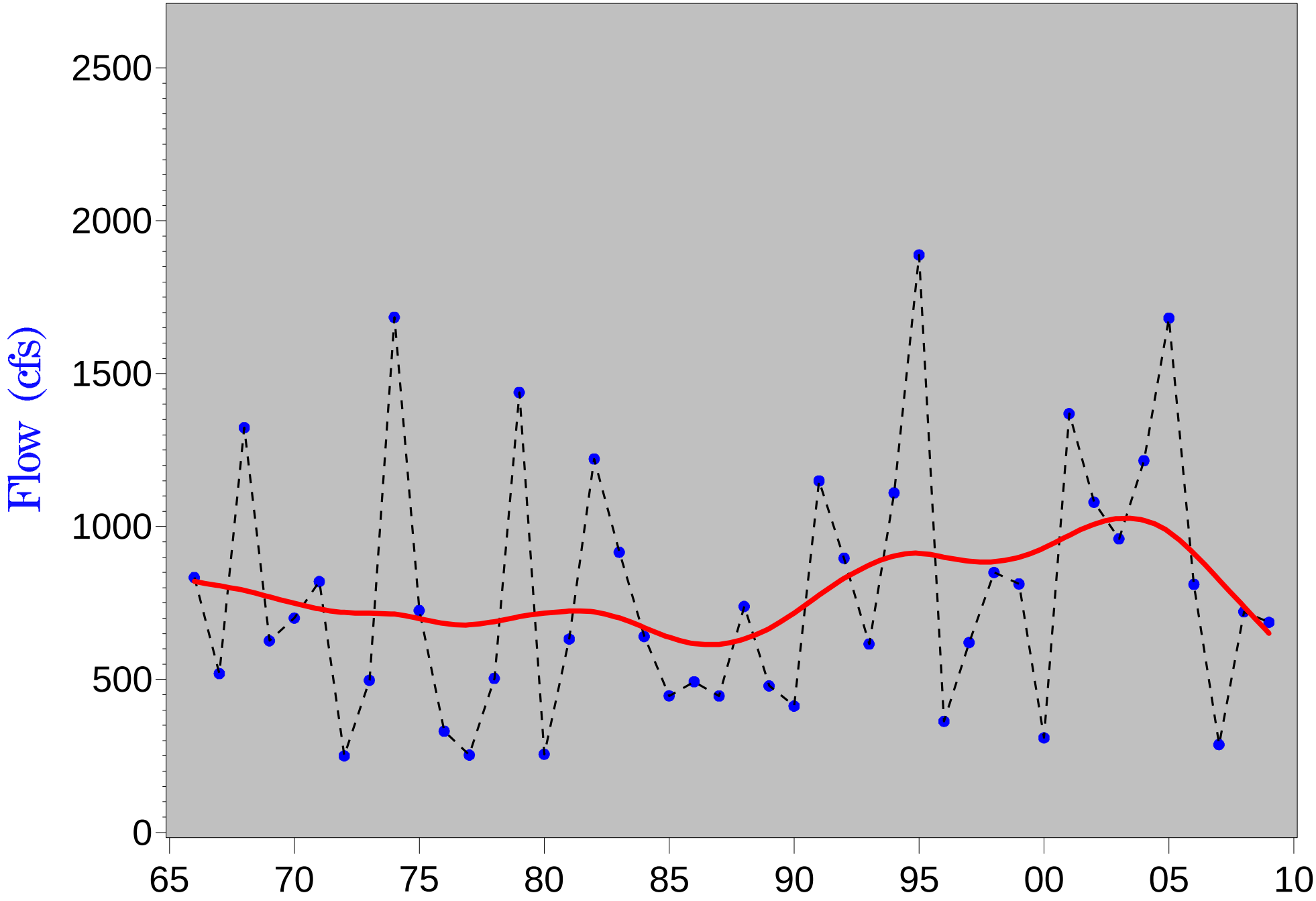


Figure 3.55a Yearly P90 90-day flow at the USGS Shell Creek gage (1965-2009)

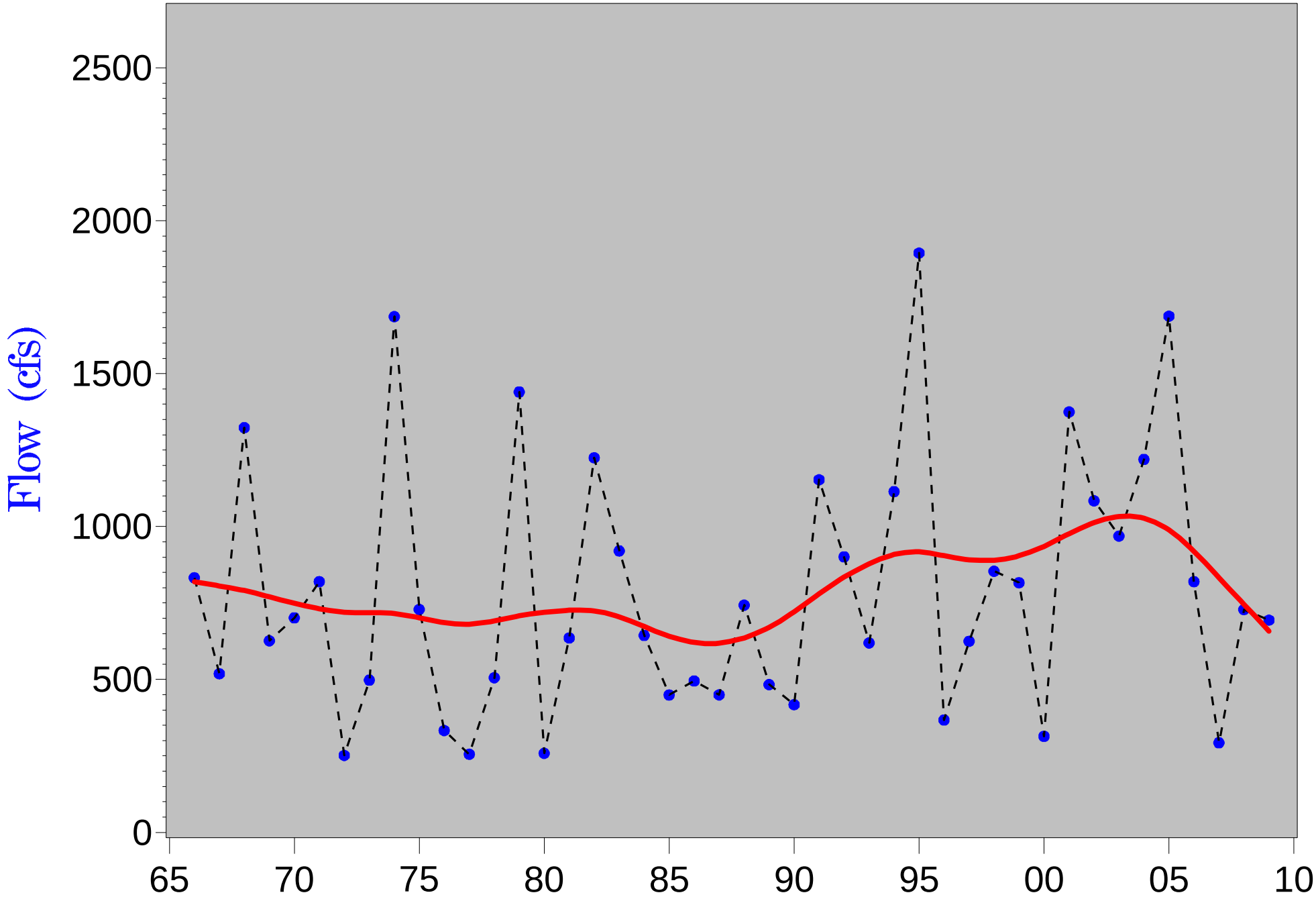


Figure 3.55b Estimated yearly P90 90-day flow without Facility withdrawals (1965-2009)

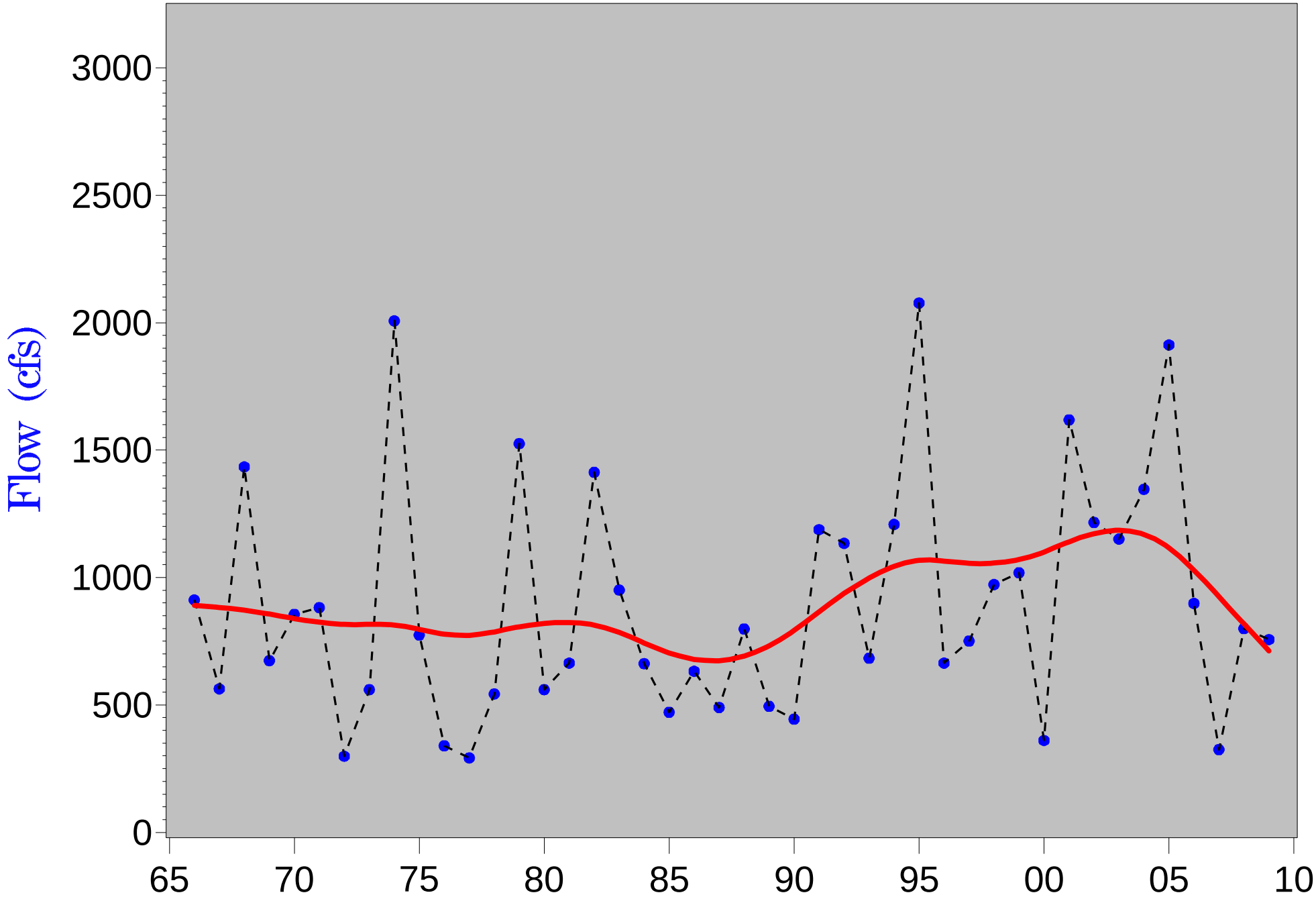


Figure 3.56a Yearly maximum 90-day flow at the USGS Shell Creek gage (1965-2009)

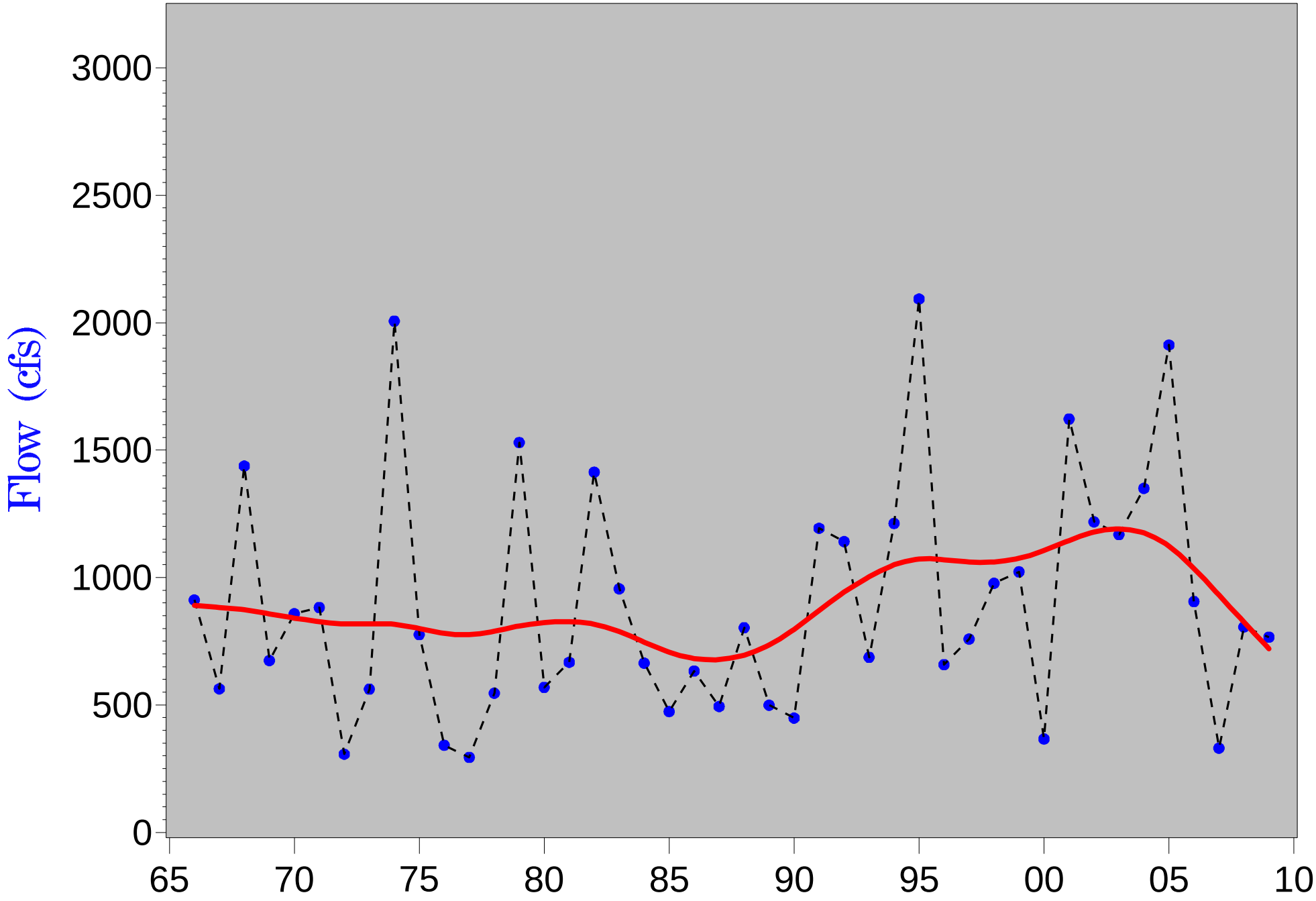


Figure 3.56b Estimated yearly maximum 90-day flow without Facility withdrawals (1965-2009)

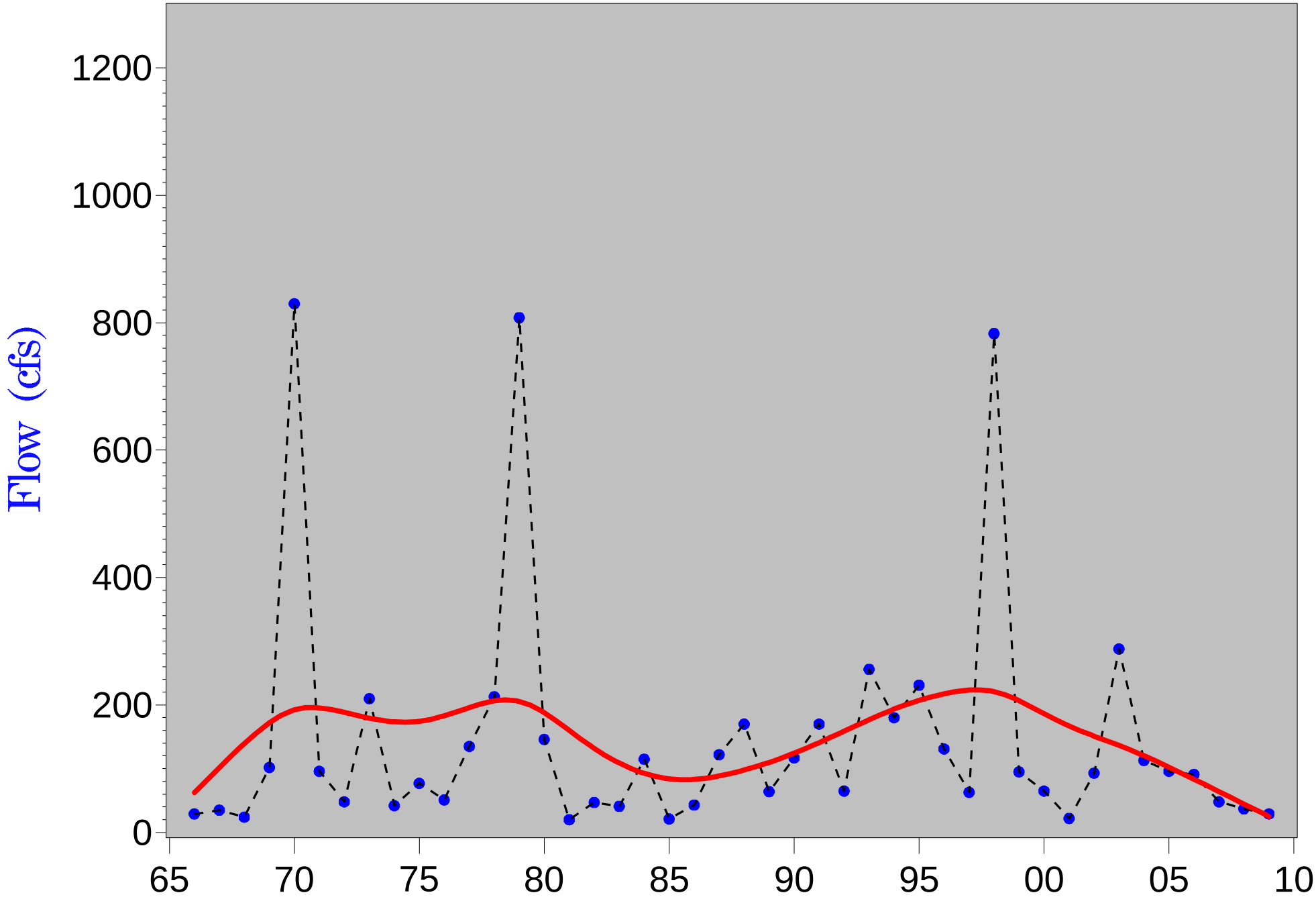


Figure 3.57a January median USGS Shell Creek gaged flow (1966-2009)

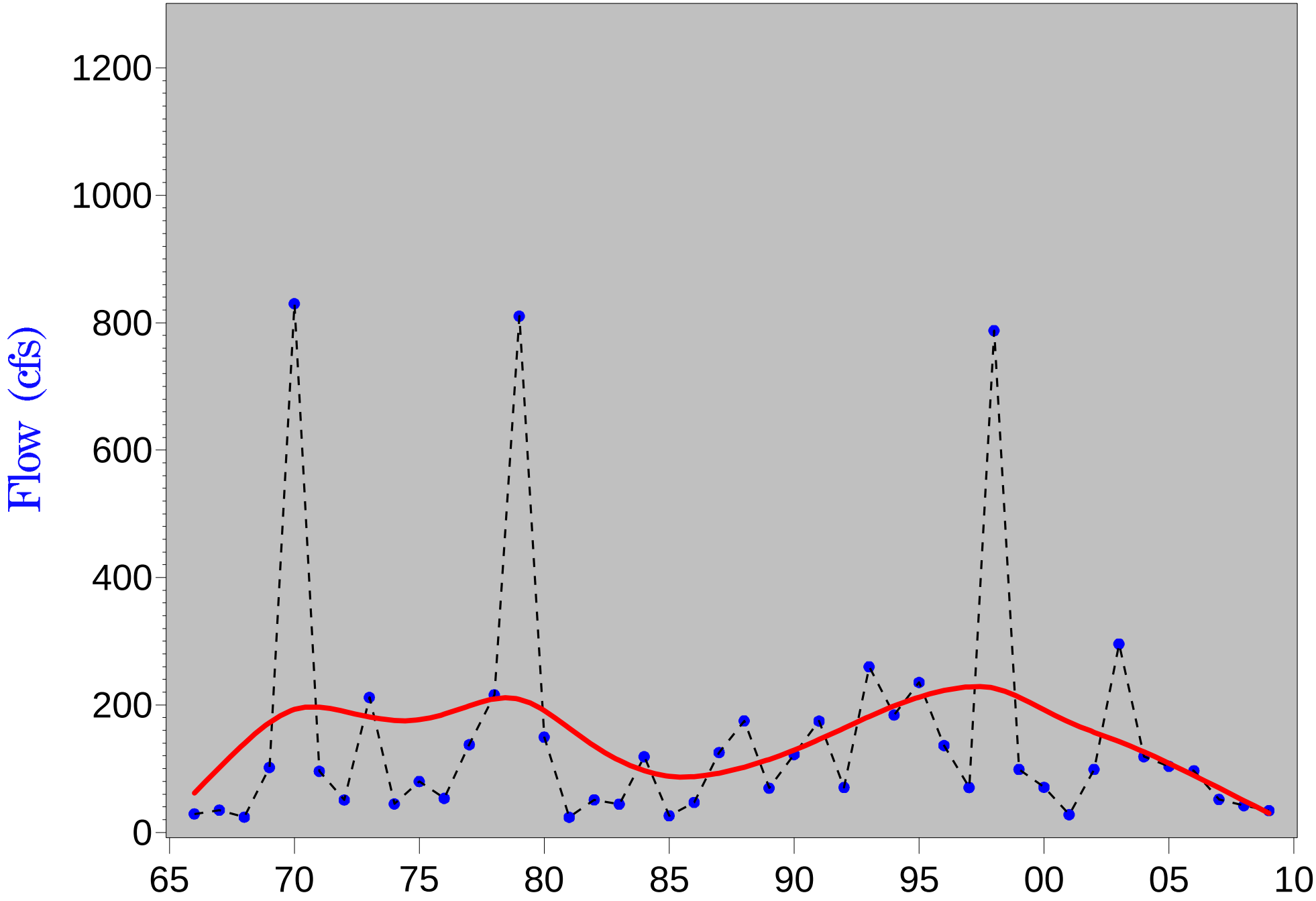


Figure 3.57b Estimated January median flow without Facility withdrawals (1966-2009)

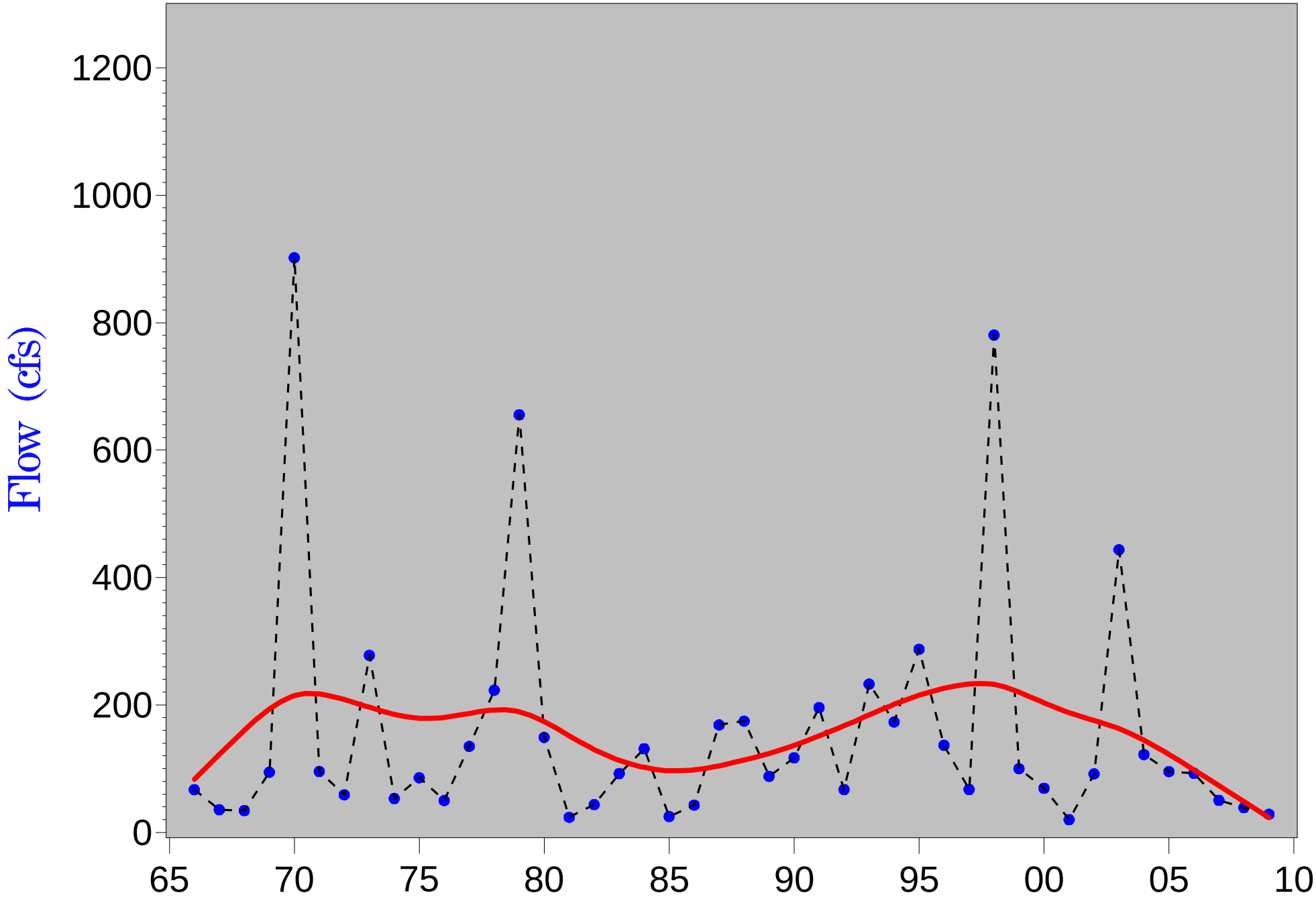


Figure 3.58a January mean USGS Shell Creek gaged flow (1966-2009)

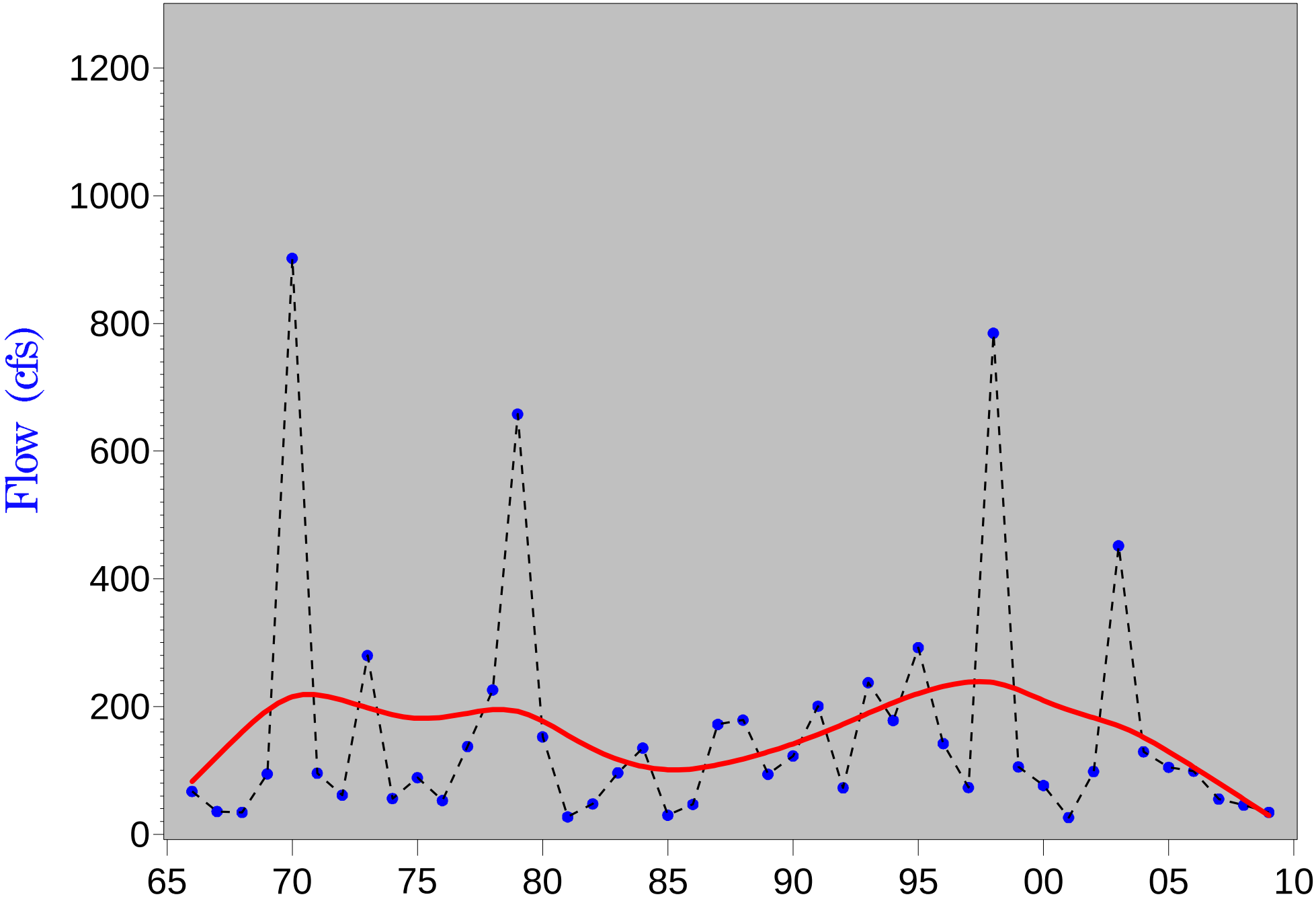


Figure 3.58b Estimated January mean flow without Facility withdrawals (1966-2009)

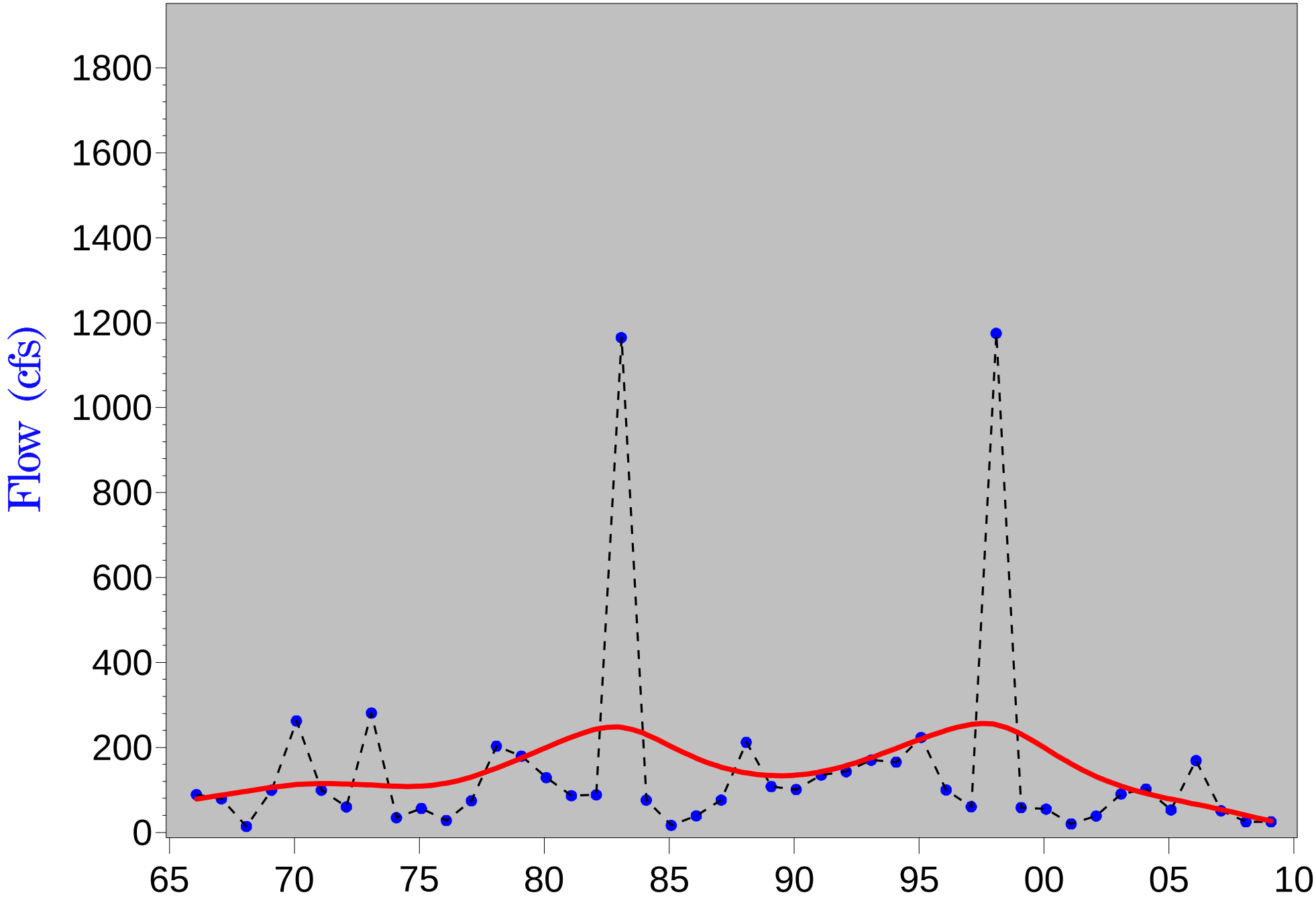


Figure 3.59a February median USGS Shell Creek gaged flow (1966-2009)

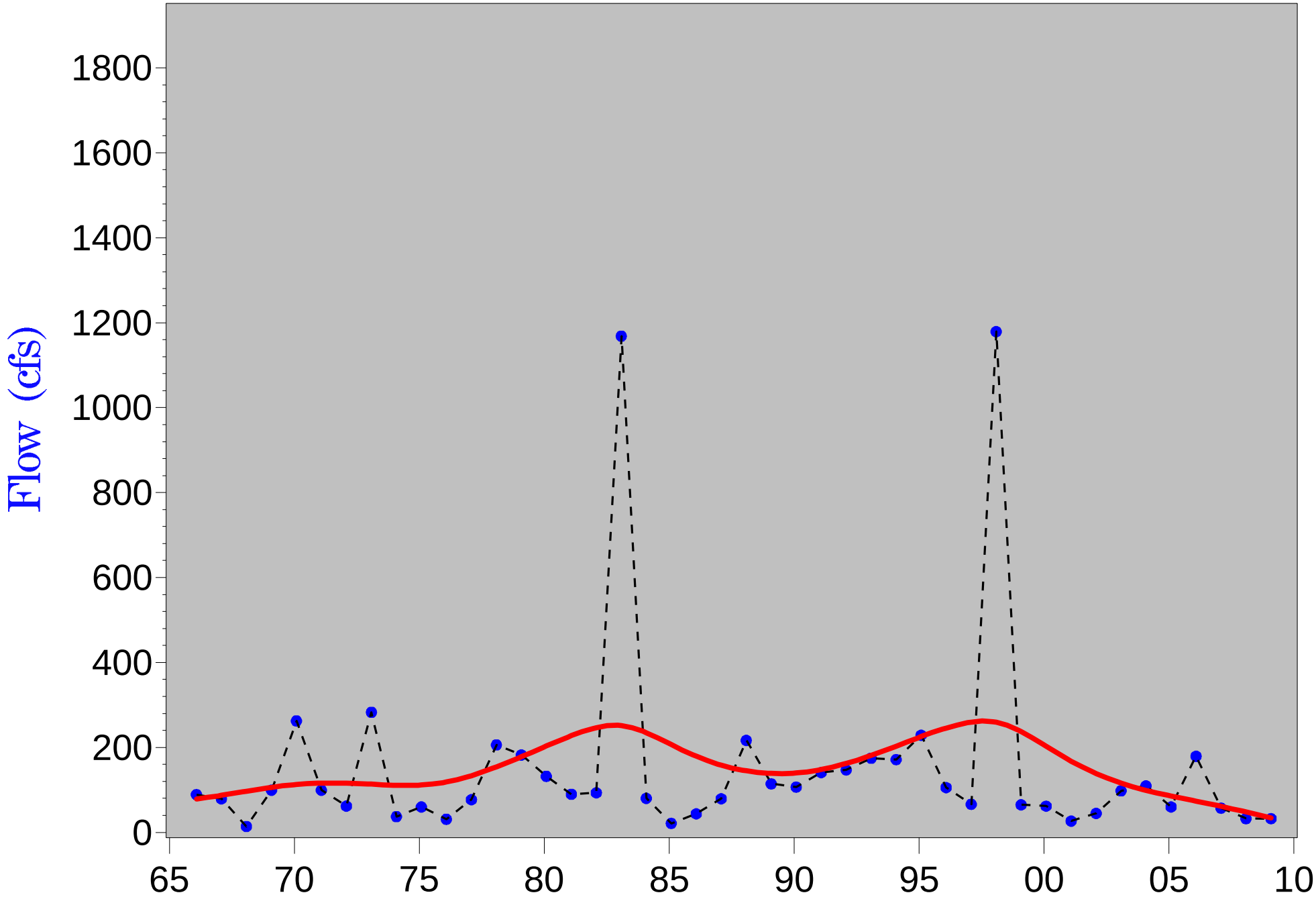


Figure 3.59b Estimated February median flow without Facility withdrawals (1966-2009)

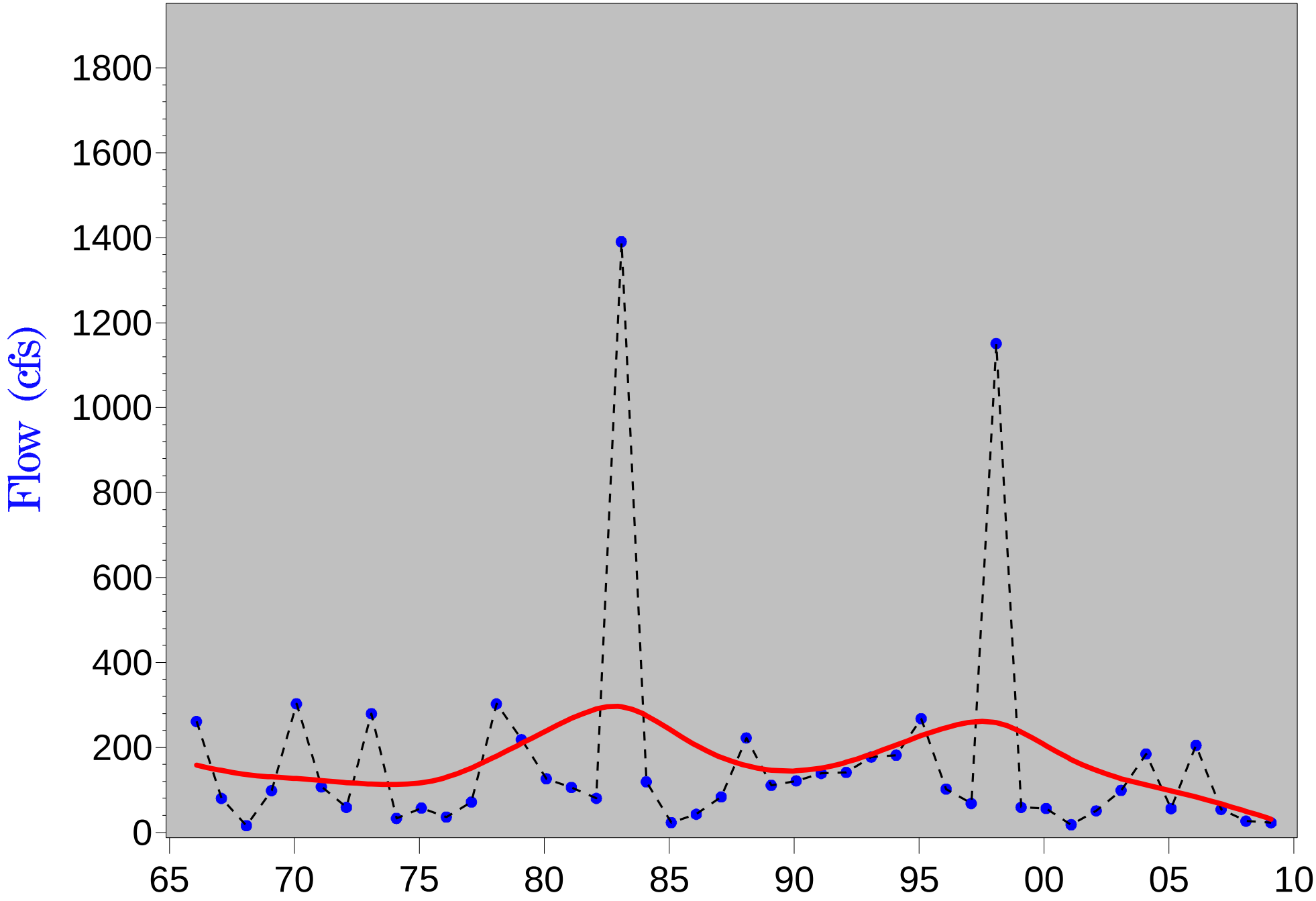


Figure 3.60a February mean USGS Shell Creek gaged flow (1966-2009)

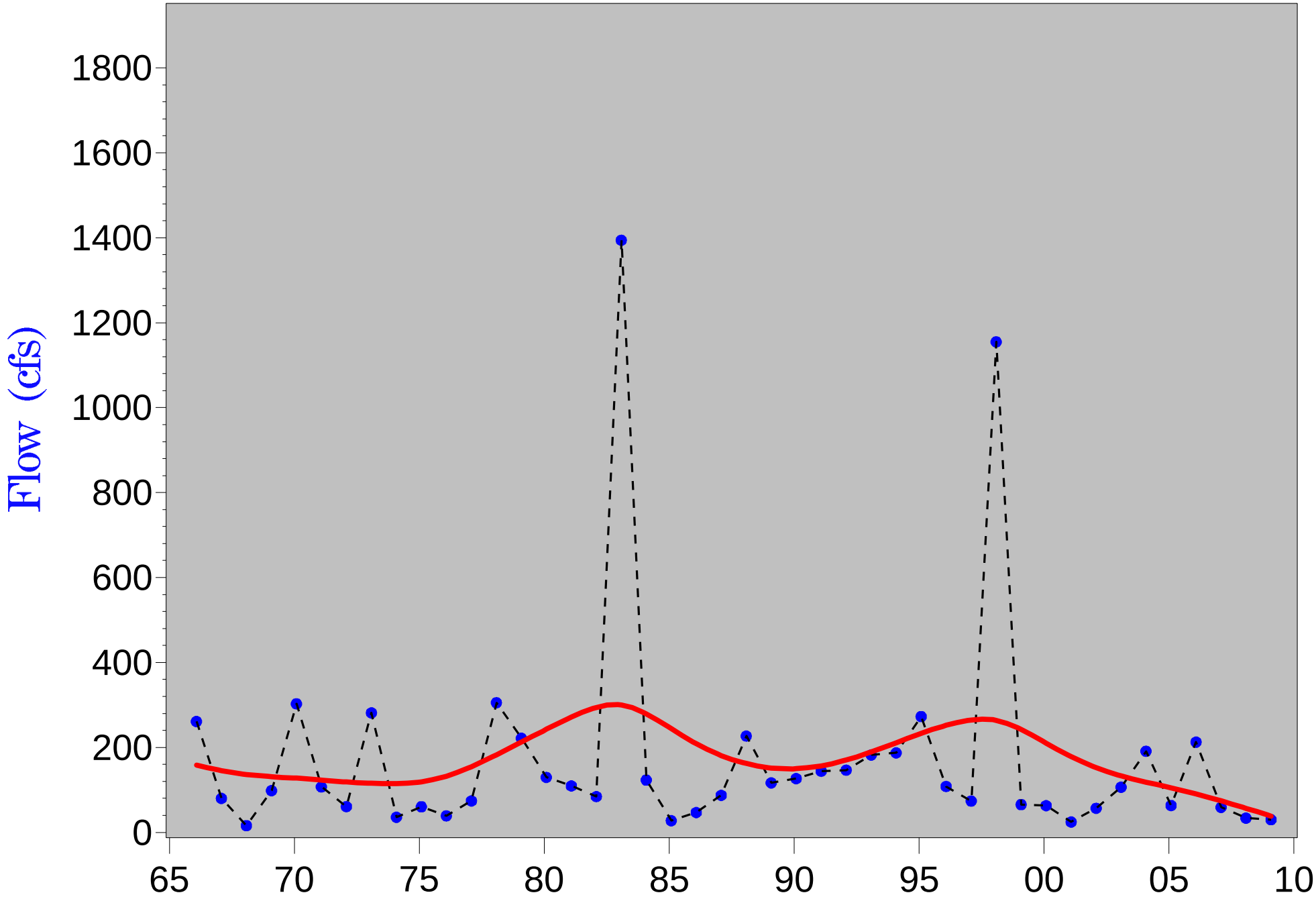


Figure 3.60b Estimated February mean flow without Facility withdrawals (1966-2009)

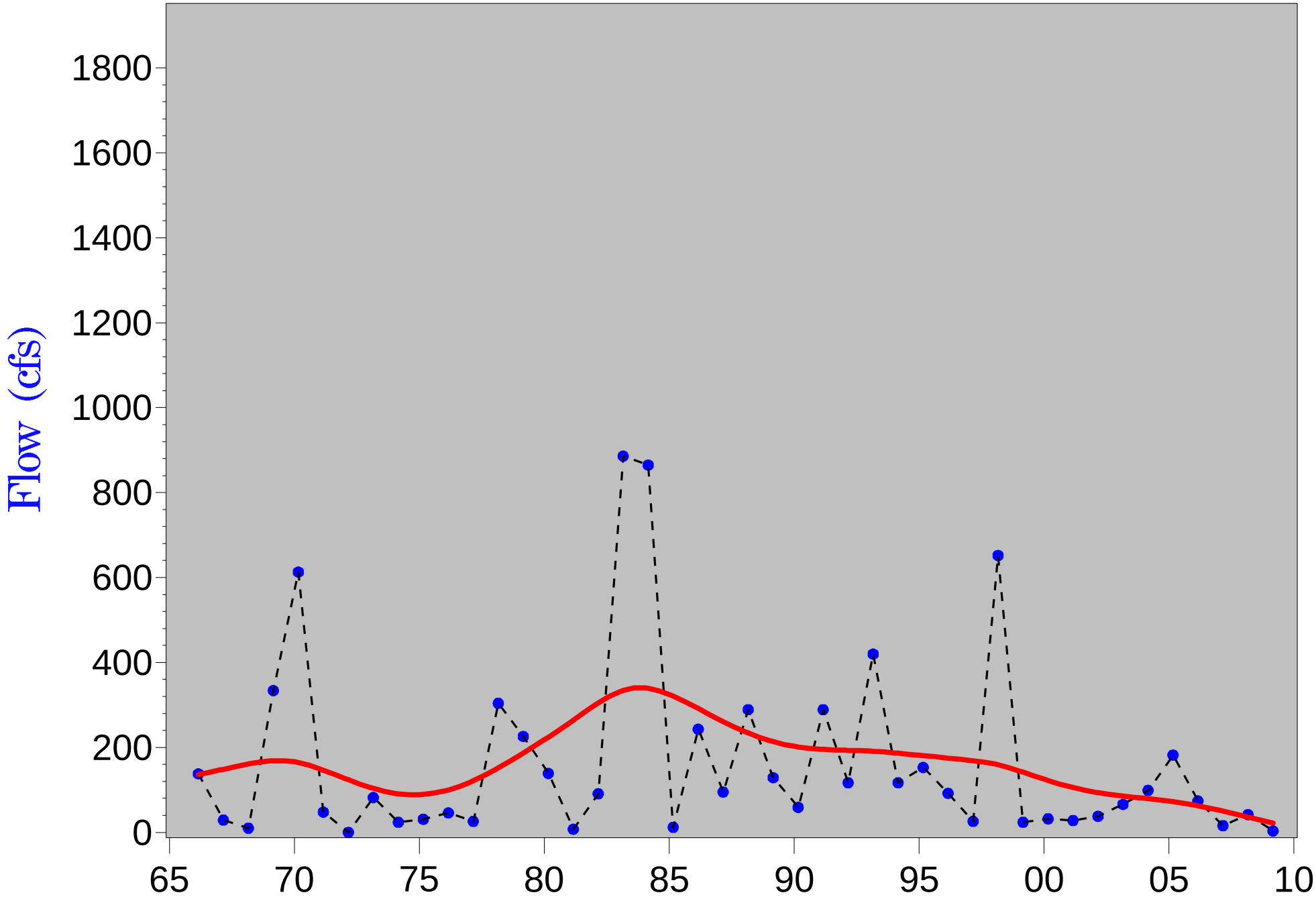


Figure 3.61a March median USGS Shell Creek gaged flow (1966-2009)

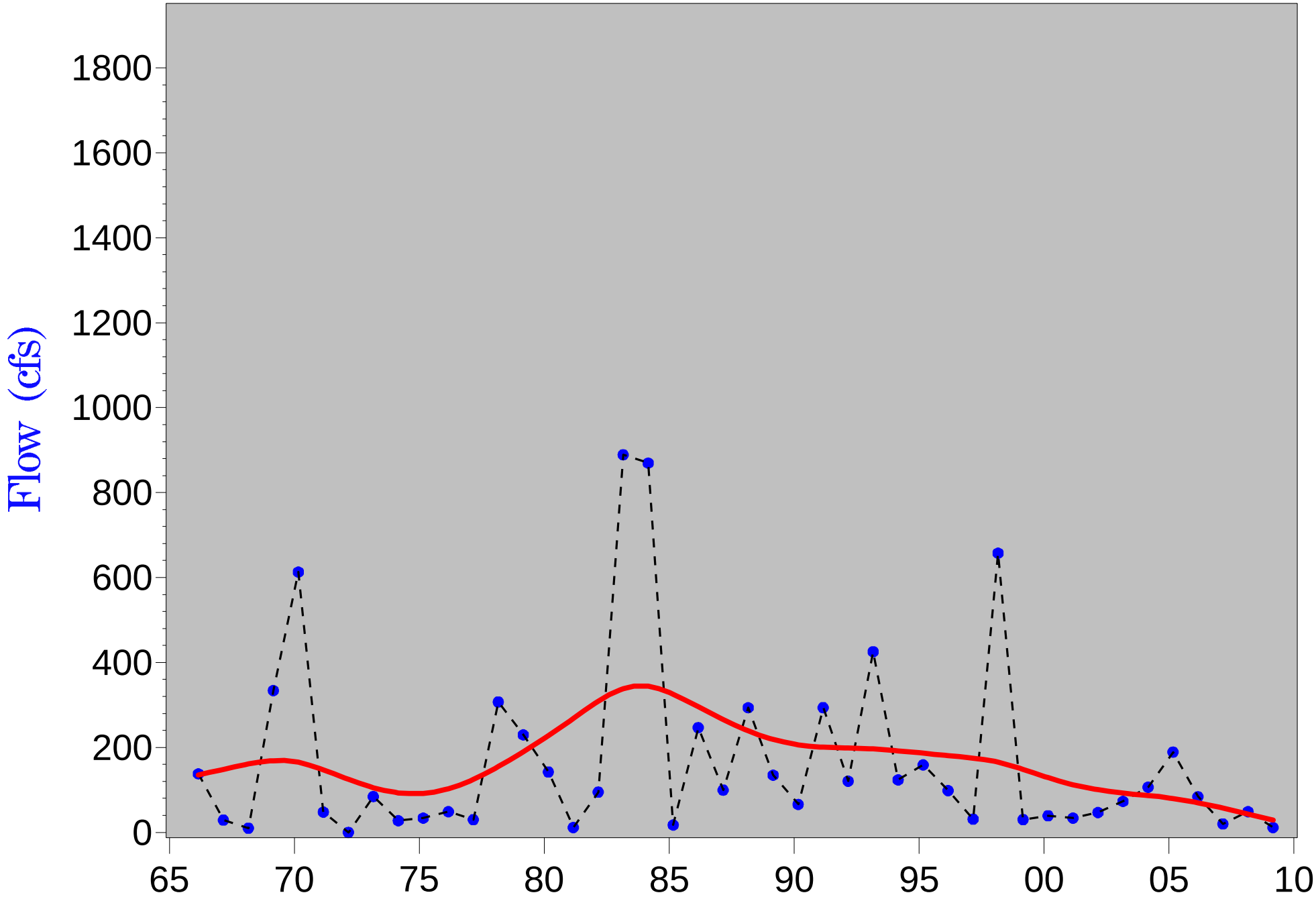


Figure 3.61b Estimated March median flow without Facility withdrawals (1966-2009)

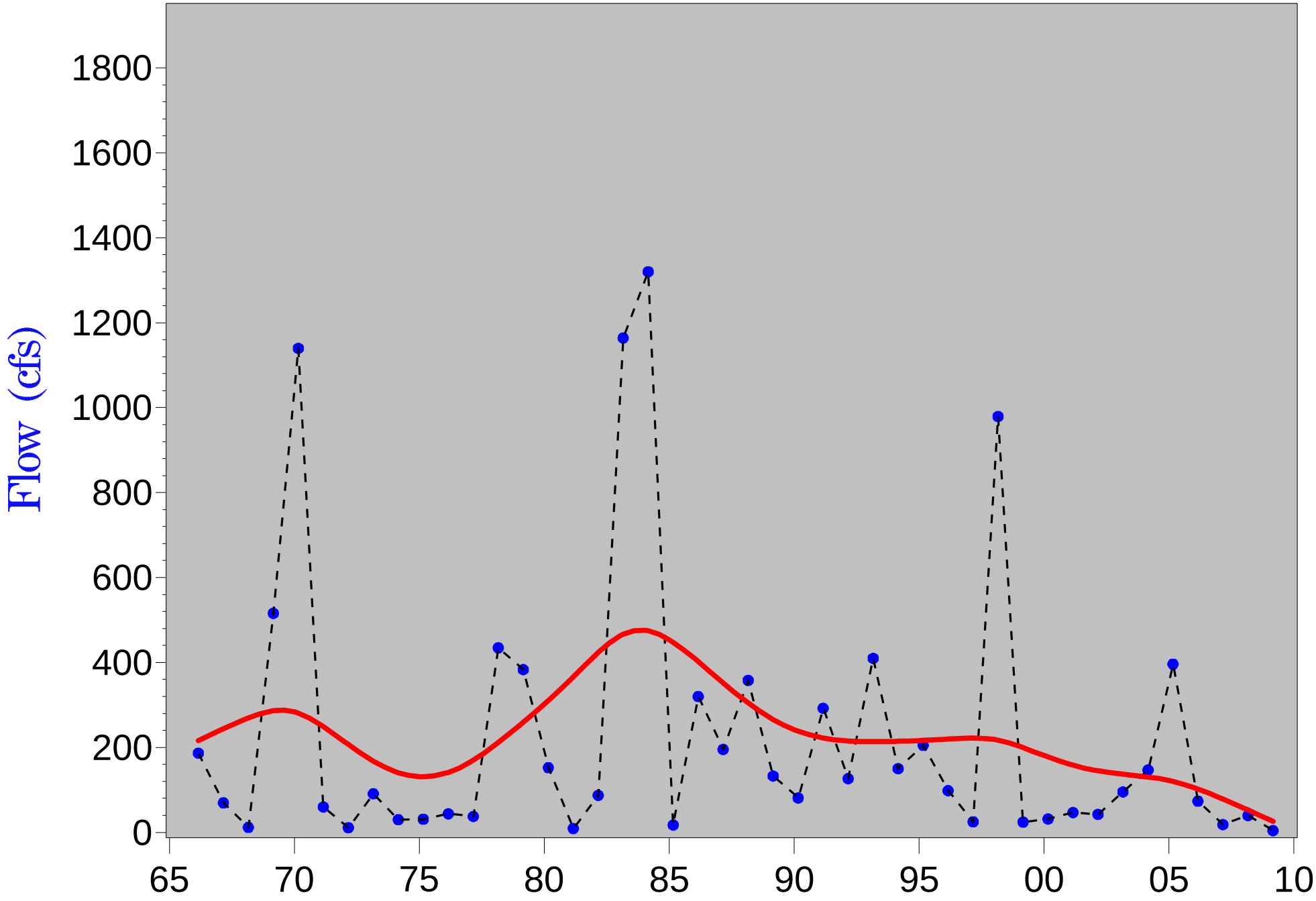


Figure 3.62a March mean USGS Shell Creek gaged flow (1966-2009)

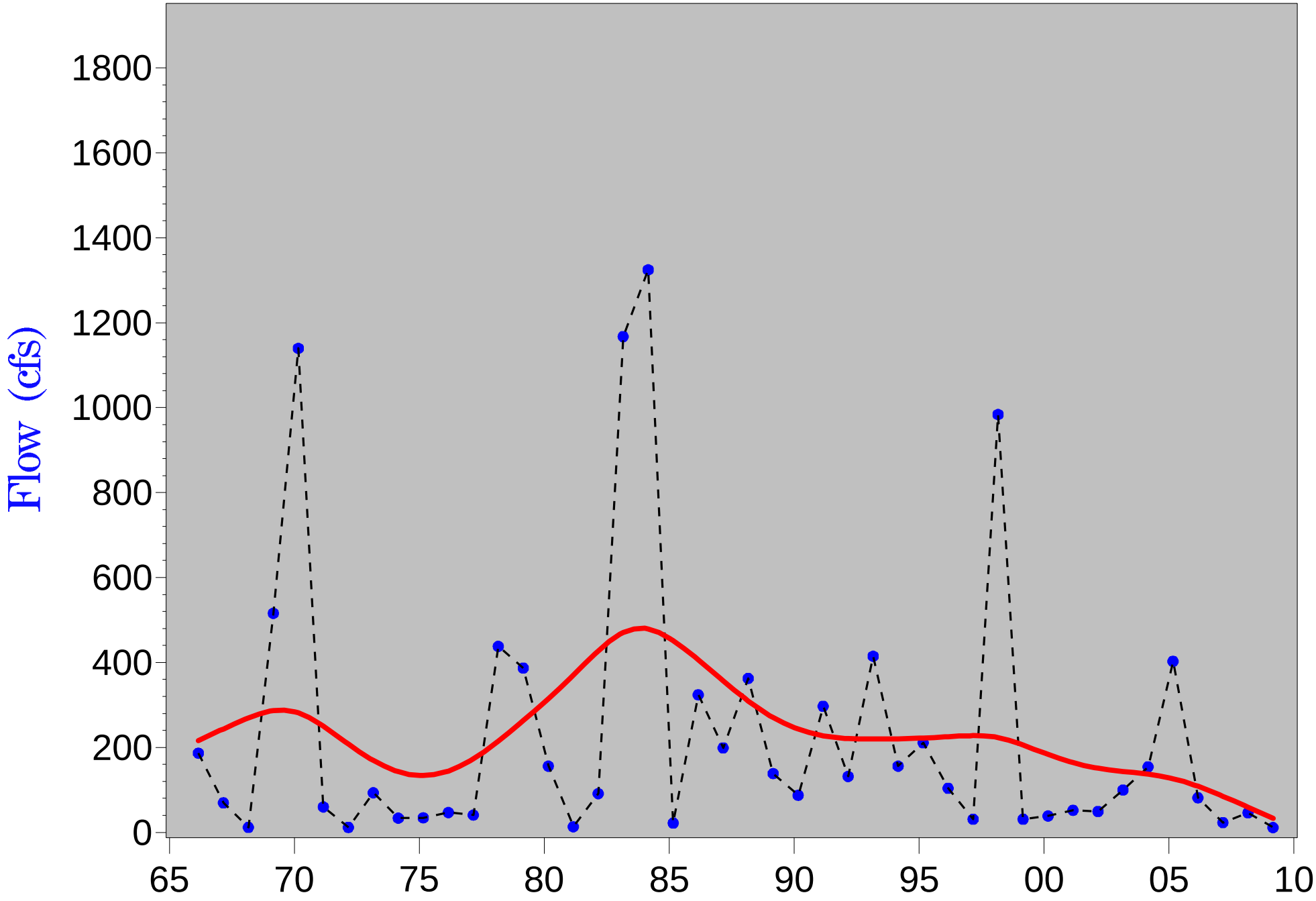


Figure 3.62b Estimated March mean flow without Facility withdrawals (1966-2009)

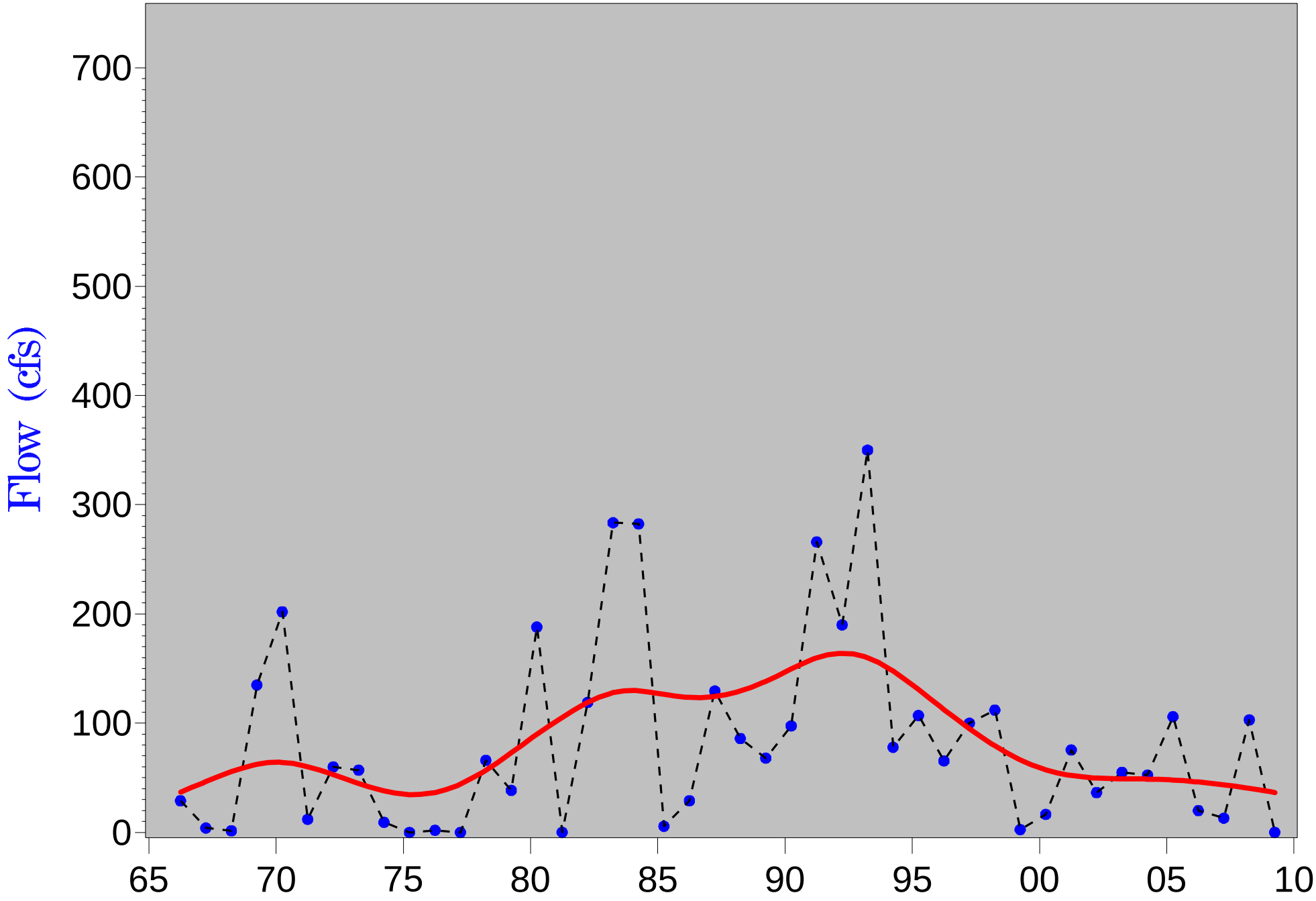


Figure 3.63a April median USGS Shell Creek gaged flow (1966-2009)

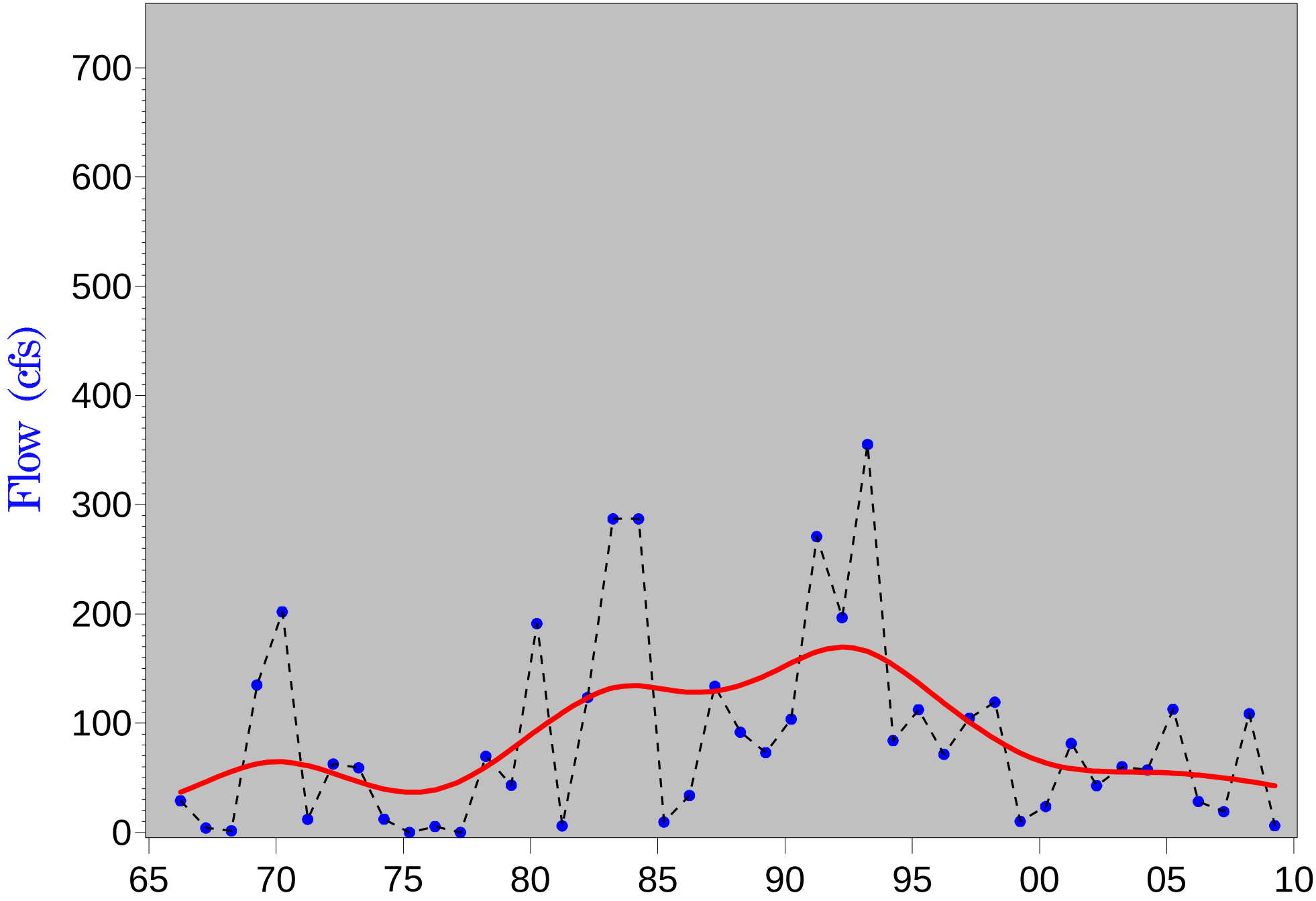


Figure 3.63b Estimated April median flow without Facility withdrawals (1966-2009)

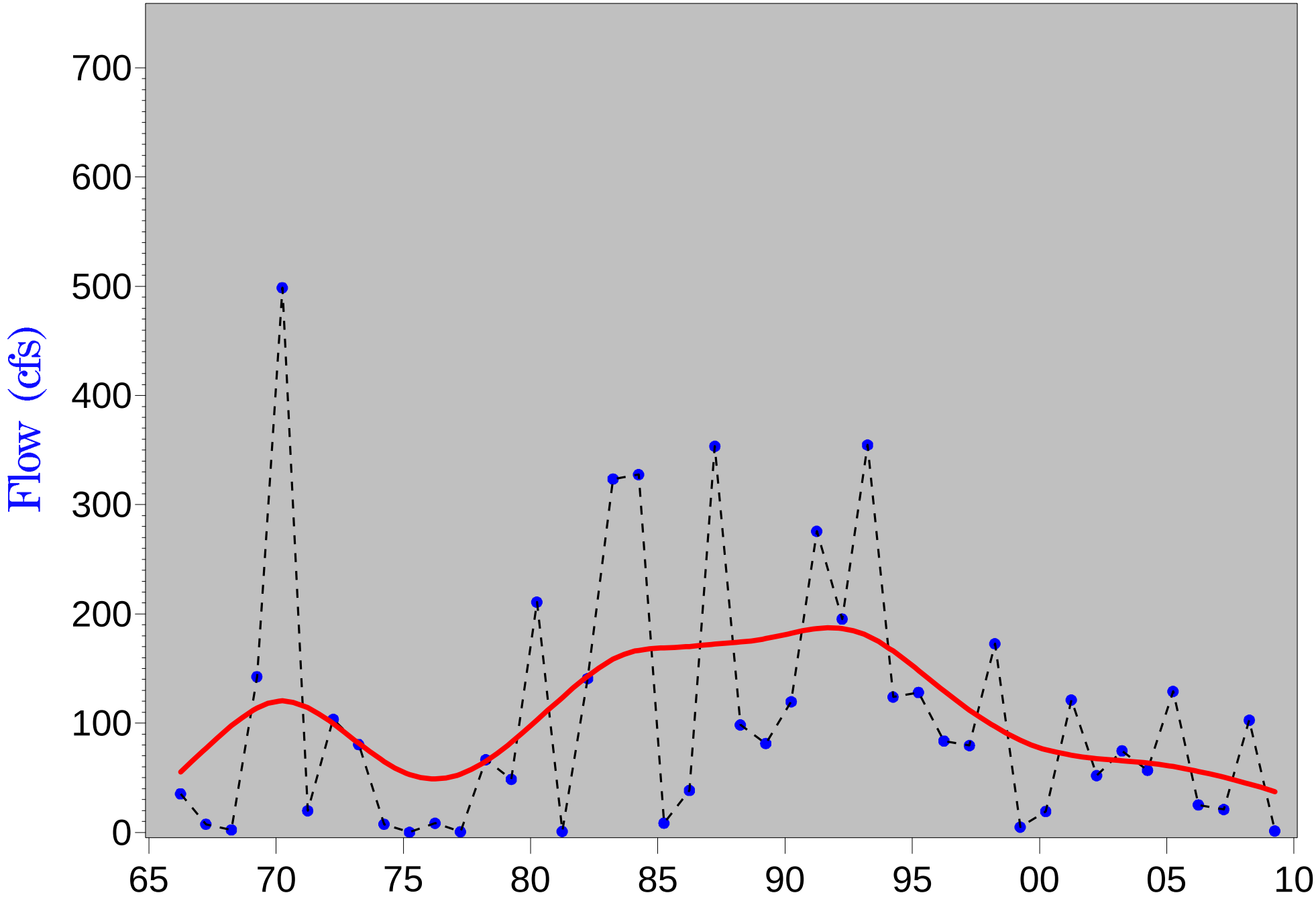


Figure 3.64a April mean USGS Shell Creek gaged flow (1966-2009)

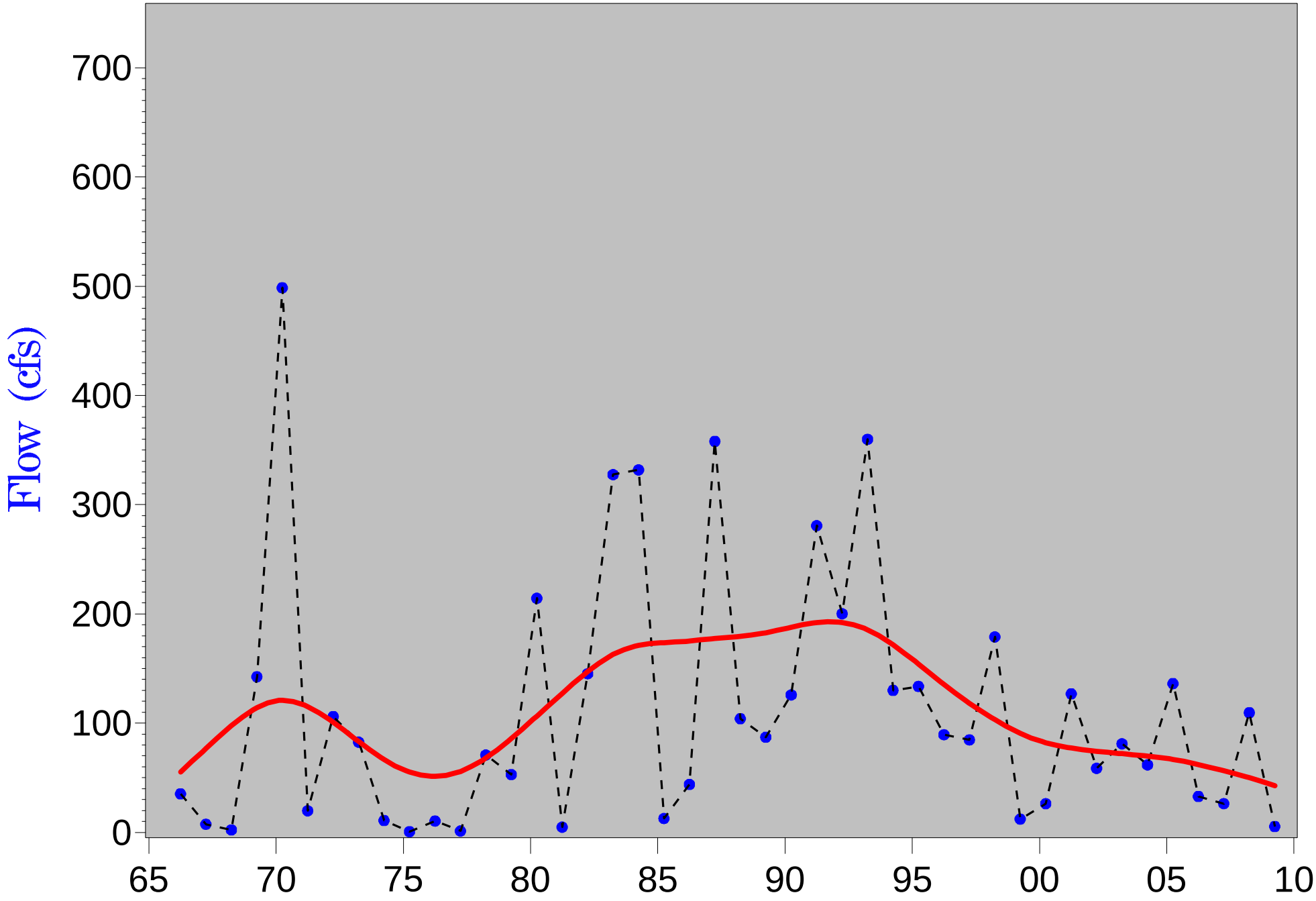


Figure 3.64b Estimated April mean flow without Facility withdrawals (1966-2009)

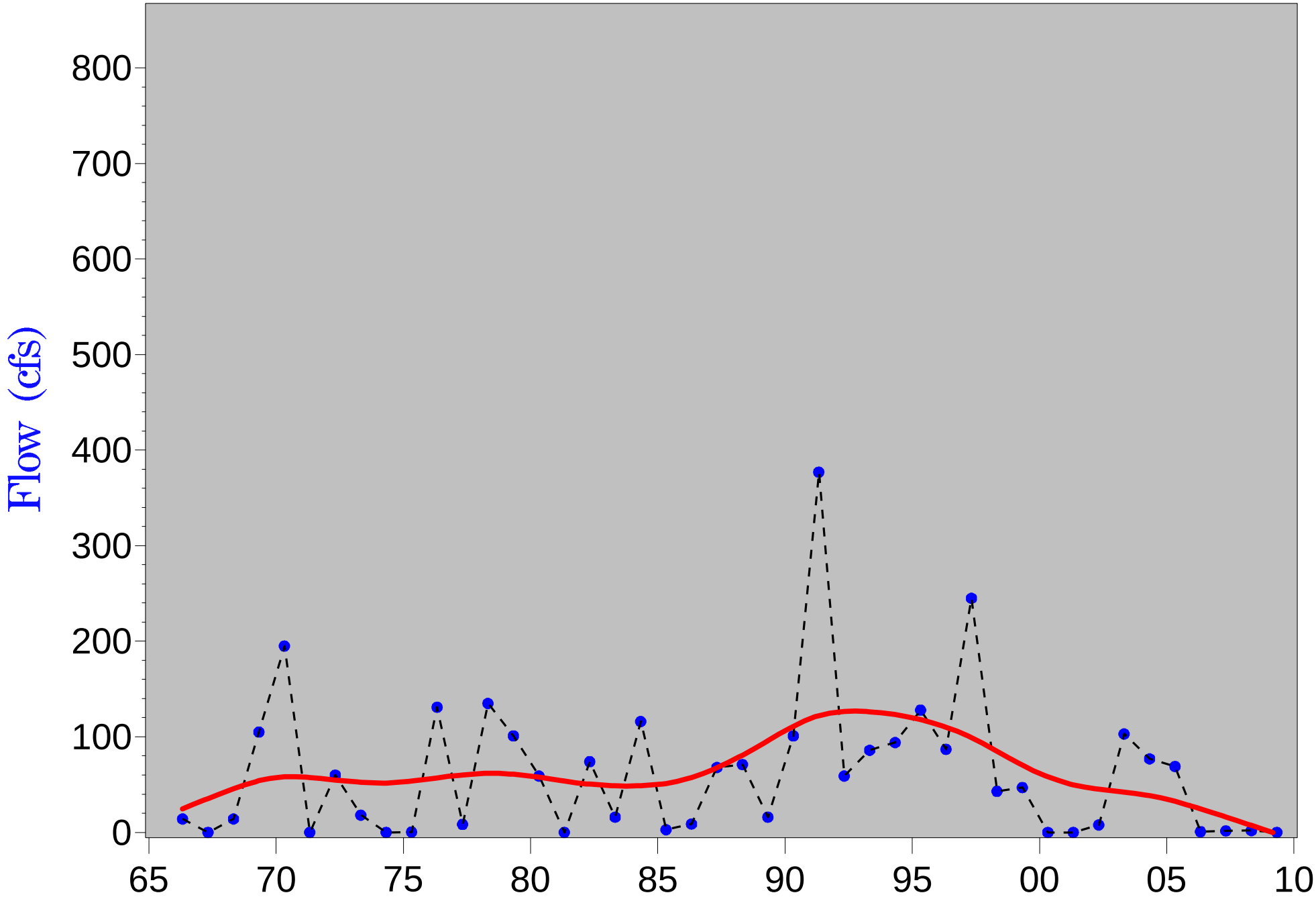


Figure 3.65a May median USGS Shell Creek gaged flow (1966-2009)

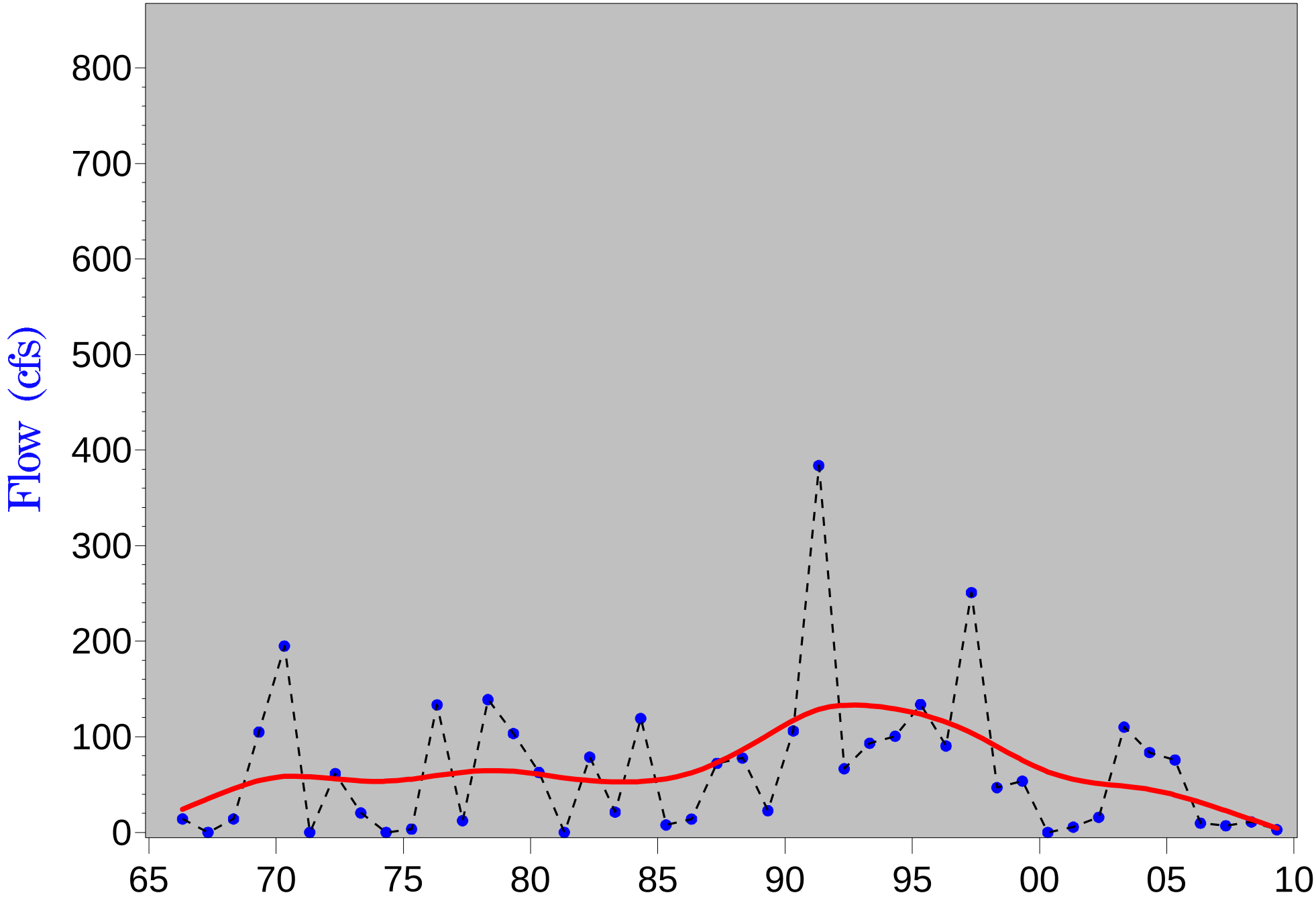


Figure 3.65b Estimated May median flow without Facility withdrawals (1966-2009)

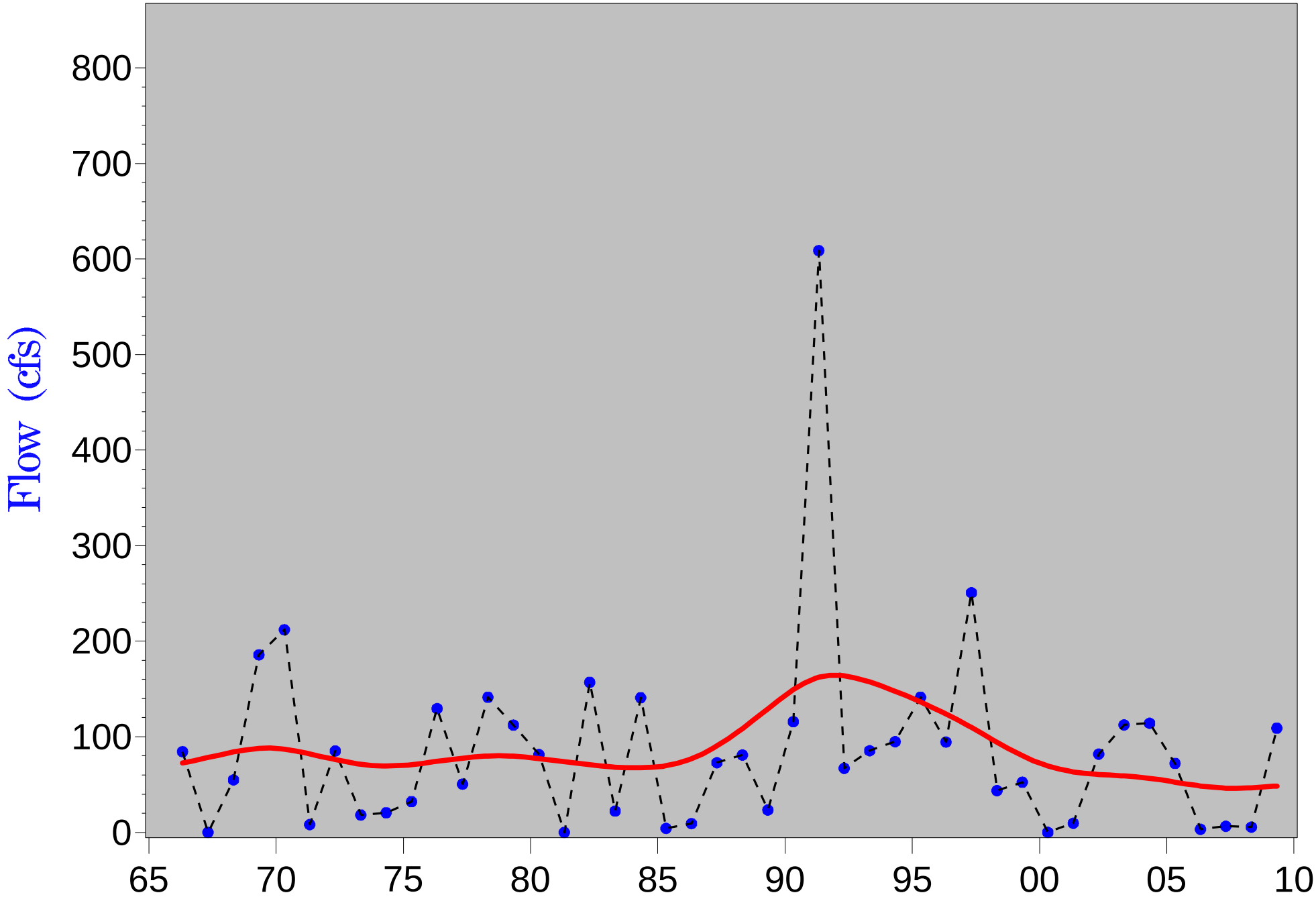


Figure 3.66a May mean USGS Shell Creek gaged flow (1966-2009)

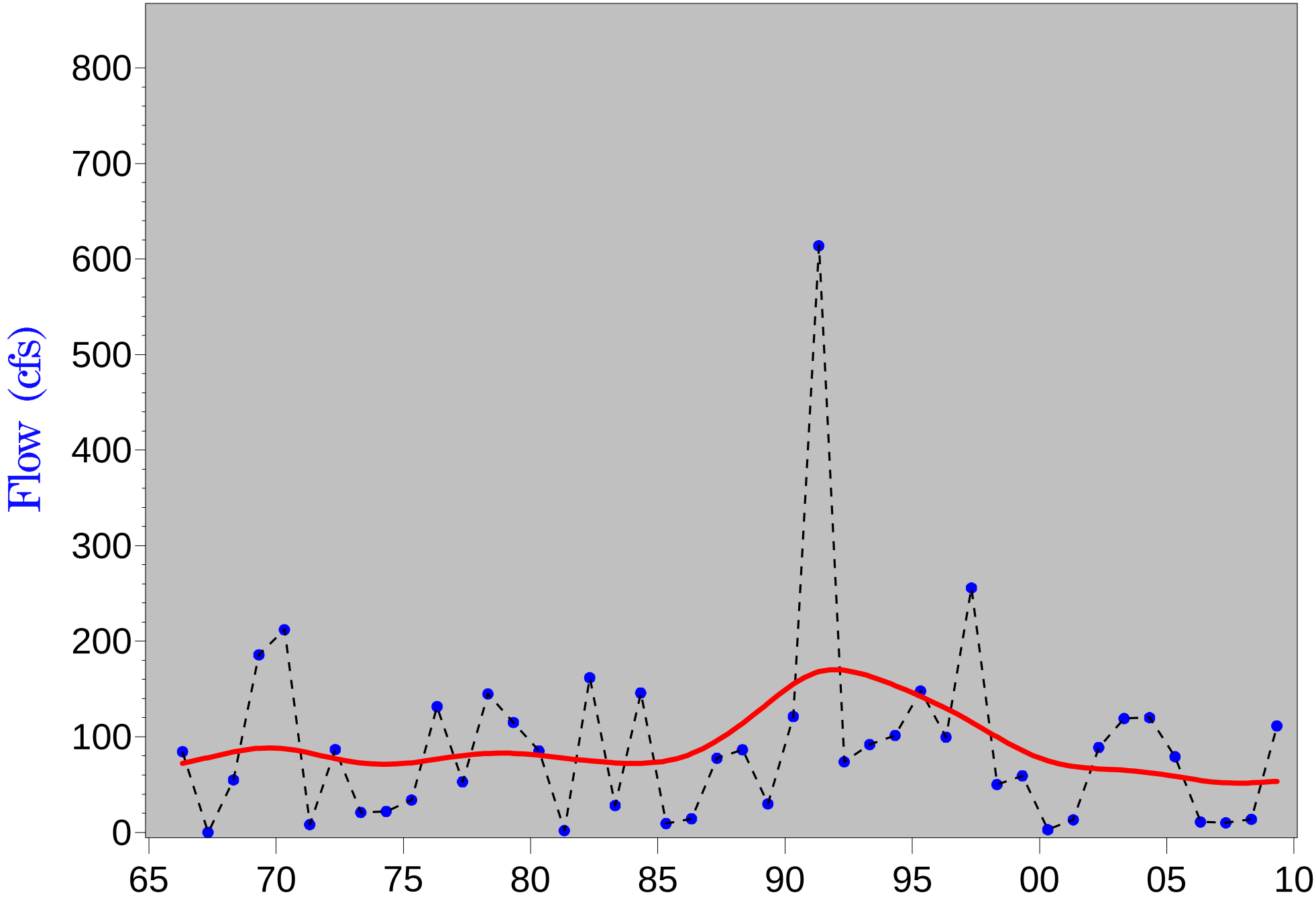


Figure 3.66b Estimated May mean flow without Facility withdrawals (1966-2009)

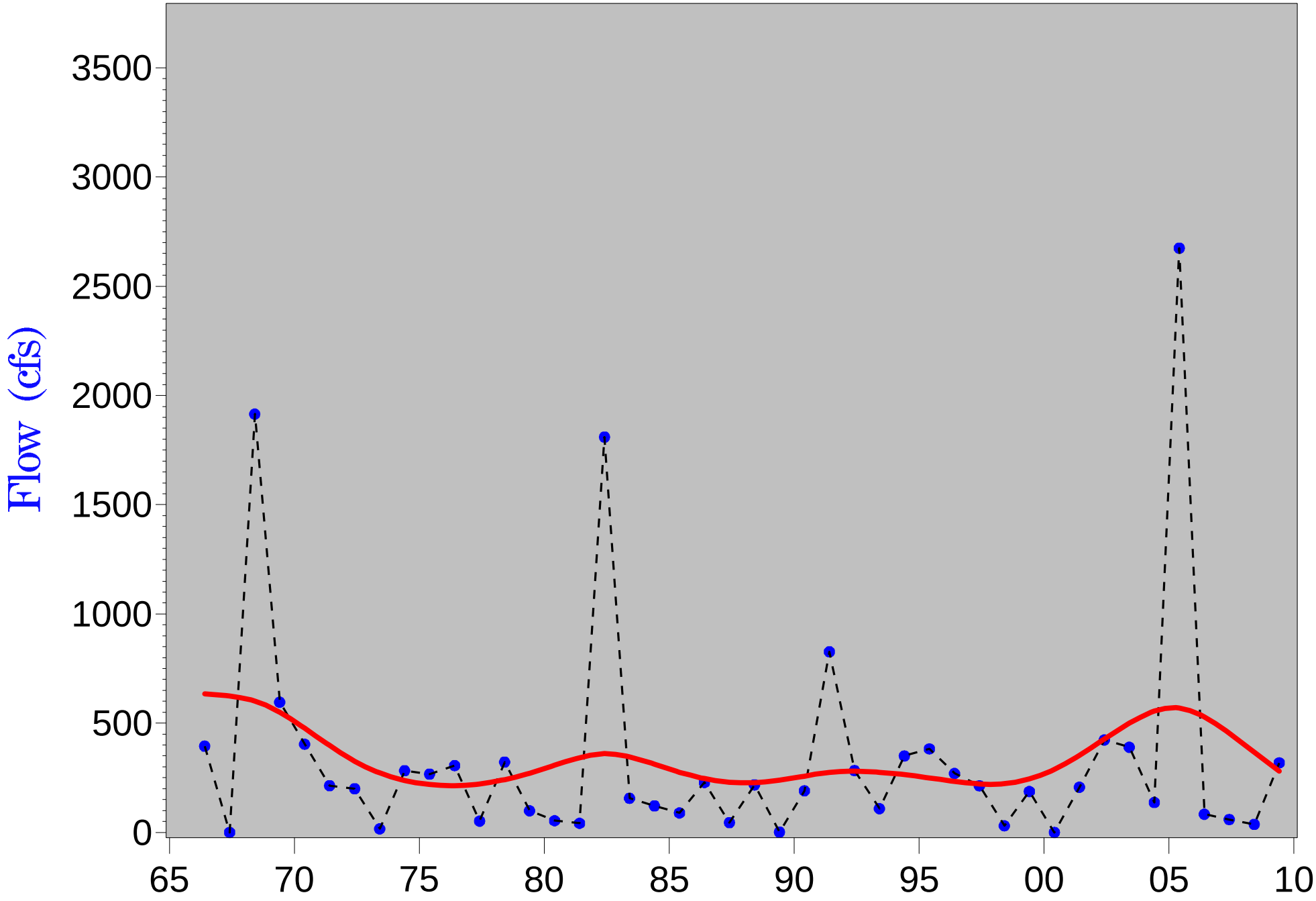


Figure 3.67a June median USGS Shell Creek gaged flow (1966-2009)

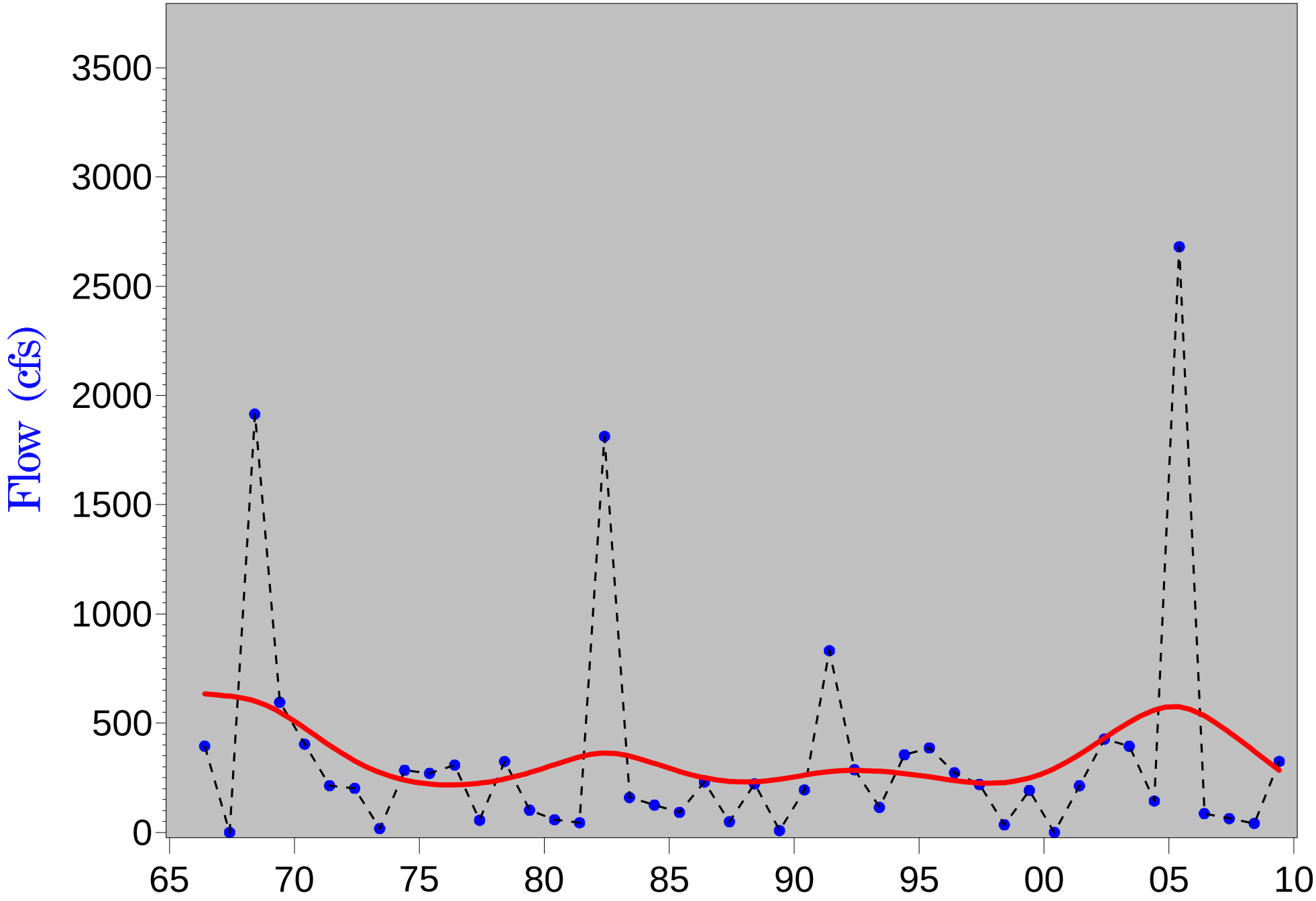


Figure 3.67b Estimated June median flow without Facility withdrawals (1966-2009)

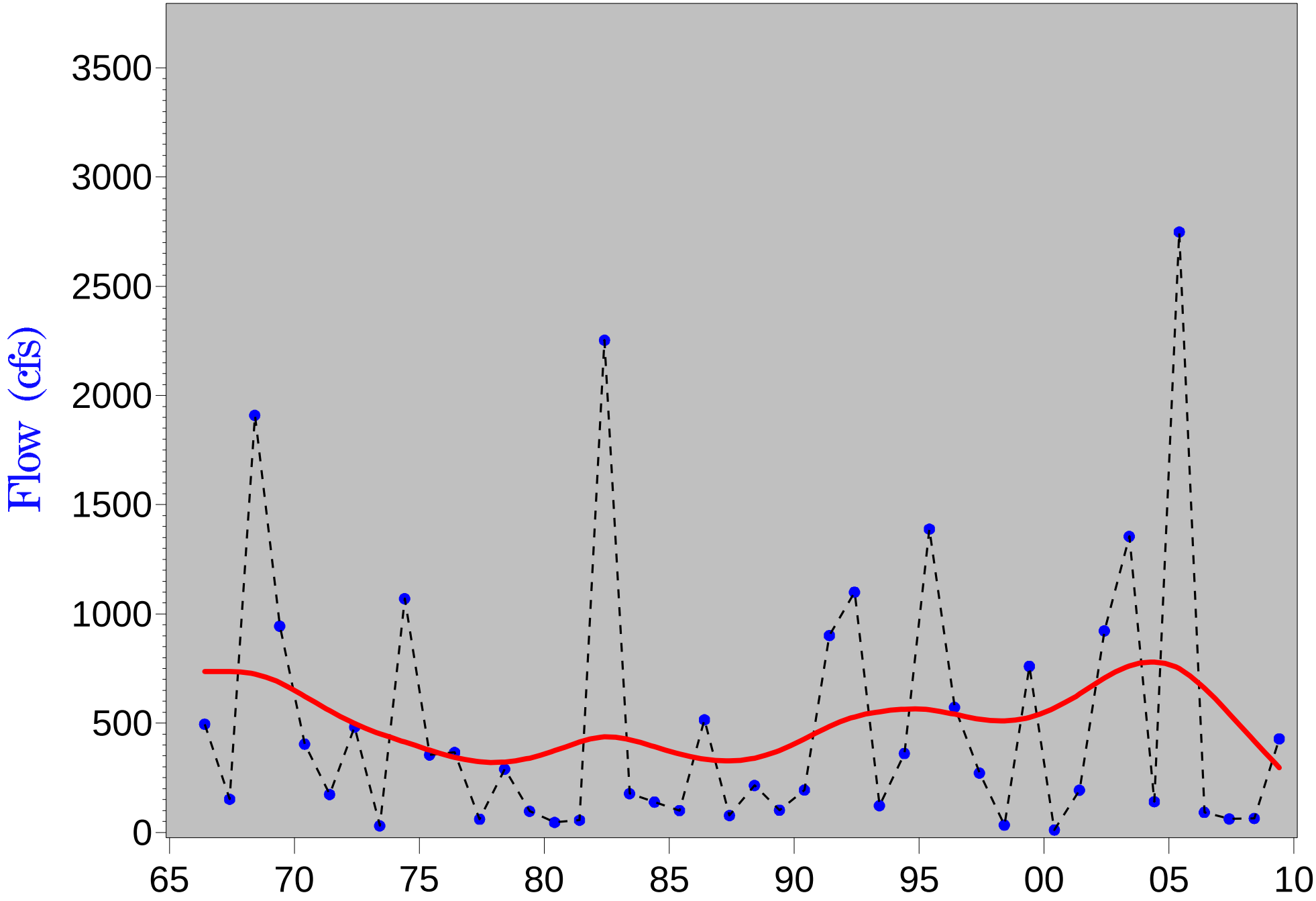


Figure 3.68a June mean USGS Shell Creek gaged flow (1966-2009)

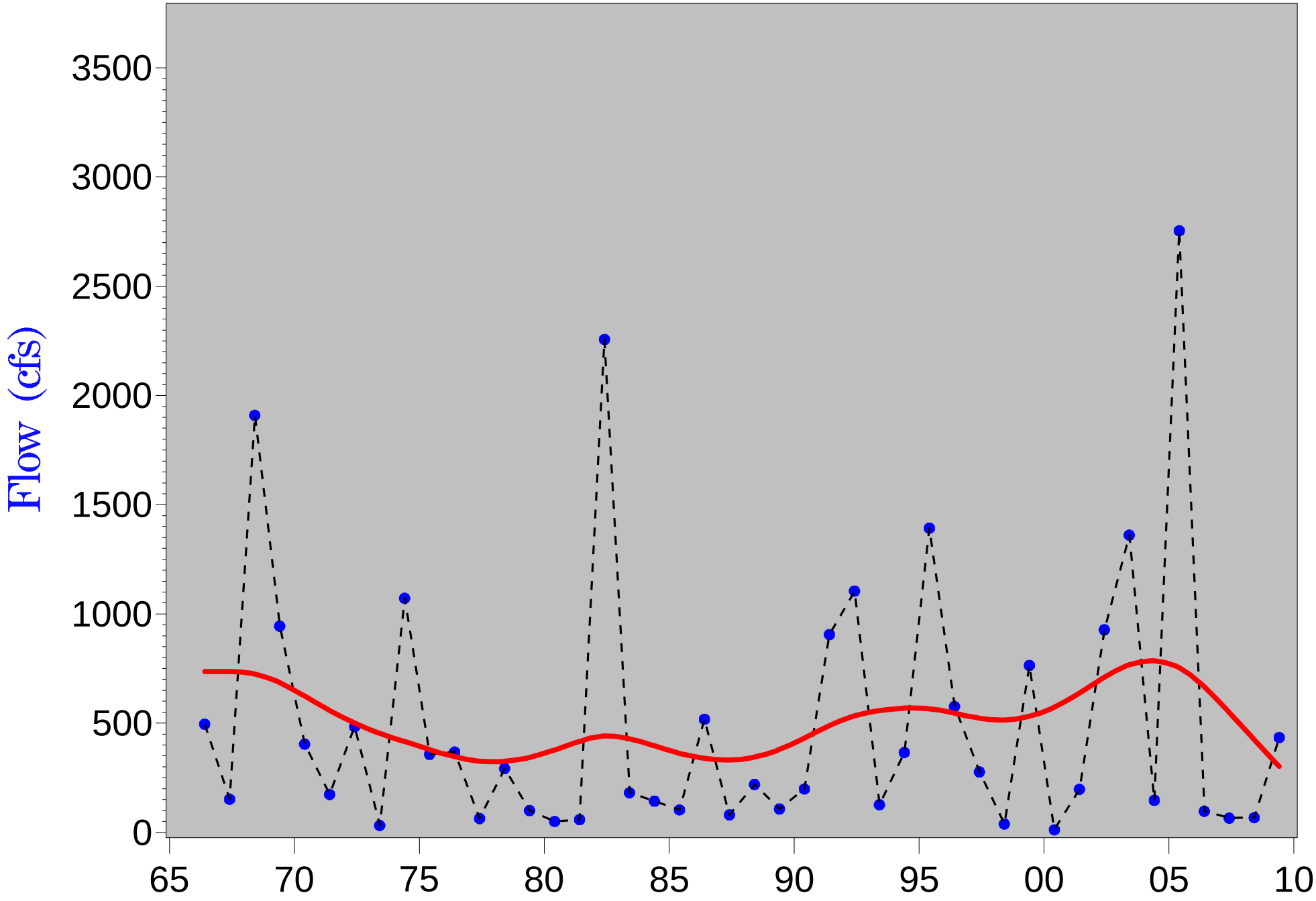


Figure 3.68b Estimated June mean flow without Facility withdrawals (1966-2009)

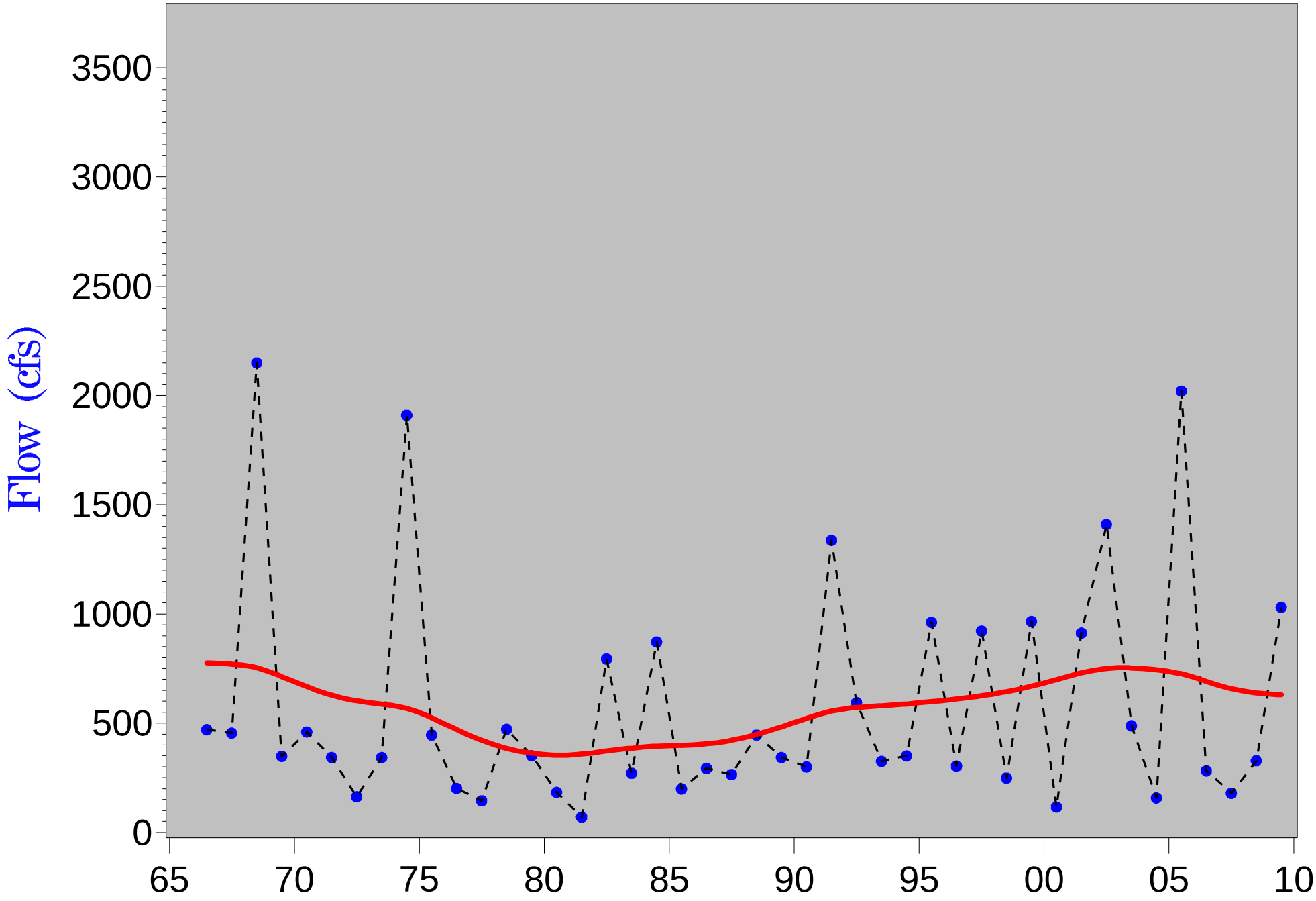


Figure 3.69a July median USGS Shell Creek gaged flow (1966-2009)

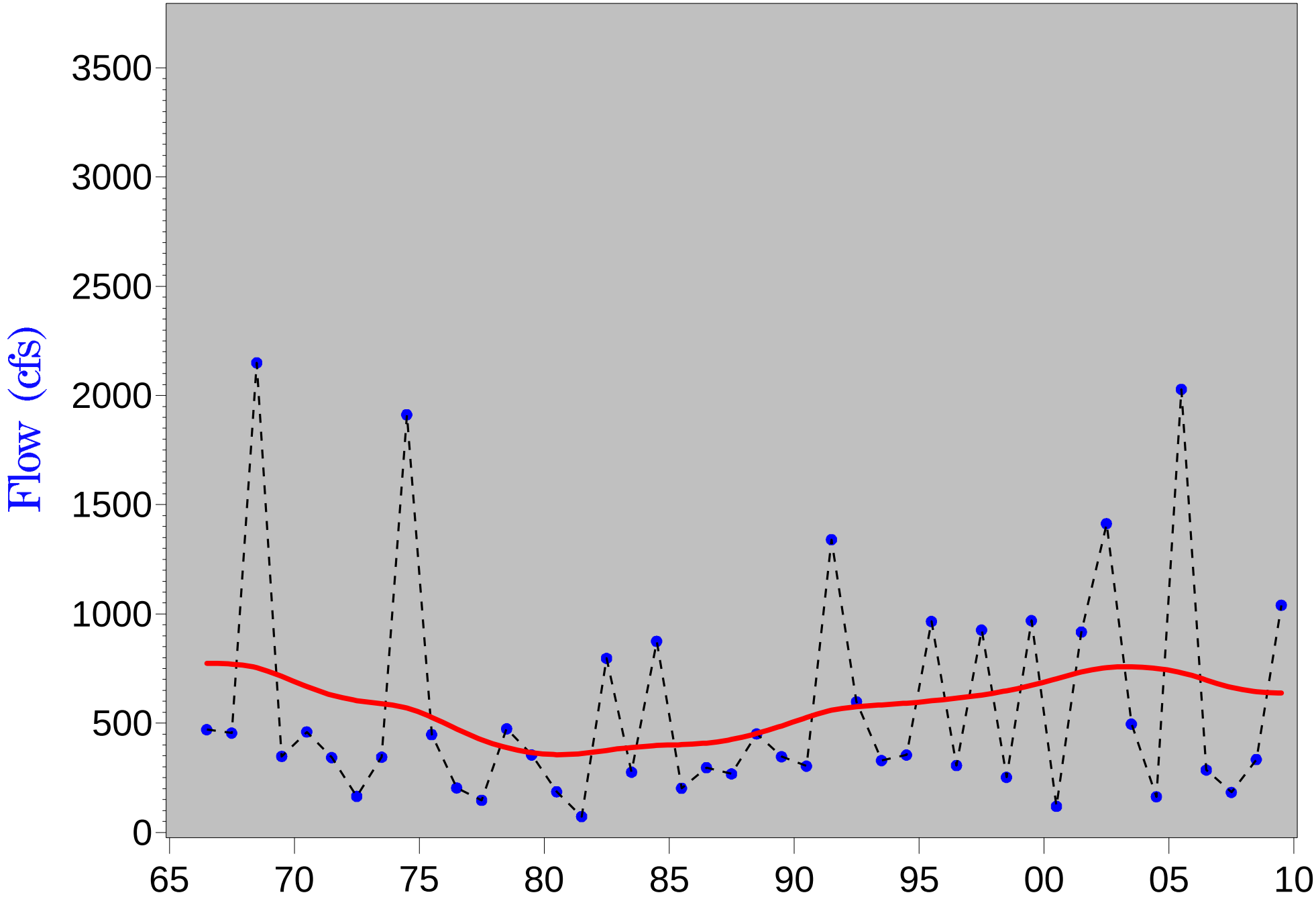


Figure 3.69b Estimated July median flow without Facility withdrawals (1966-2009)

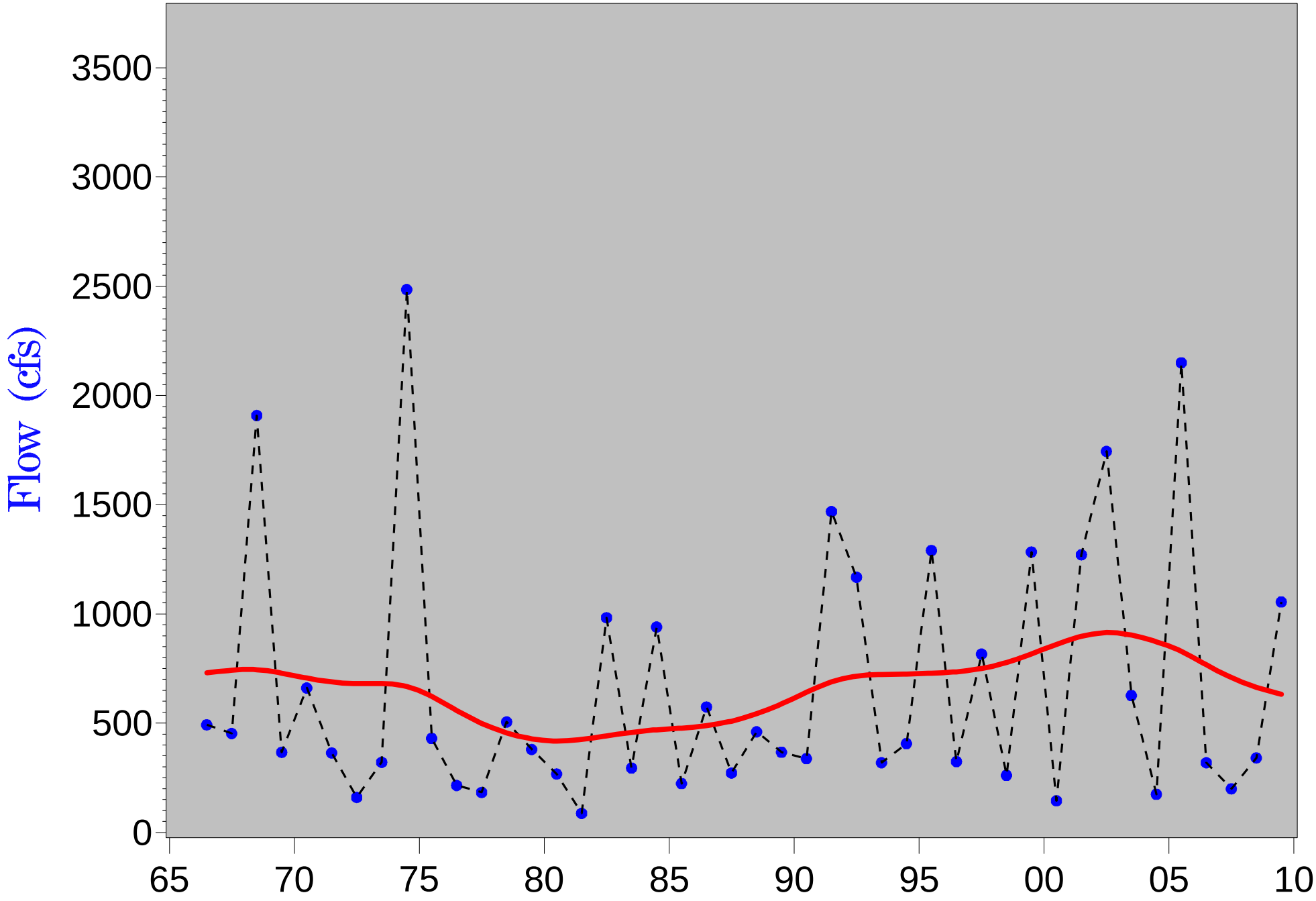


Figure 3.70a July mean USGS Shell Creek gaged flow (1966-2009)

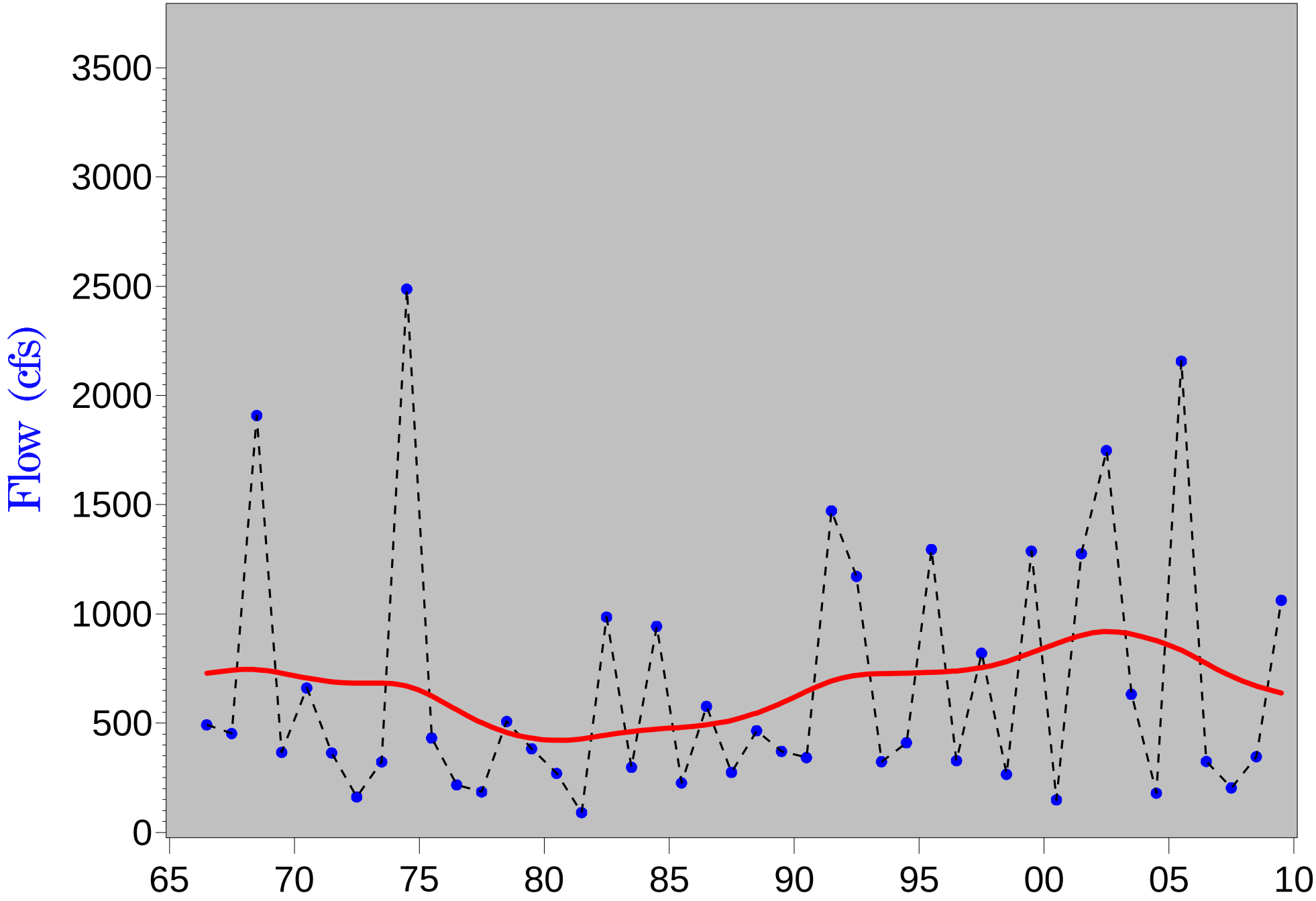


Figure 3.70b Estimated July mean flow without Facility withdrawals (1966-2009)

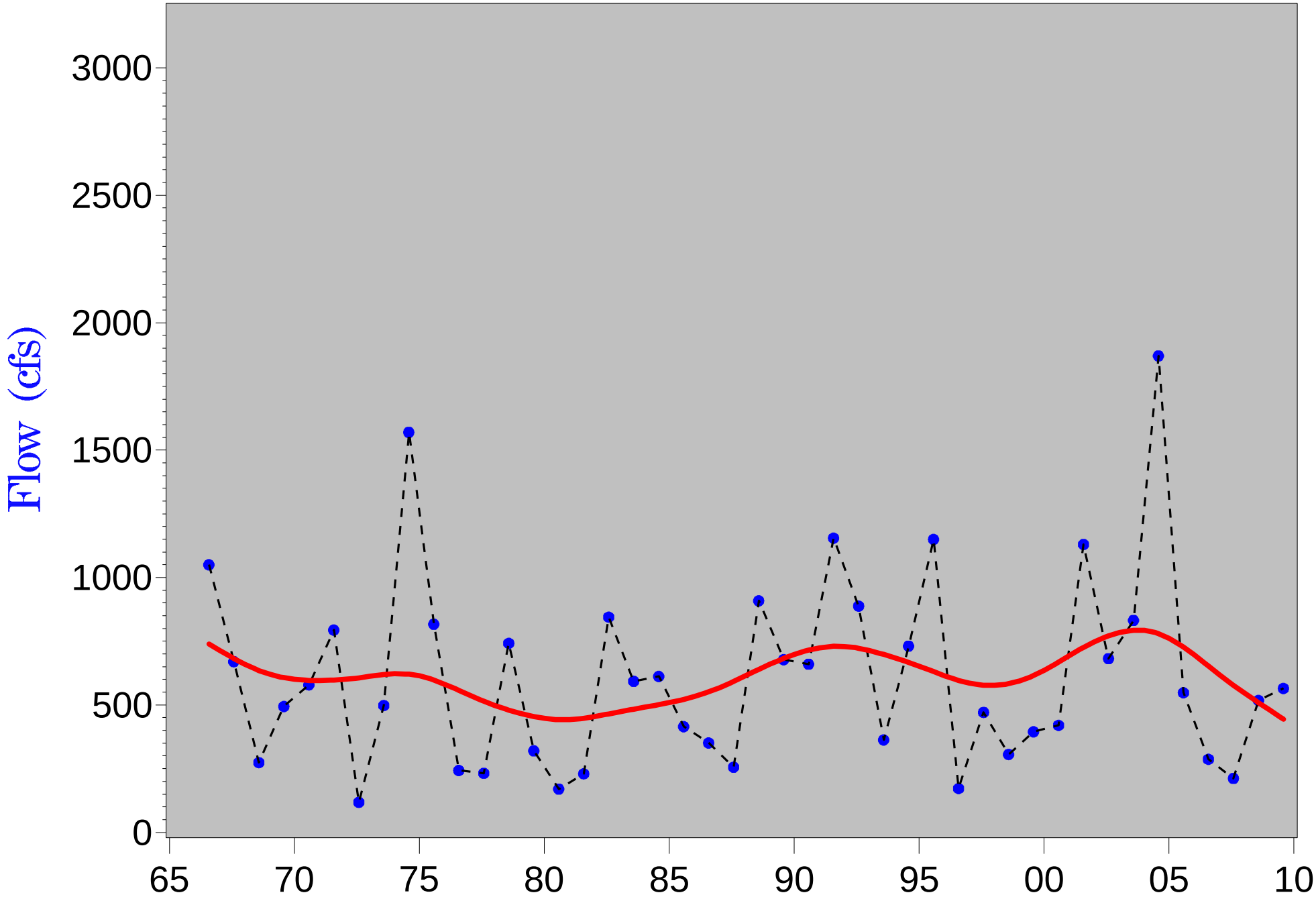


Figure 3.71a August median USGS Shell Creek gaged flow (1966-2009)

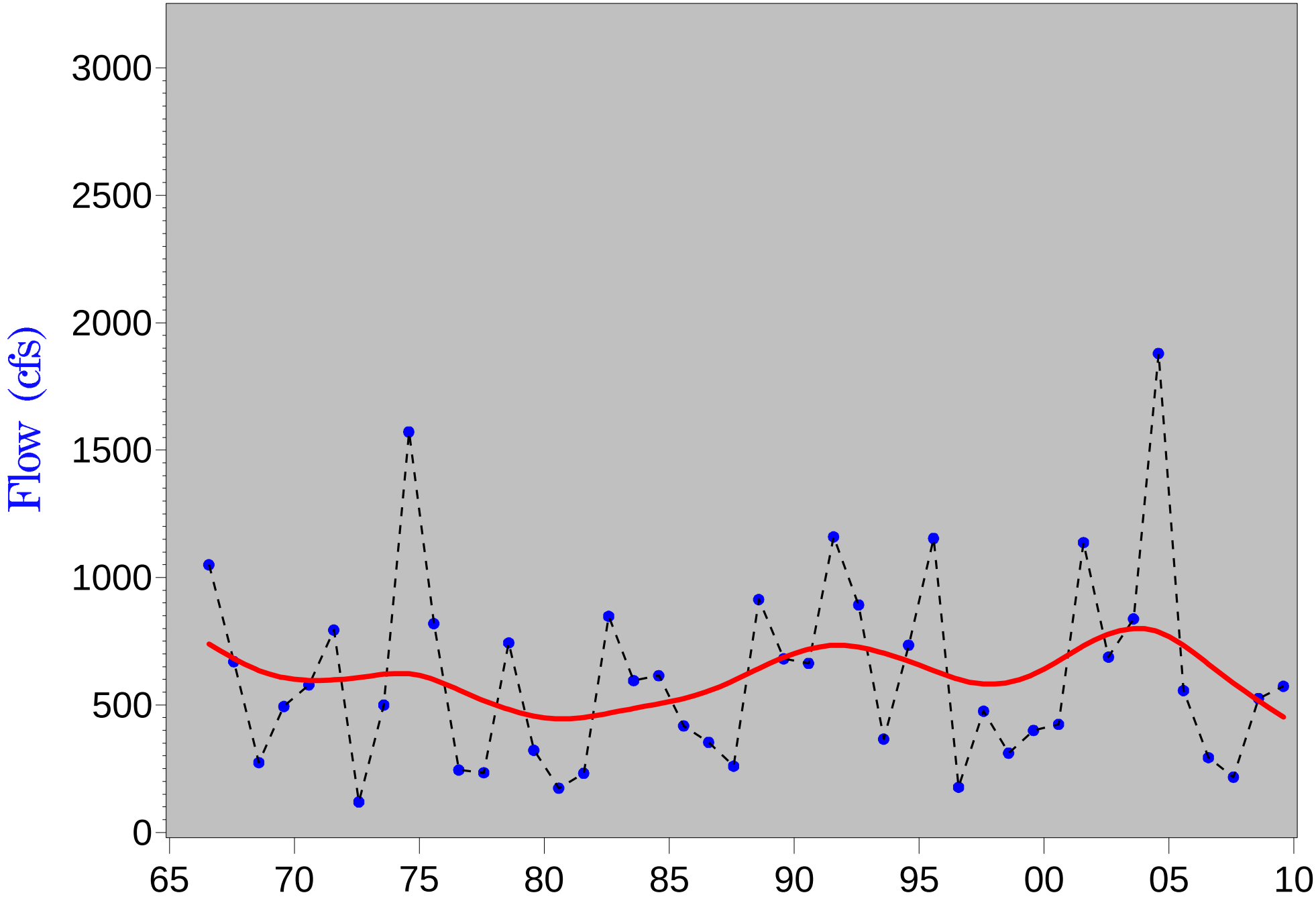


Figure 3.71b Estimated August median flow without Facility withdrawals (1966-2009)

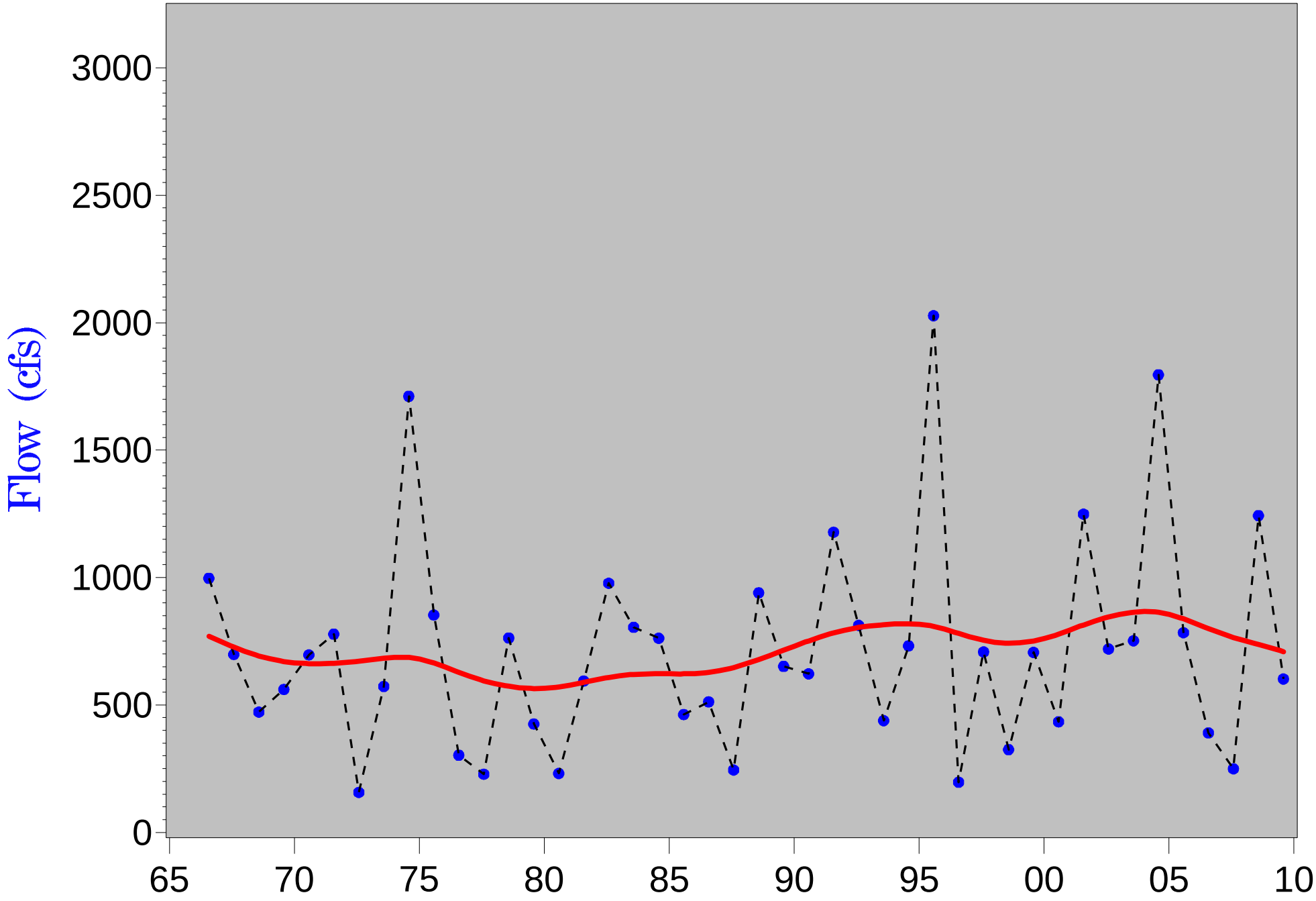


Figure 3.72a August mean USGS Shell Creek gaged flow (1966-2009)

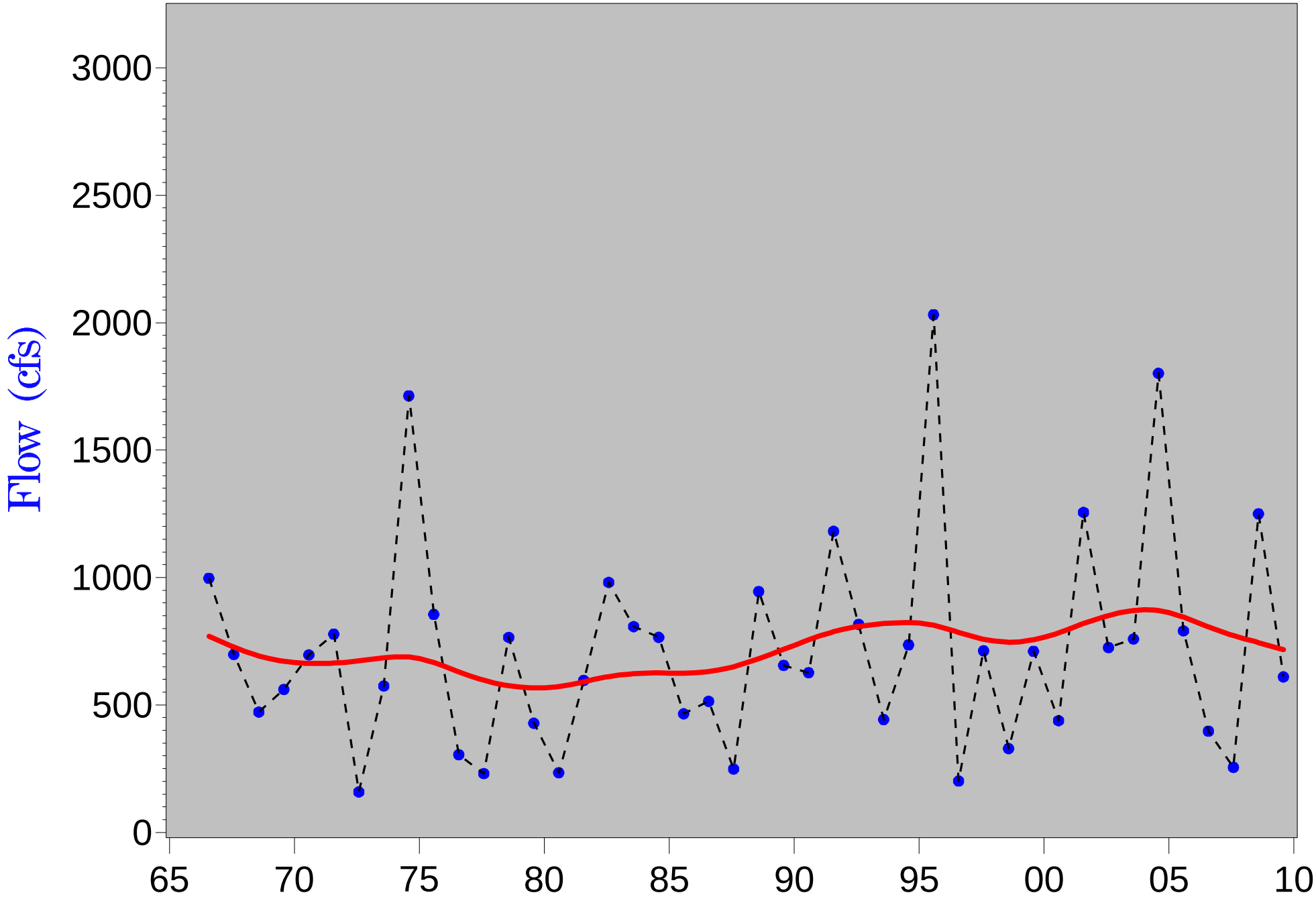


Figure 3.72b Estimated August mean flow without Facility withdrawals (1966-2009)

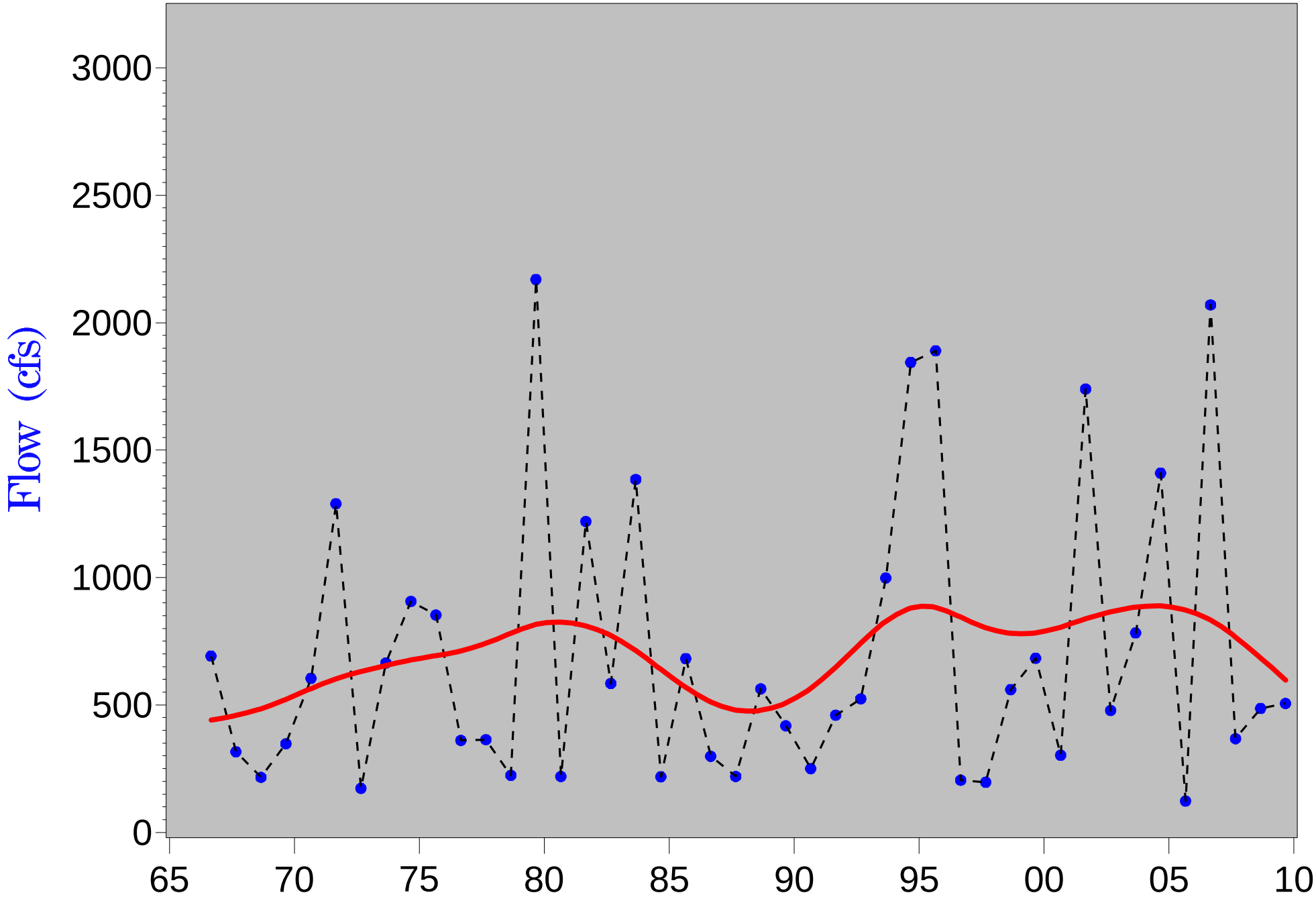


Figure 3.73a September median USGS Shell Creek gaged flow (1966-2009)

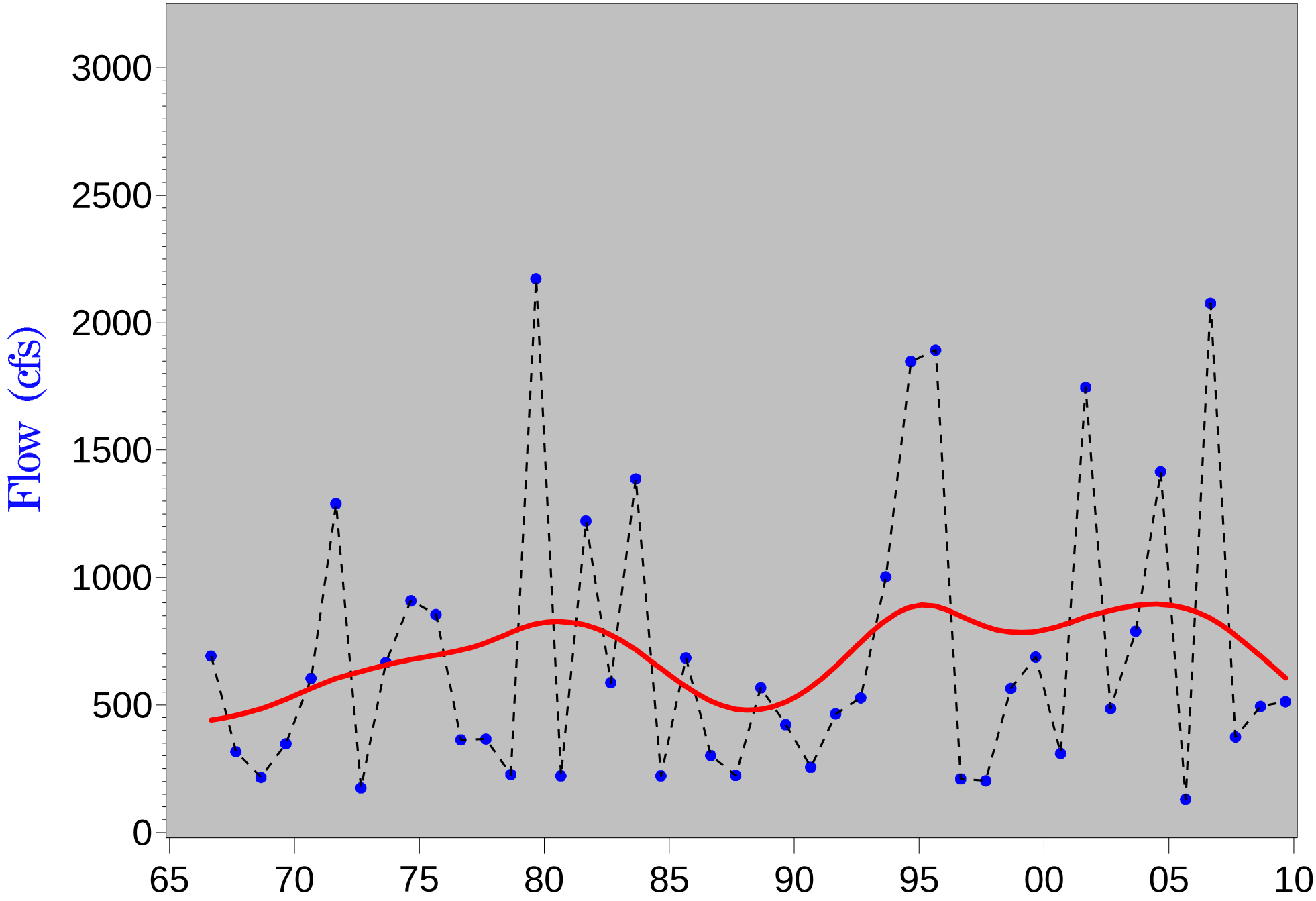


Figure 3.73b Estimated September median flow without Facility withdrawals (1966-2009)

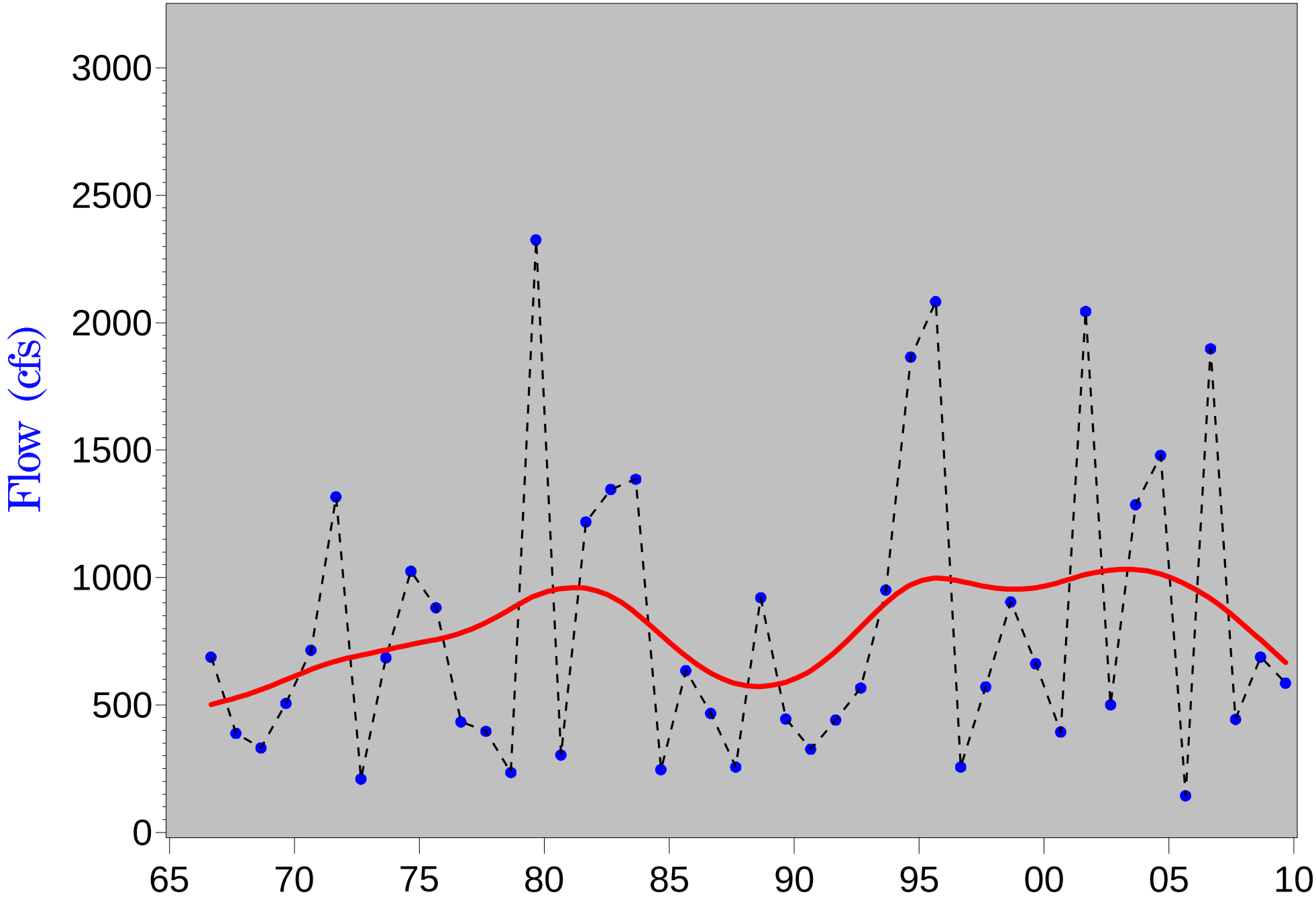


Figure 3.74a September mean USGS Shell Creek gaged flow (1966-2009)

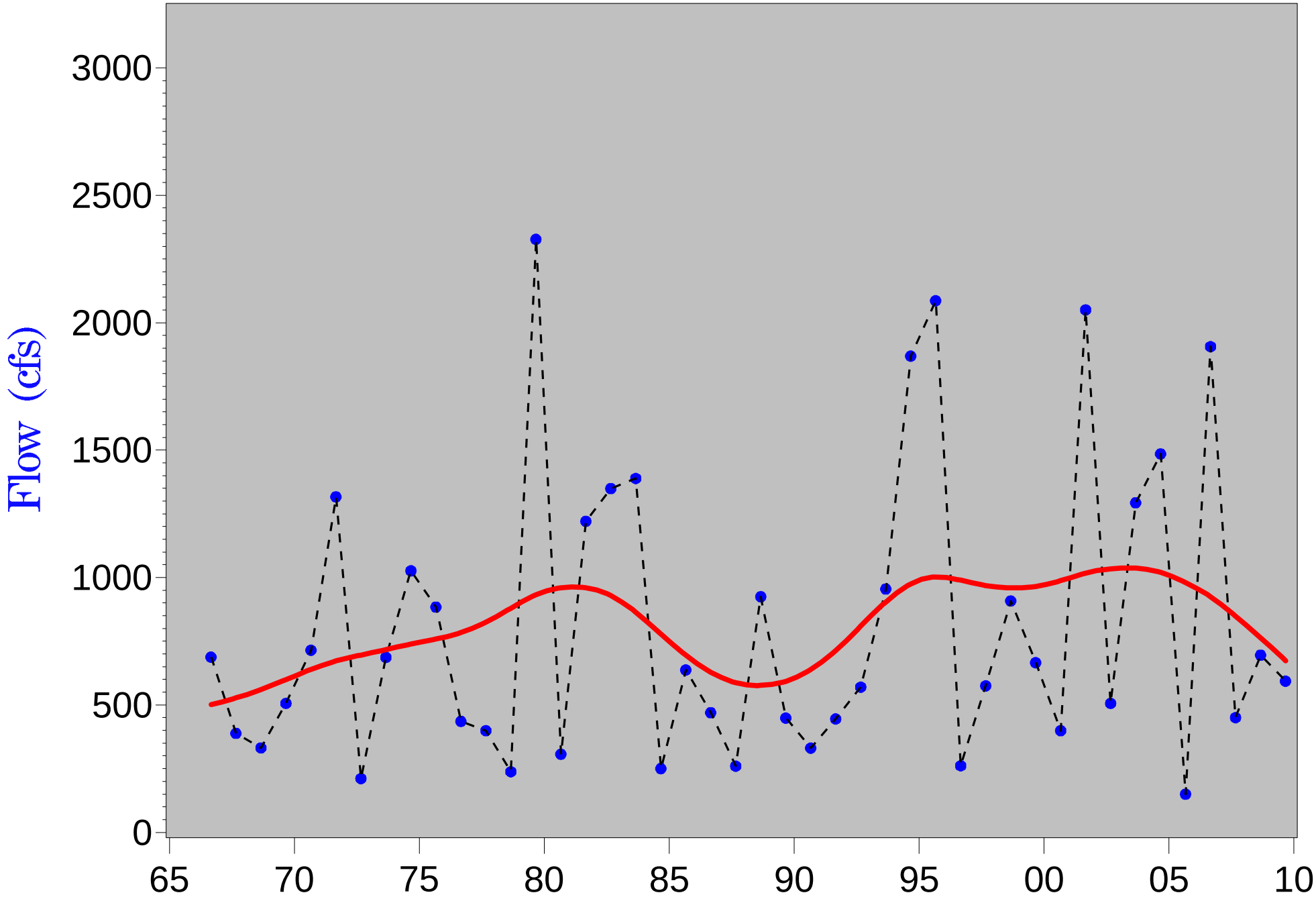


Figure 3.74b Estimated September mean flow without Facility withdrawals (1966-2009)

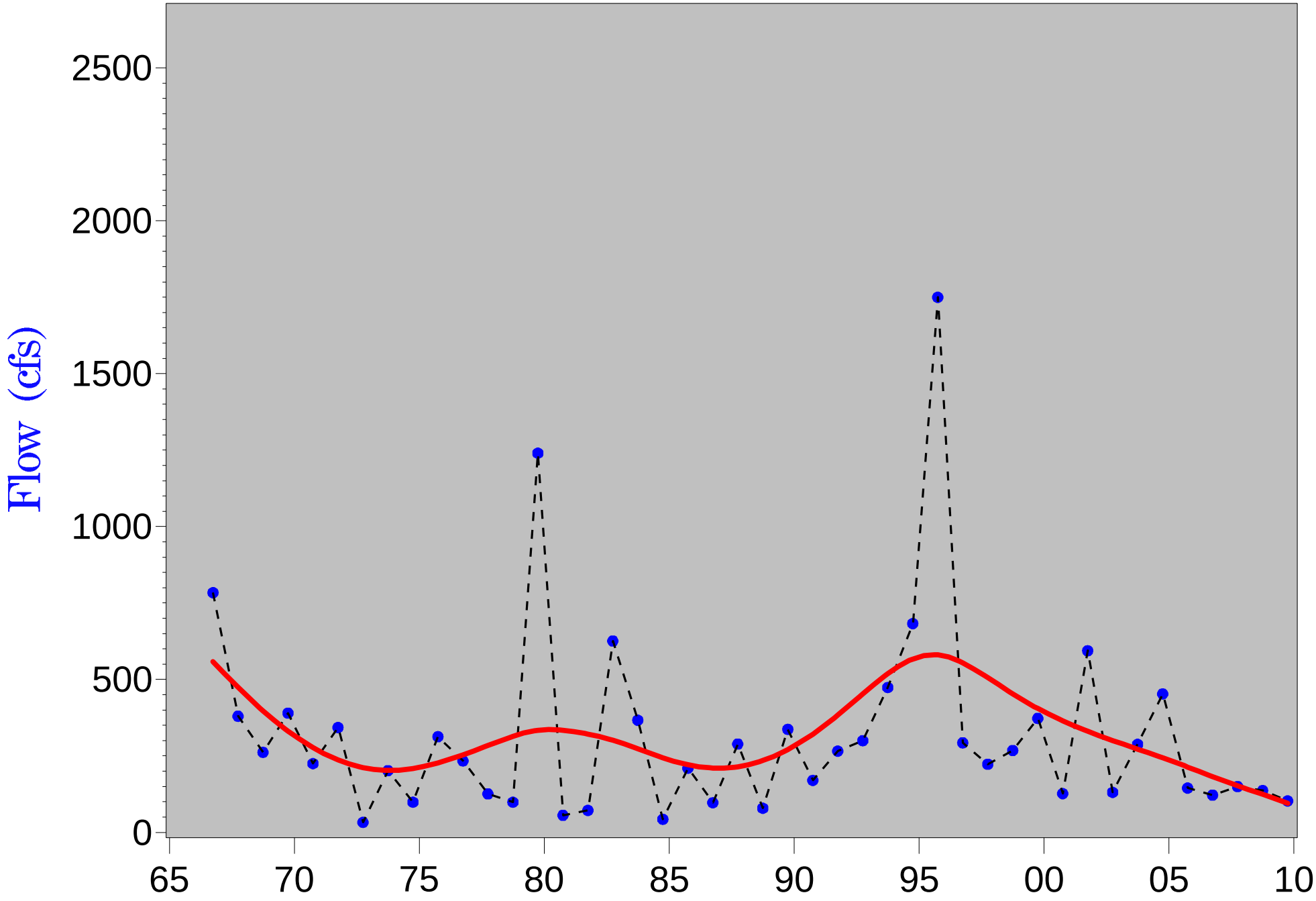


Figure 3.75a October median USGS Shell Creek gaged flow (196662009)

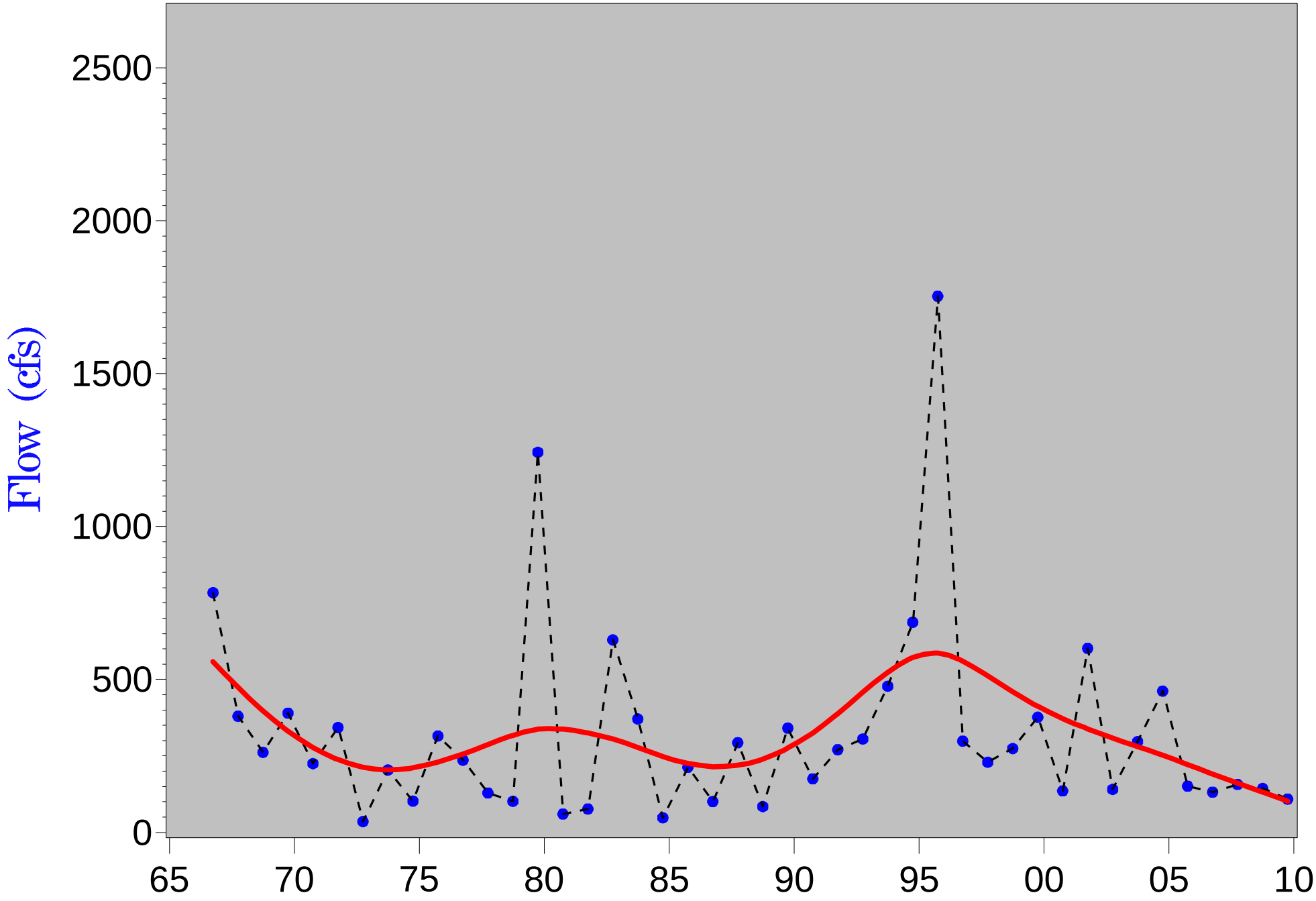


Figure 3.75b Estimated October median flow without Facility withdrawals (1966-2009)

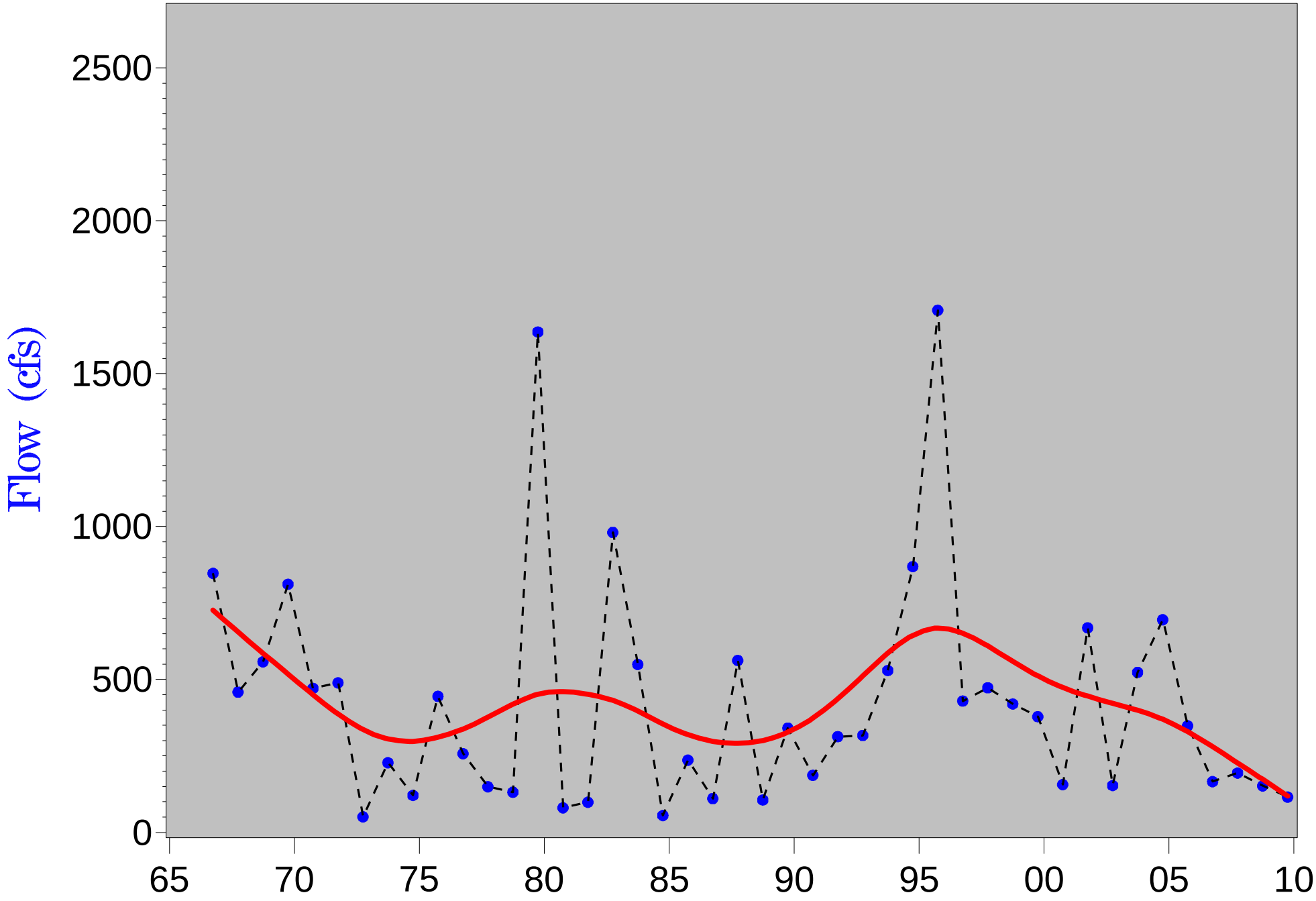


Figure 3.76a October mean USGS Shell Creek gaged flow (1966-2009)

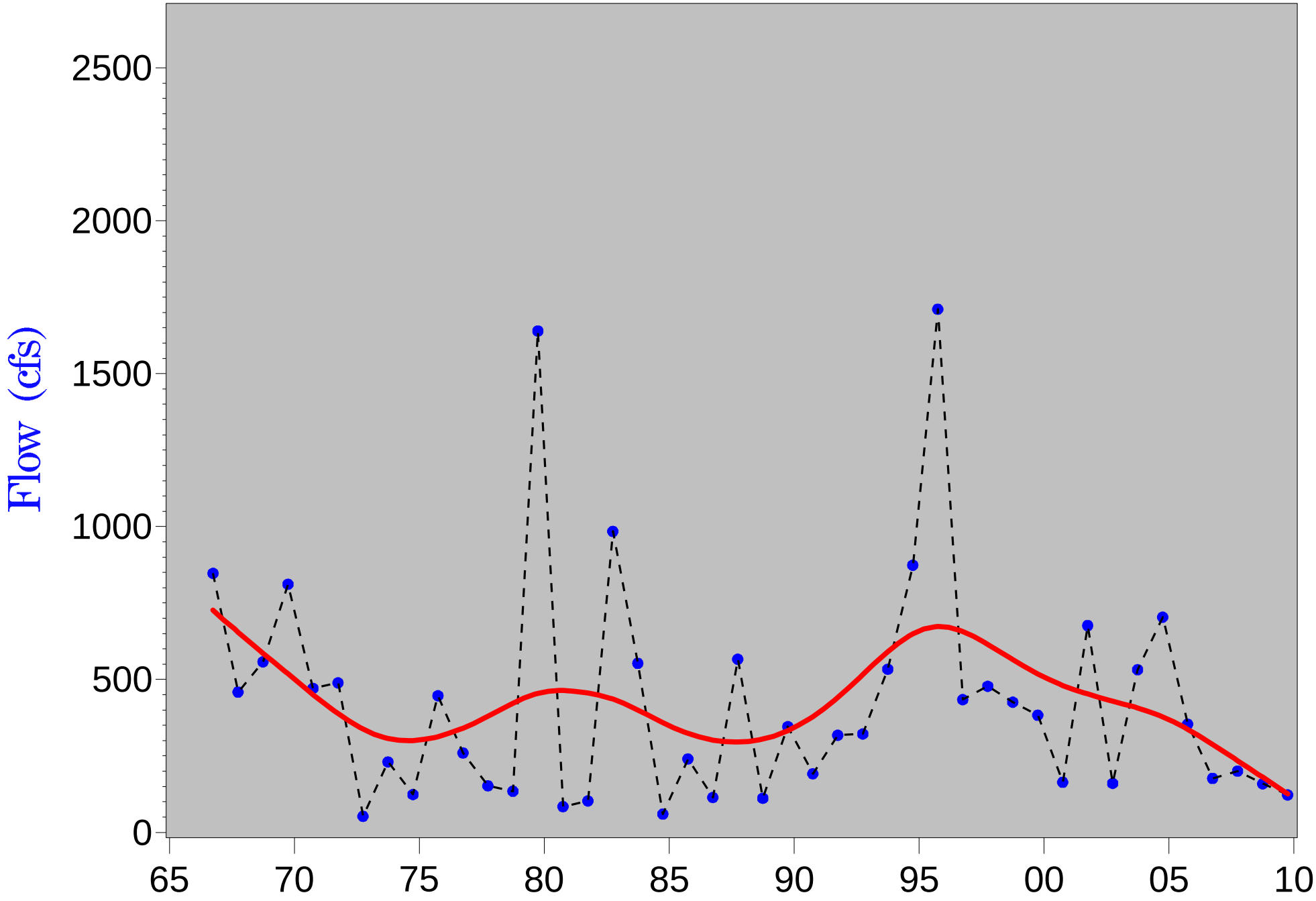


Figure 3.76b Estimated October mean flow without Facility withdrawals (1966-2009)

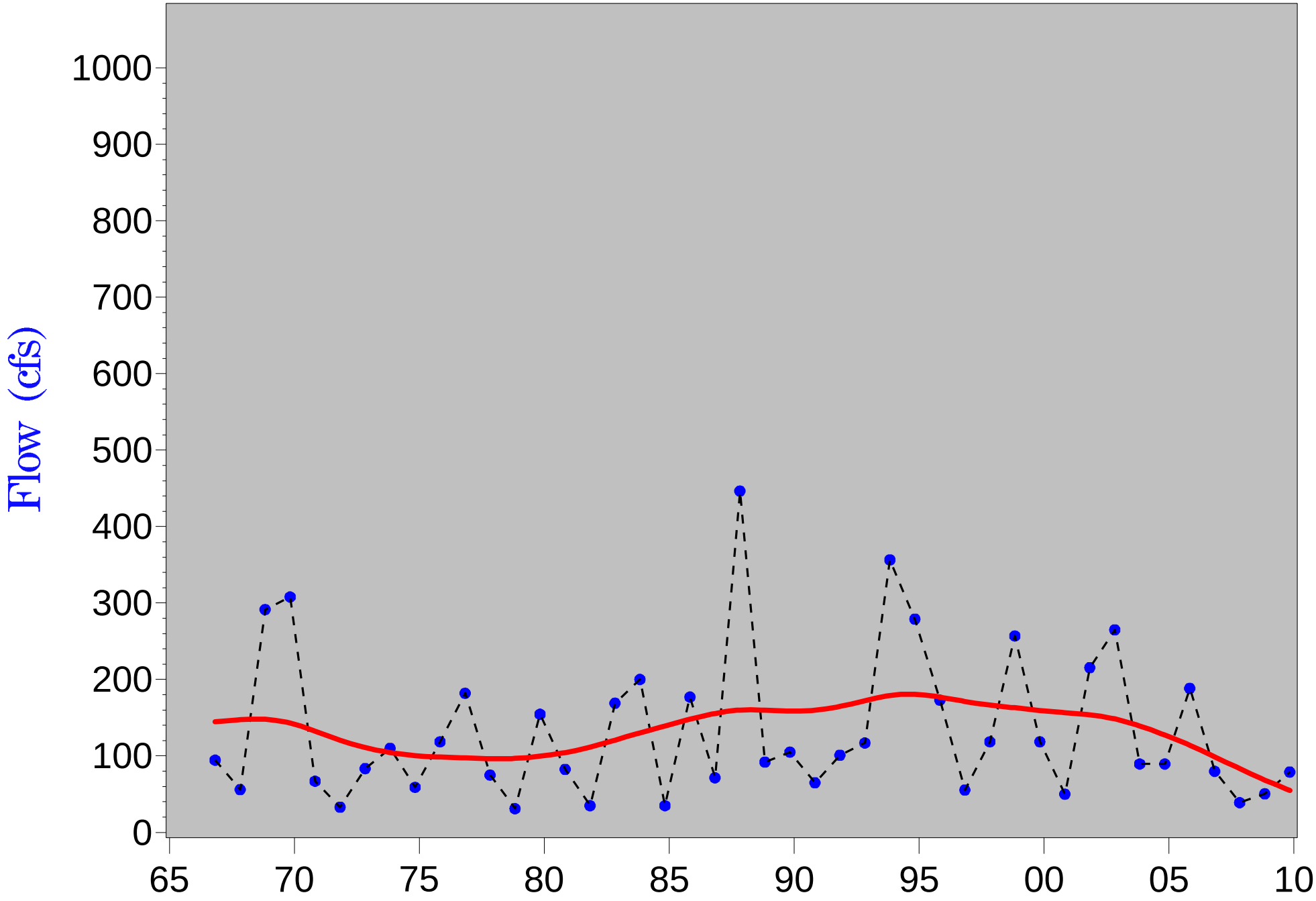


Figure 3.77a November median USGS Shell Creek gaged flow (1966-2009)

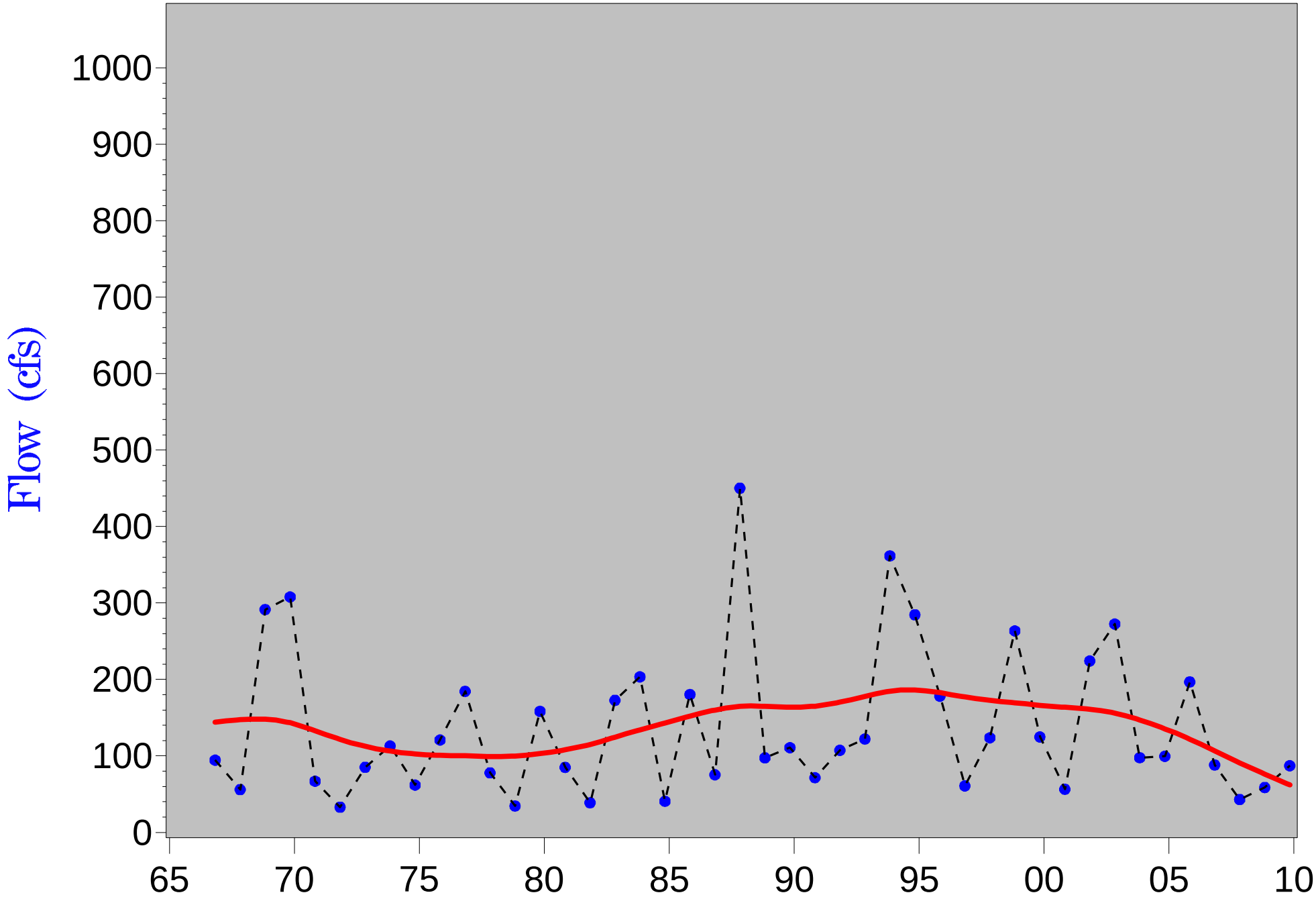


Figure 3.77b Estimated November median flow without Facility withdrawals (1966-2009)

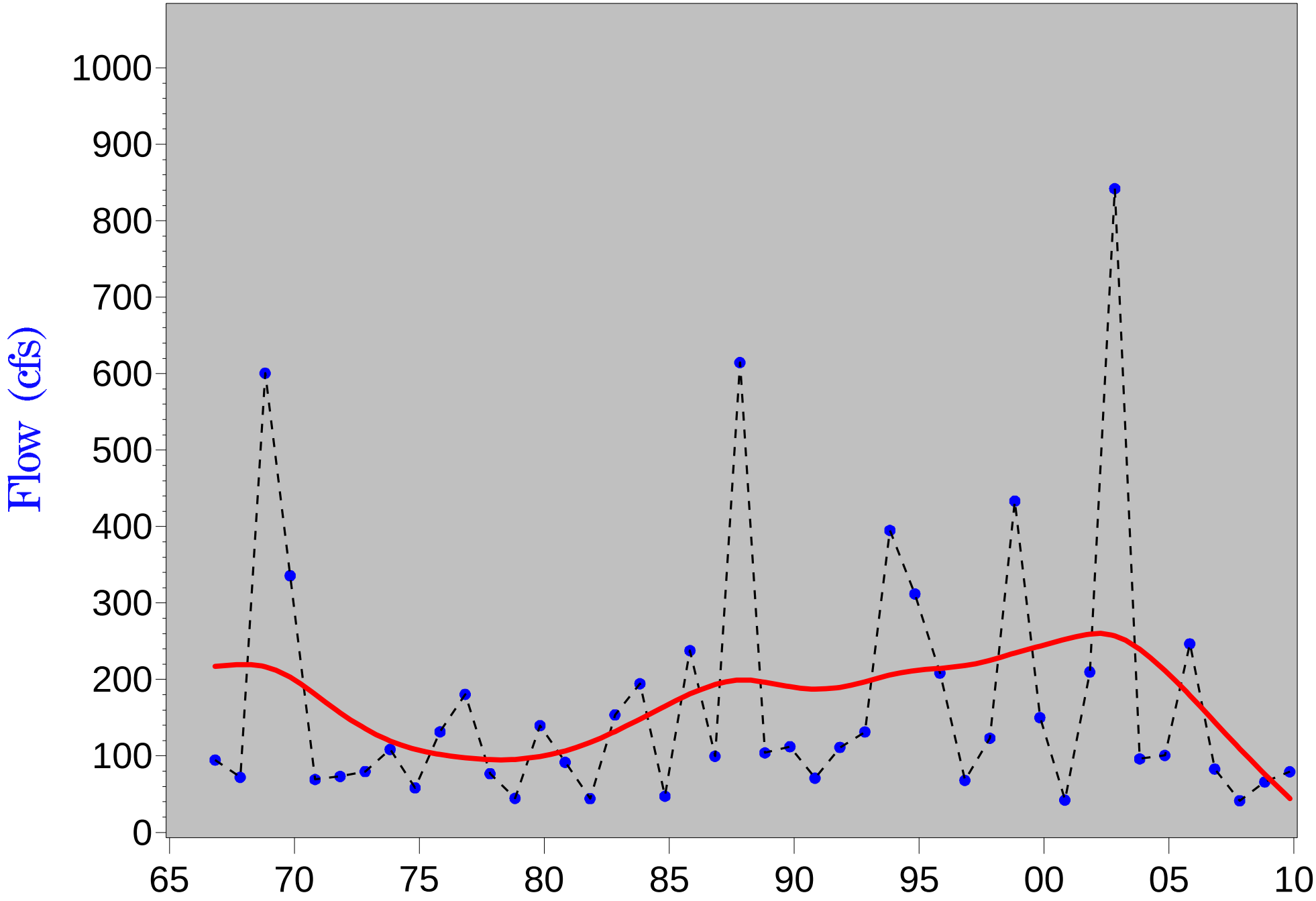


Figure 3.78a November mean USGS Shell Creek gaged flow (1966-2009)

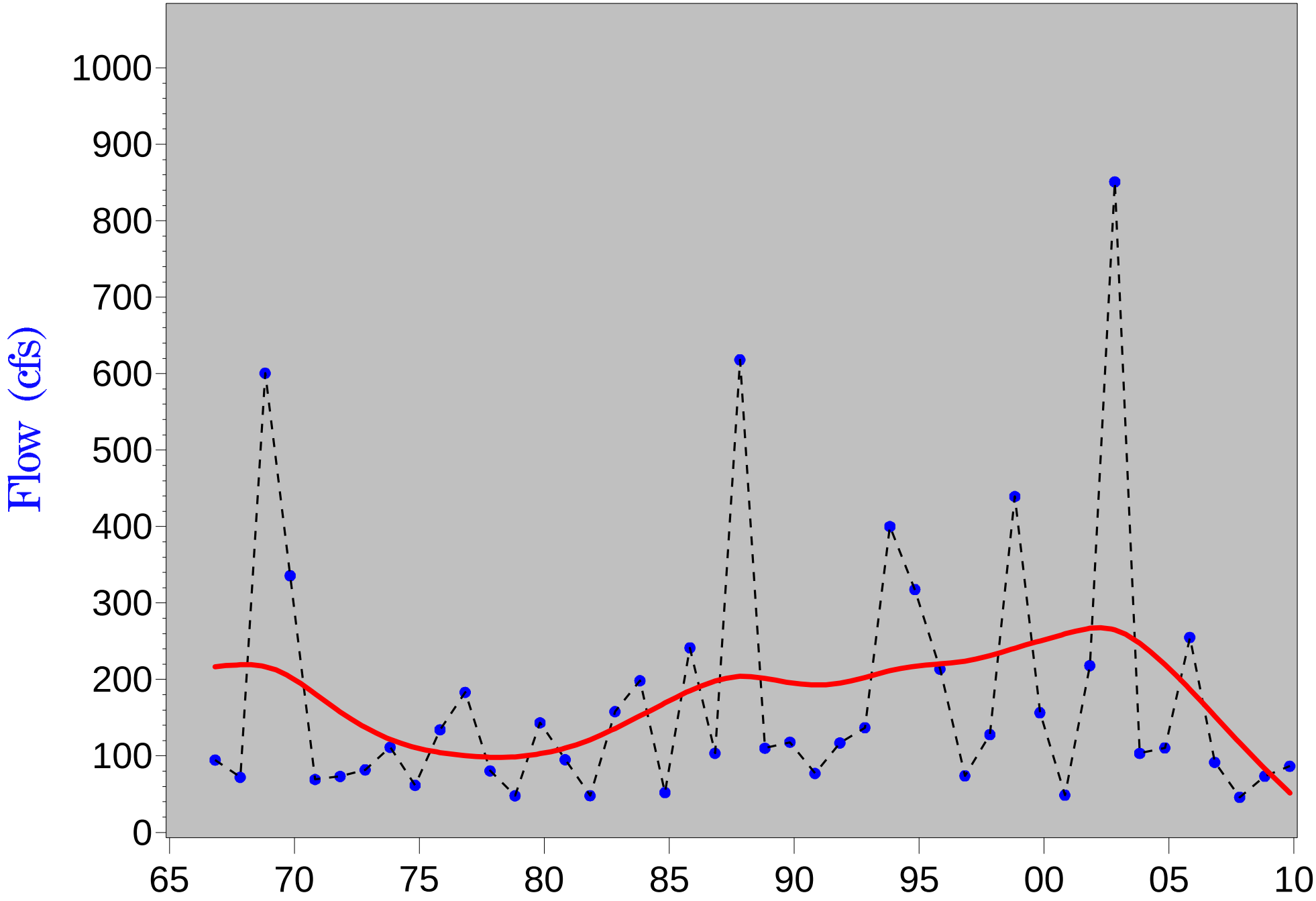


Figure 3.78b Estimated November mean flow without Facility withdrawals (1966-2009)

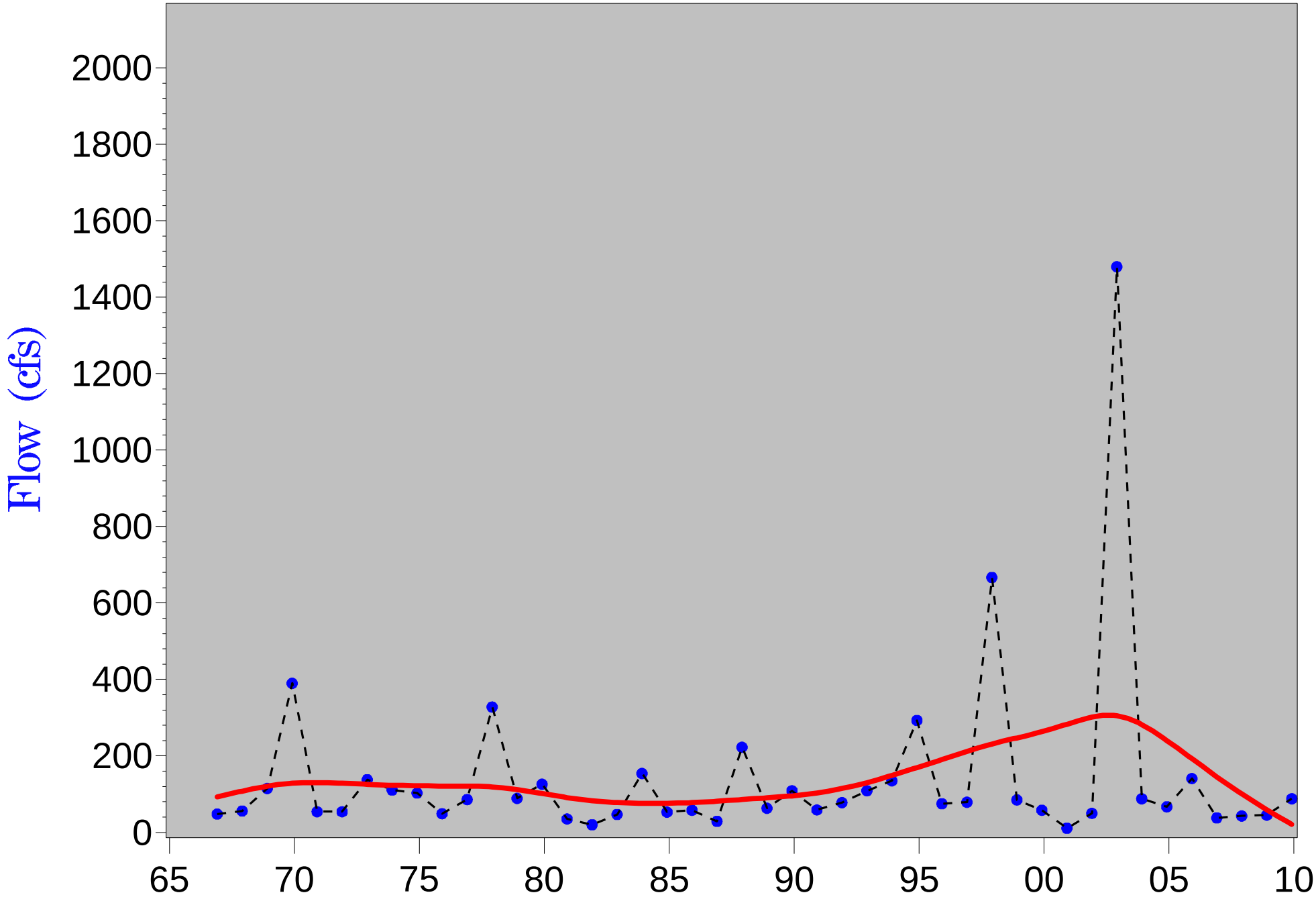


Figure 3.79a December median USGS Shell Creek gaged flow (1966-2009)

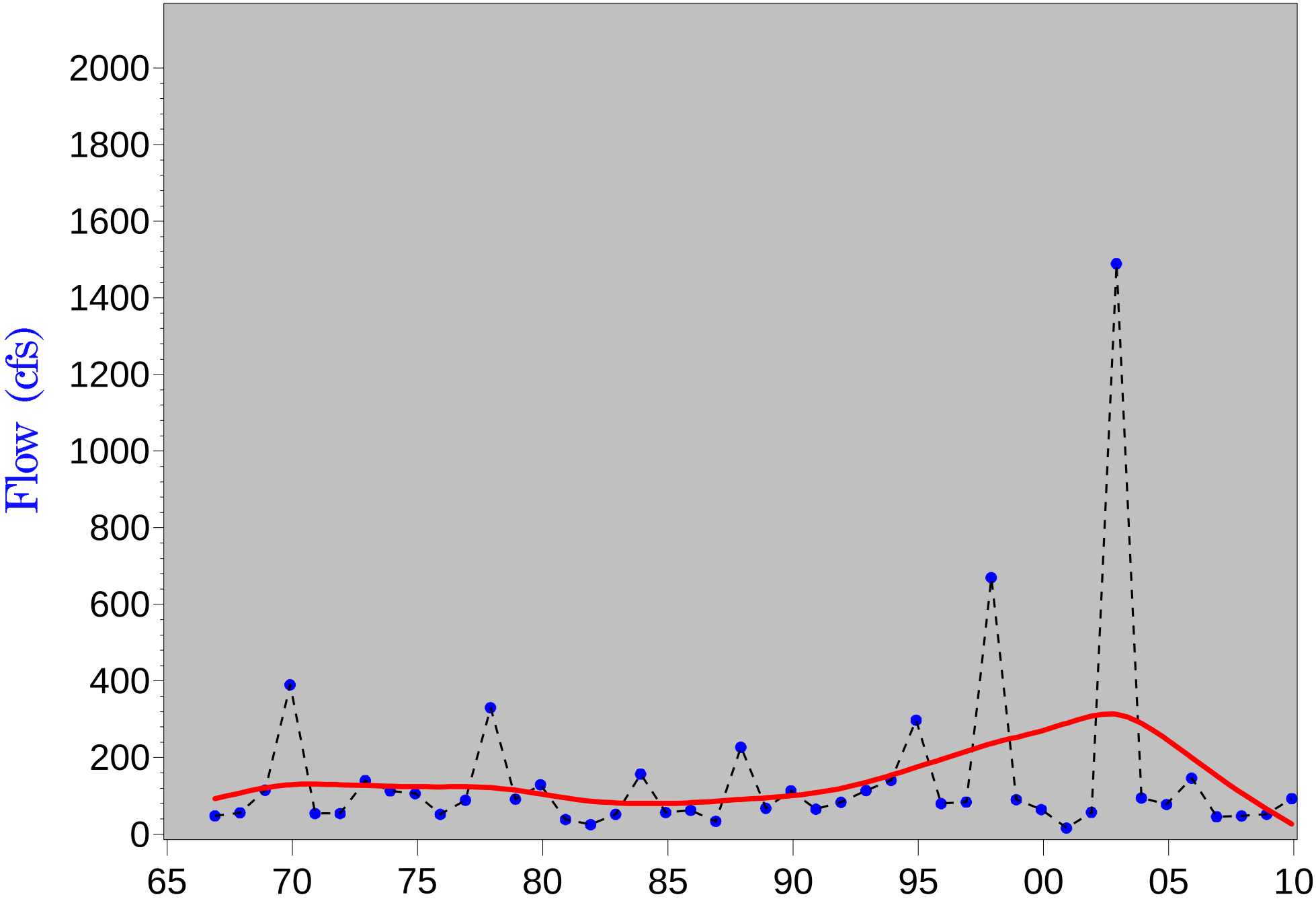


Figure 3.79b Estimated December median flow without Facility withdrawals (1966-2009)

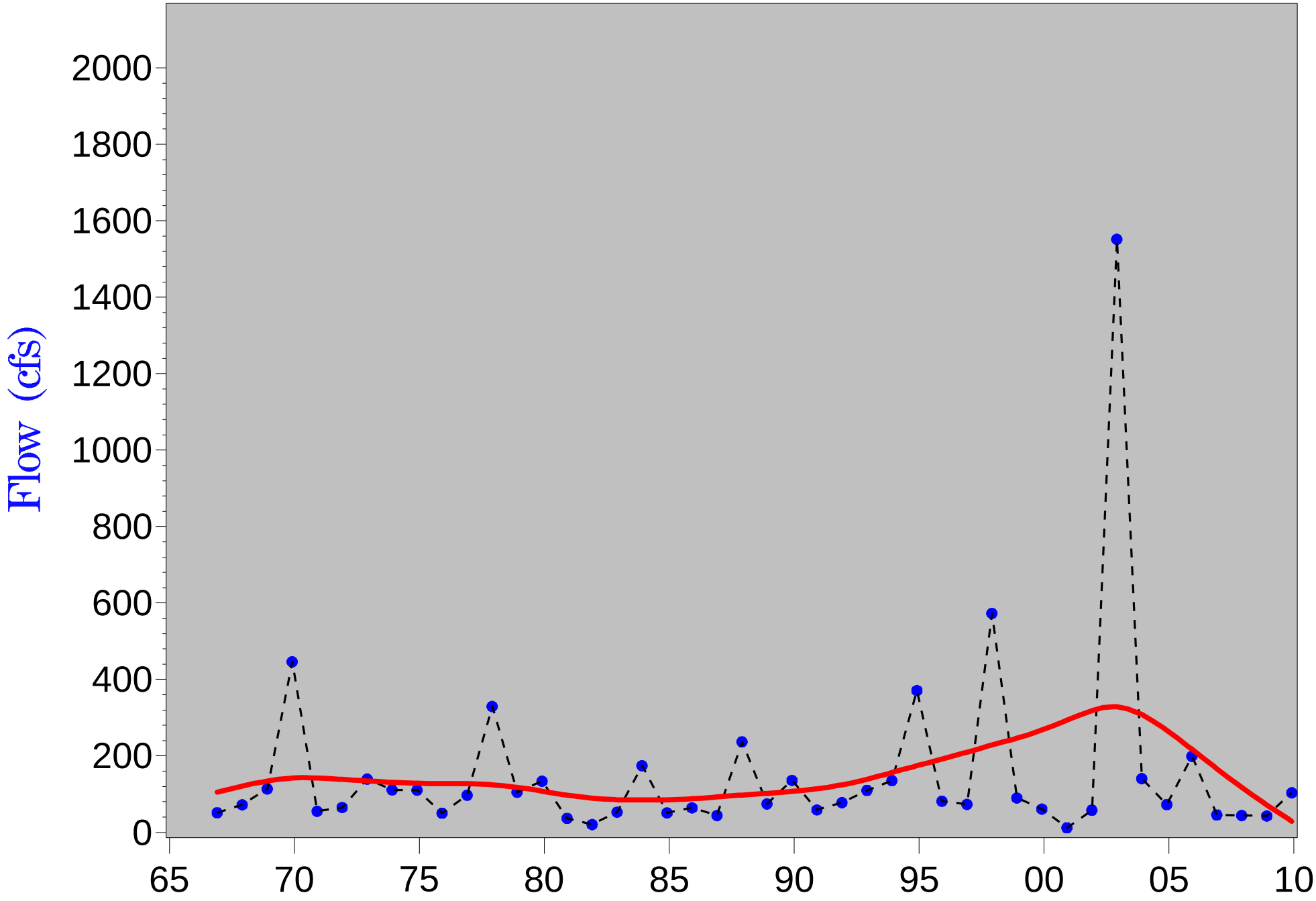


Figure 3.80a December mean USGS Shell Creek gaged flow (1966-2009)

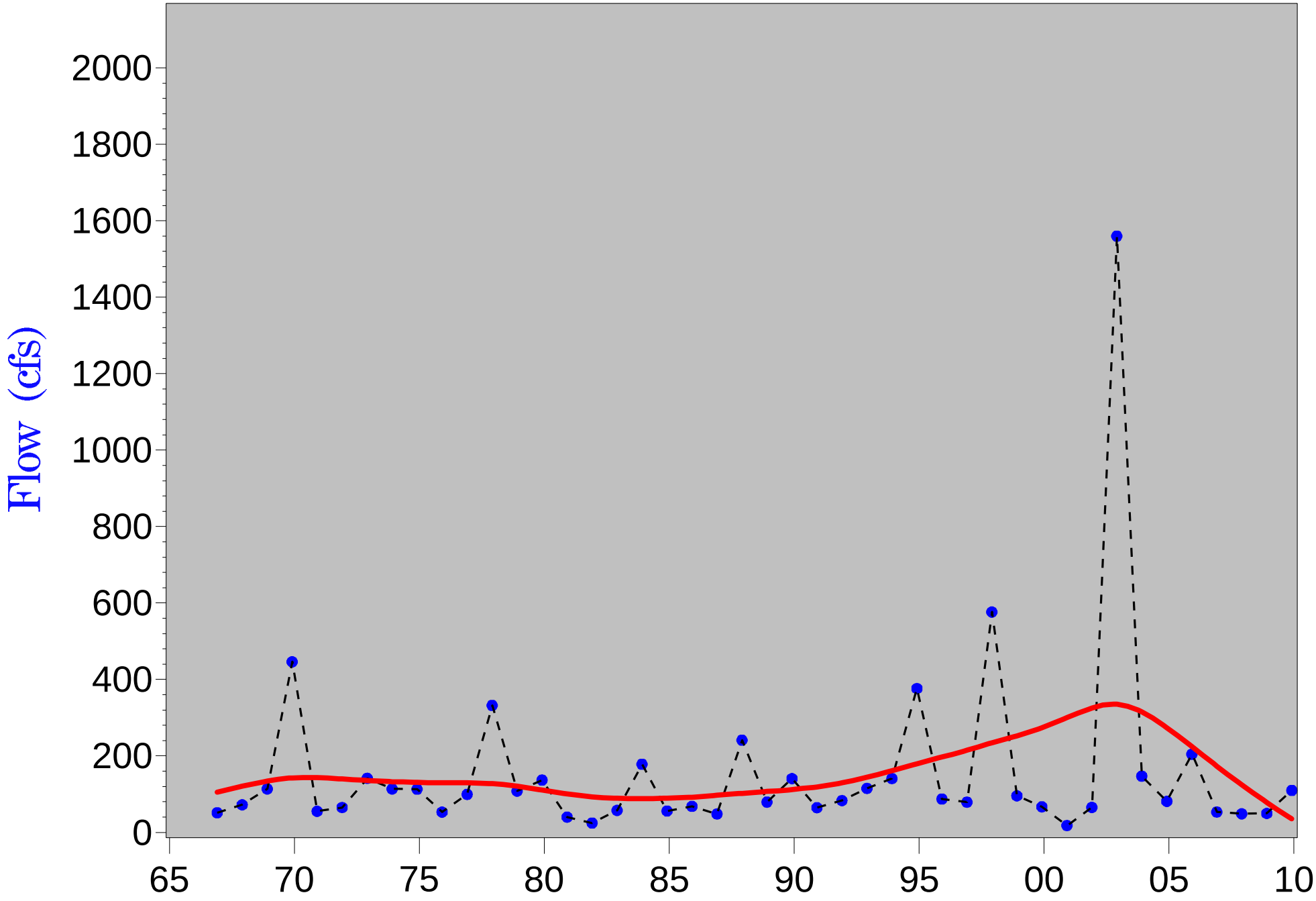


Figure 3.80b Estimated December mean flow without Facility withdrawals (1966-2009)

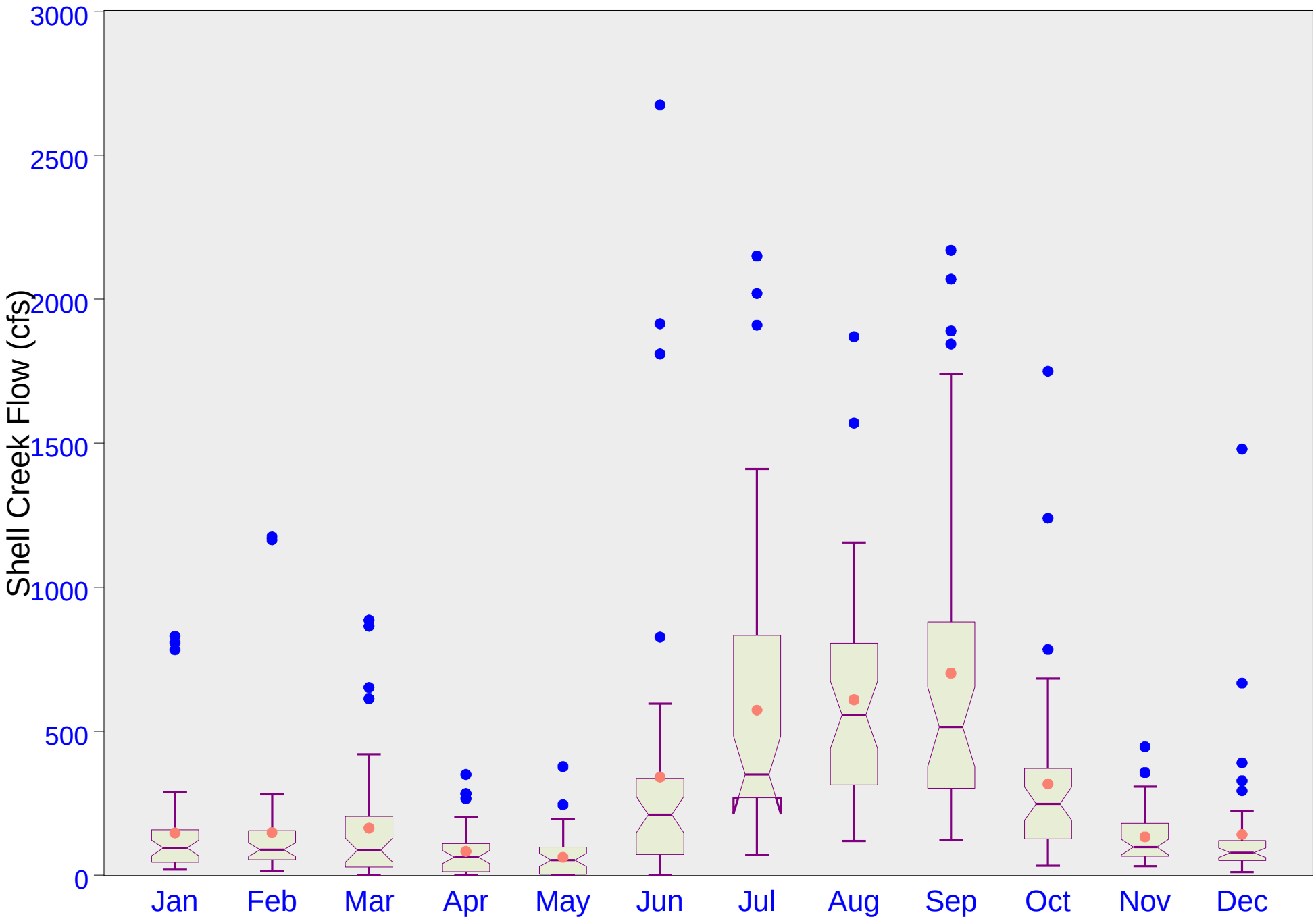


Figure 3.81a Hydrograph of annual monthly median USGS Shell Creek gaged flow (1966-2009)

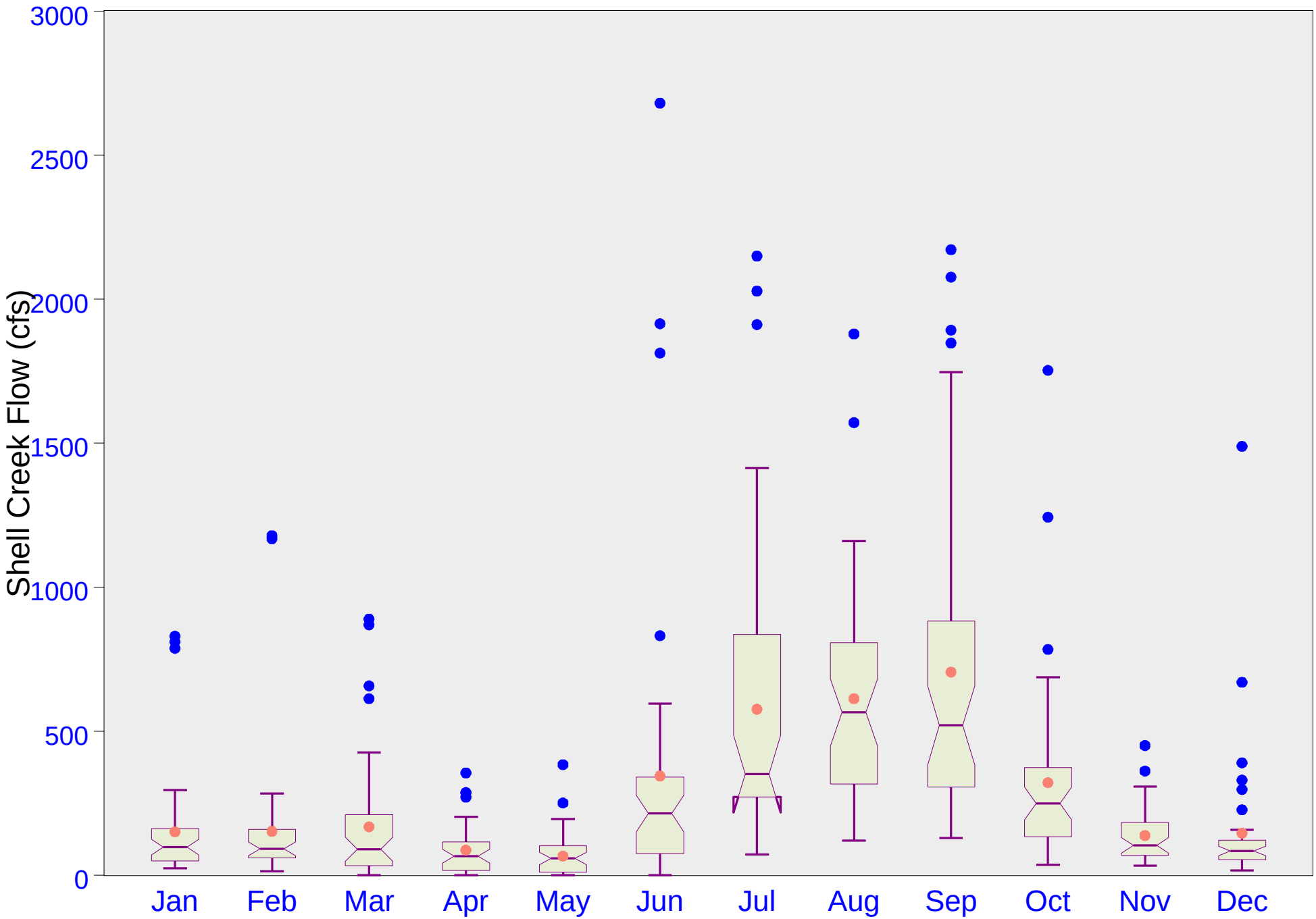


Figure 3.81b Hydrograph of annual monthly median estimated flow without withdrawals (1966-2009)

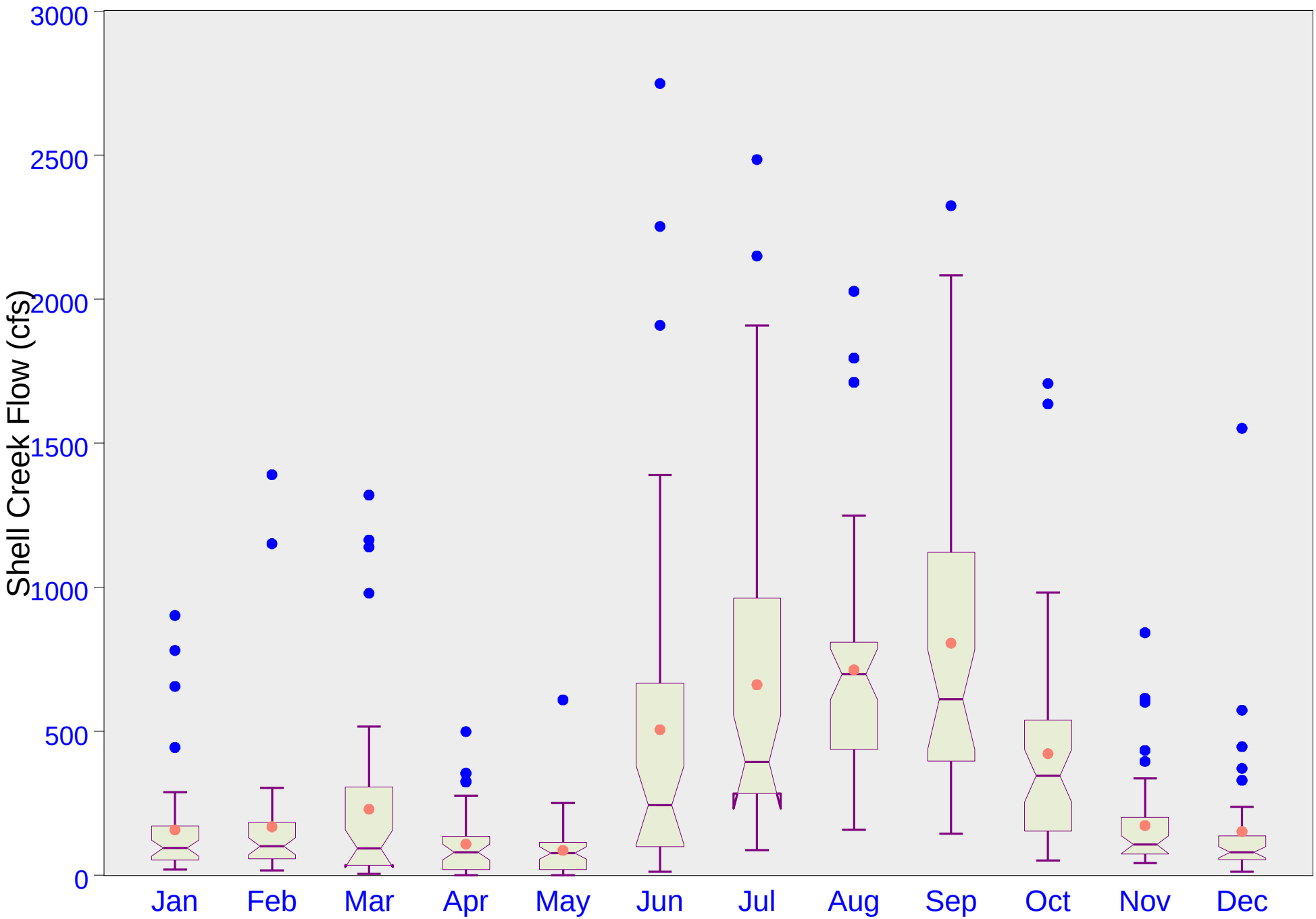


Figure 3.82a Hydrograph of annual monthly mean USGS Shell Creek gaged flow (1966-2009)

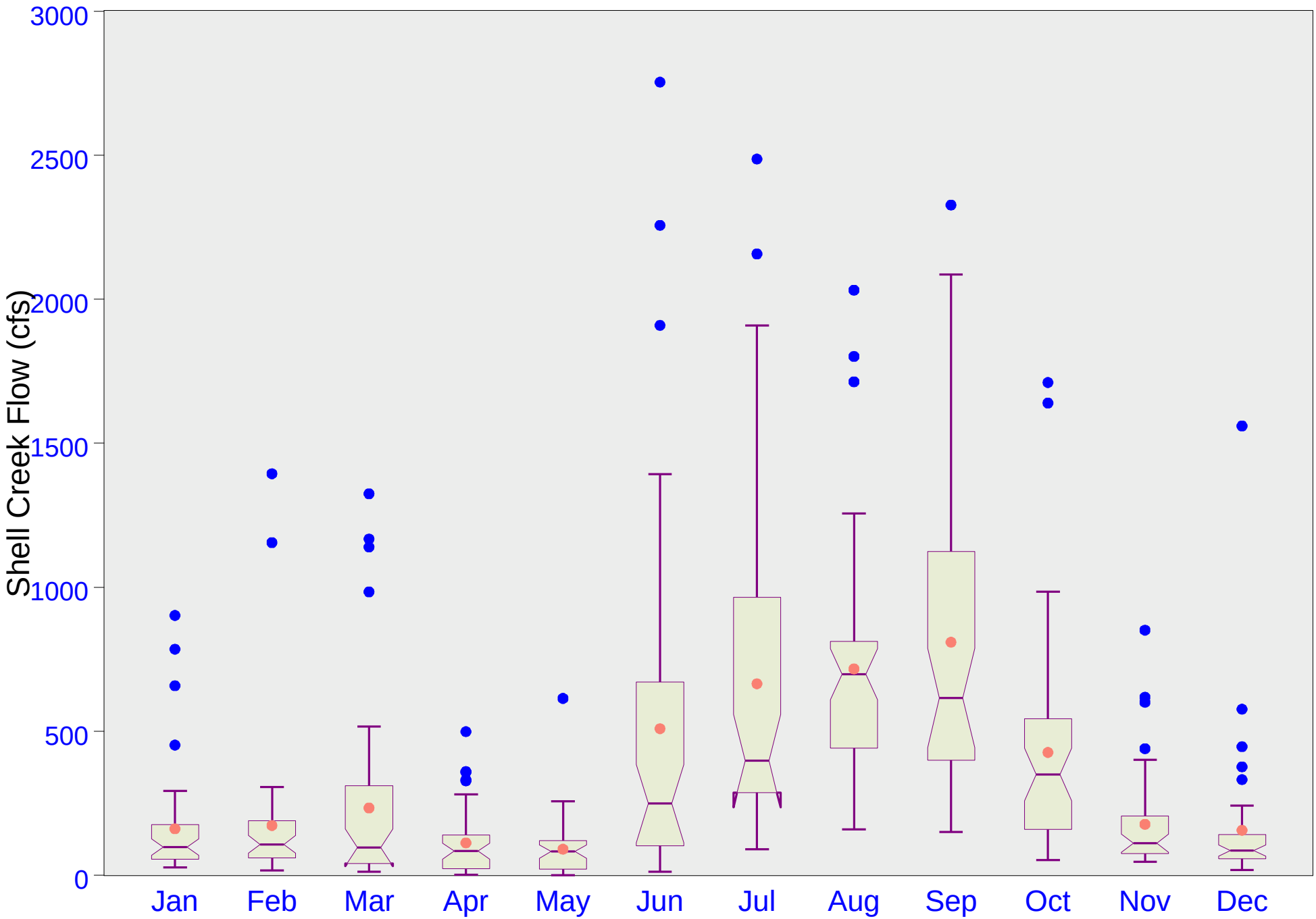


Figure 3.82b Hydrograph of annual monthly mean estimated flow without withdrawals (1966-2009)

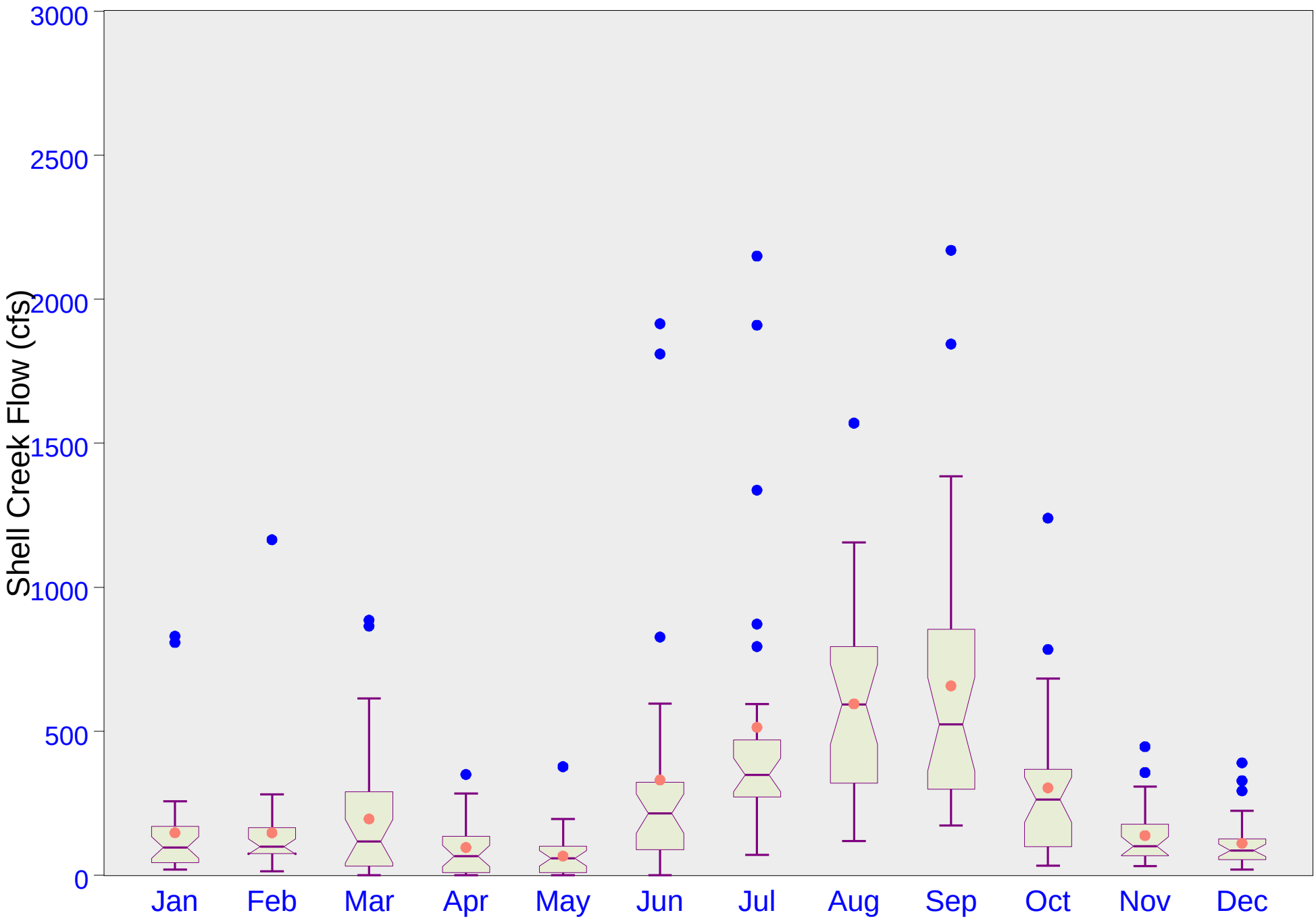


Figure 3.83a Hydrograph of annual monthly median USGS Shell Creek gaged flow (1966-1994)

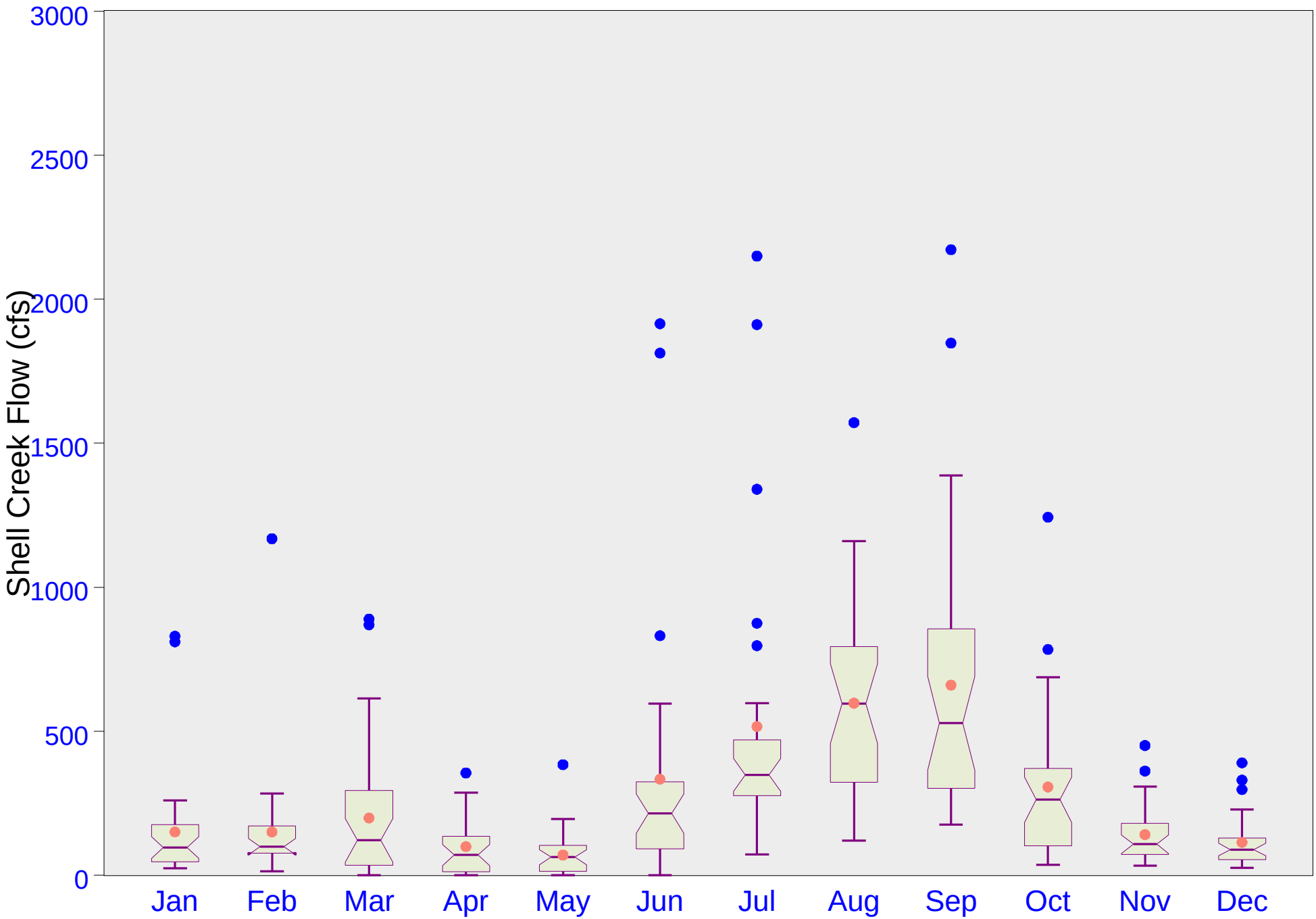


Figure 3.83b Hydrograph of annual monthly median estimated flow without withdrawals (1966-1994)

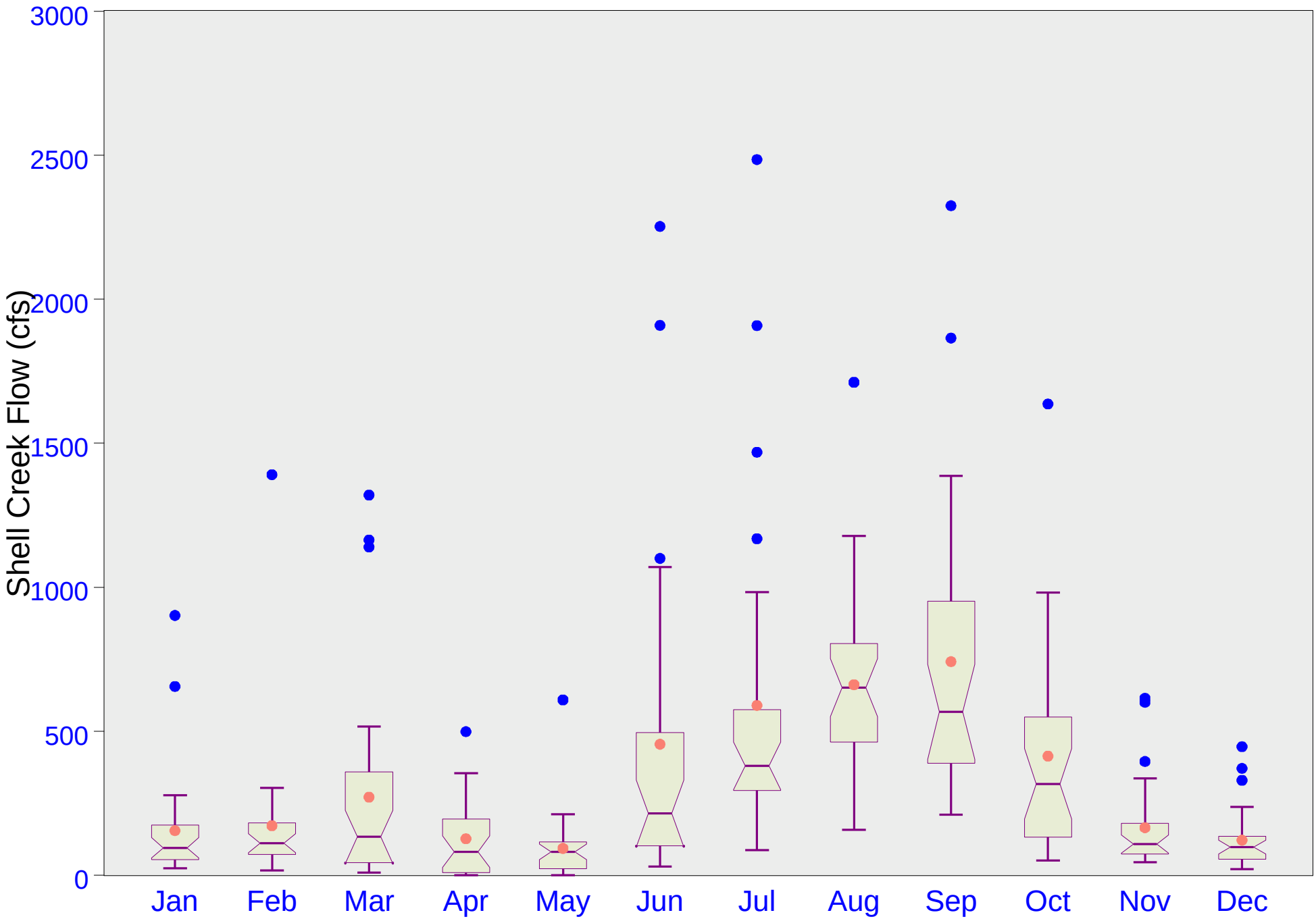


Figure 3.84a Hydrograph of annual monthly mean USGS Shell Creek gaged flow (1966-1994)

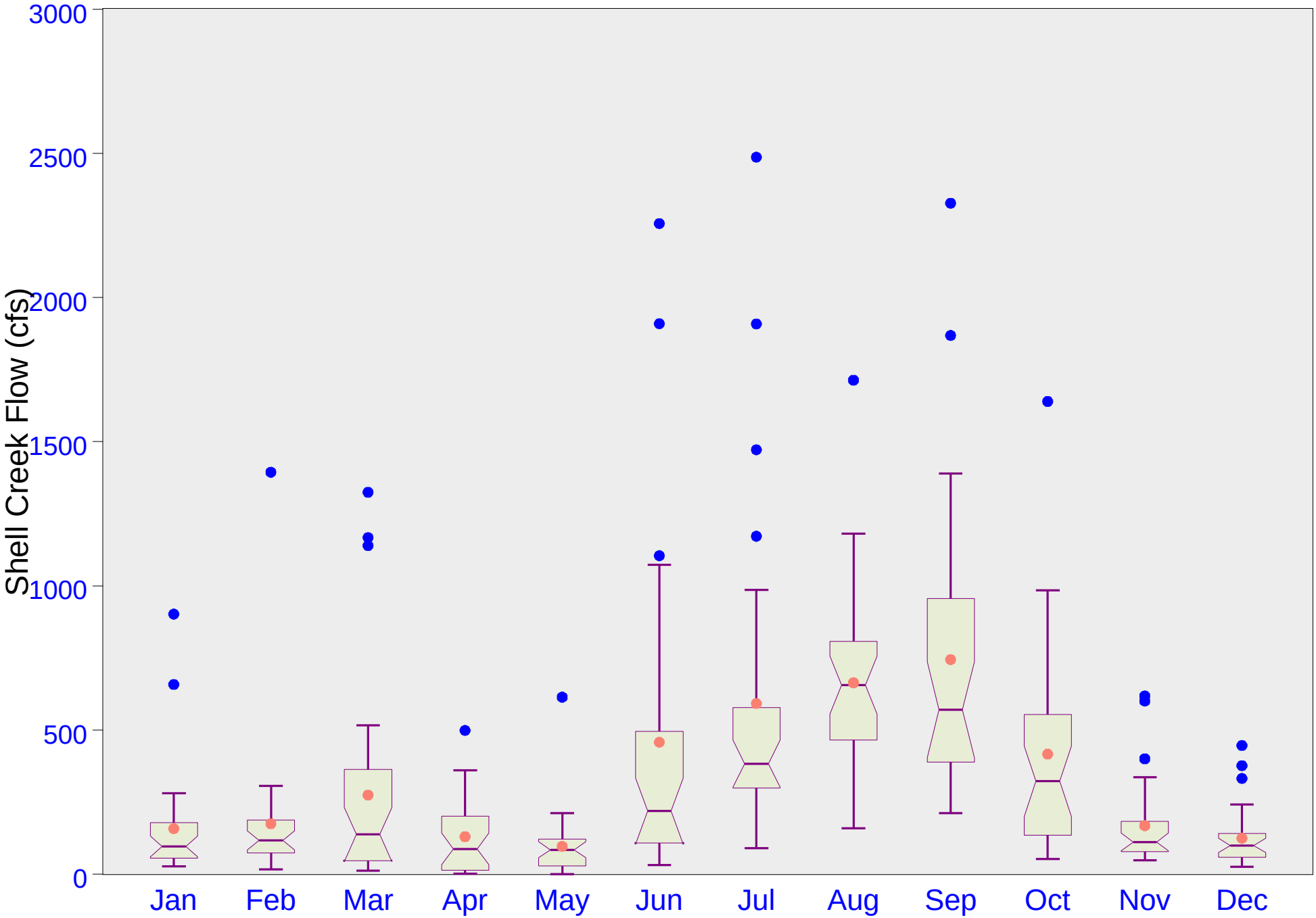


Figure 3.84b Hydrograph of annual monthly mean estimated flow without withdrawals (1966-1994)

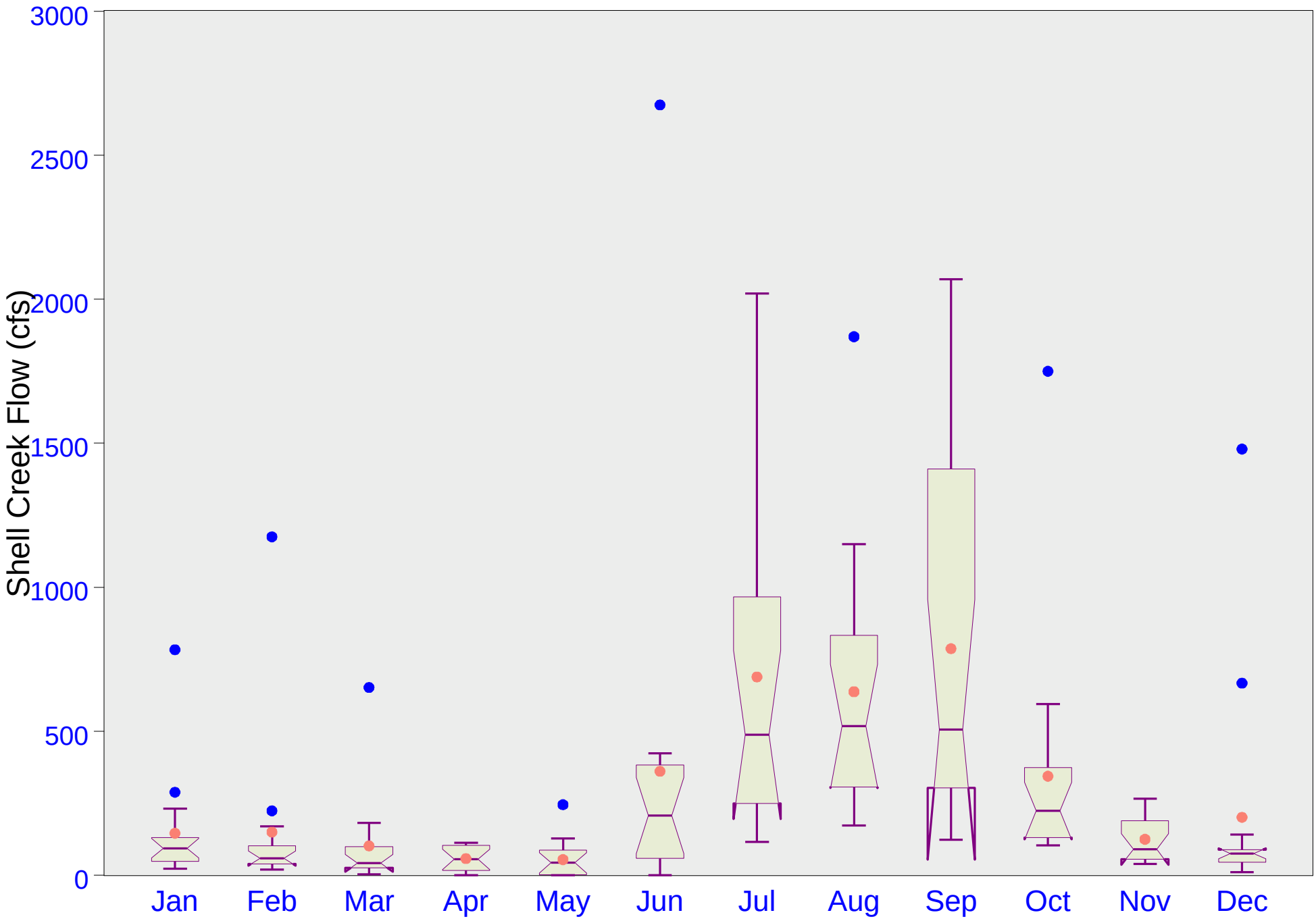


Figure 3.85a Hydrograph of annual monthly median USGS Shell Creek gaged flow (1995-2009)

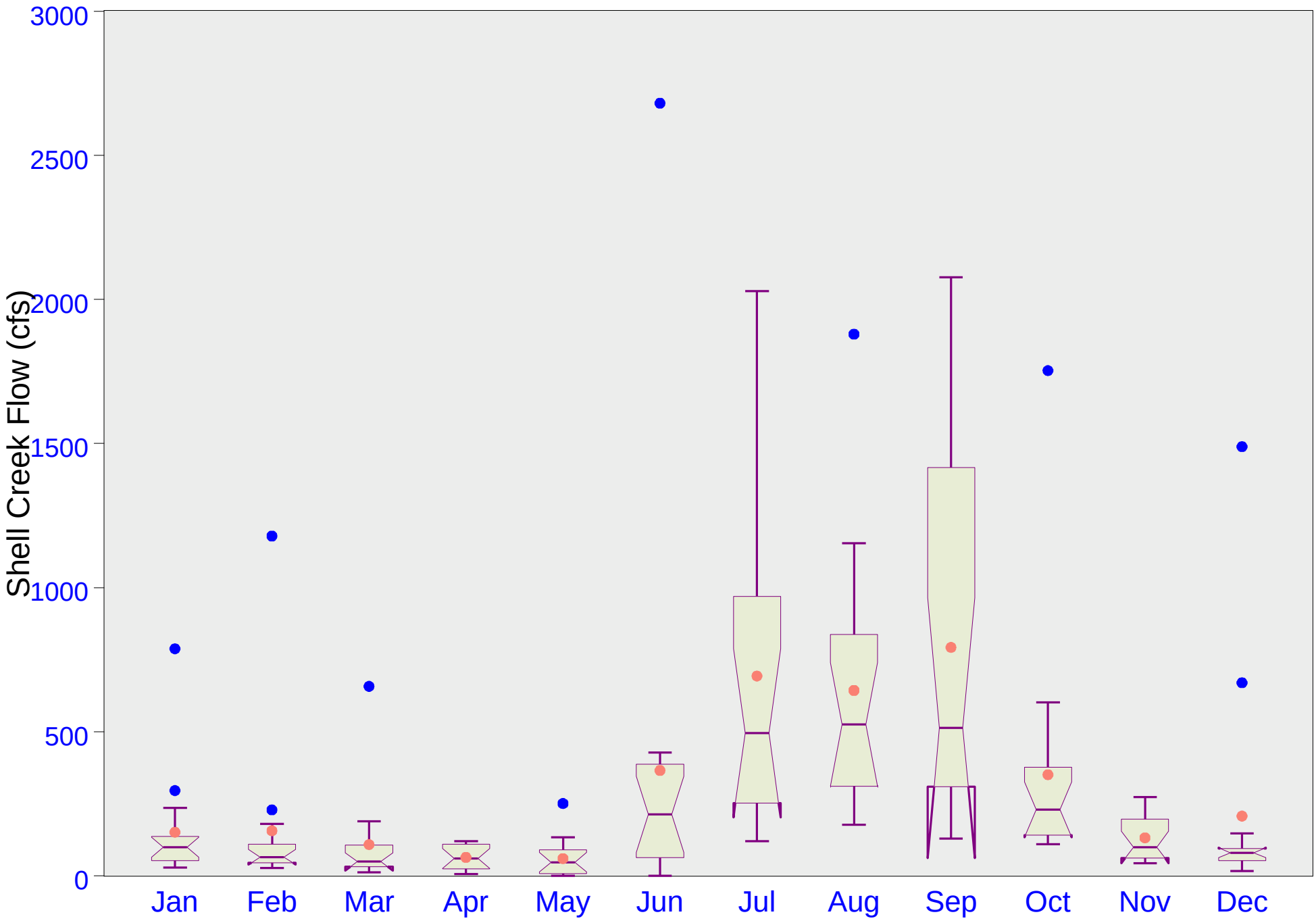


Figure 3.85b Hydrograph of annual monthly median estimated flow without withdrawals (1995-2009)

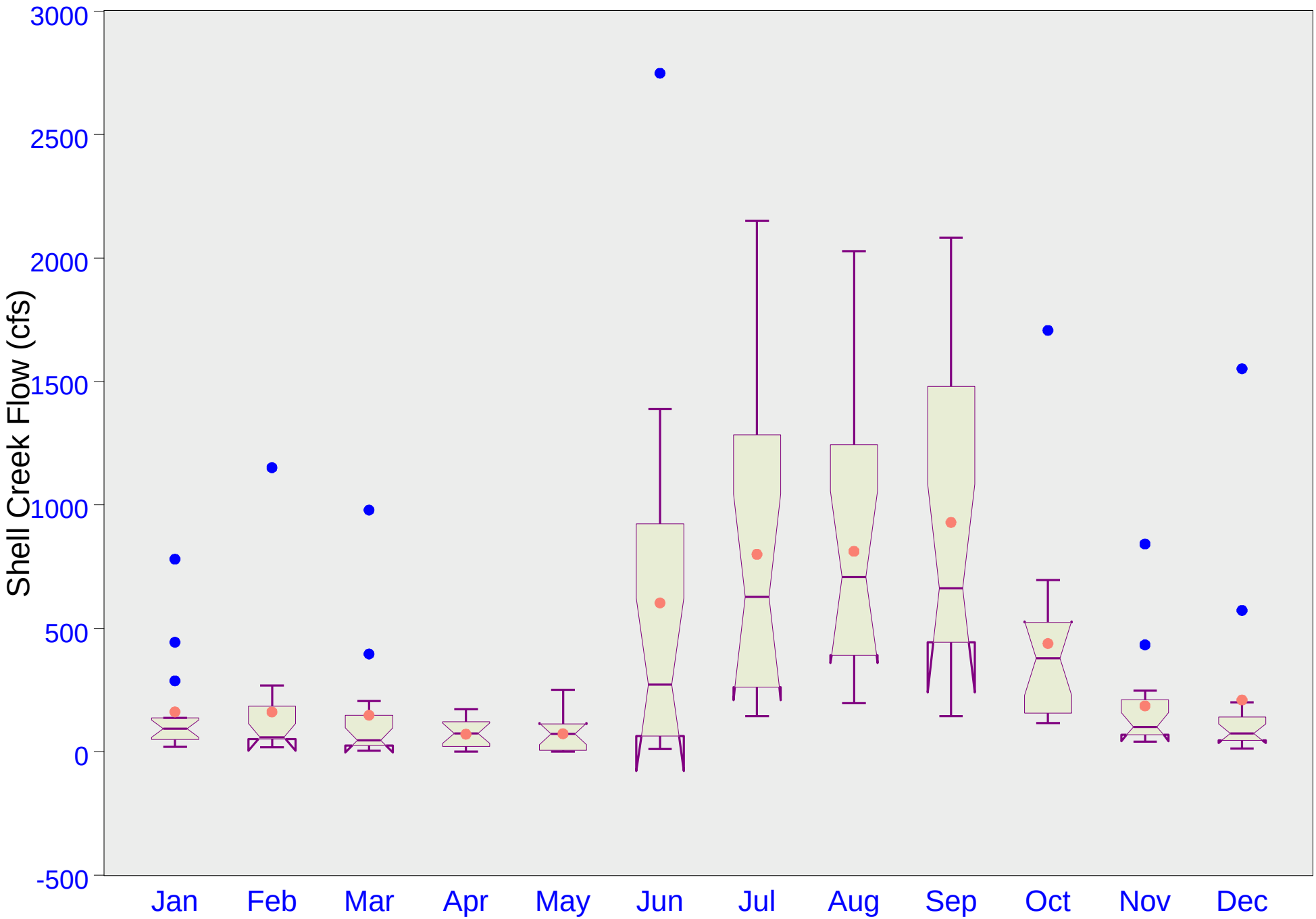


Figure 3.86a Hydrograph of annual monthly mean USGS Shell Creek gaged flow (1995-2009)

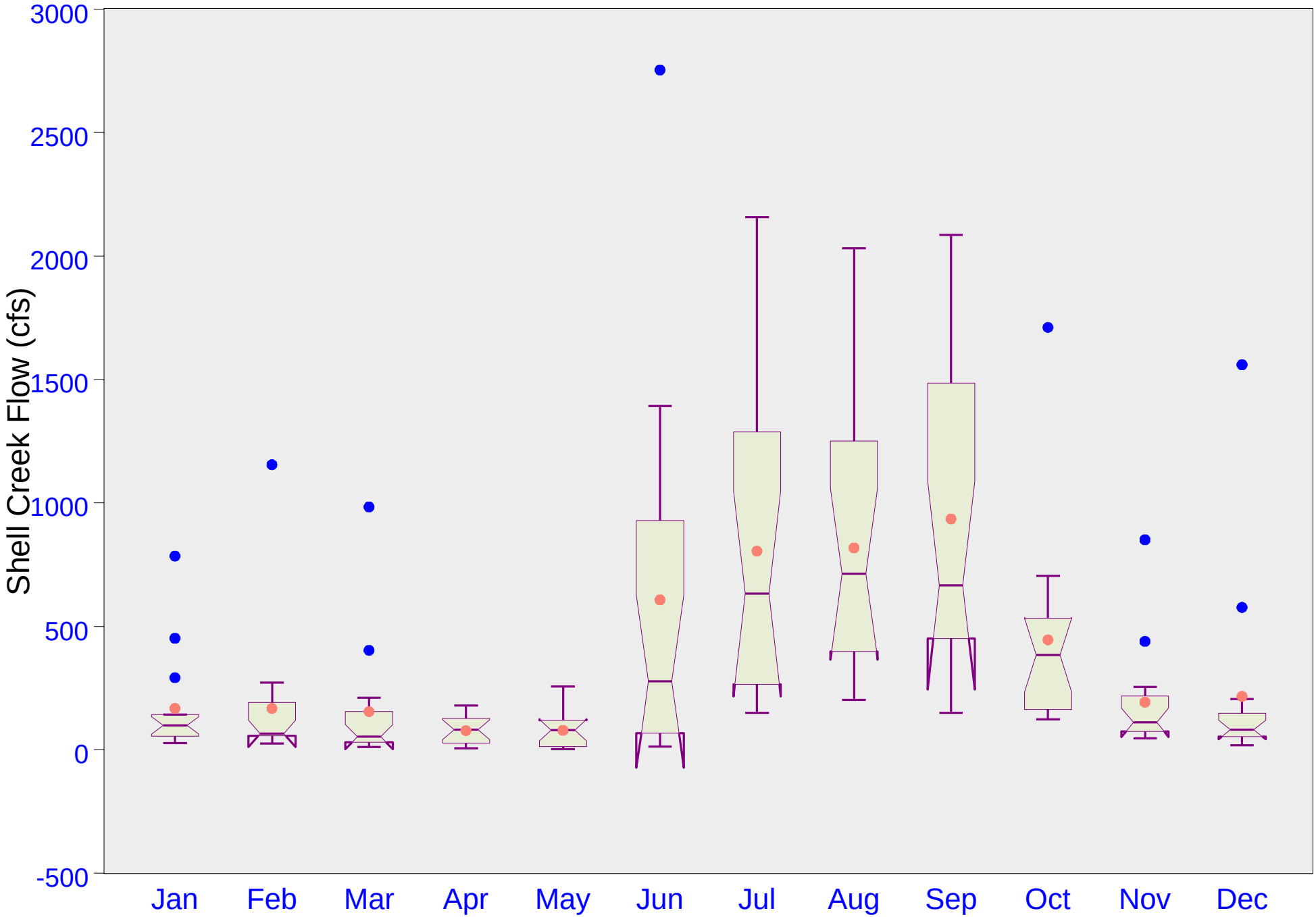


Figure 3.86b Hydrograph of annual monthly mean estimated flow without withdrawals (1995-2009)

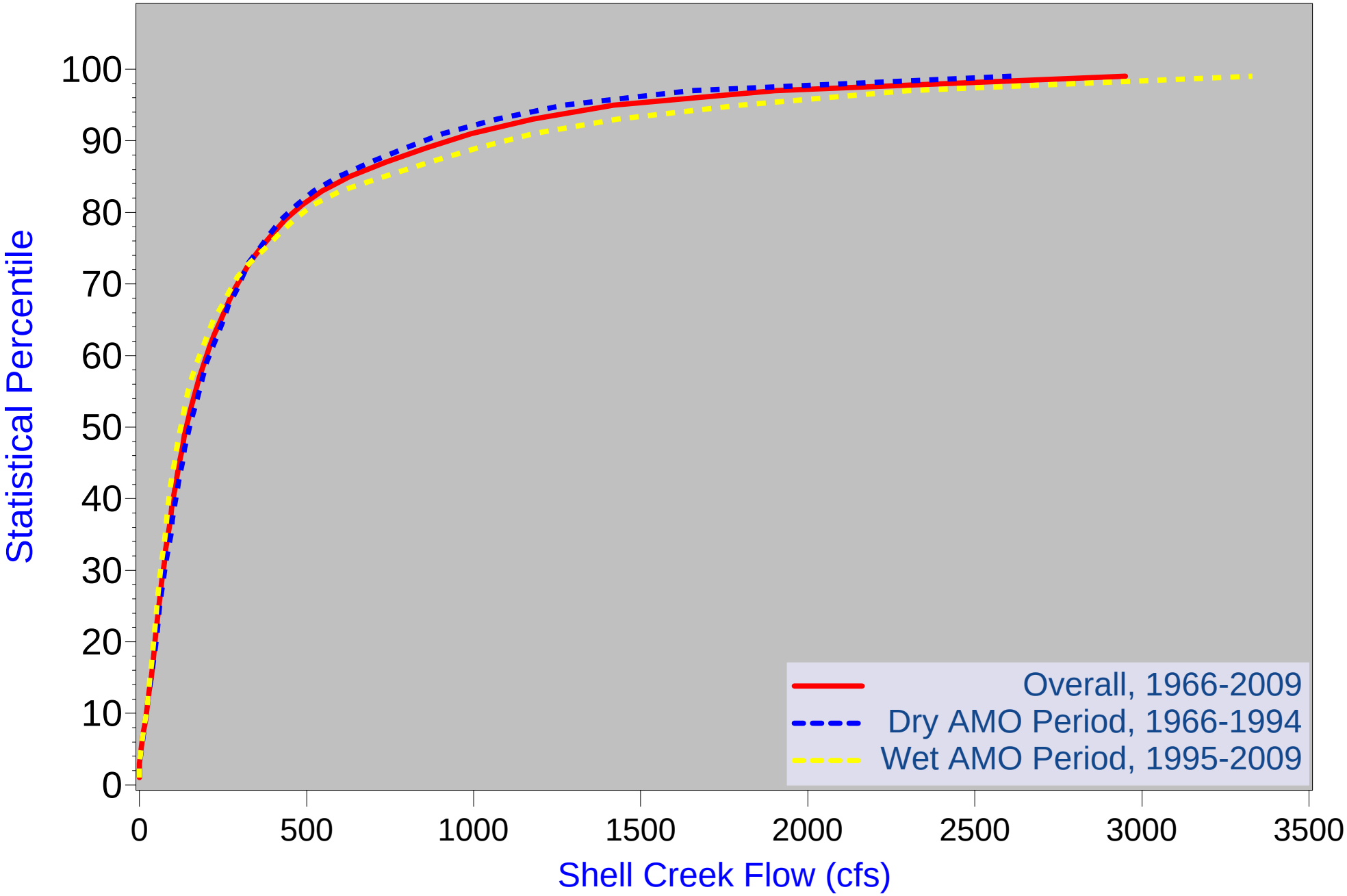


Figure 3.87a Differences in CDFs among AMO periods in Shell Creek gage flow (USGS #2298202)
All seasons combined

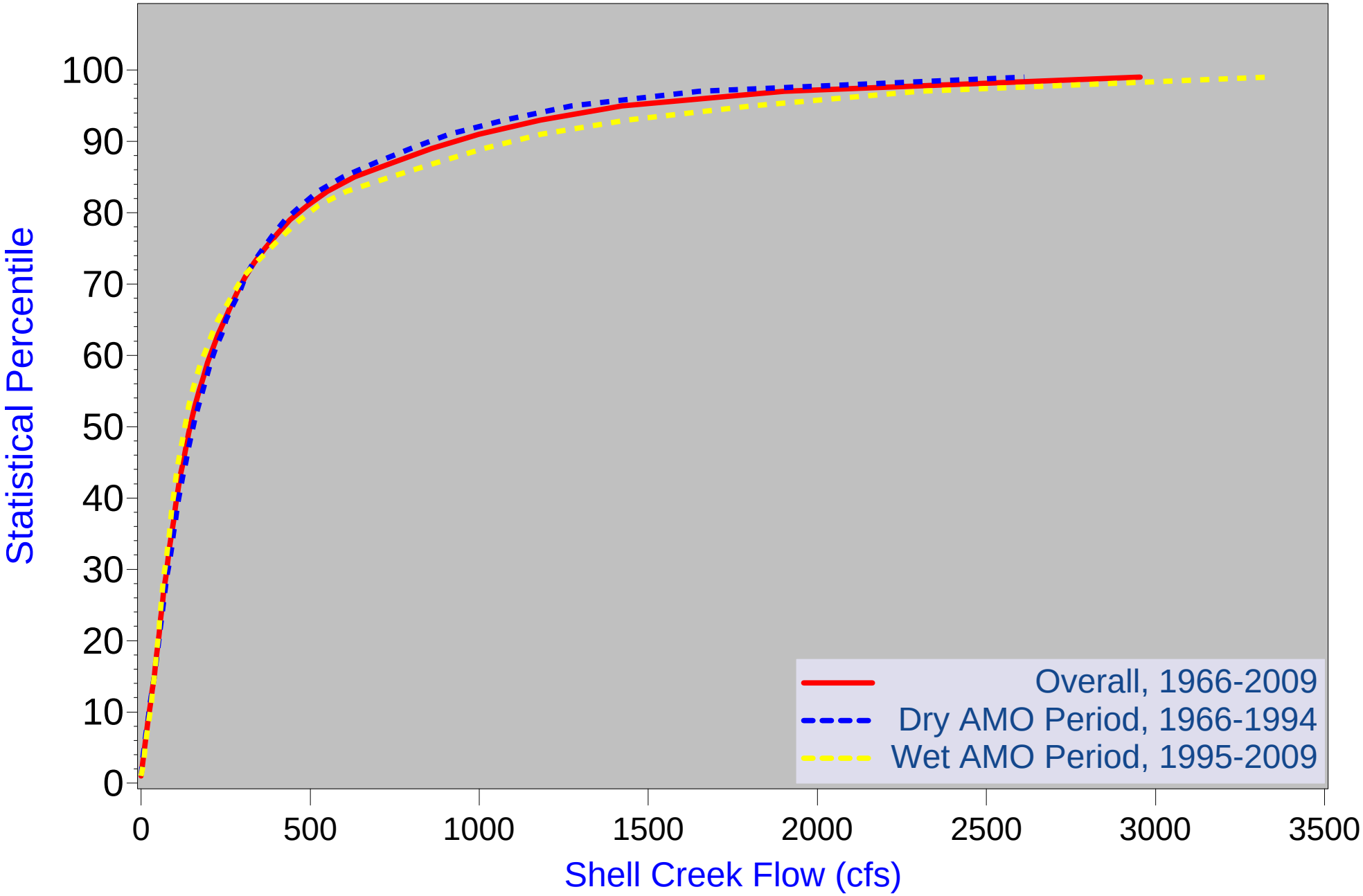


Figure 3.87b Differences in CDFs among AMO periods in estimated Shell Creek flow
All seasons combined

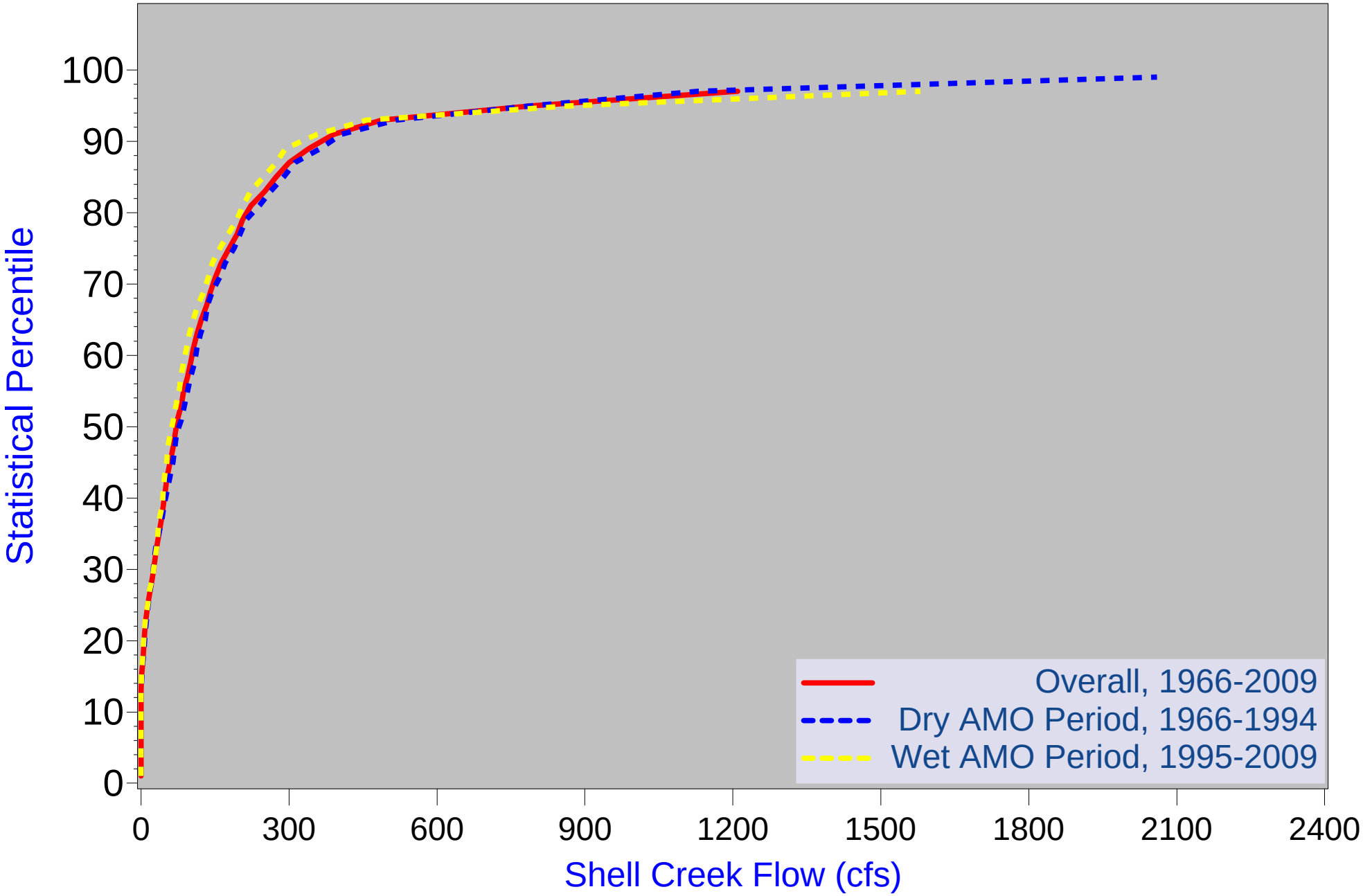


Figure 3.88a Differences in CDFs among AMO periods in Shell Creek gage flow (USGS #2298202) Spring dry-season (District Block 1 - April 20th through June 25th)

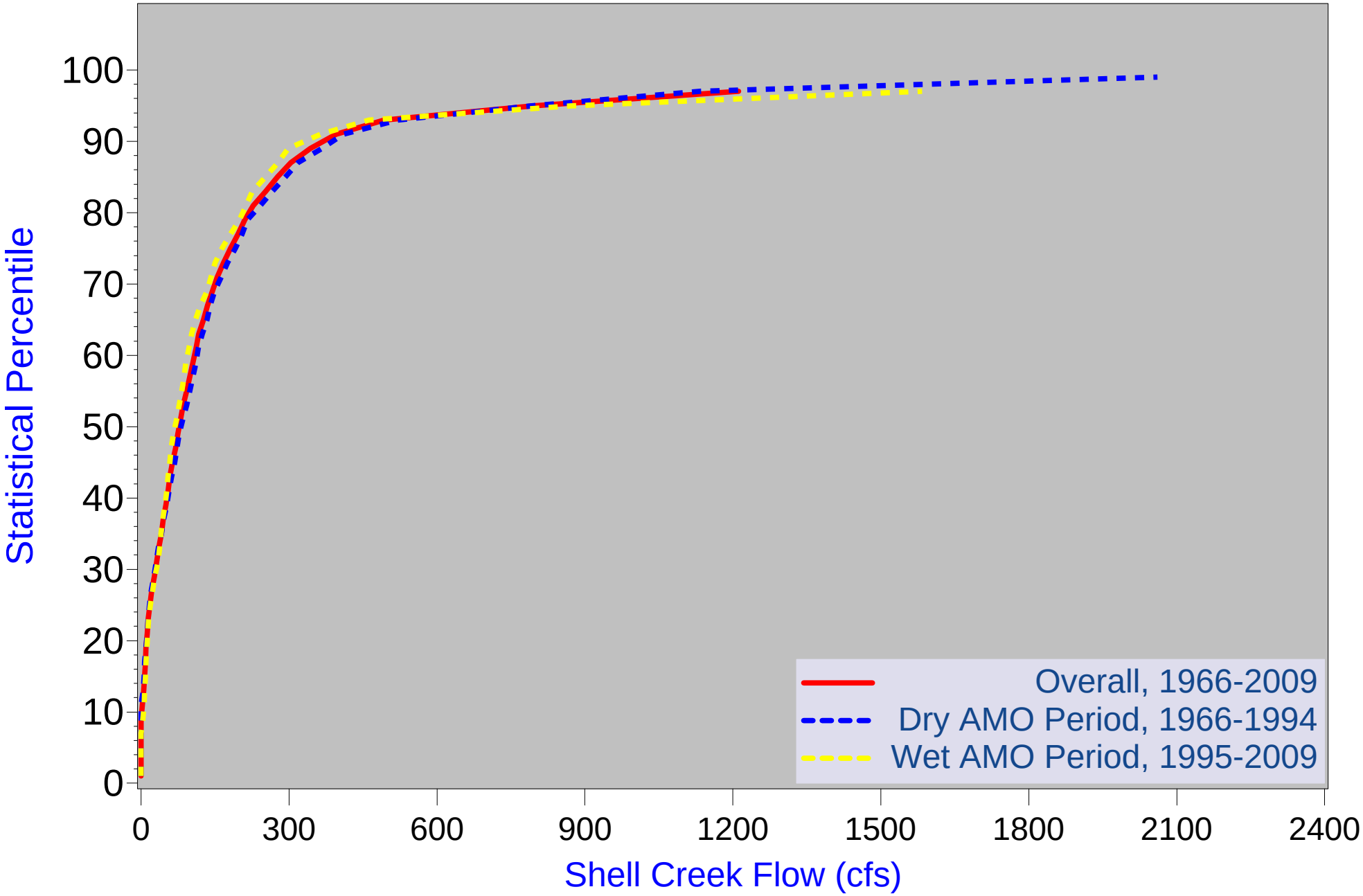


Figure 3.88b Differences in CDFs among AMO periods in estimated Shell Creek flow
Spring dry-season (District Block 1 - April 20th through June 25th)

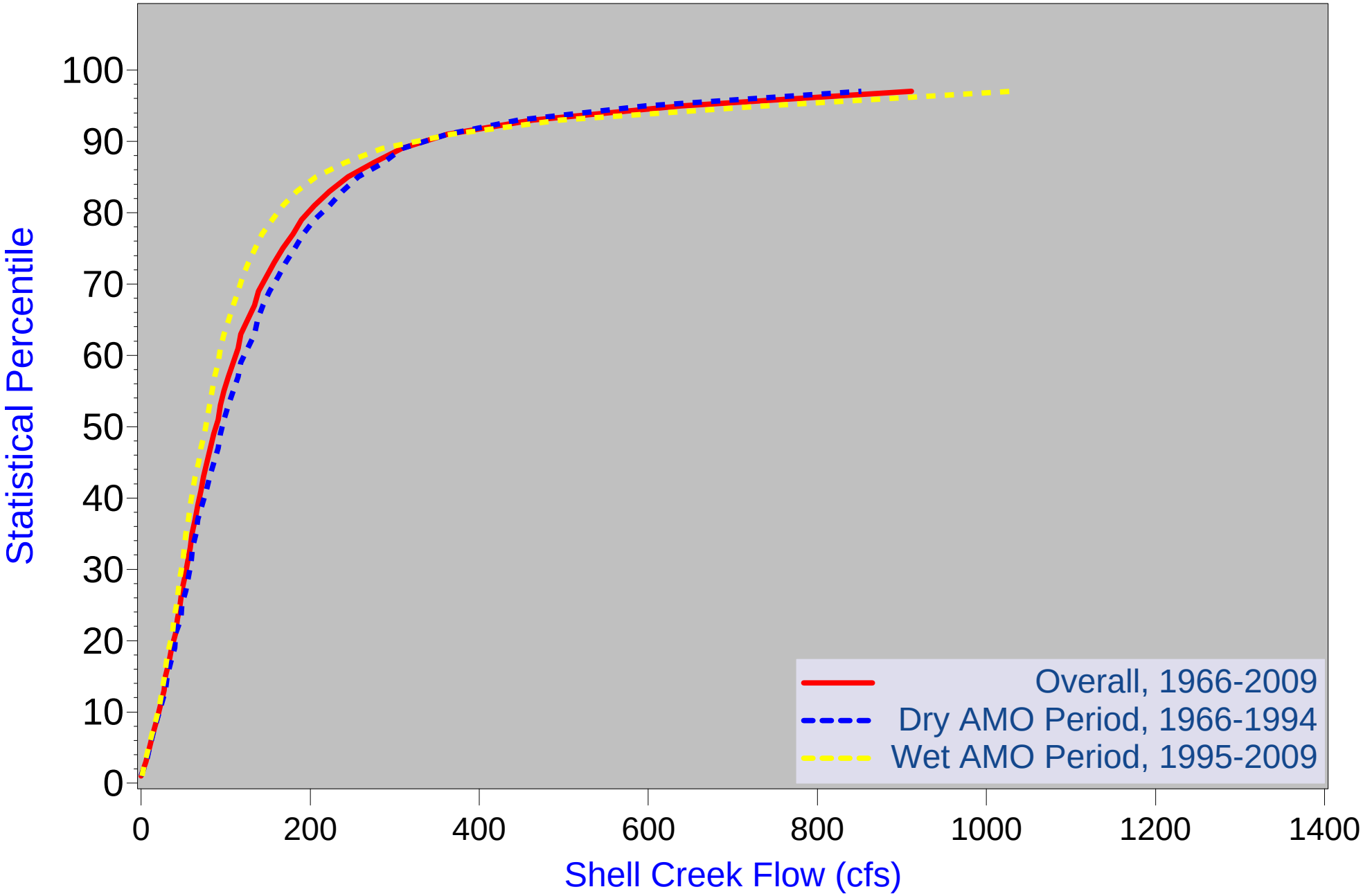


Figure 3.89a Differences in CDFs among AMO periods in Shell Creek gage flow (USGS #2298202)
Summer wet-season (District Block 3 - June 26th through October 26th)

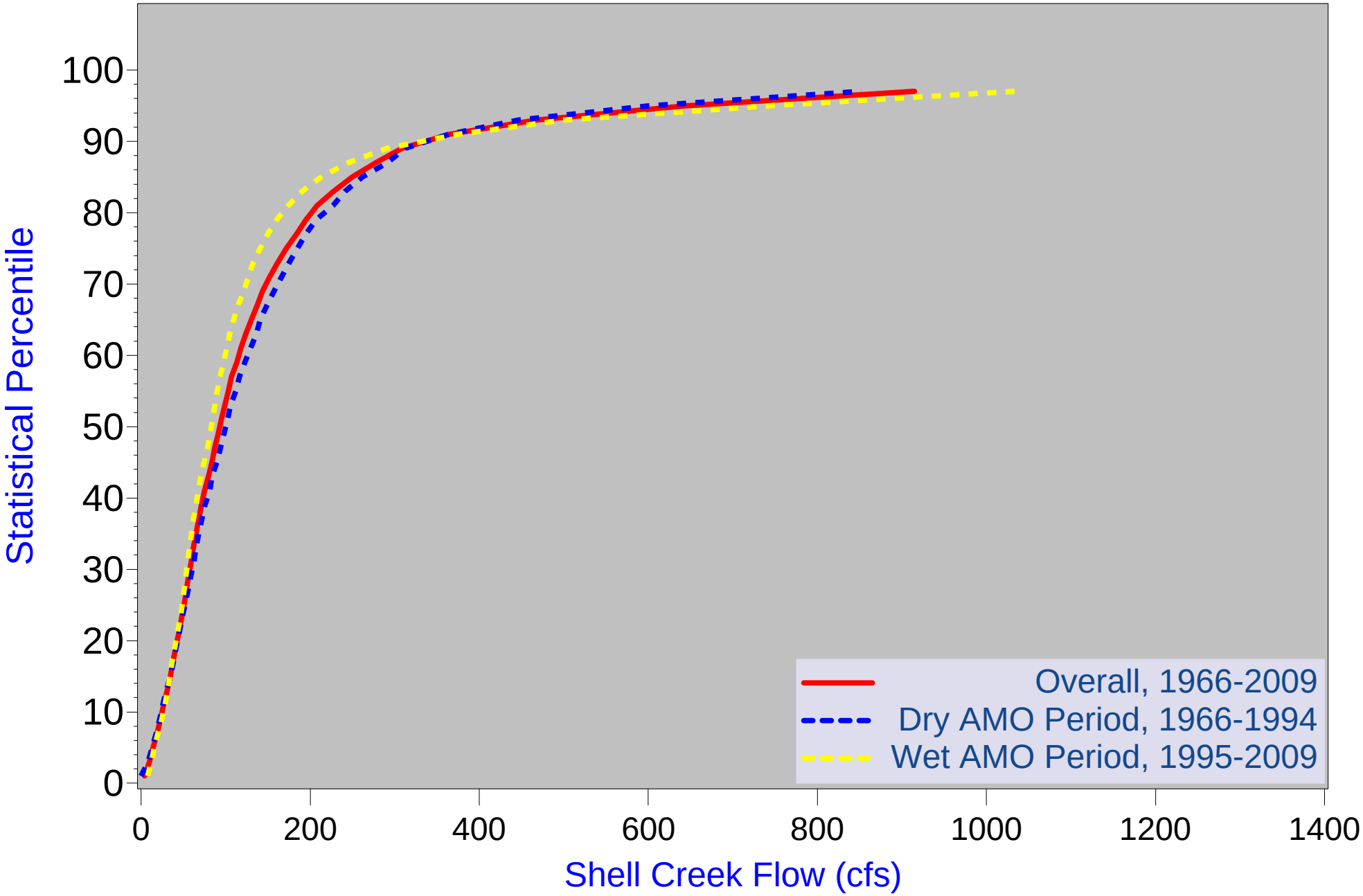


Figure 3.89b Differences in CDFs among AMO periods in estimated Shell Creek flow
Summer wet-season (District Block 3 - June 26th through October 26th)

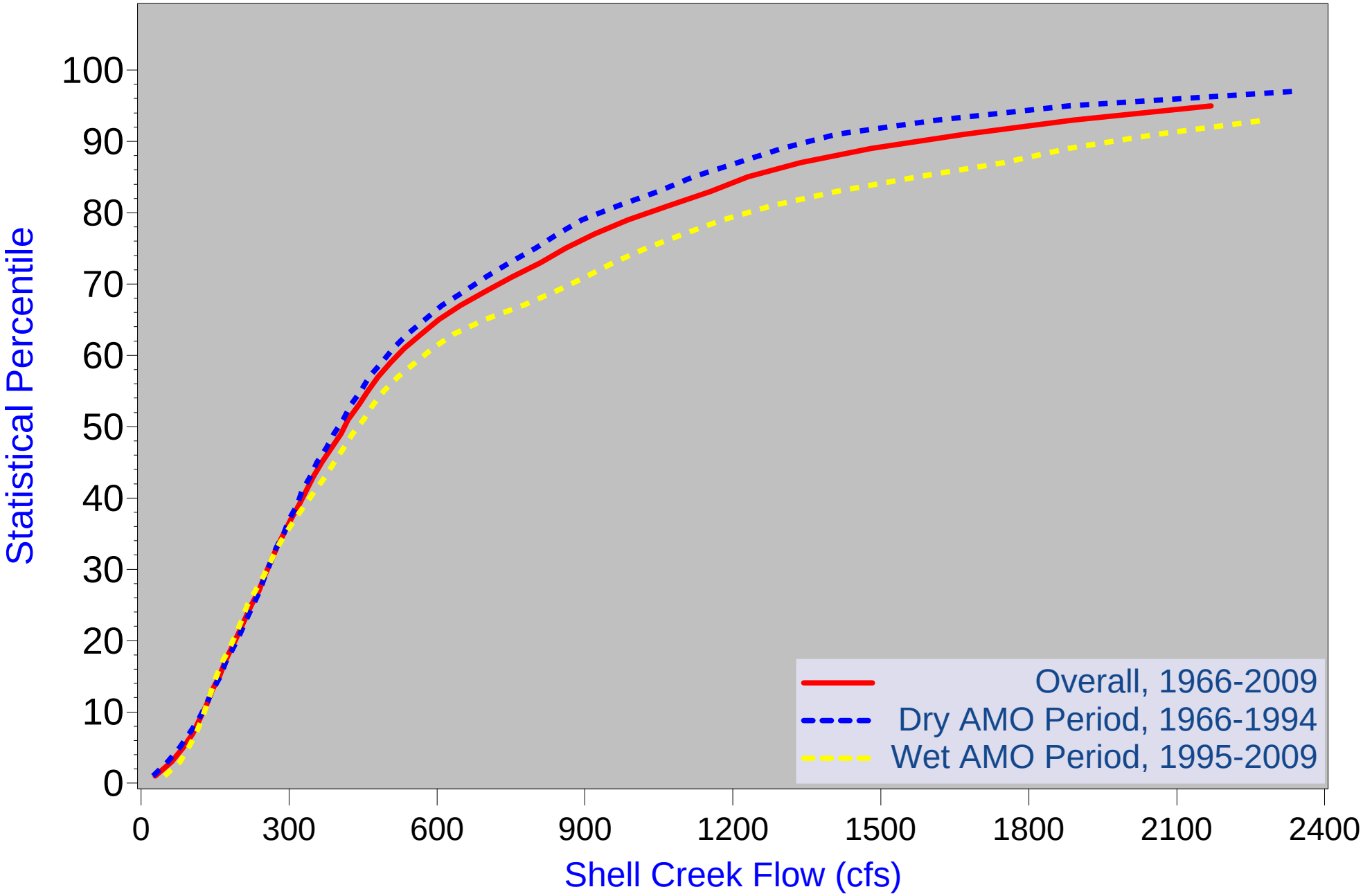


Figure 3.90a Differences in CDFs among AMO periods in Shell Creek gage flow (USGS #2298202) Fall/Winter/Spring season (District Block 2 - October 27th through April 19th)

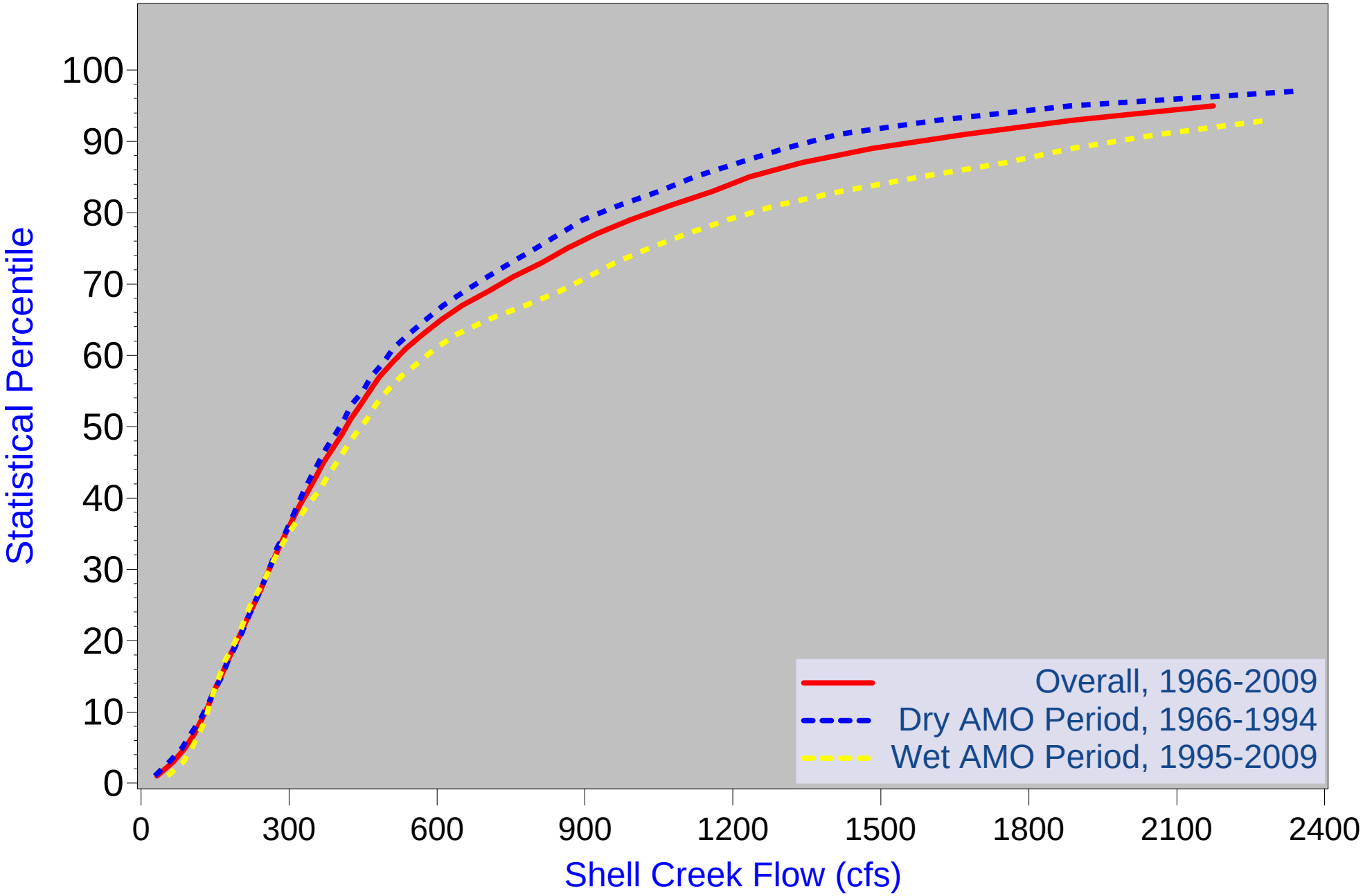


Figure 3.90b Differences in CDFs among AMO periods in estimated Shell Creek flow Fall/Winter/Spring season (District Block 2 - October 27th through April 19th)

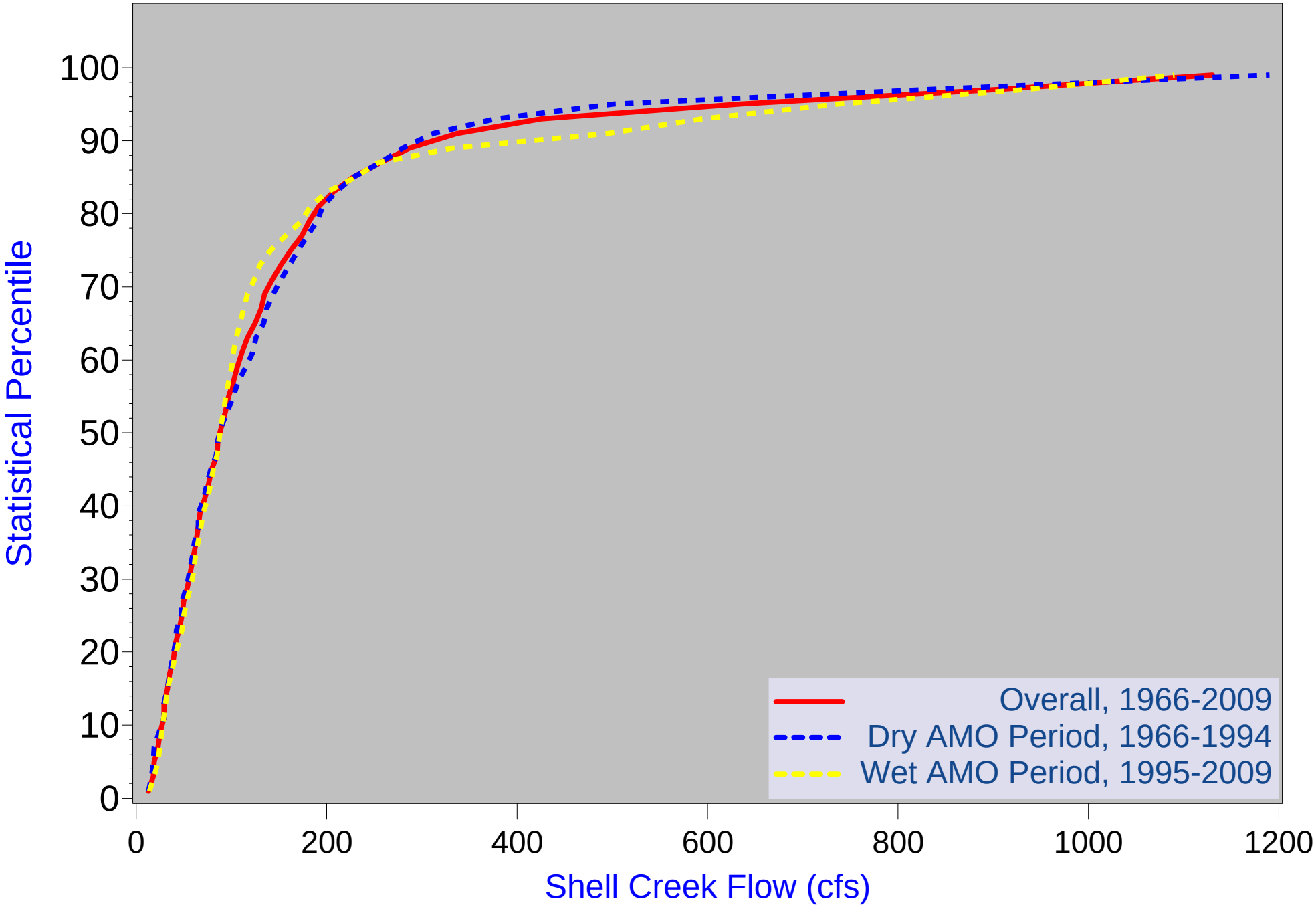


Figure 3.91a January differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

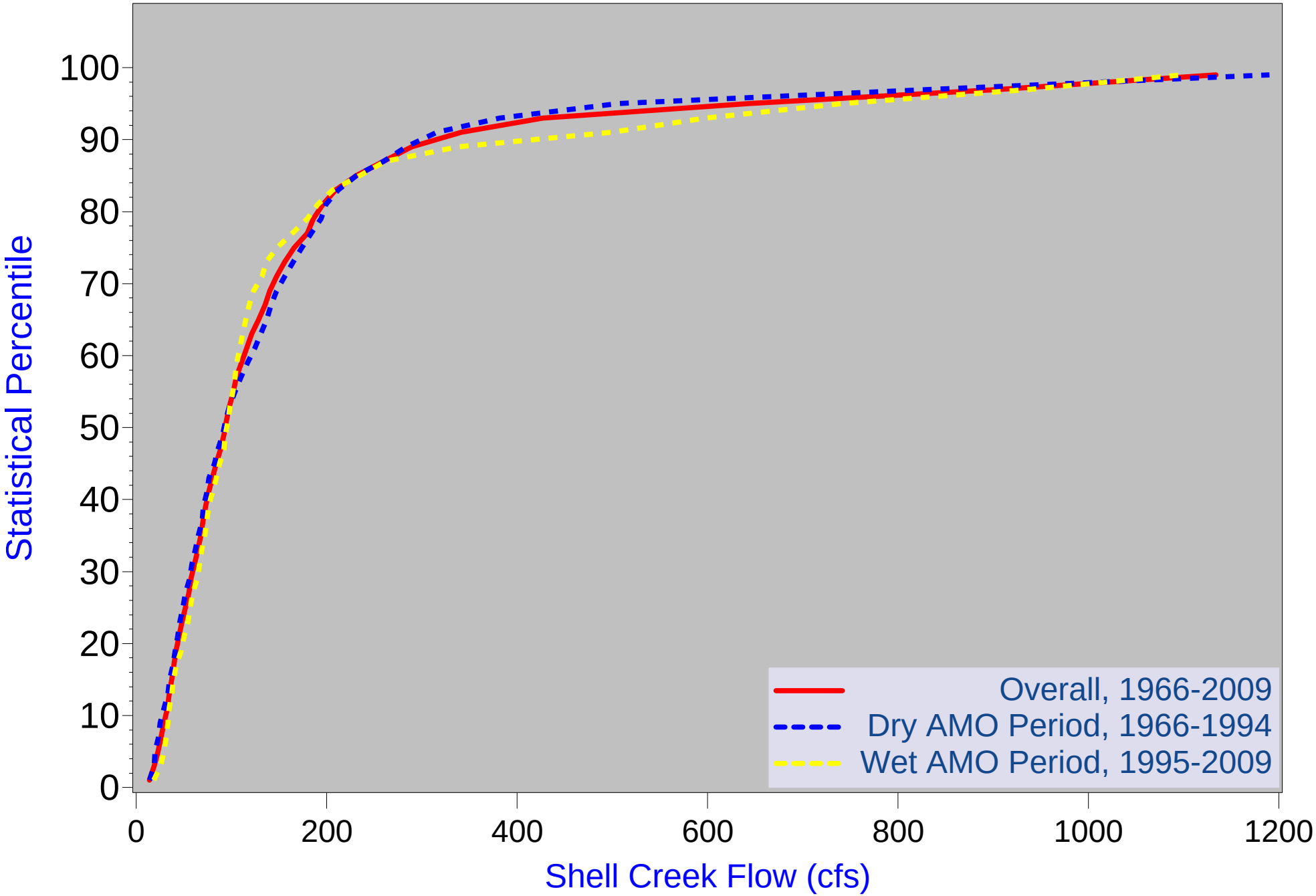


Figure 3.91b8 January differences in CDFs among AMO periods in estimated flow without withdrawals

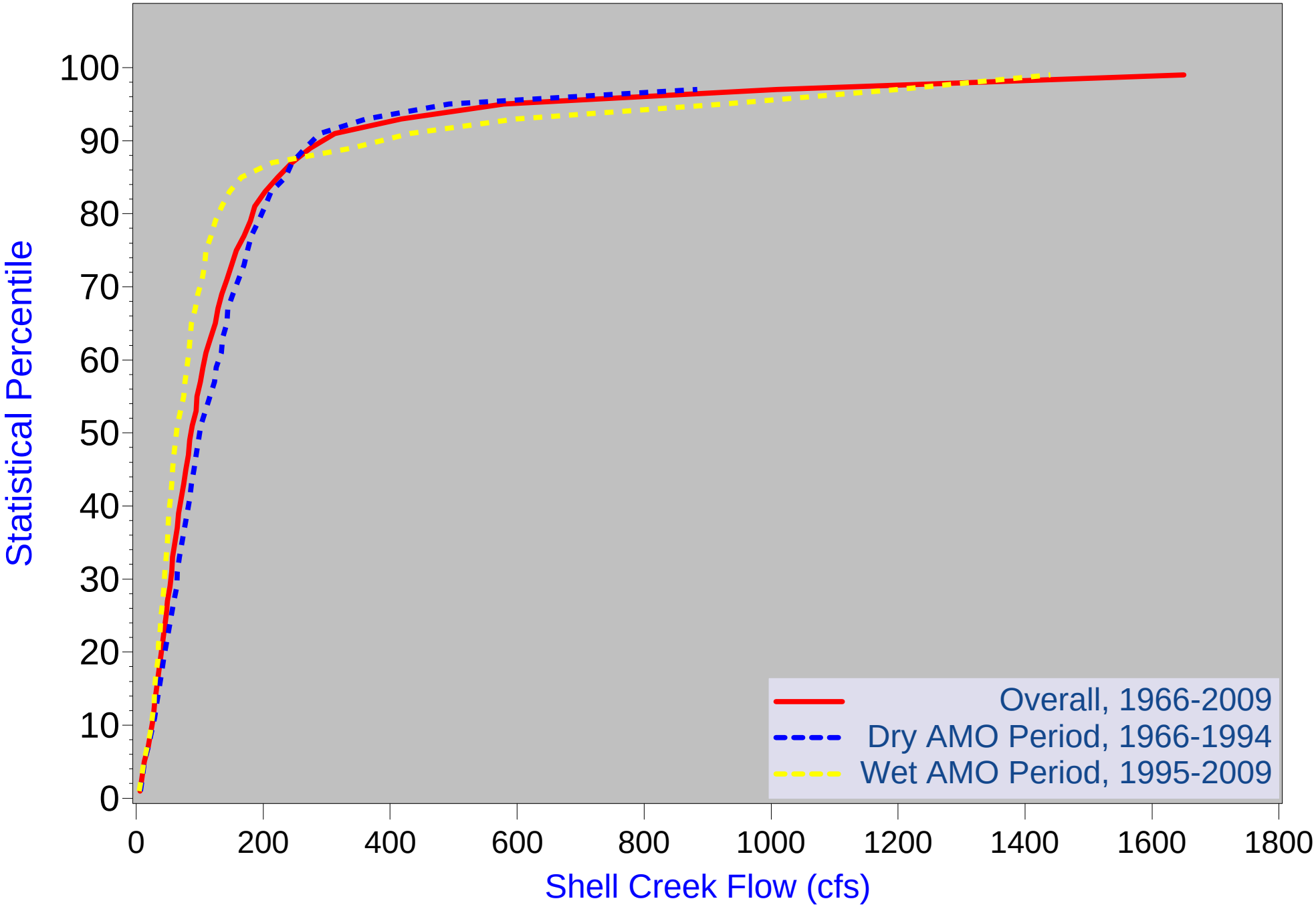


Figure 3.92a February differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

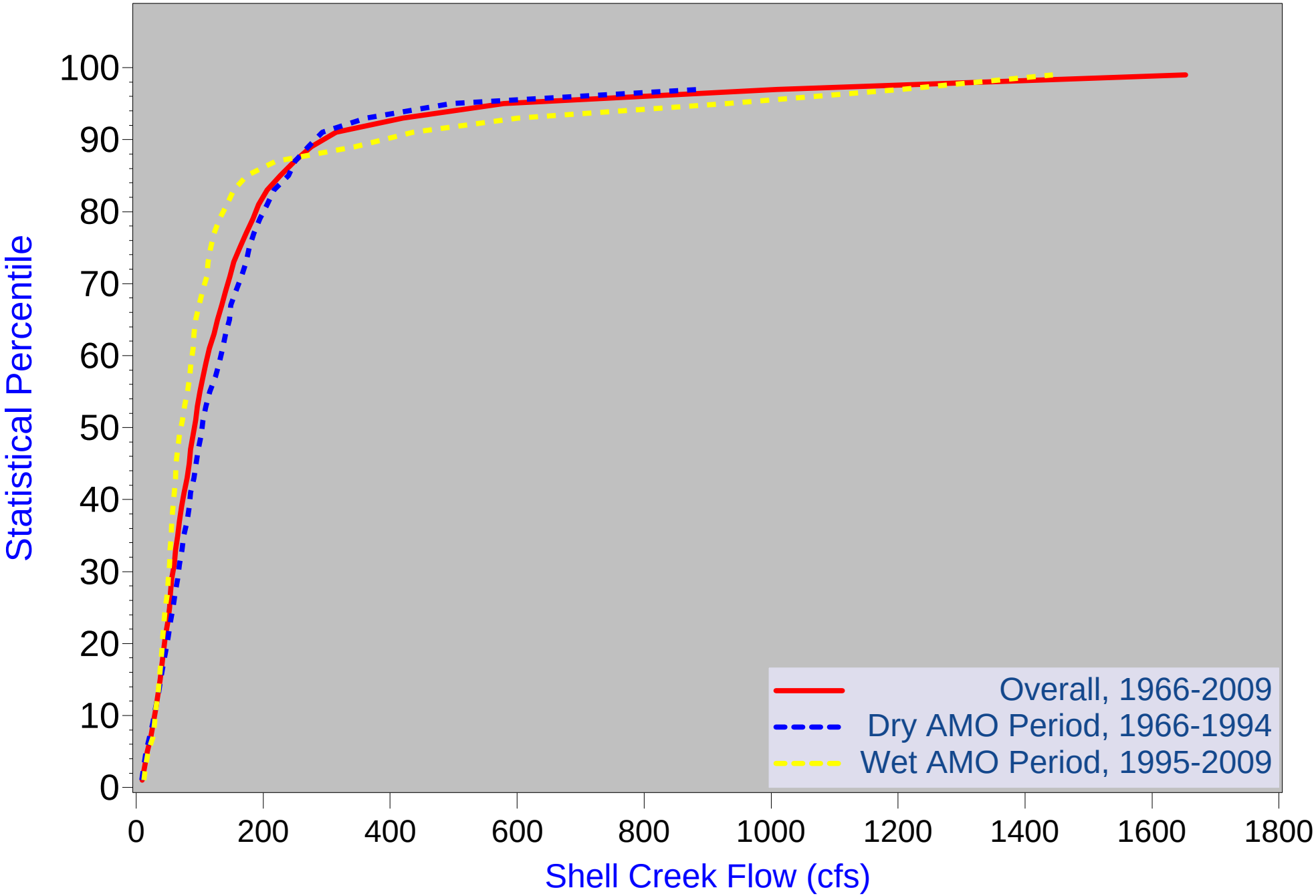


Figure 3.92b February differences in CDFs among AMO periods in estimated flow without withdrawals

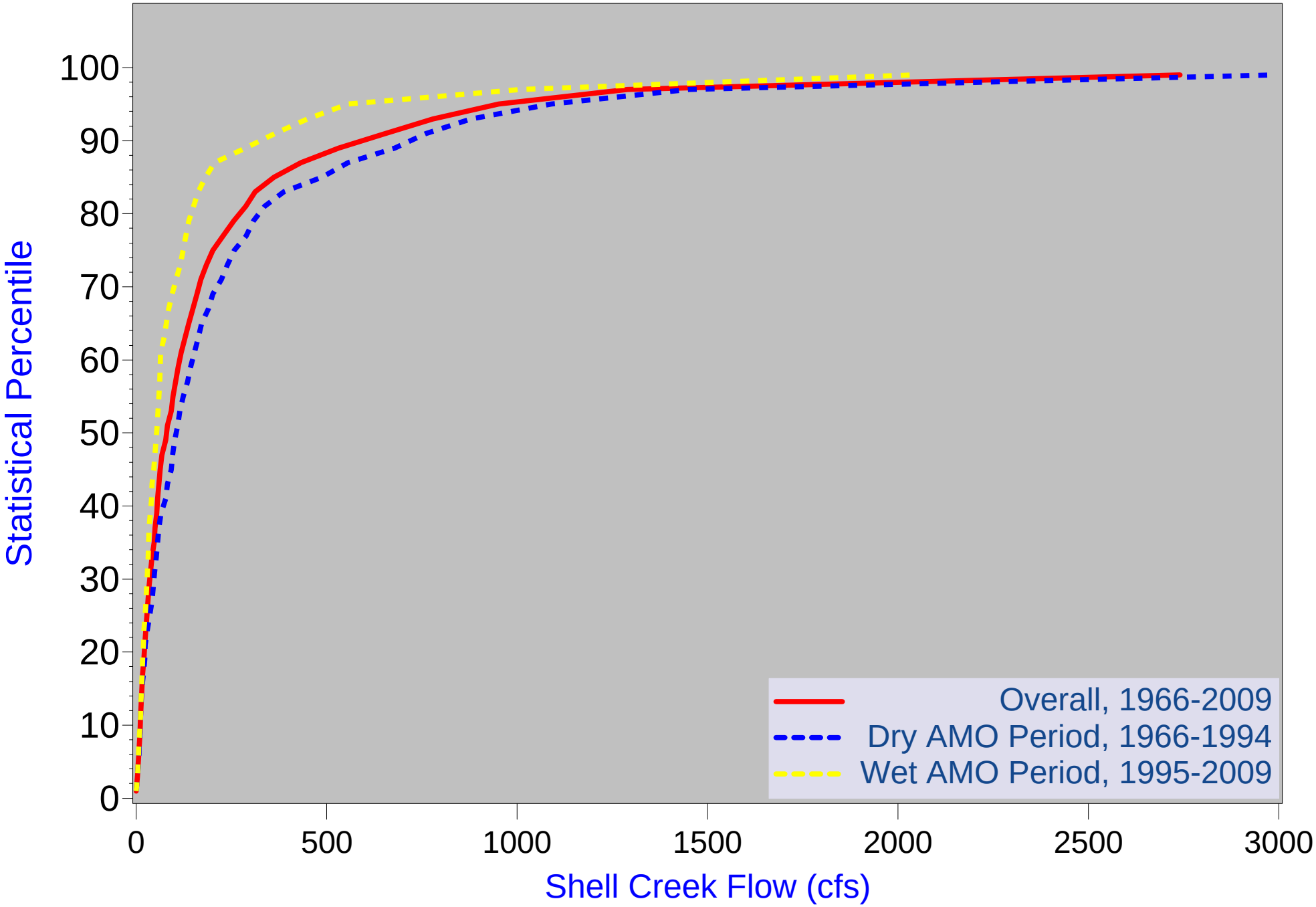


Figure 3.93a March differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

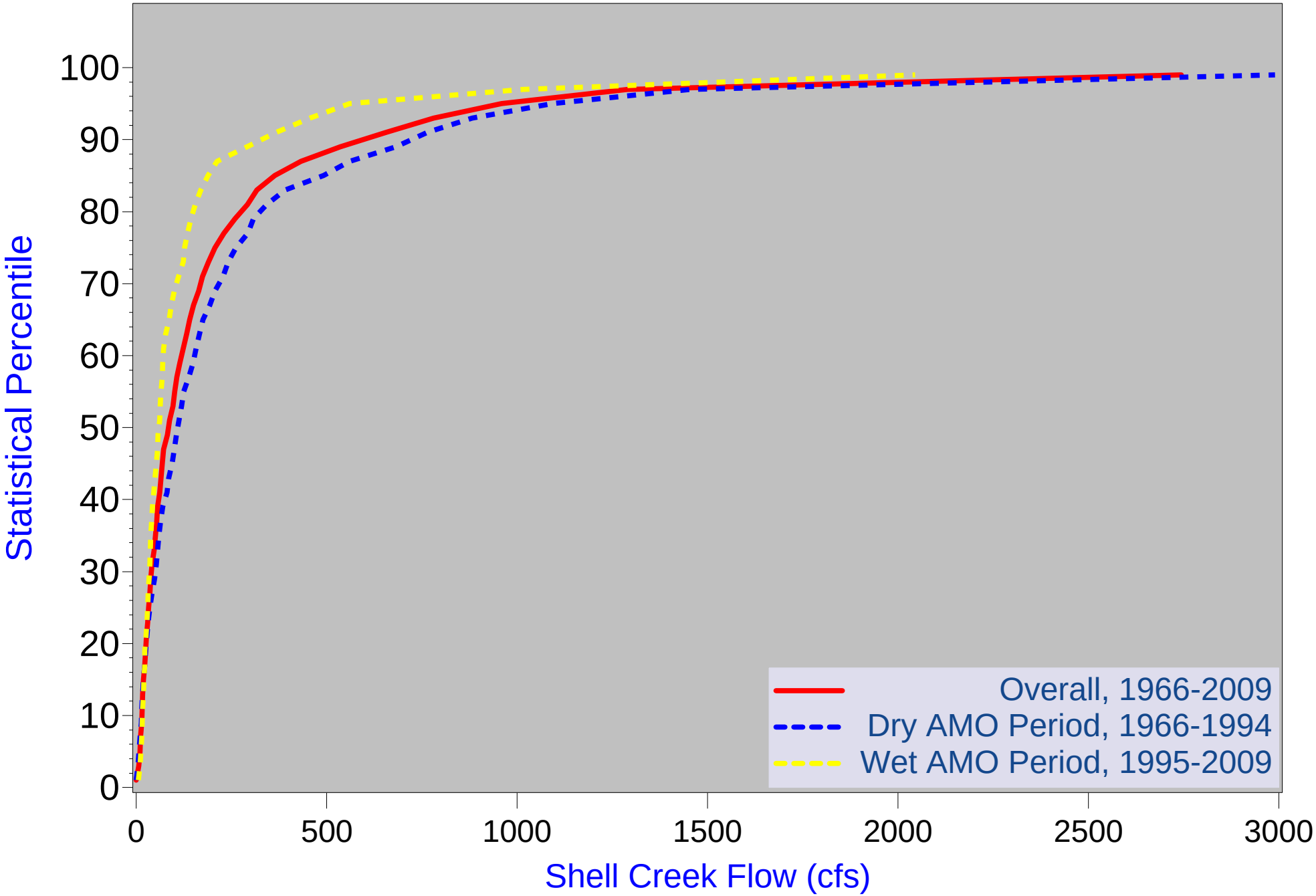


Figure 3.93b March differences in CDFs among AMO periods in estimated flow without withdrawals

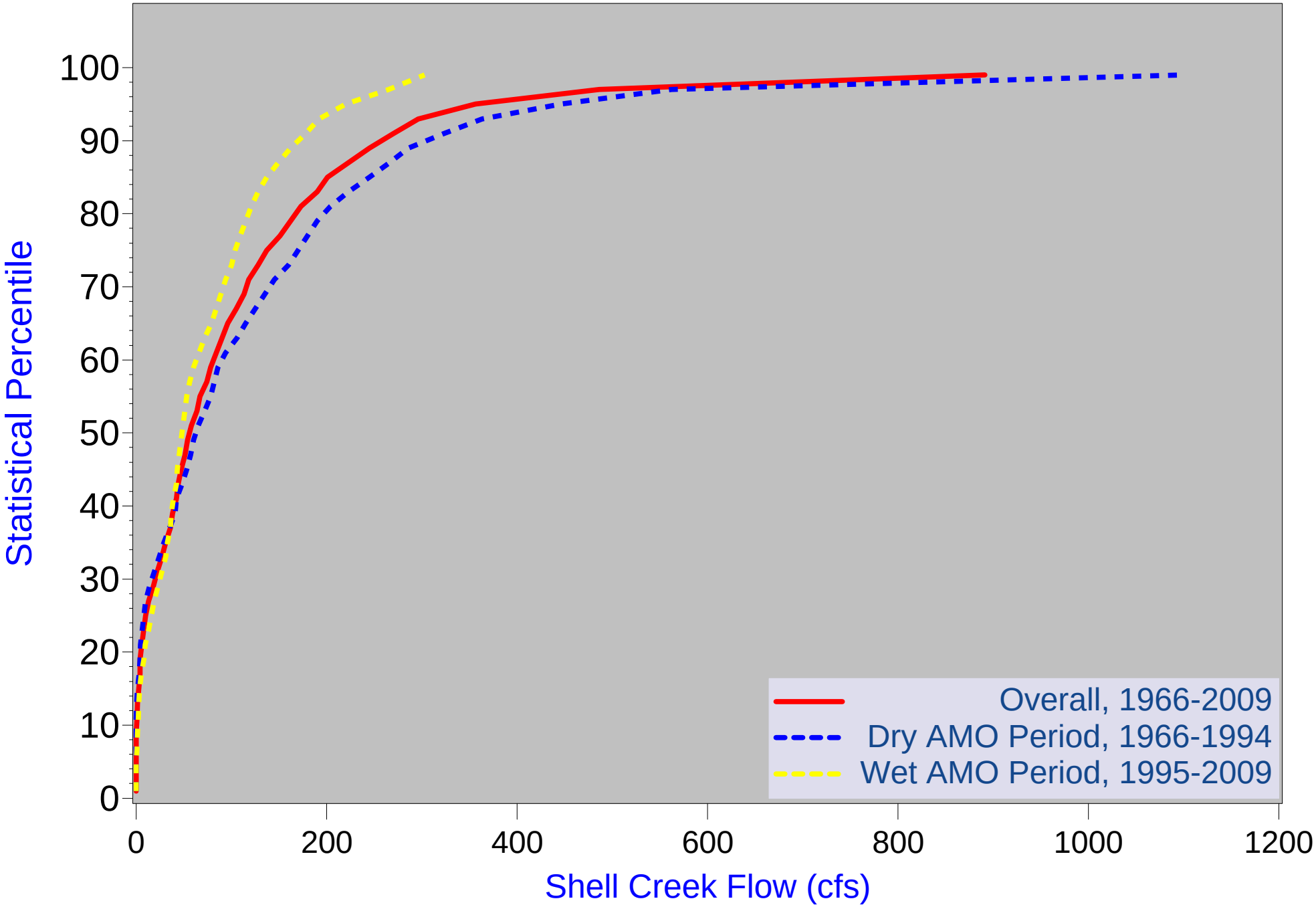


Figure 3.94a April differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

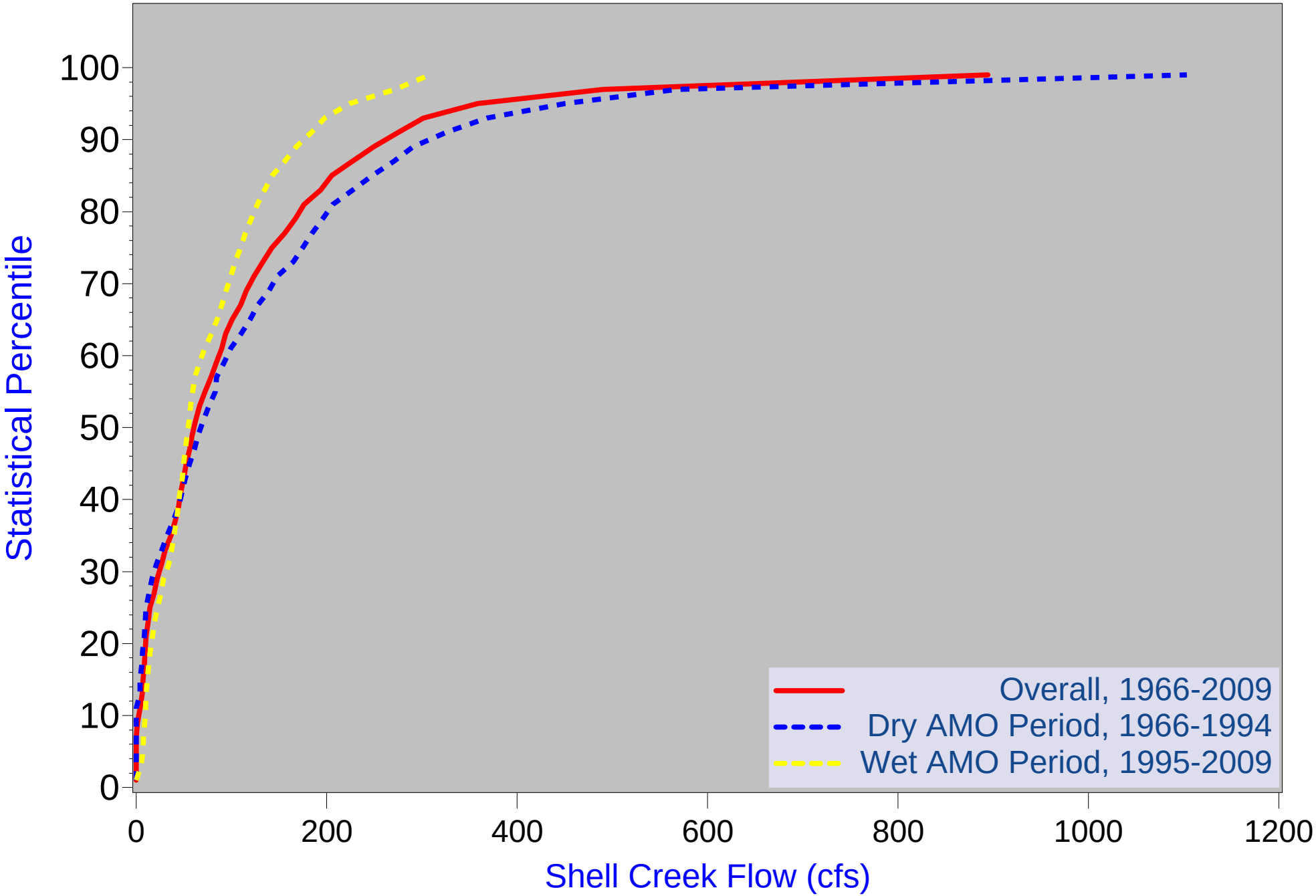


Figure 3.94b April differences in CDFs among AMO periods in estimated flow without withdrawals

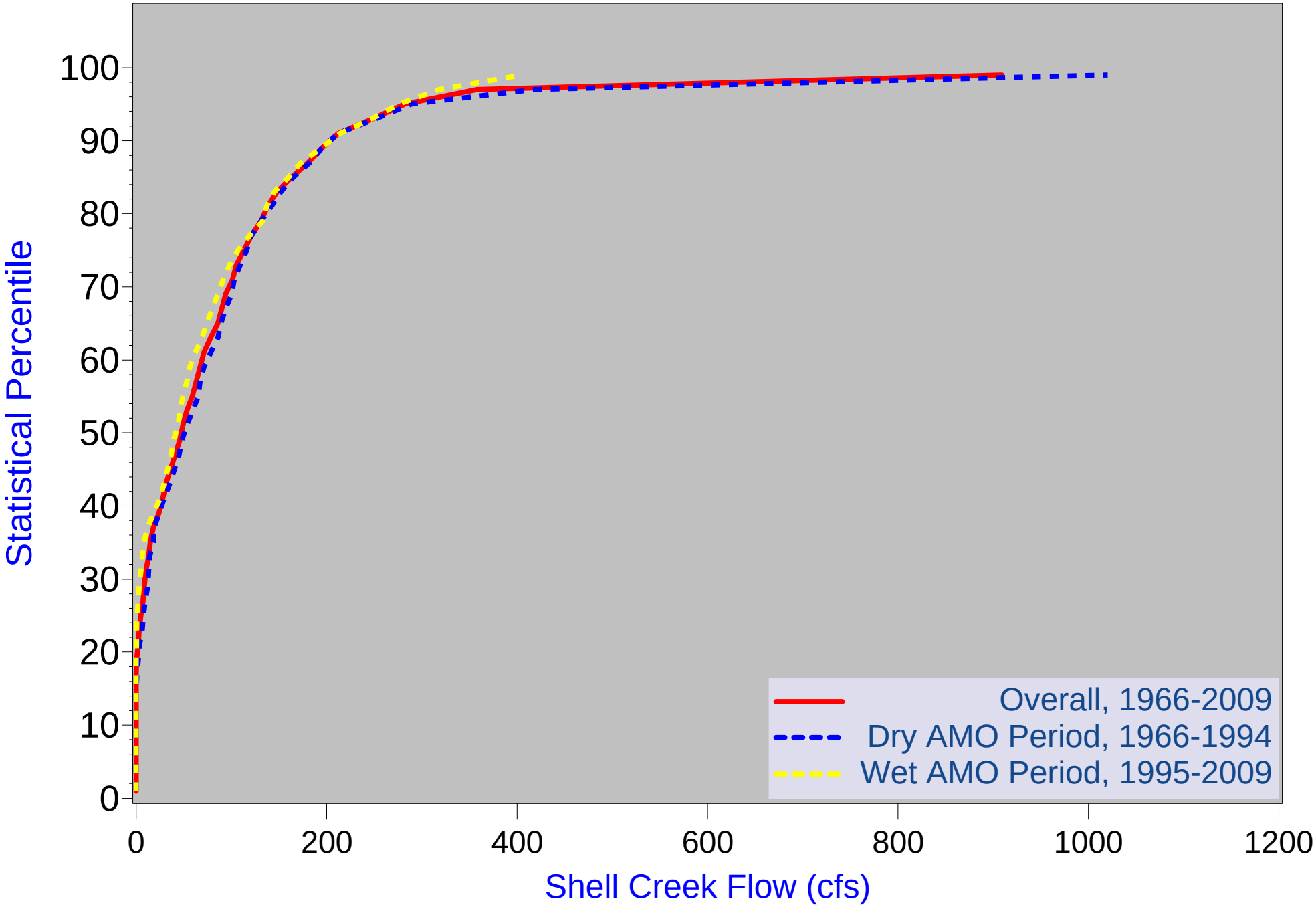


Figure 3.95a May differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

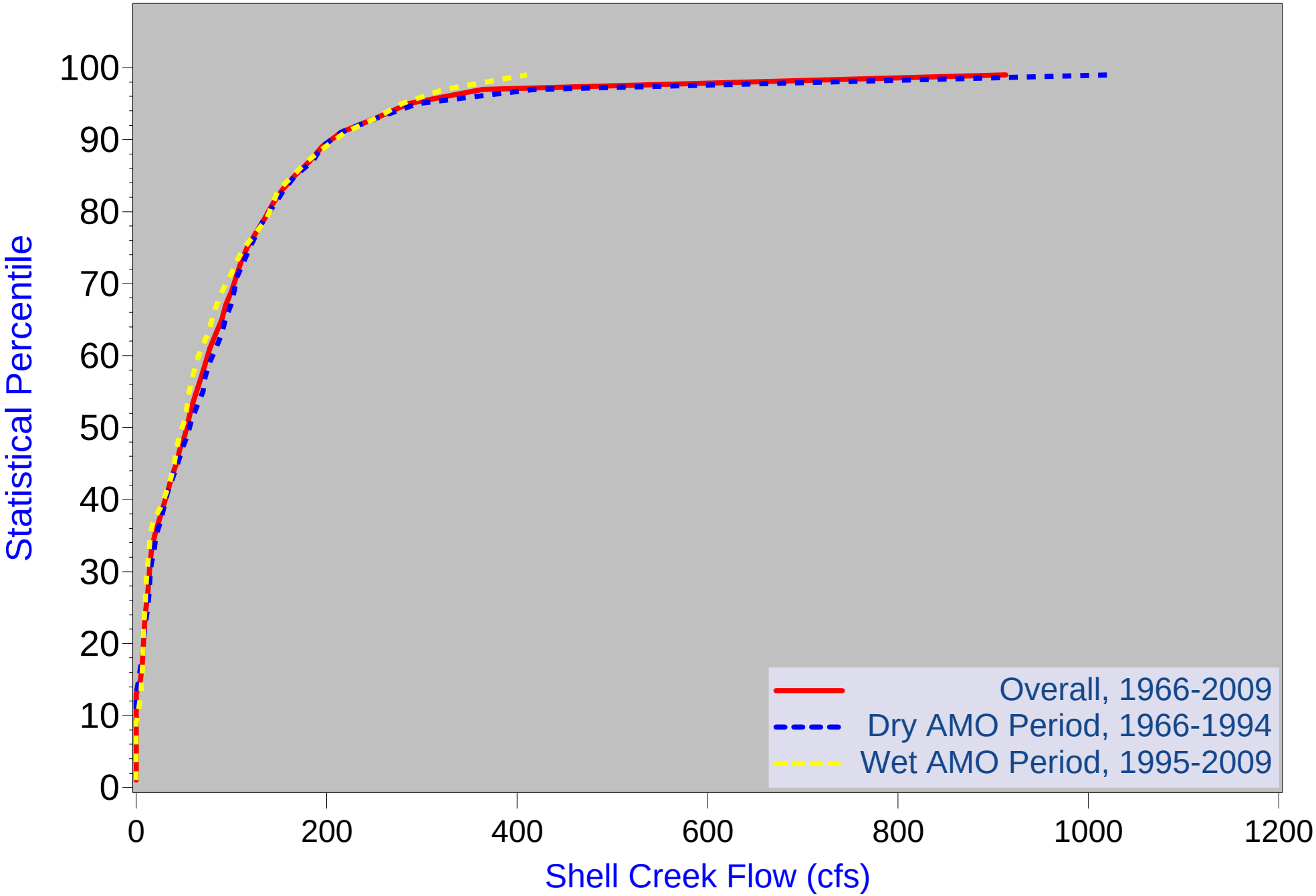


Figure 3.95b May differences in CDFs among AMO periods in estimated flow without withdrawals

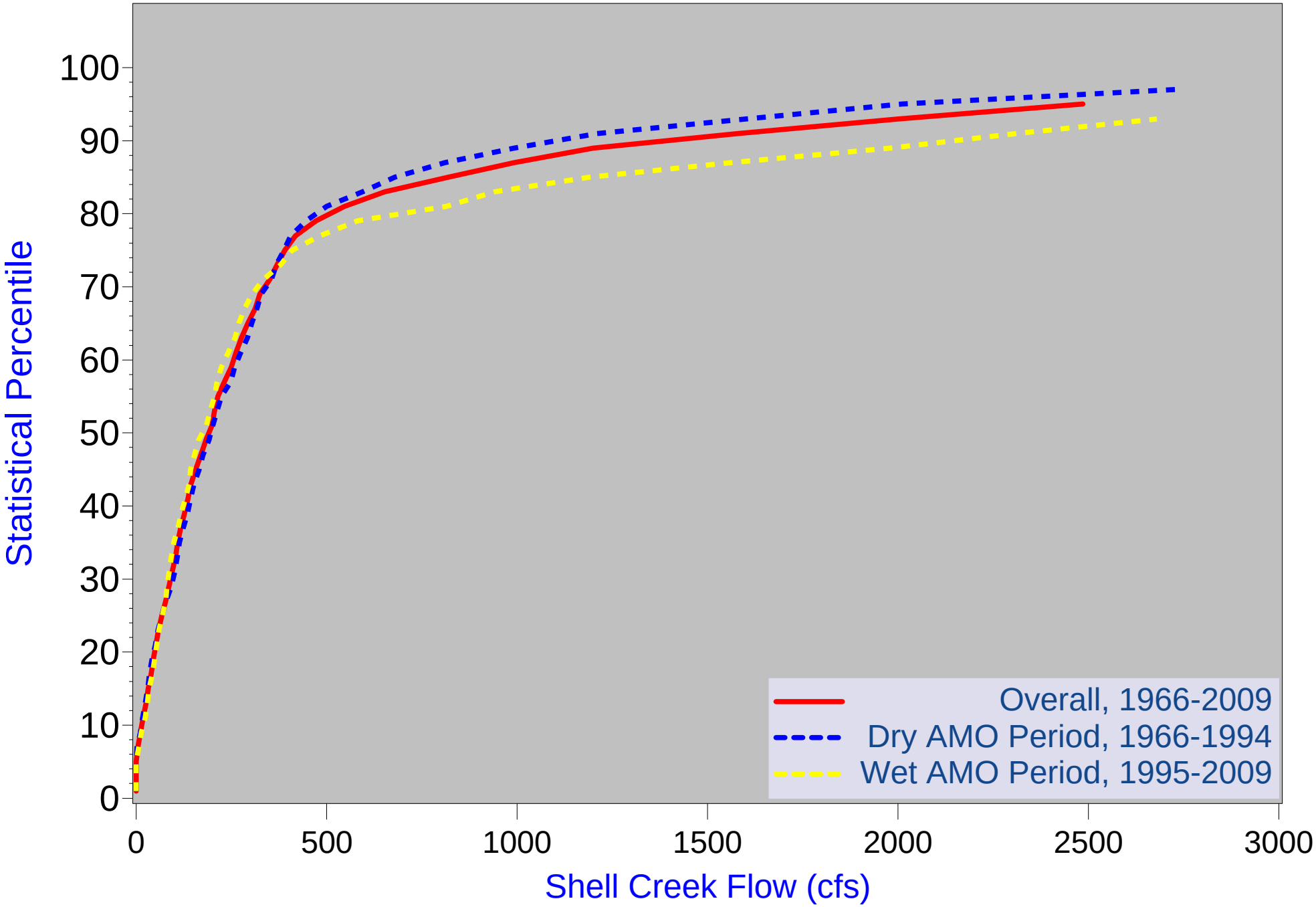


Figure 3.96a June differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

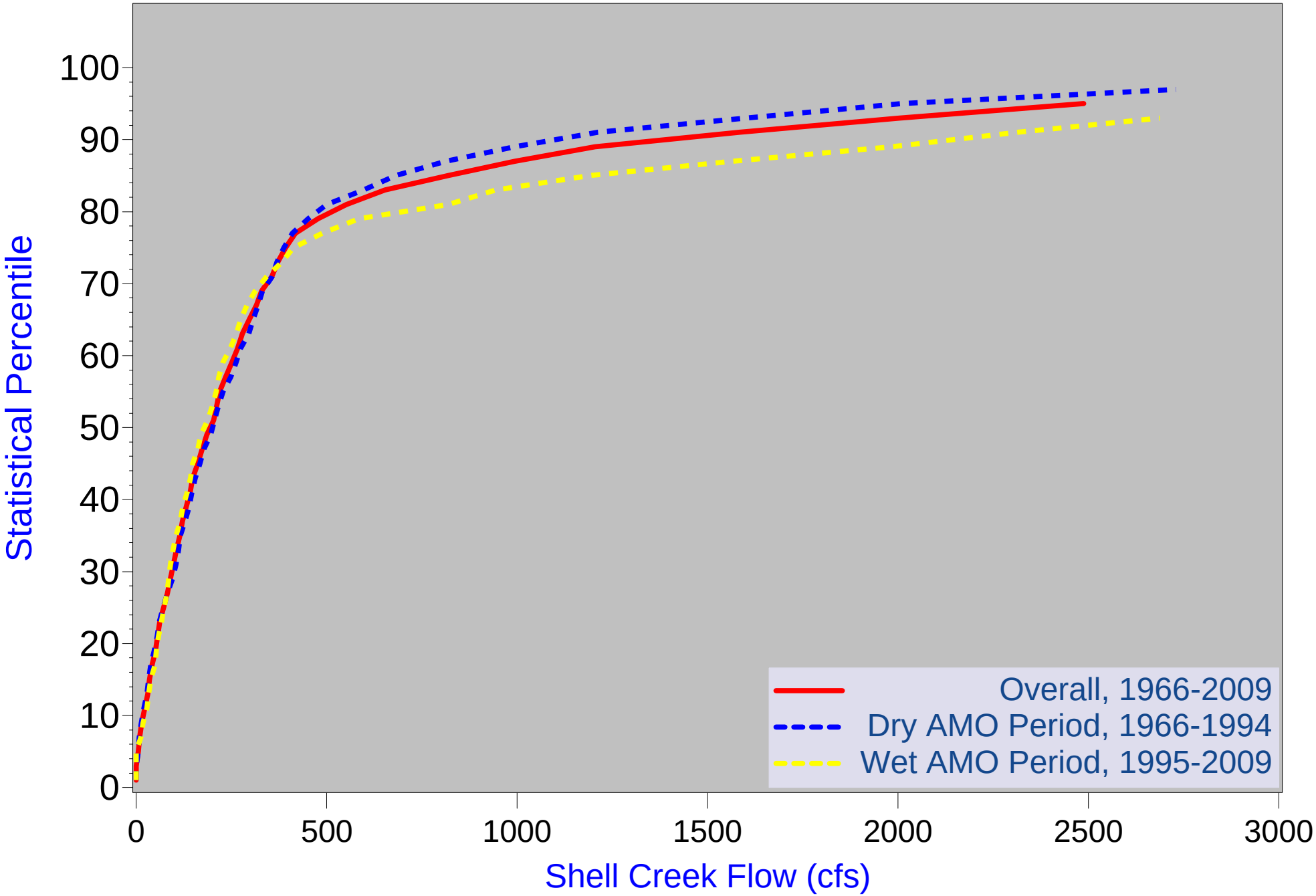


Figure 3.96b June differences in CDFs among AMO periods in estimated flow without withdrawals

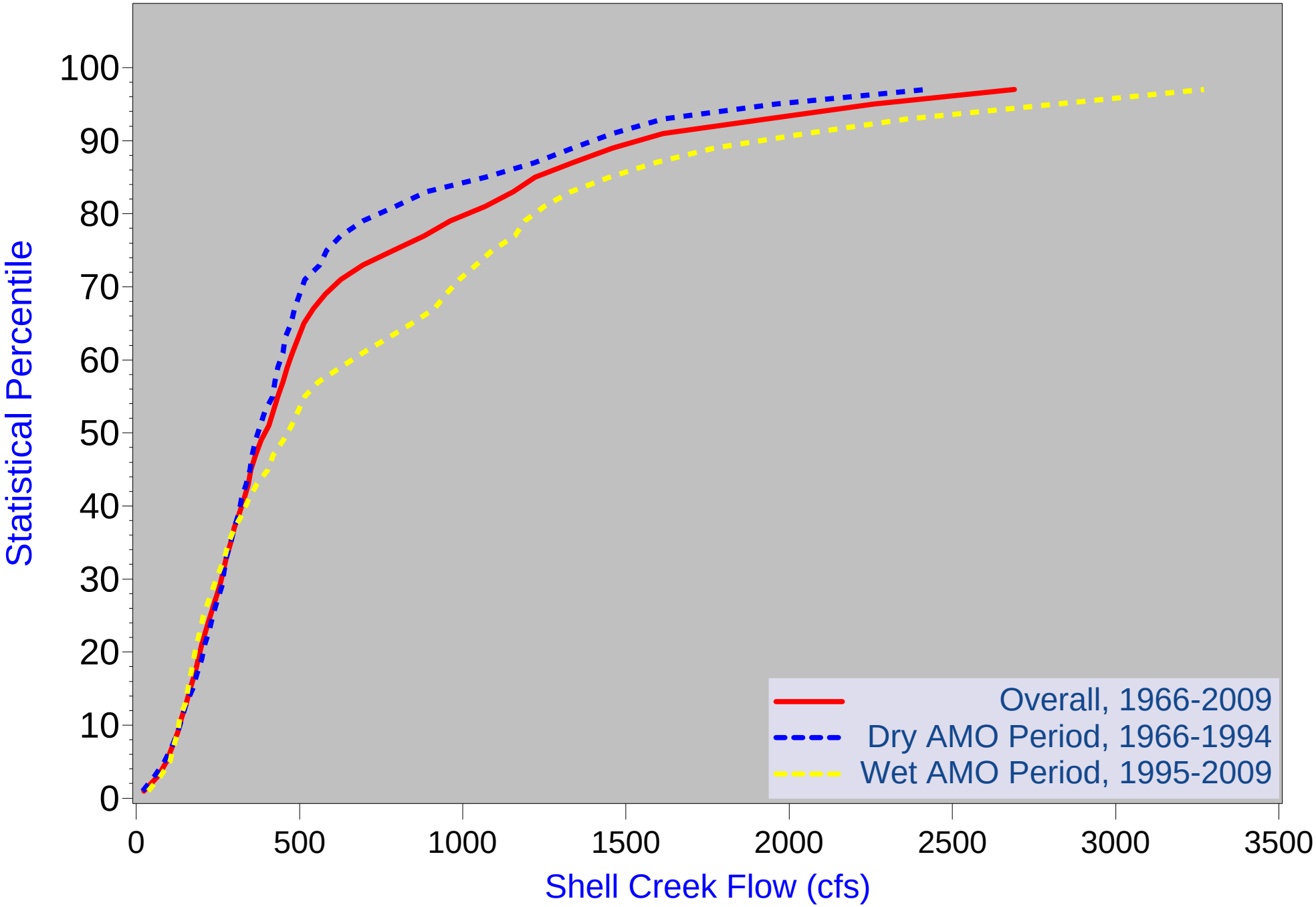


Figure 3.97a July differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

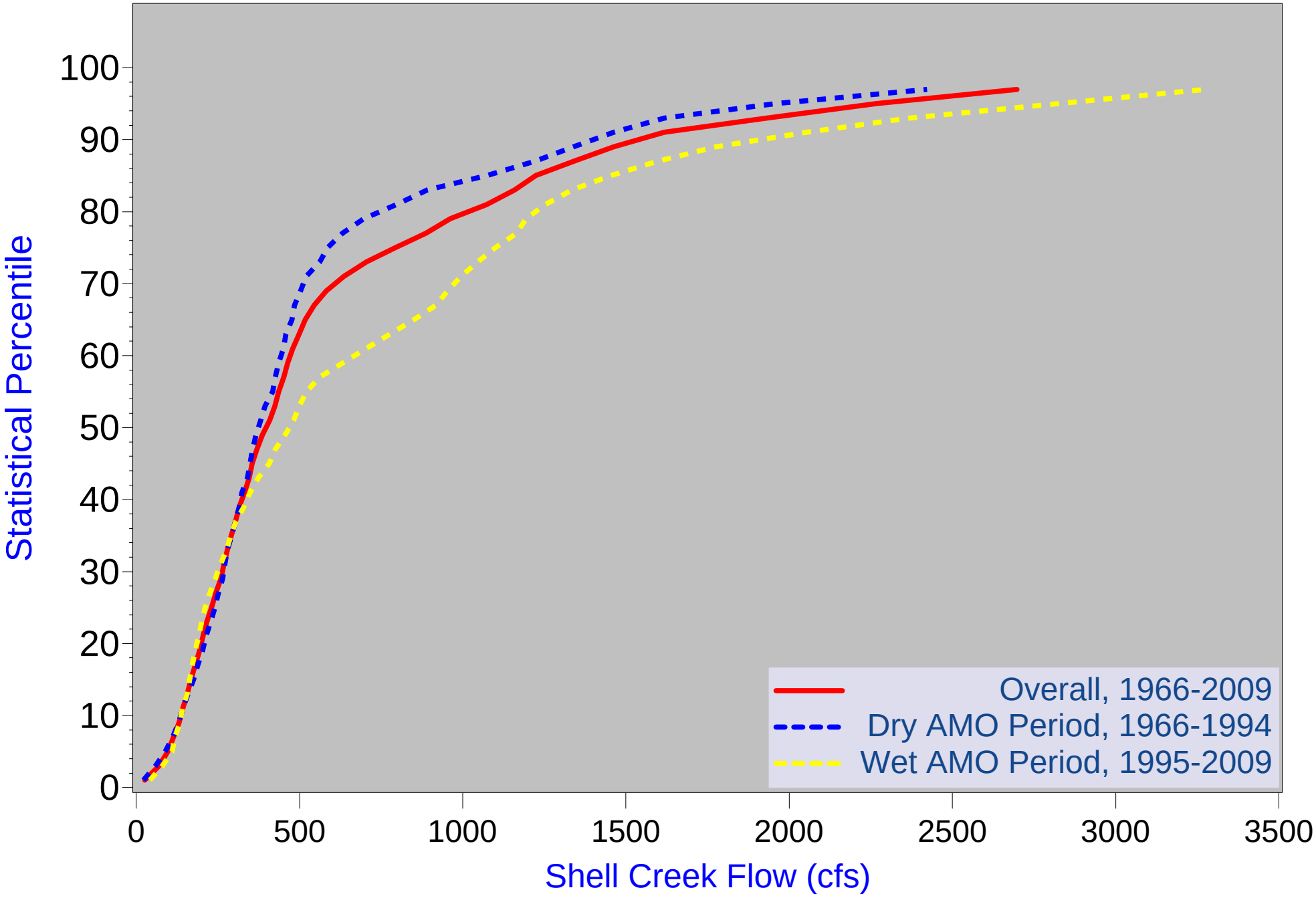


Figure 3.97b July differences in CDFs among AMO periods in estimated flow without withdrawals

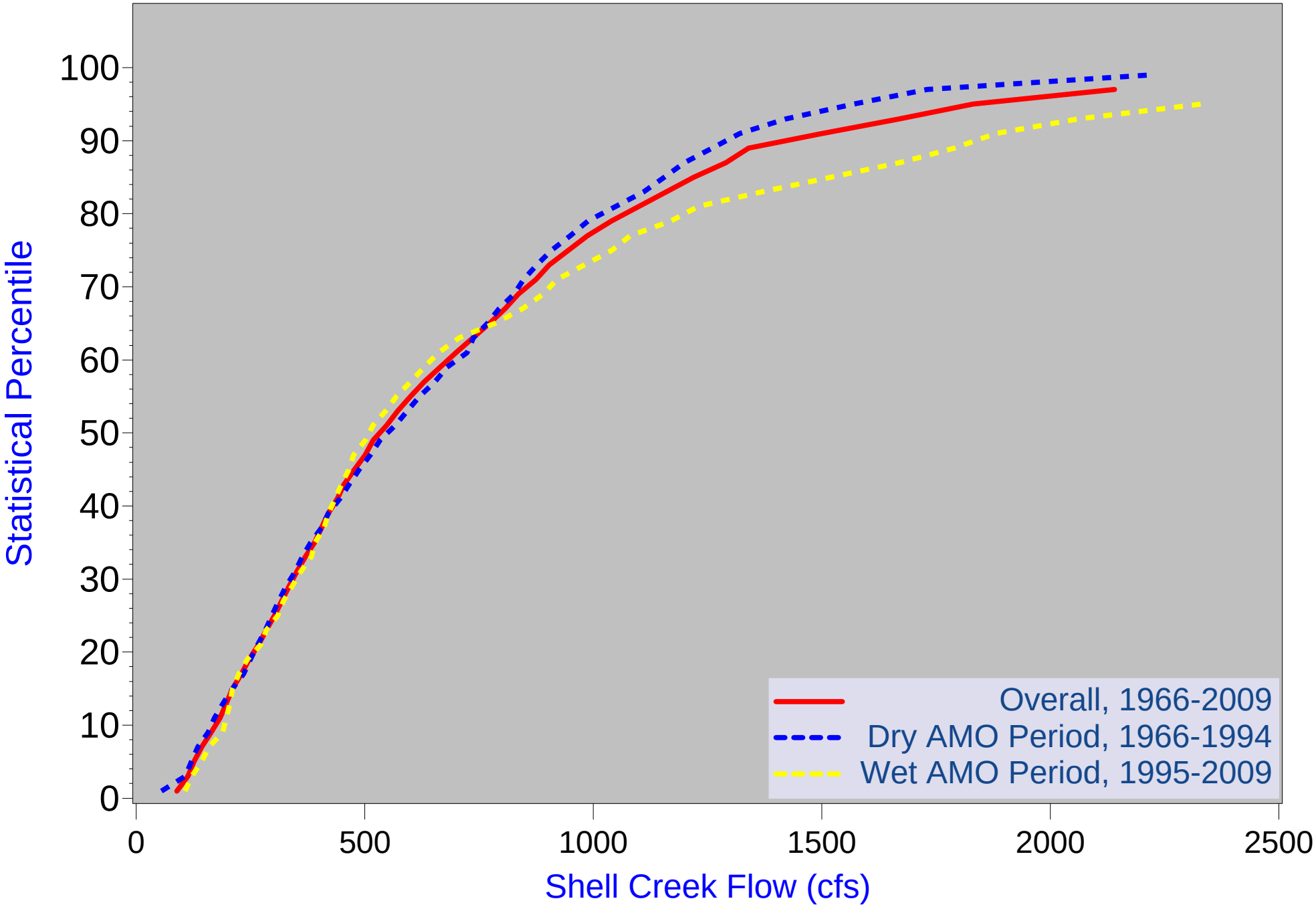


Figure 3.98a August differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

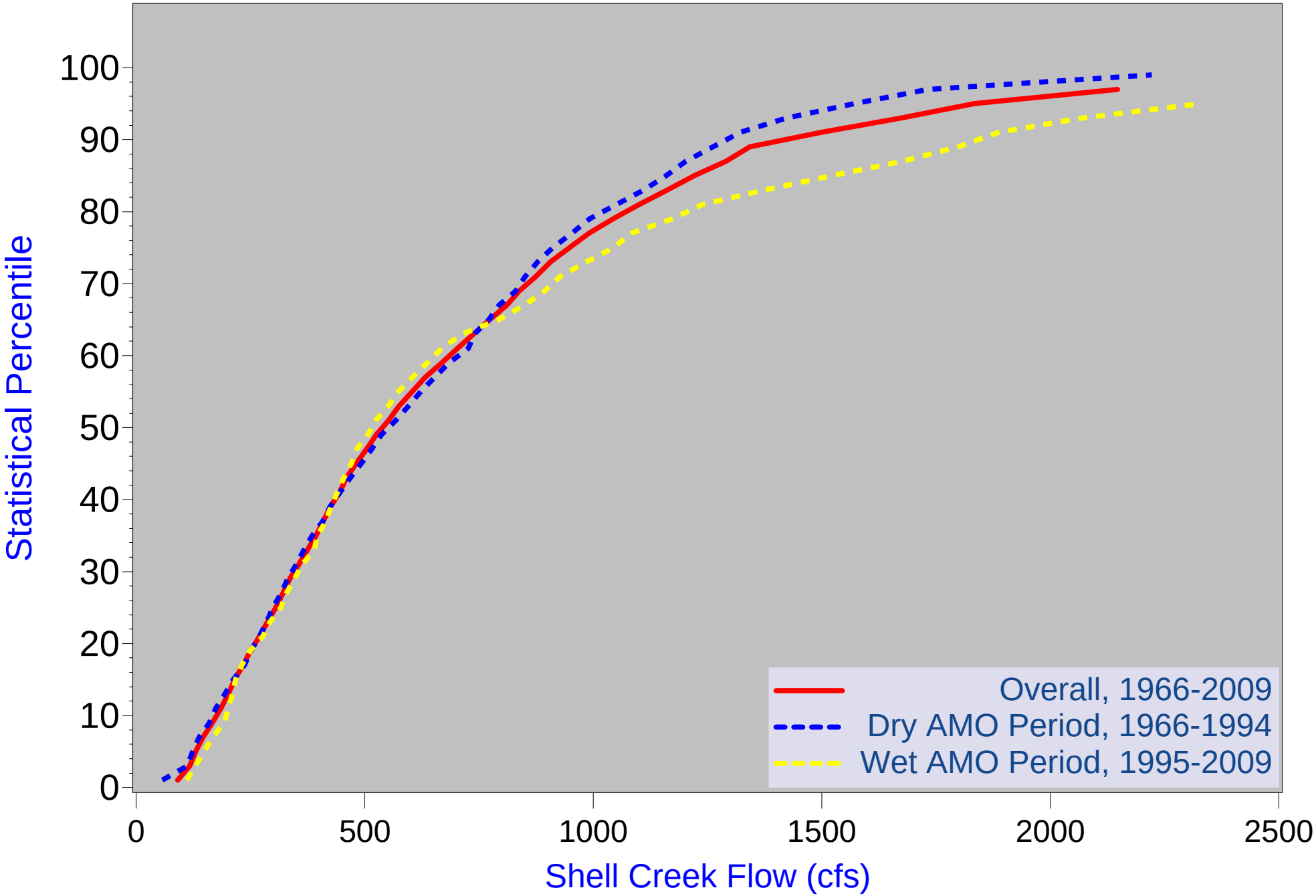


Figure 3.98b August differences in CDFs among AMO periods in estimated flow without withdrawals

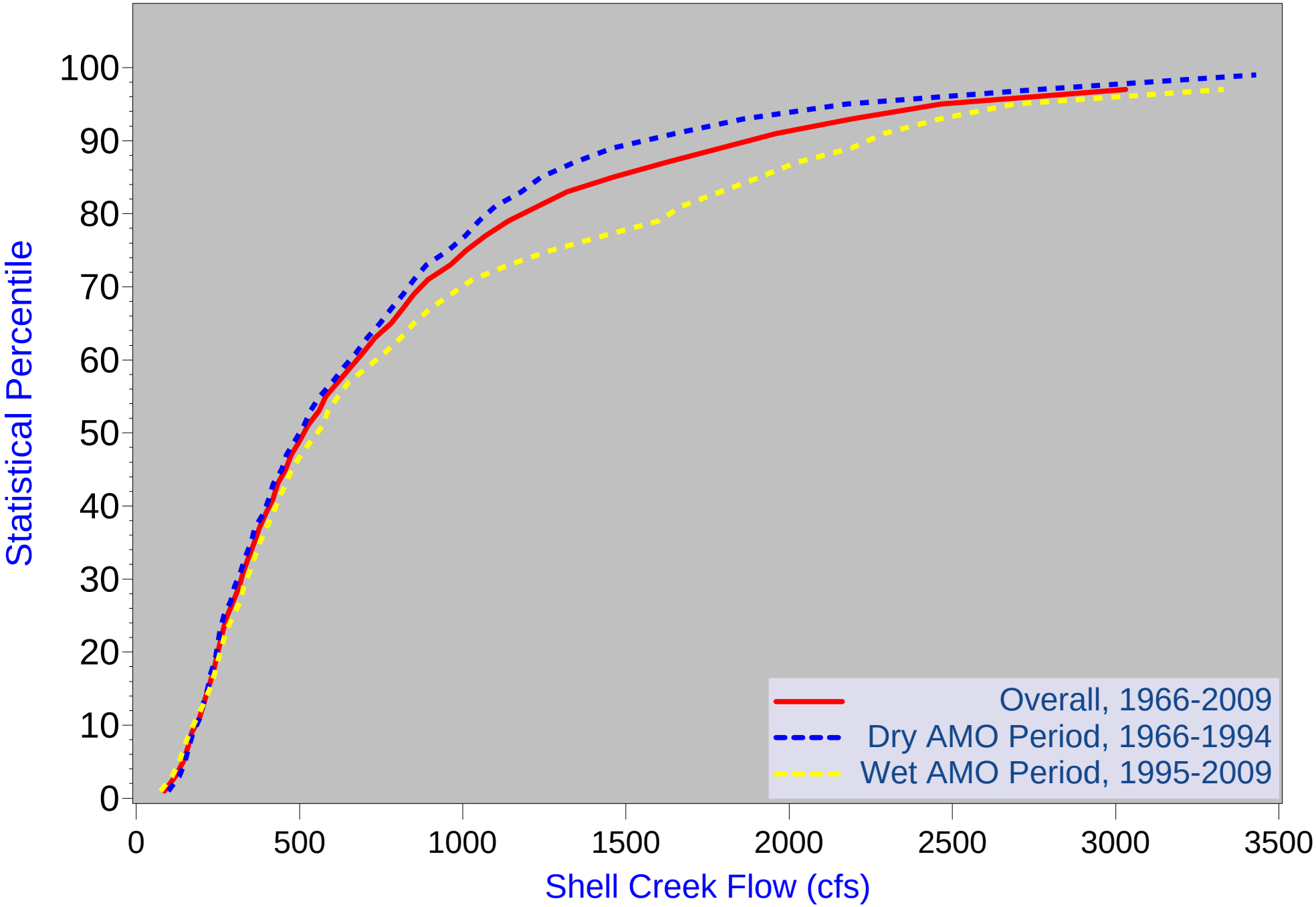


Figure 3.99a September differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

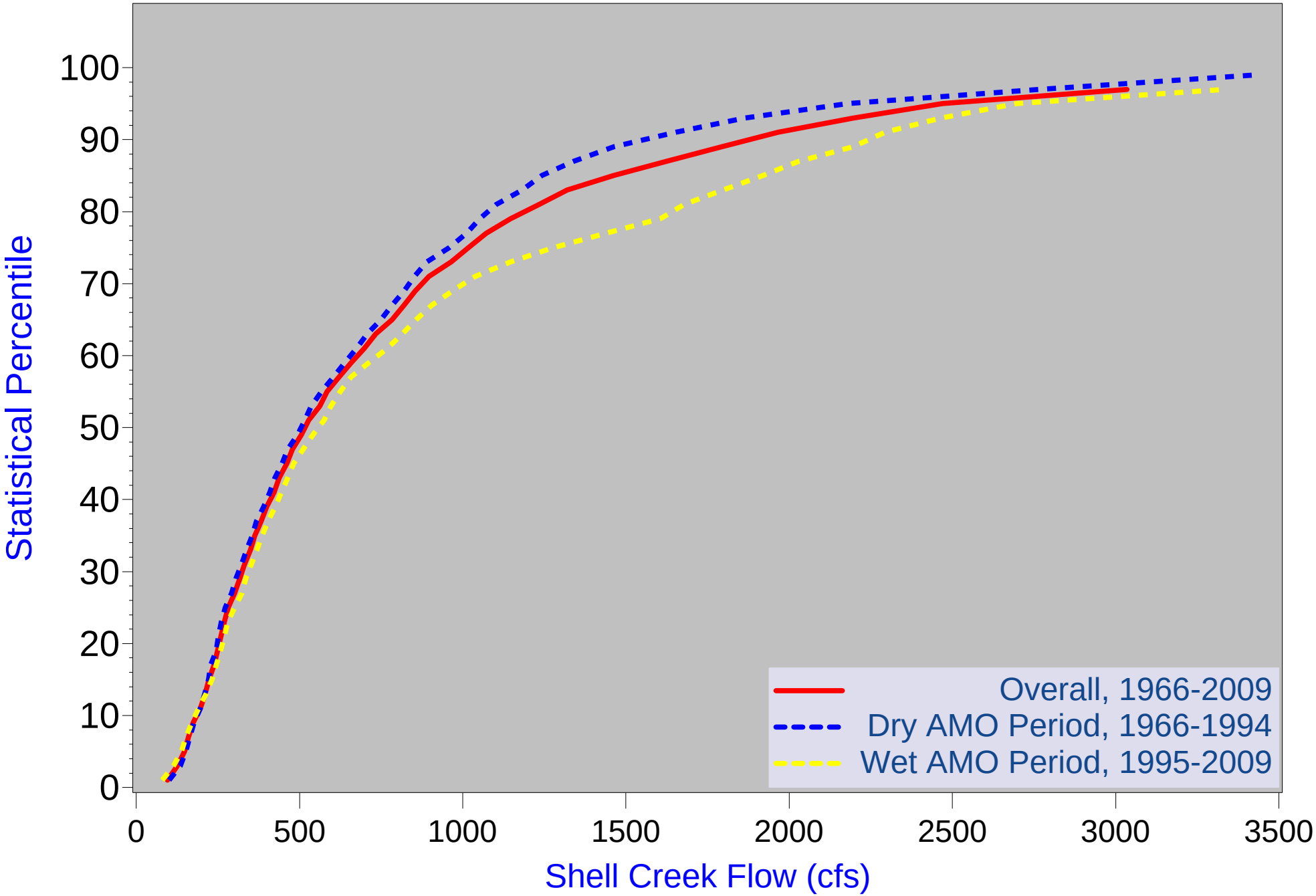


Figure 3.99b September differences in CDFs among AMO periods in estimated flow without withdrawals

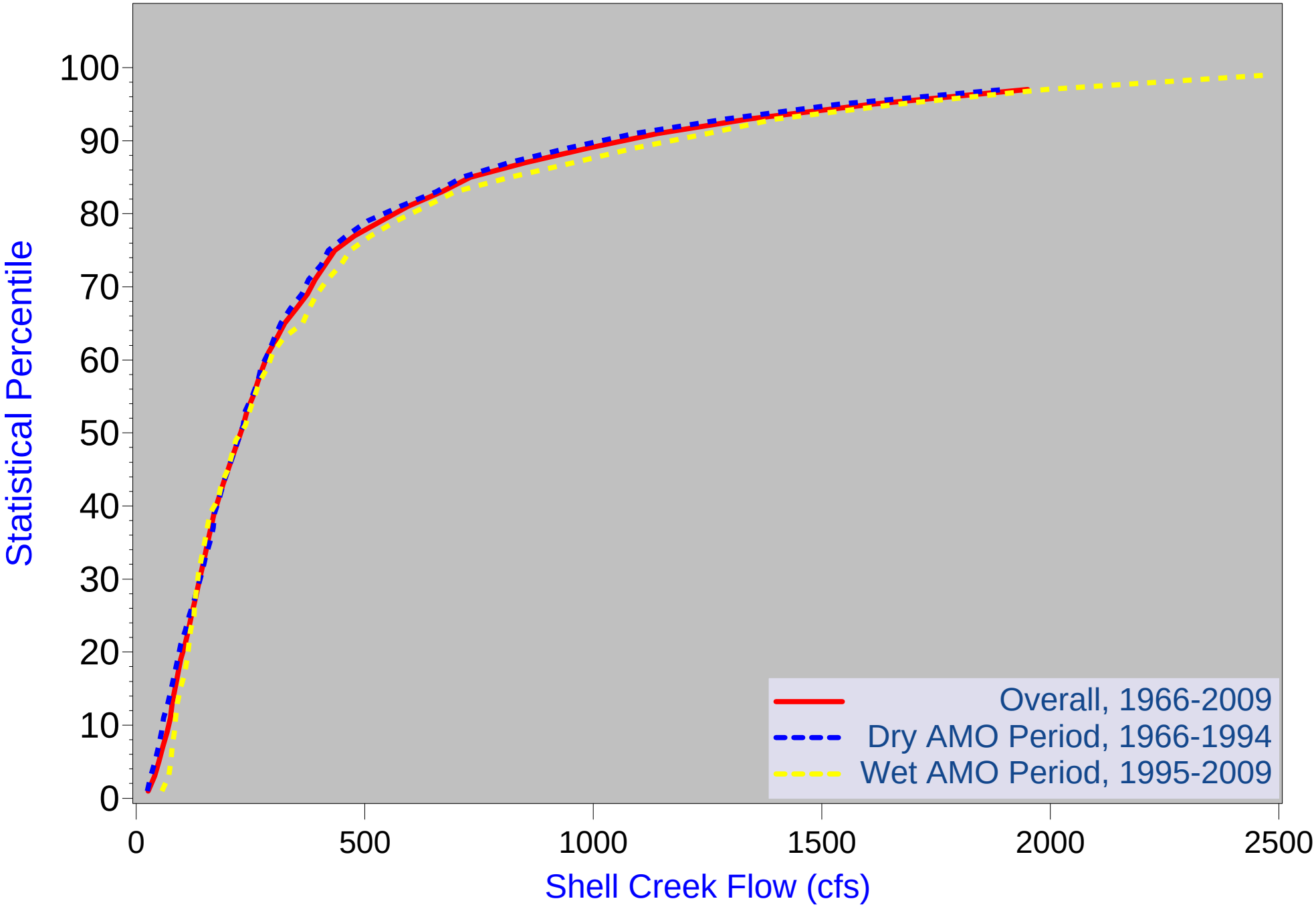


Figure 3.100a October differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

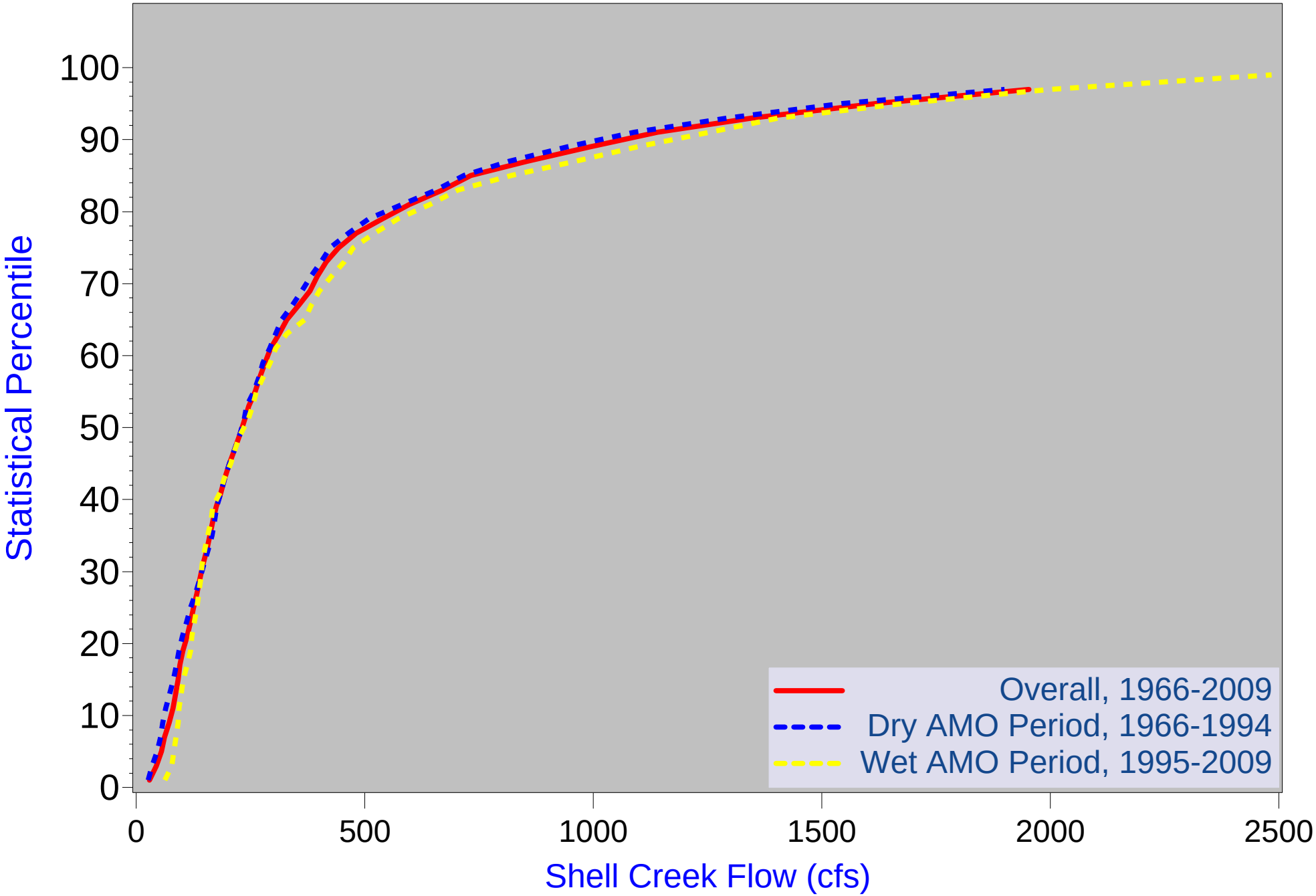


Figure 3.100b October differences in CDFs among AMO periods in estimated flow without withdrawals

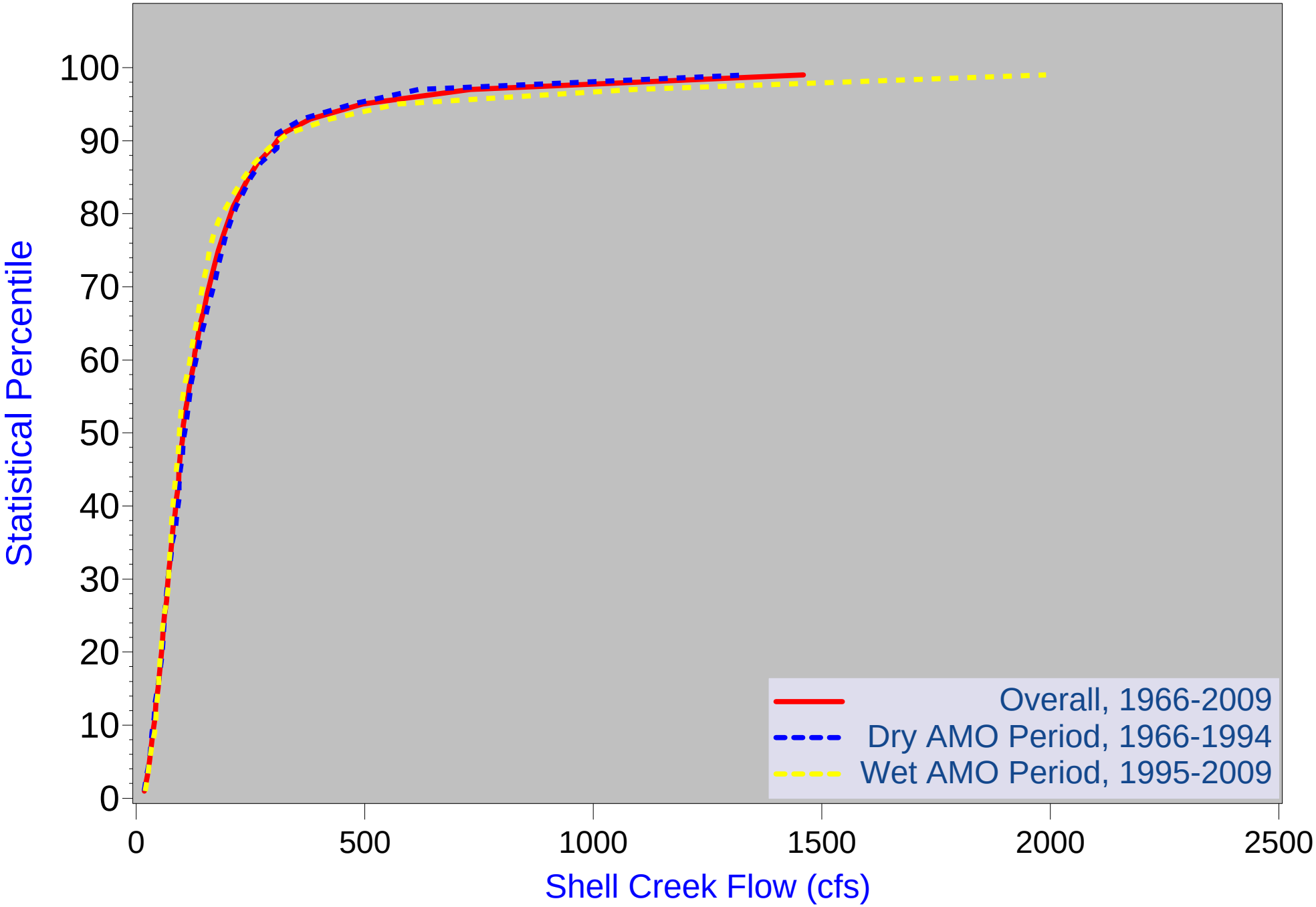


Figure 3.101a November differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

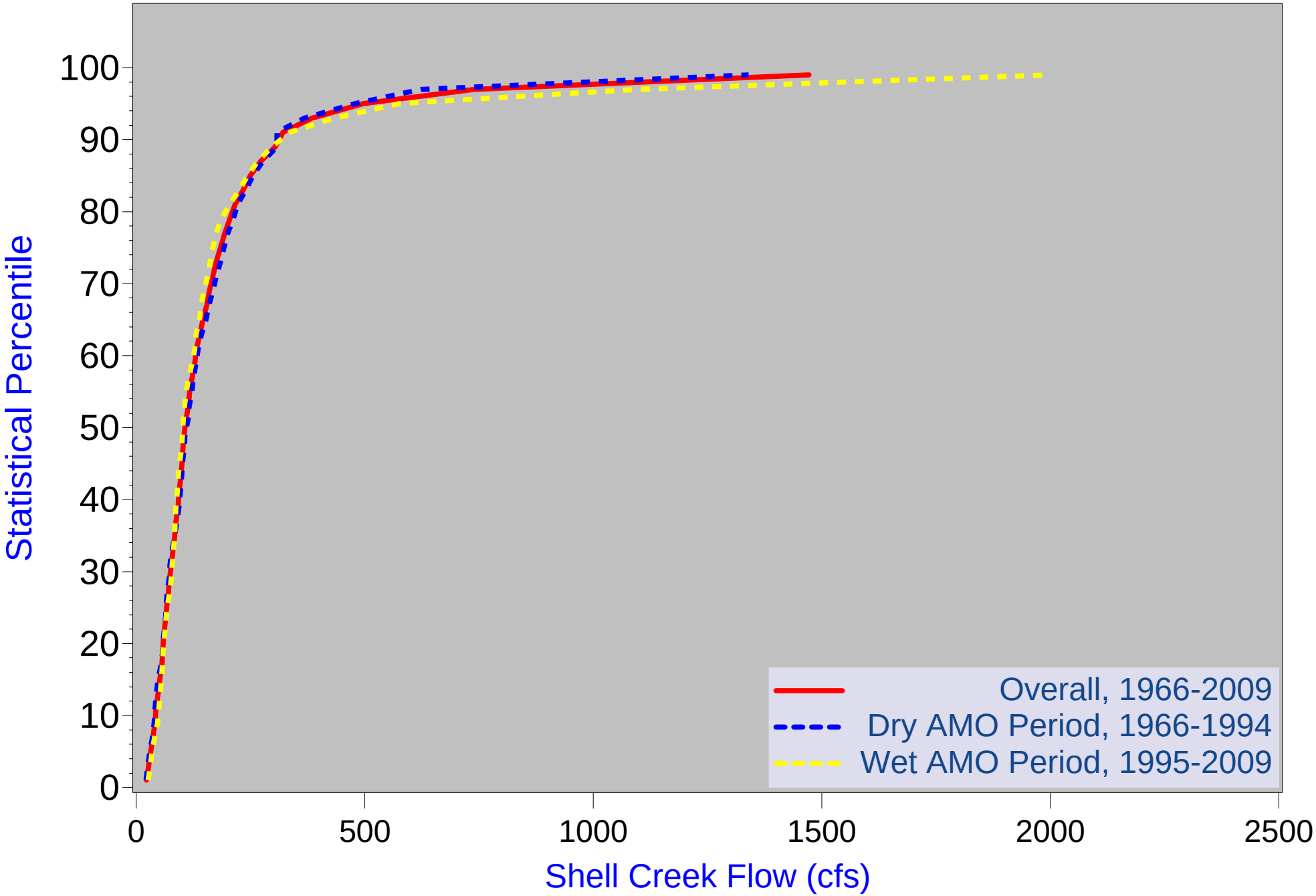


Figure 3.101b November differences in CDFs among AMO periods in estimated flow without withdrawals

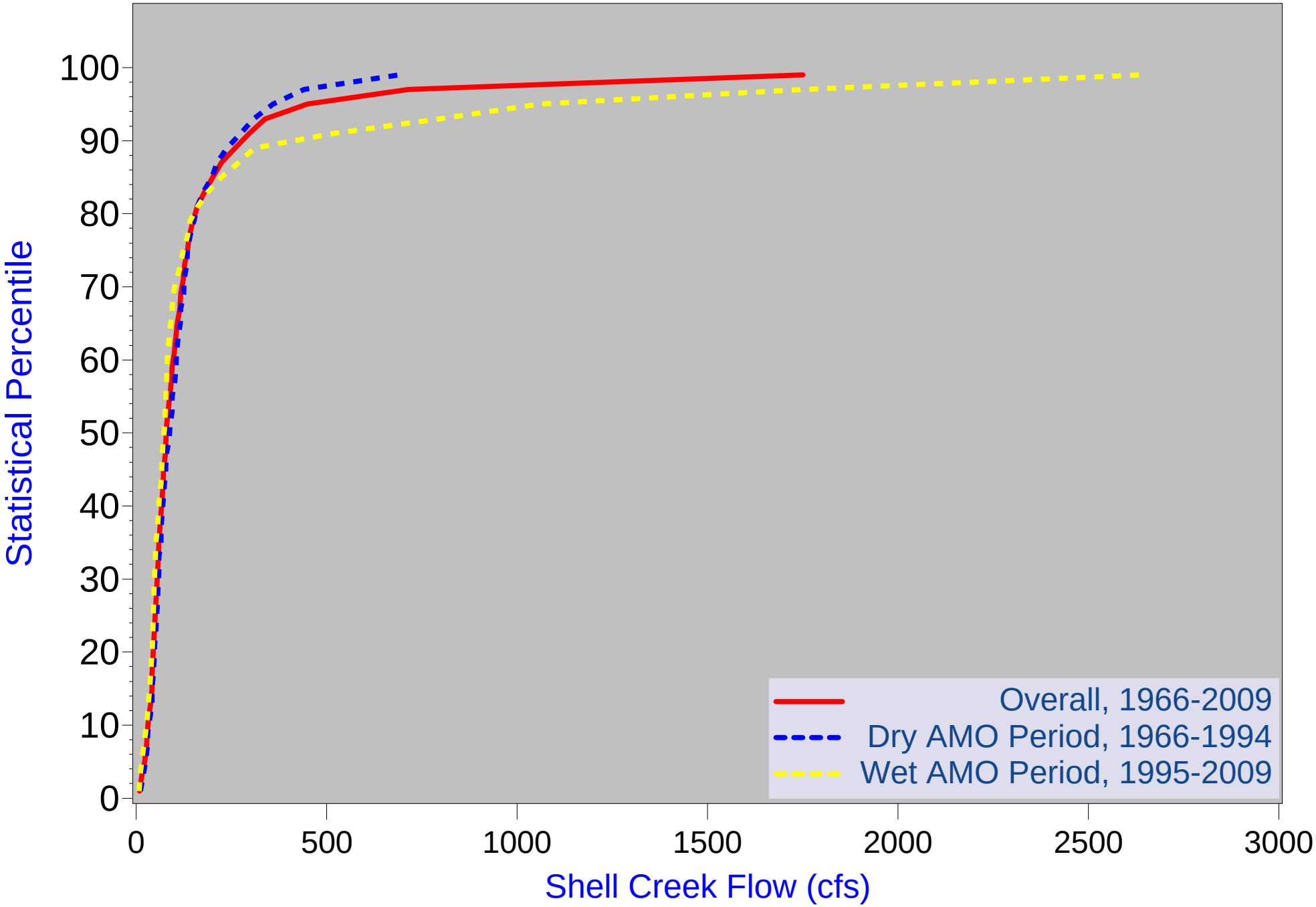


Figure 3.102a December differences in CDFs among AMO periods in flow at Shell Creek gage (USGS #2298202)

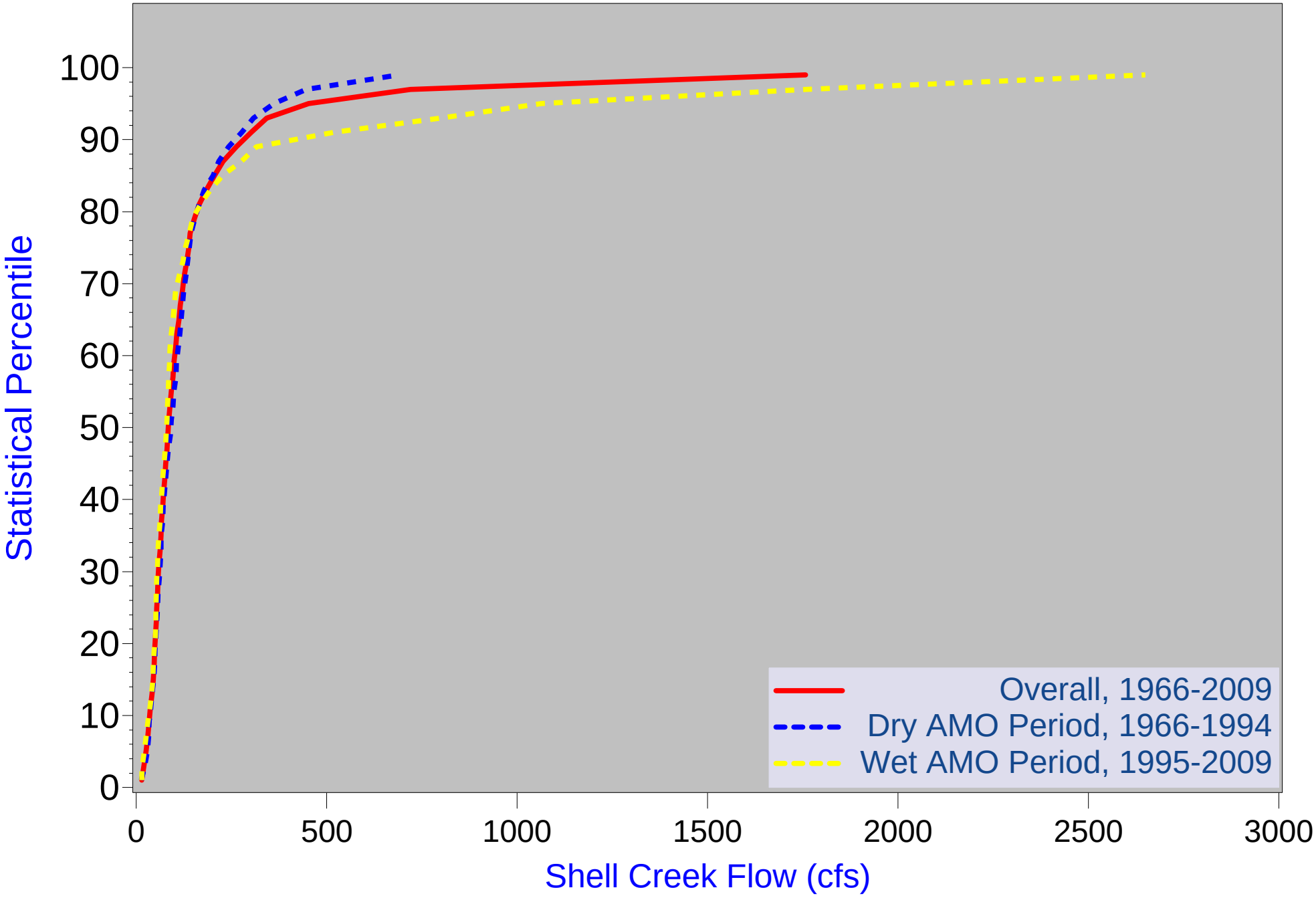


Figure 3.102b December differences in CDFs among AMO periods in estimated flow without withdrawals

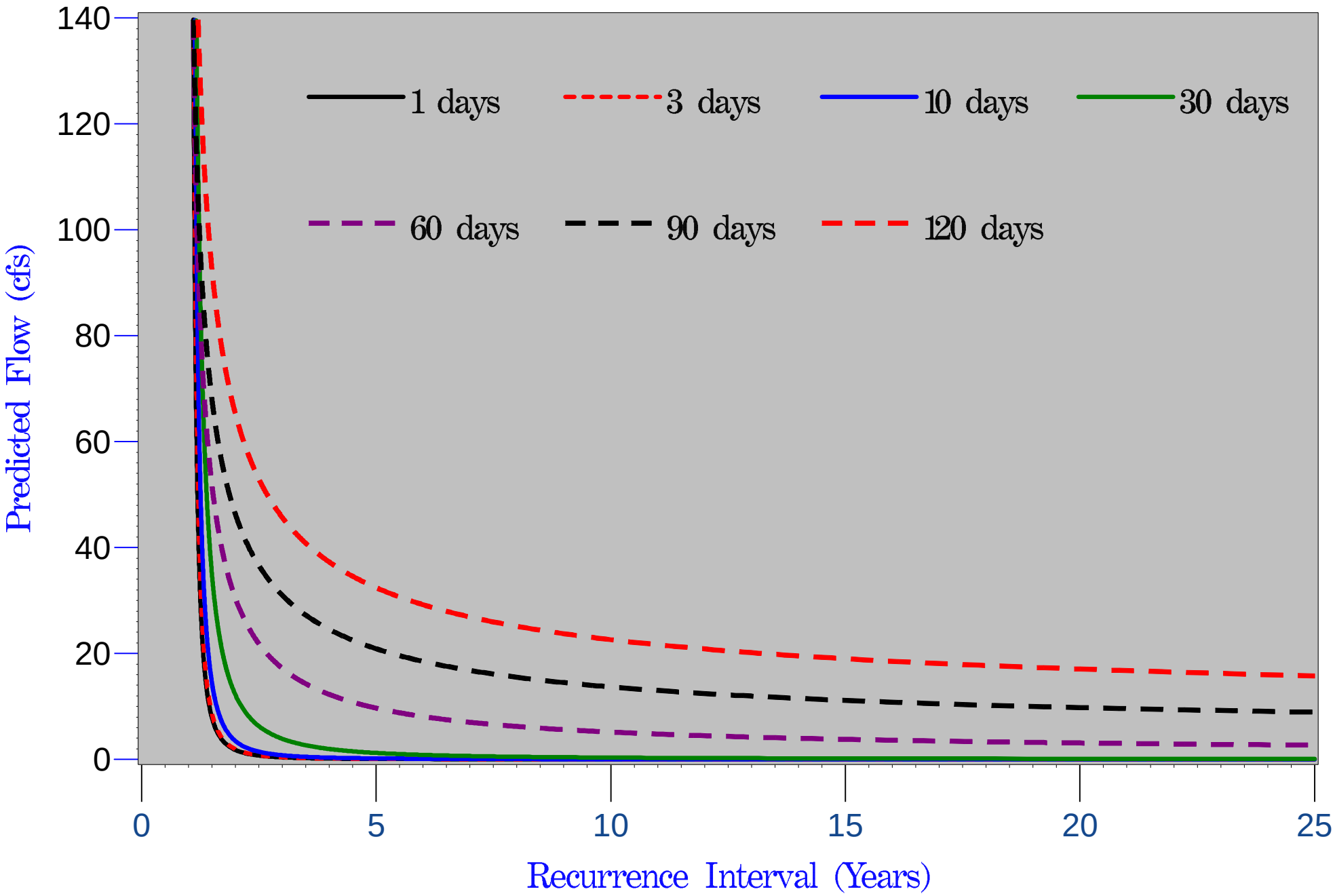


Figure 3.103 Consecutive day/low frequency analysis of Shell Creek flows without withdrawals (1966-2009)

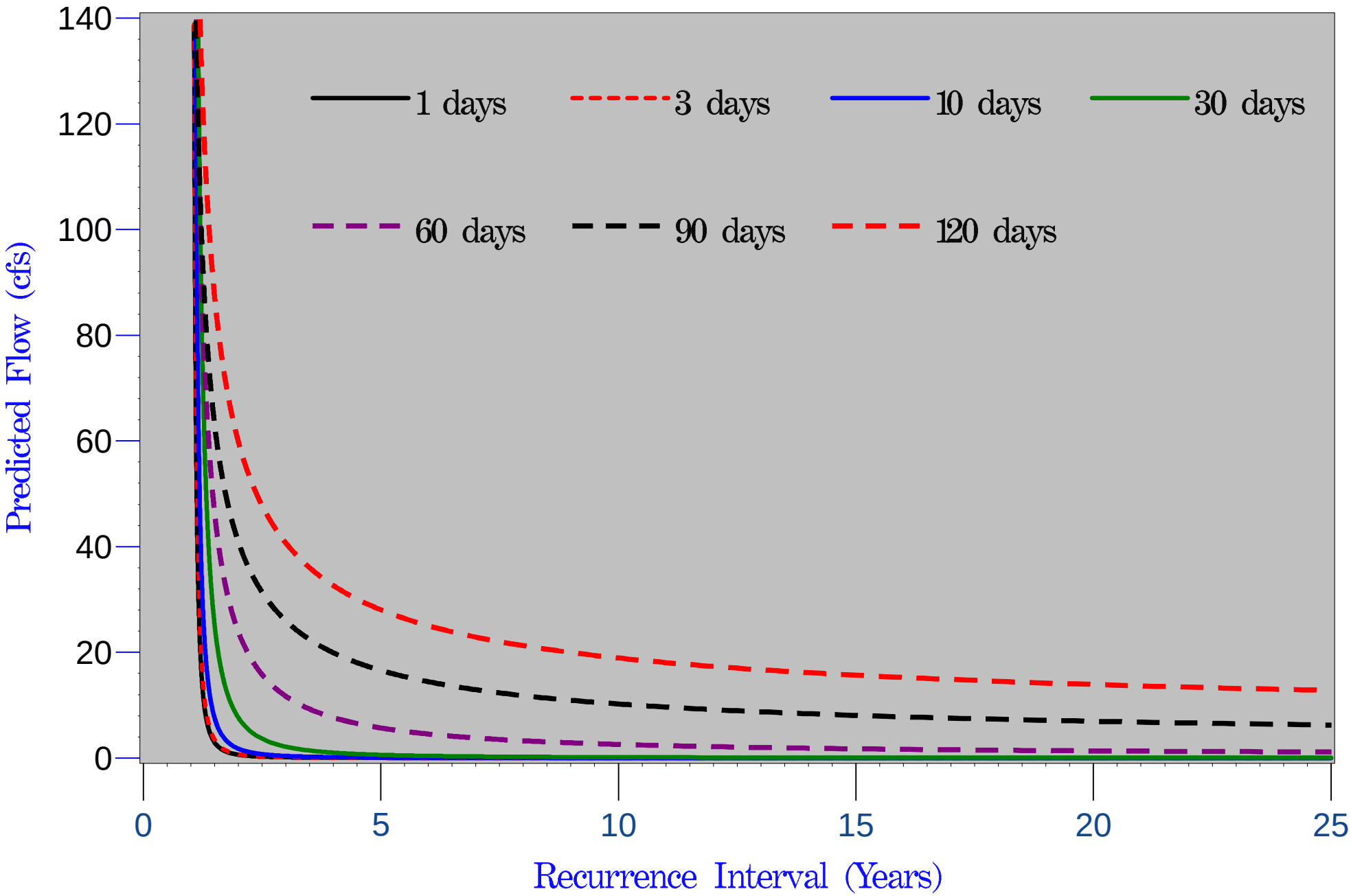


Figure 3.104 Consecutive day/low frequency analysis of USGS gaged Shell Creek flow (1966-2009)

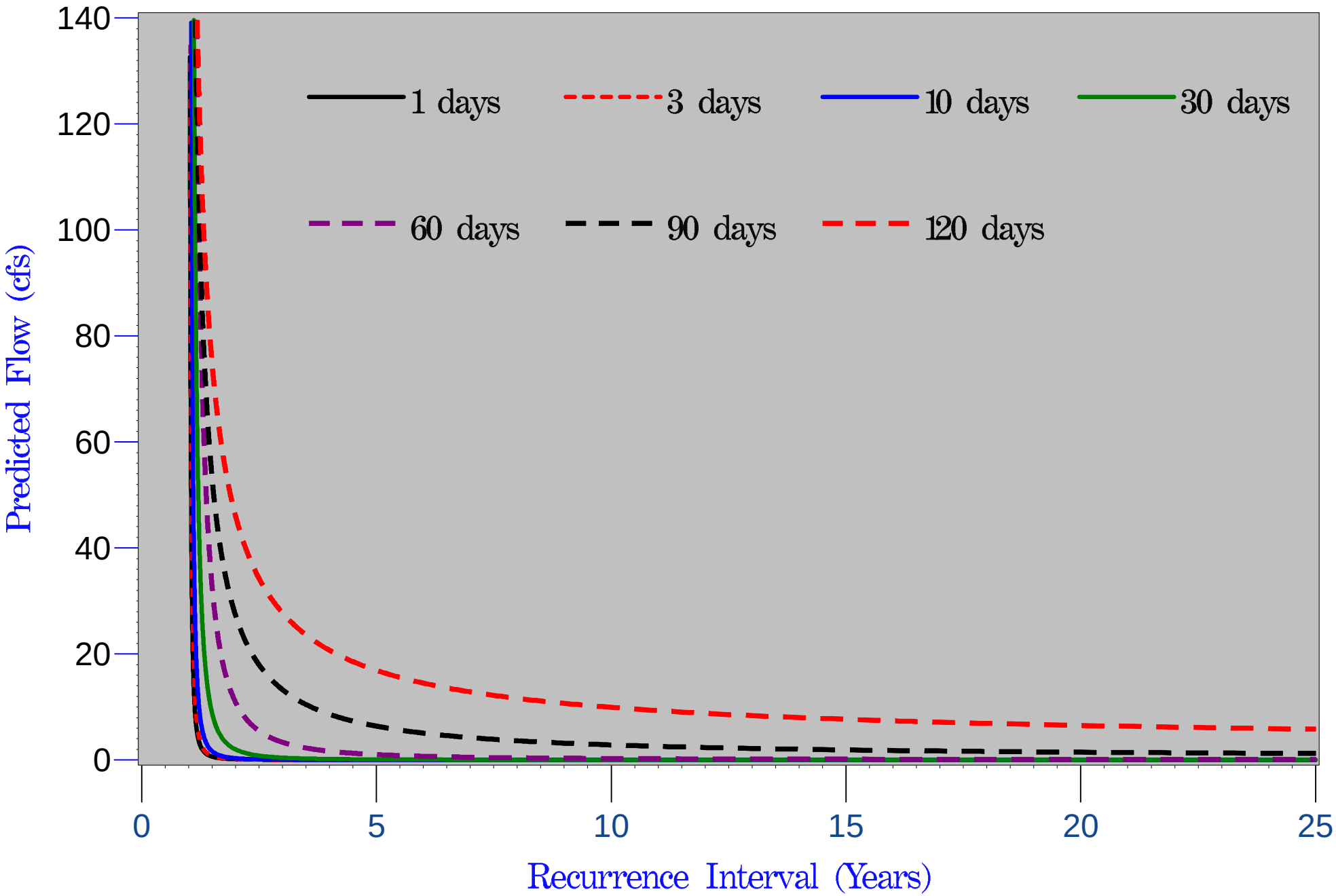


Figure 3.105 Consecutive day/low frequency analysis assuming maximum permitted withdrawals (1966-2009)

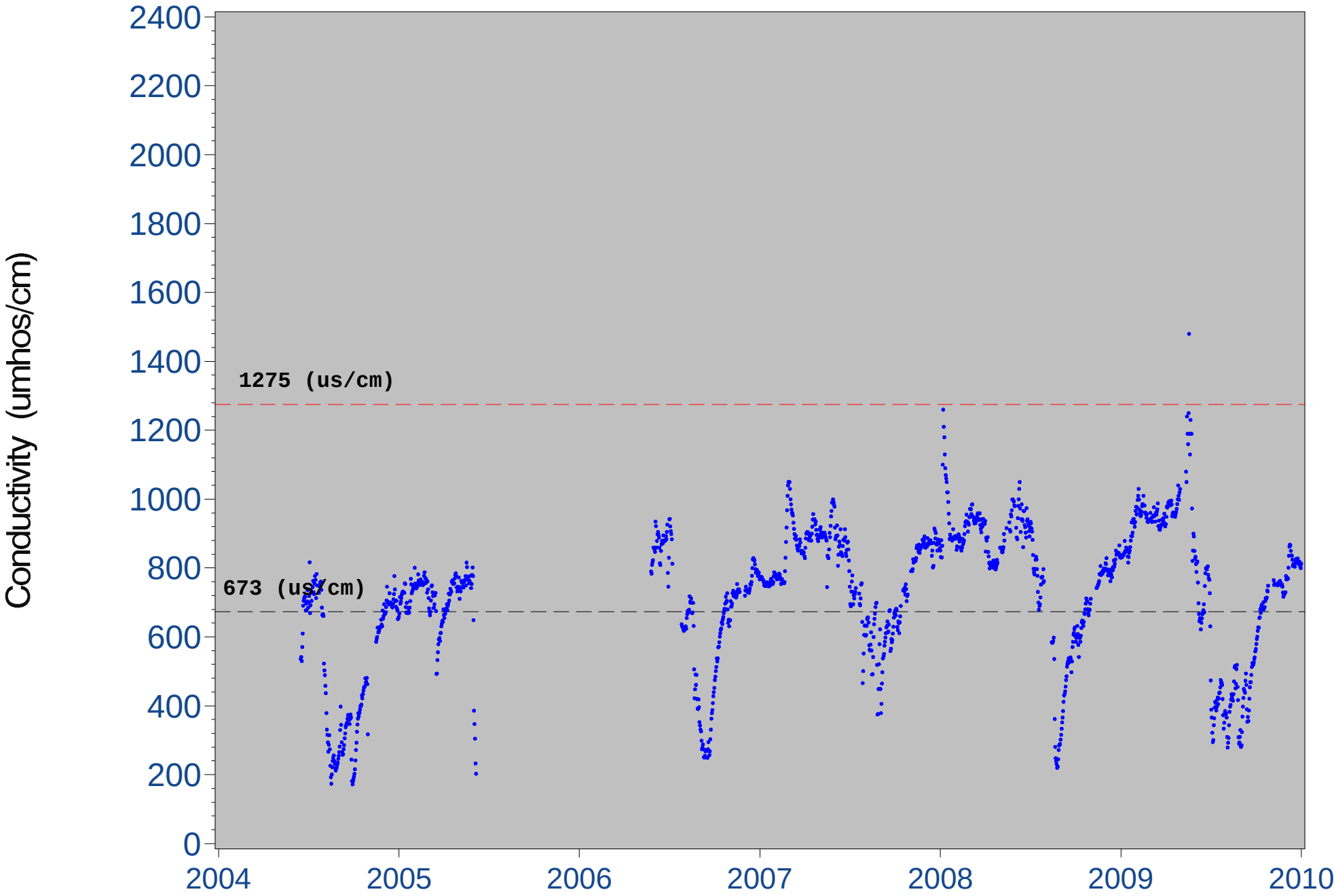


Figure 3.106a USGS measured conductivity at Prairie Creek near Ft. Ogden

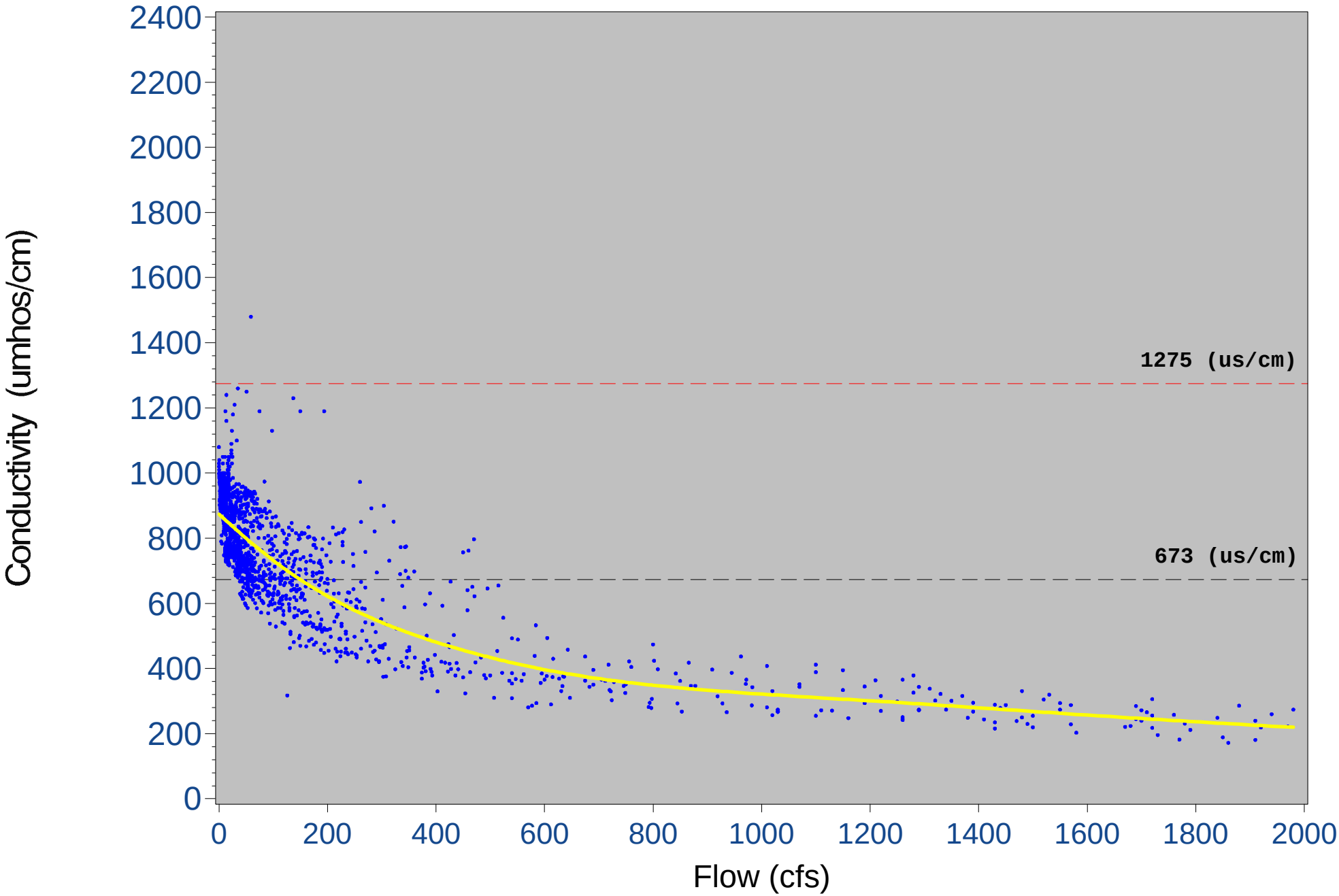


Figure 3.106b Flow vs. conductivity at Prairie Creek near Ft. Ogden

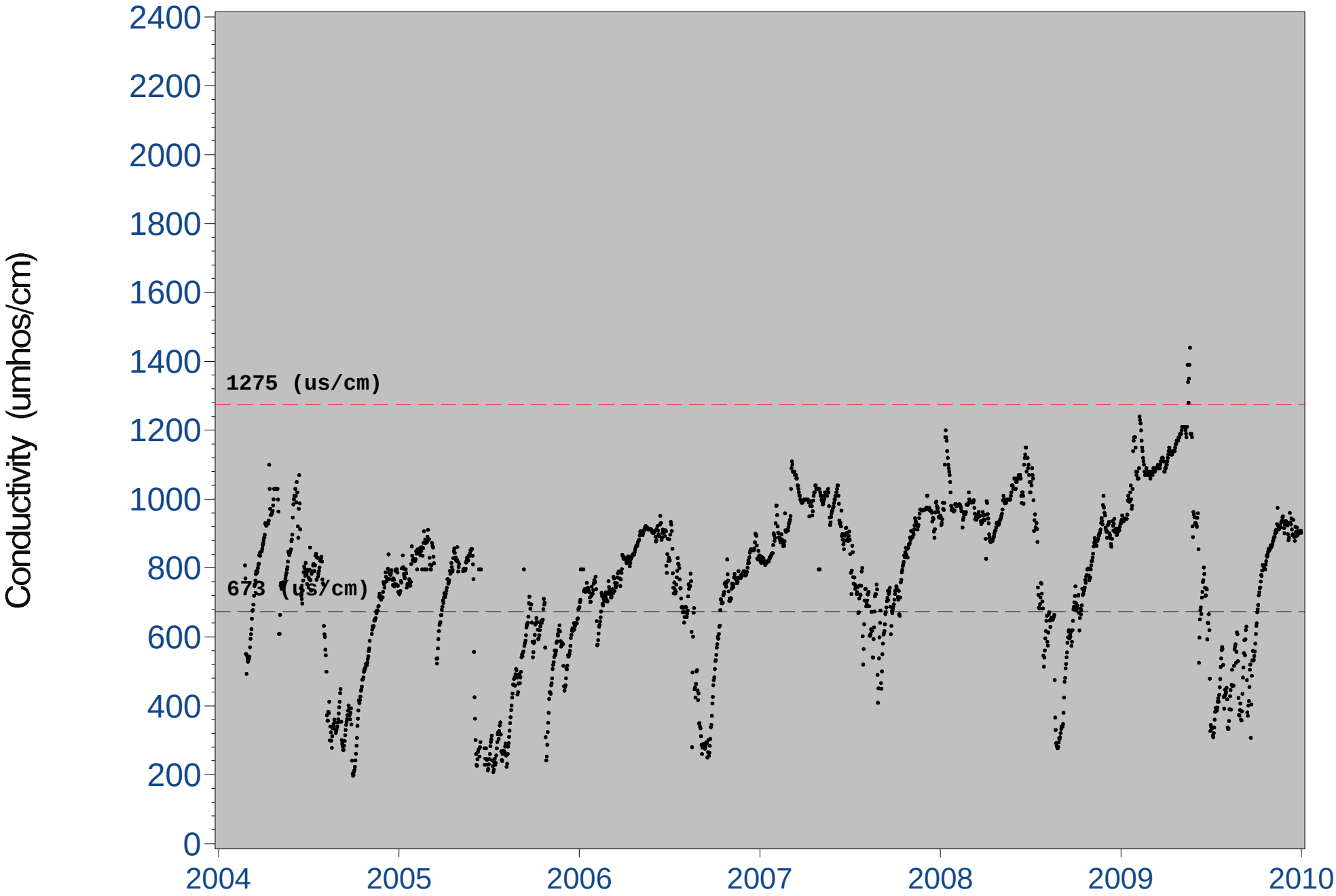


Figure 3.107a USGS measured conductivity for Prairie Creek at C.R. 764

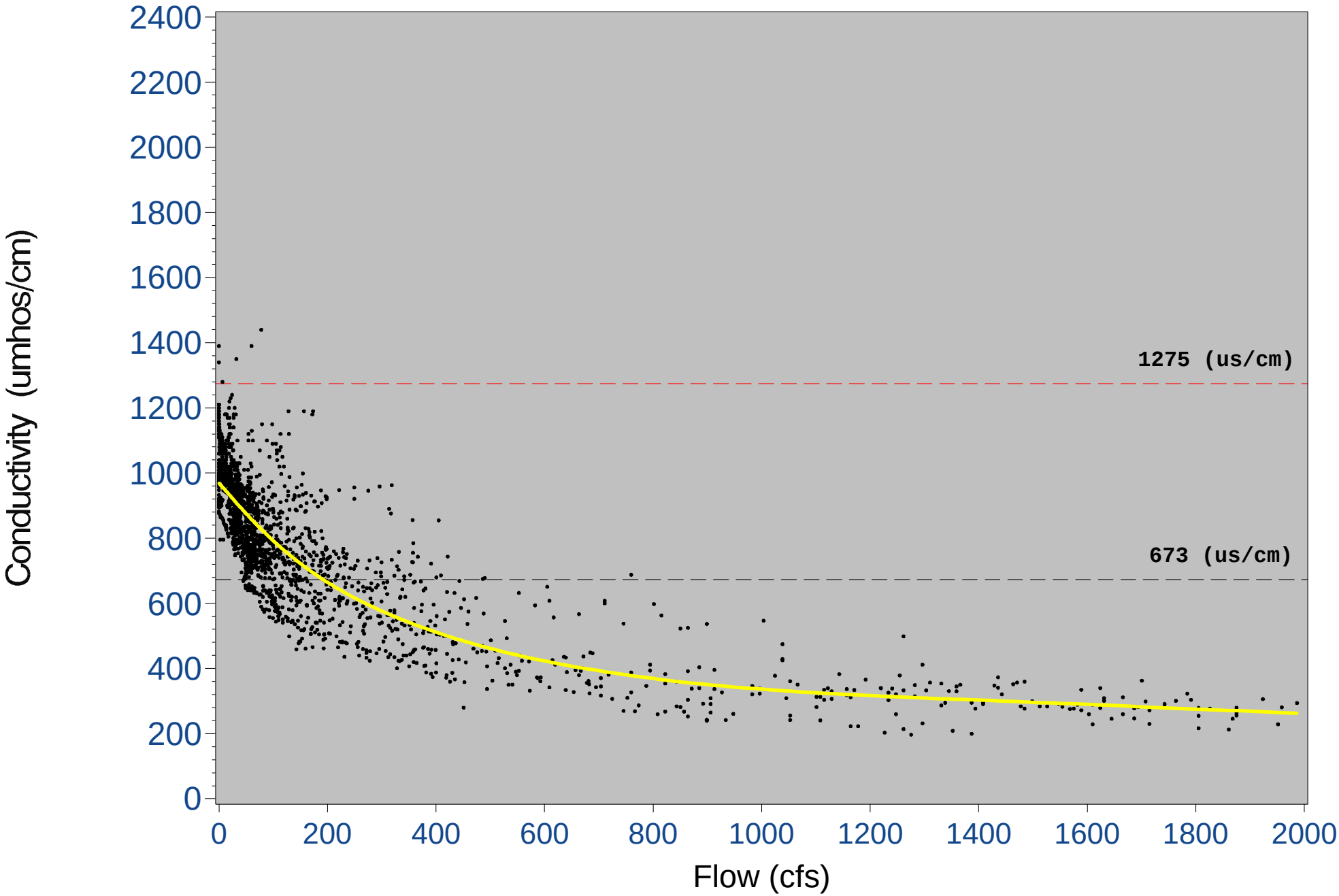


Figure 3.107b Flow vs. conductivity for Prairie Creek at C.R. 764

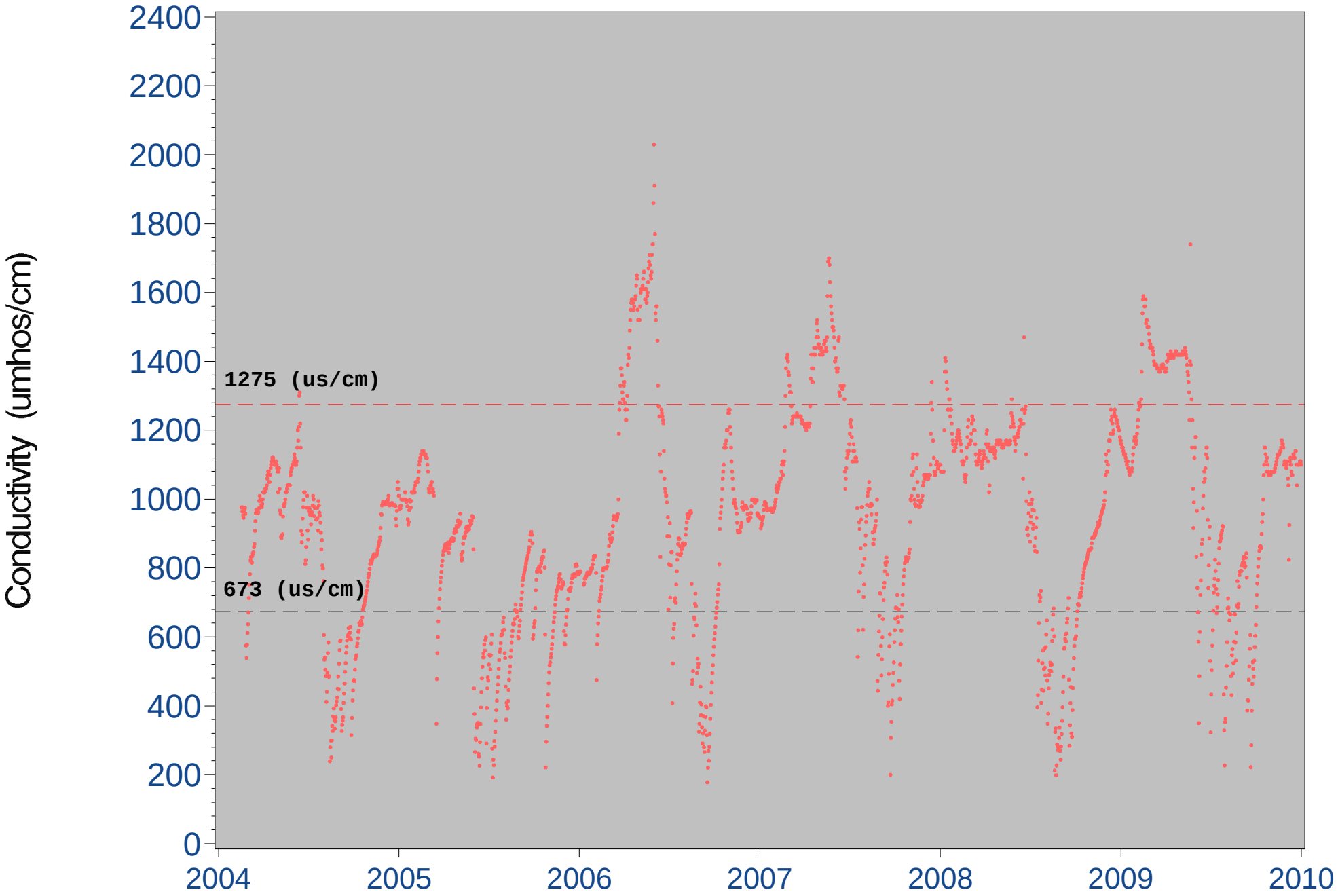


Figure 3.108a USGS measured conductivity for Shell Creek at C.R. 764

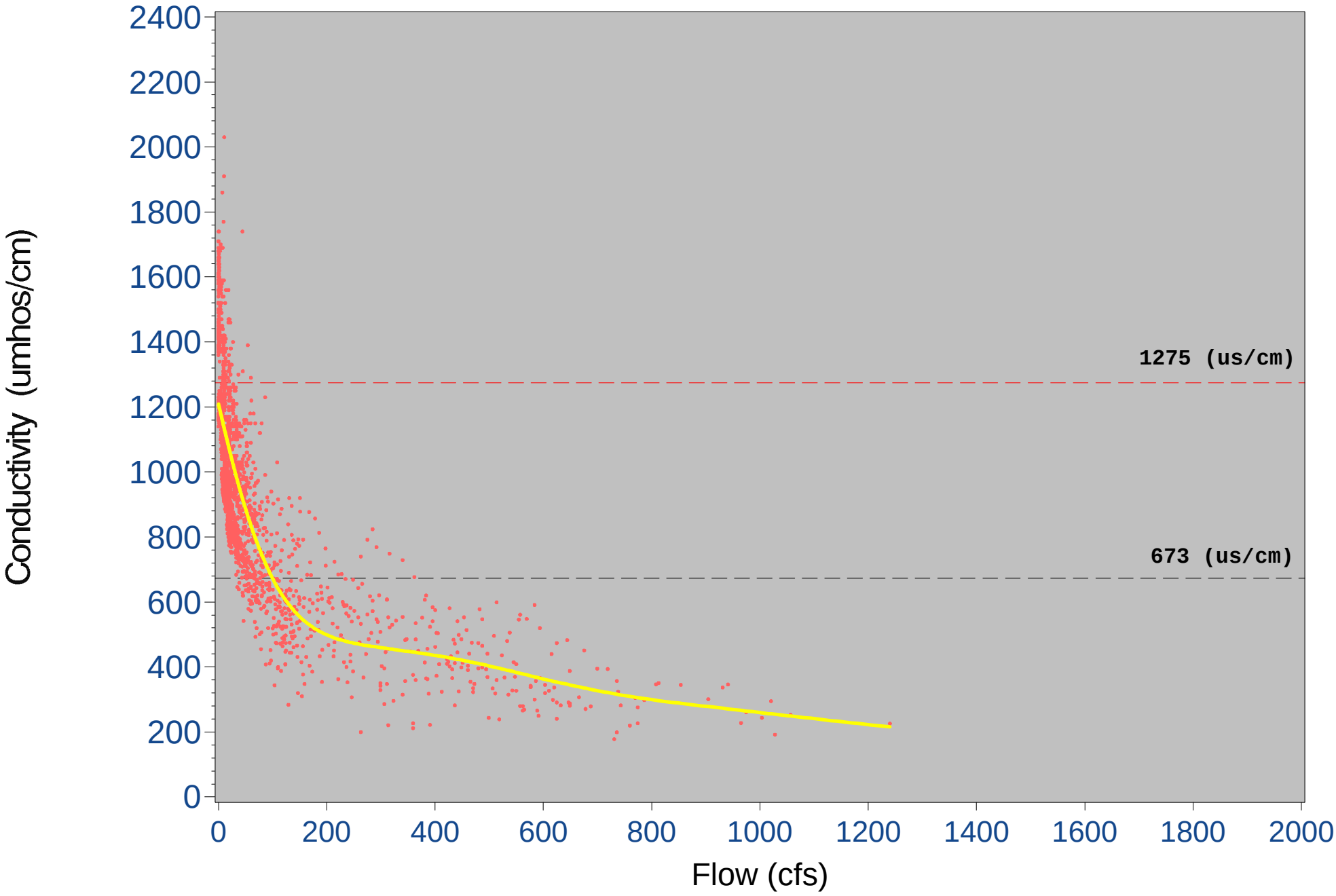


Figure 3.108b Flow vs. conductivity for Shell Creek at C.R. 764

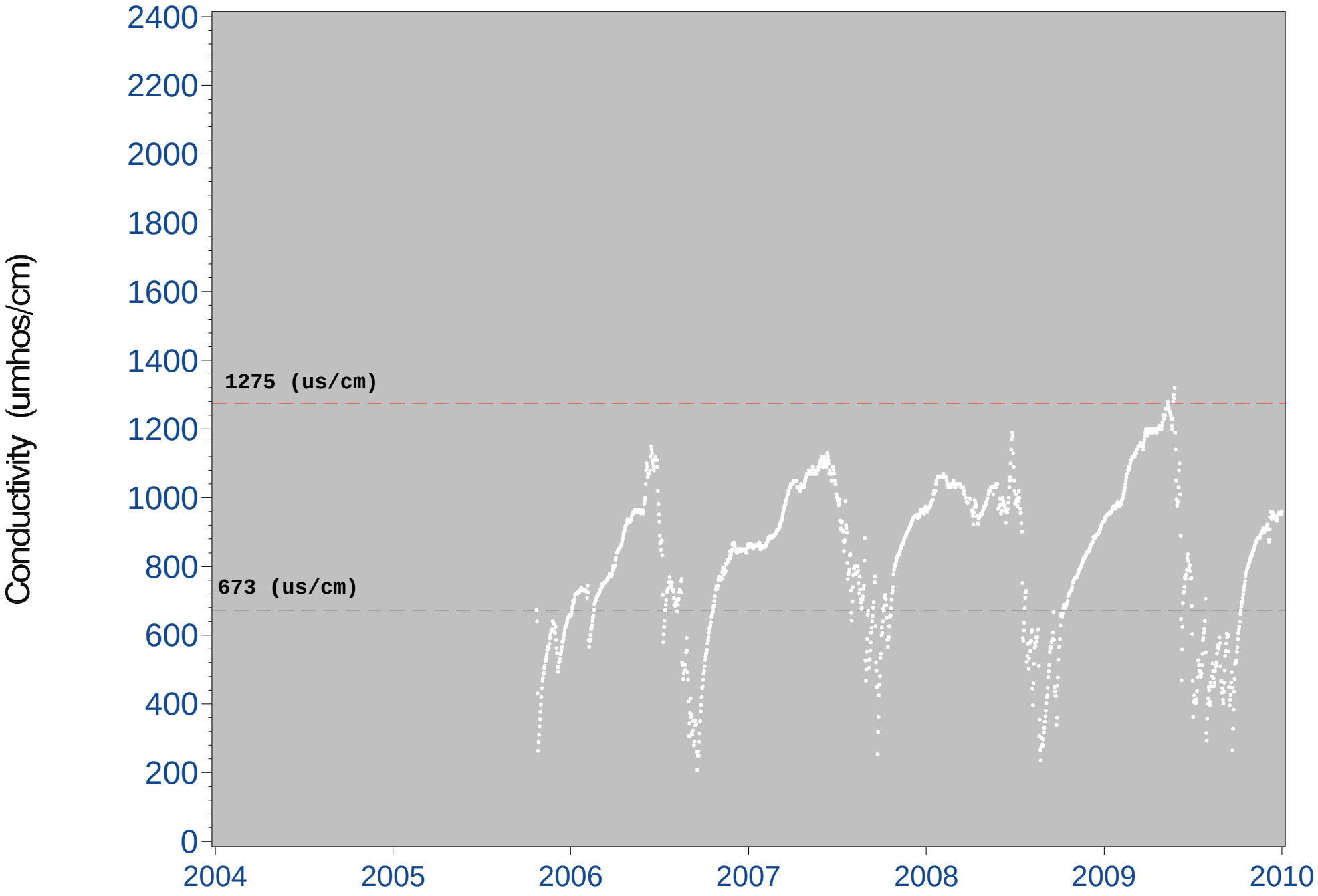


Figure 3.109a USGS measured conductivity at Shell Creek near Punta Gorda (reservoir upstream of the Dam)

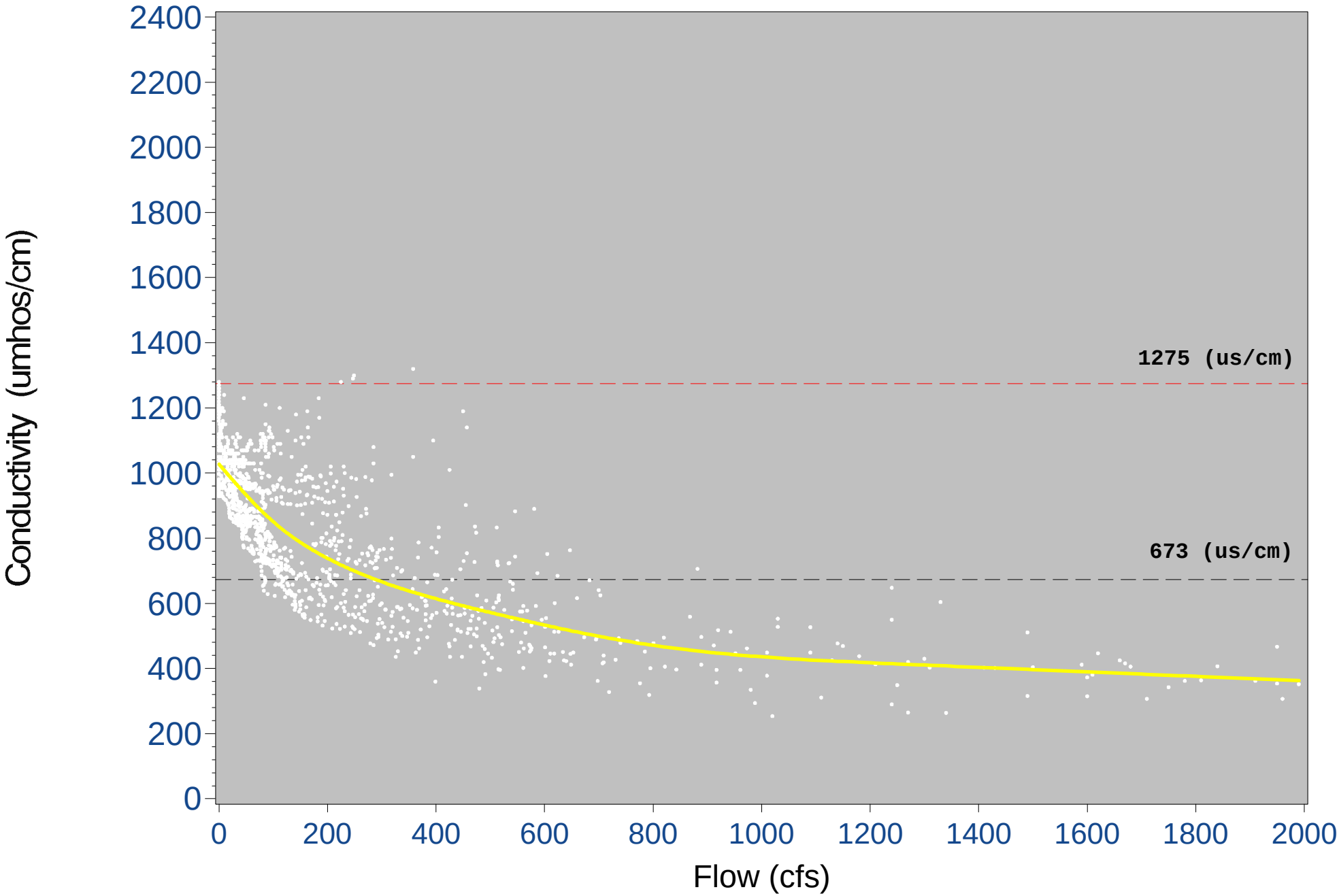


Figure 3.109b Flow vs. at Shell Creek near Punta Gorda (reservoir upstream of the Dam)

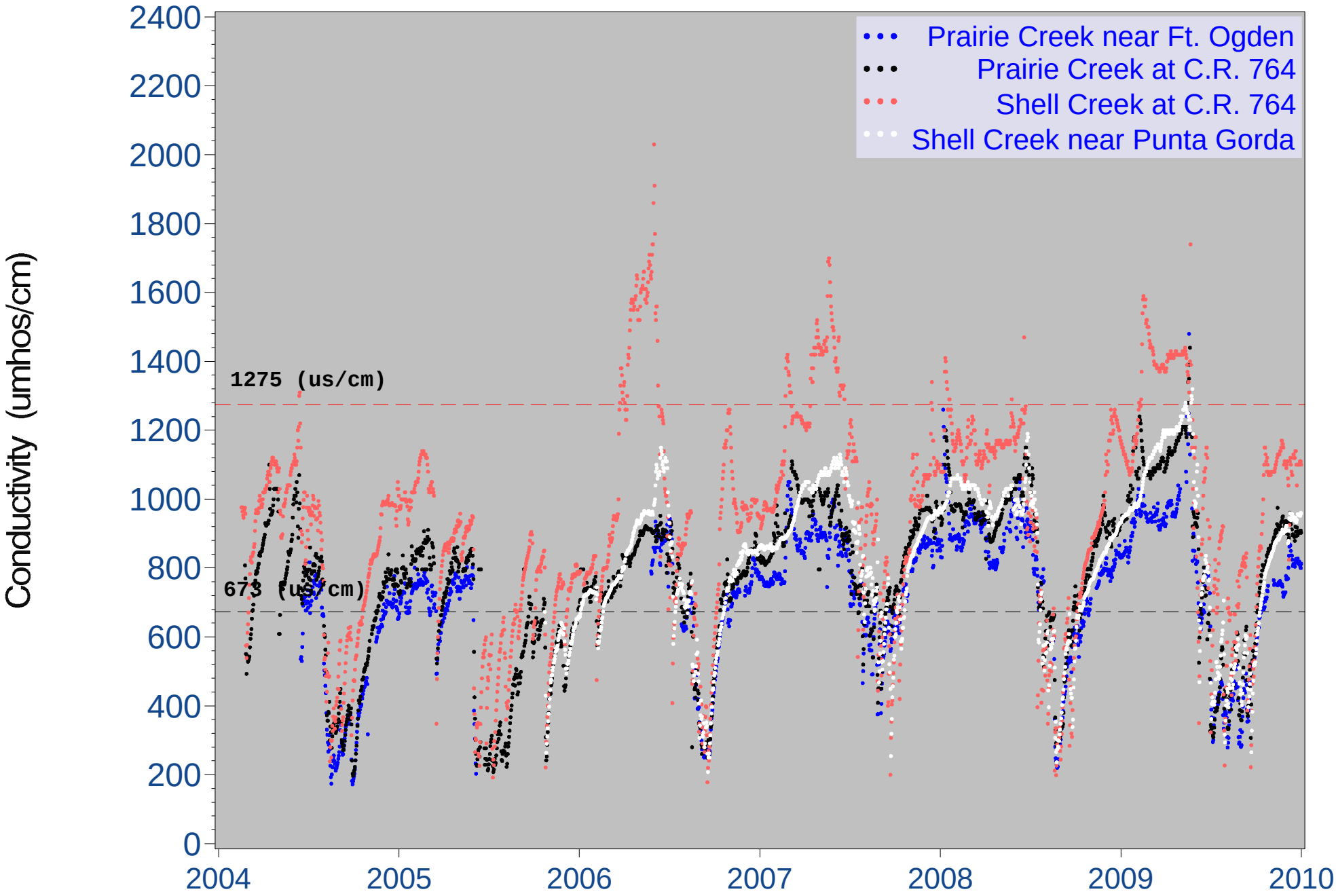


Figure 3.110a USGS measured conductivity in the Prairie/Shell Creek Watershed upstream of the Dam

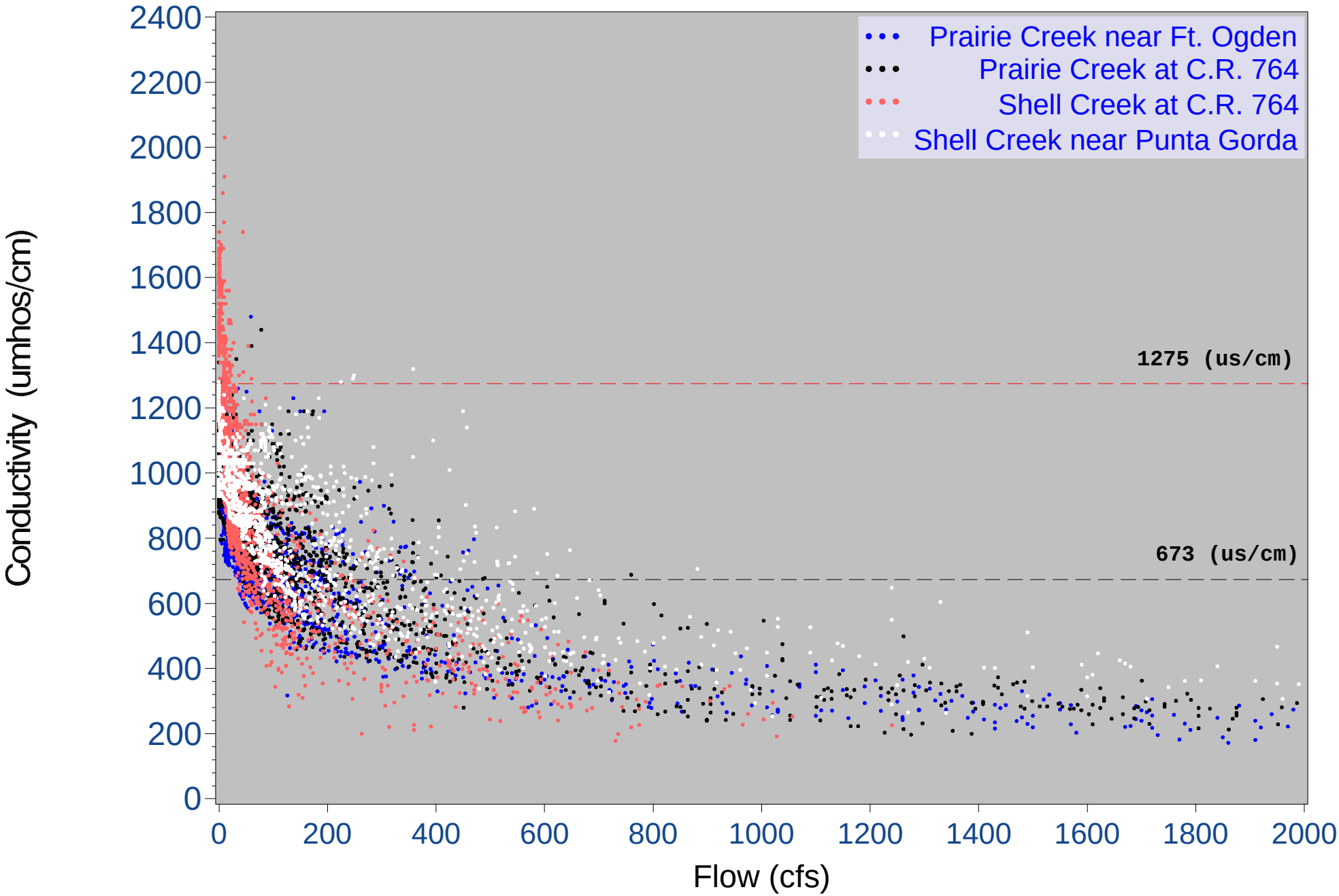


Figure 3.110b USGS measured conductivity in the Prairie/Shell Creek Watershed upstream of the Dam

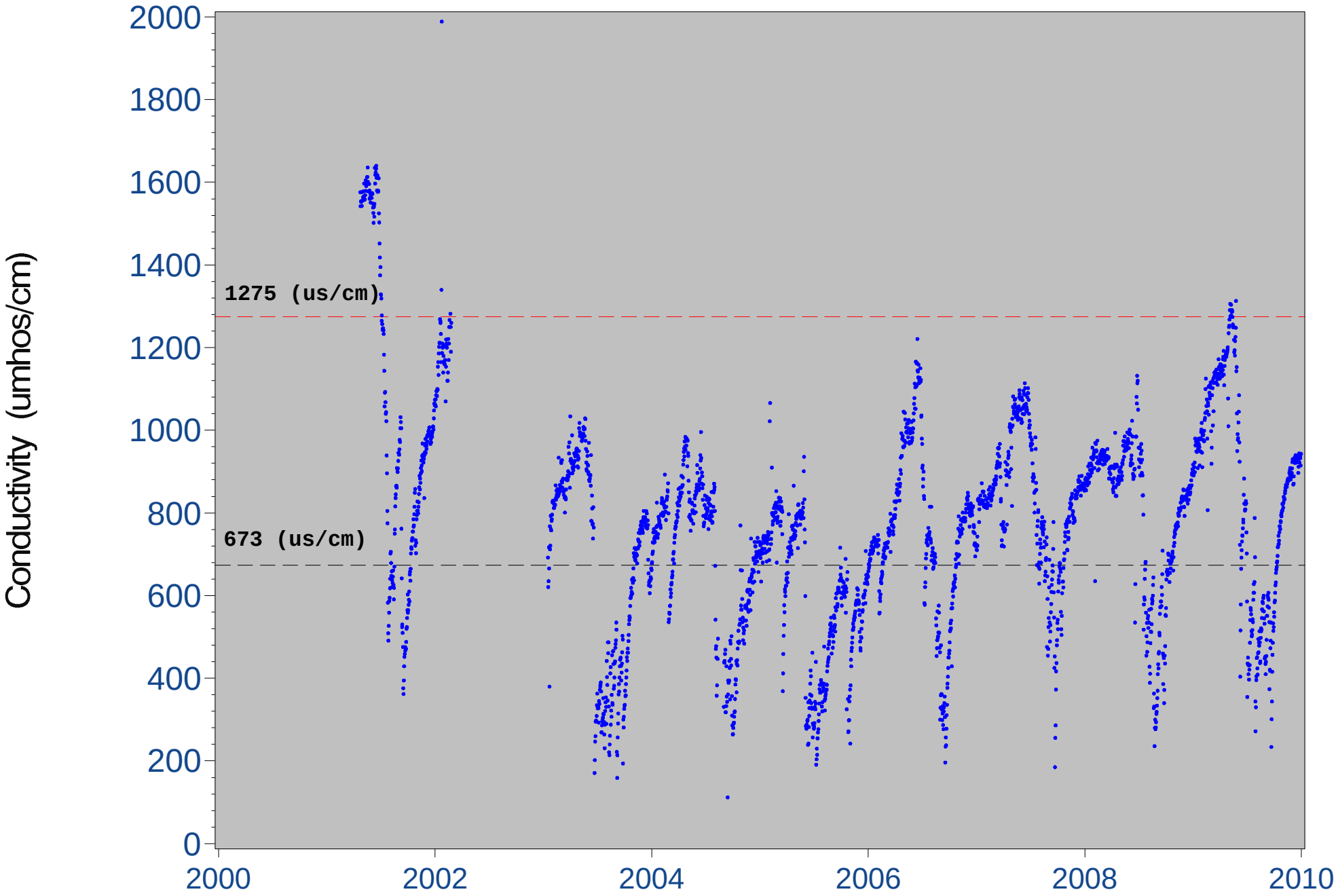


Figure 3.111a Conductivity from the City's intake

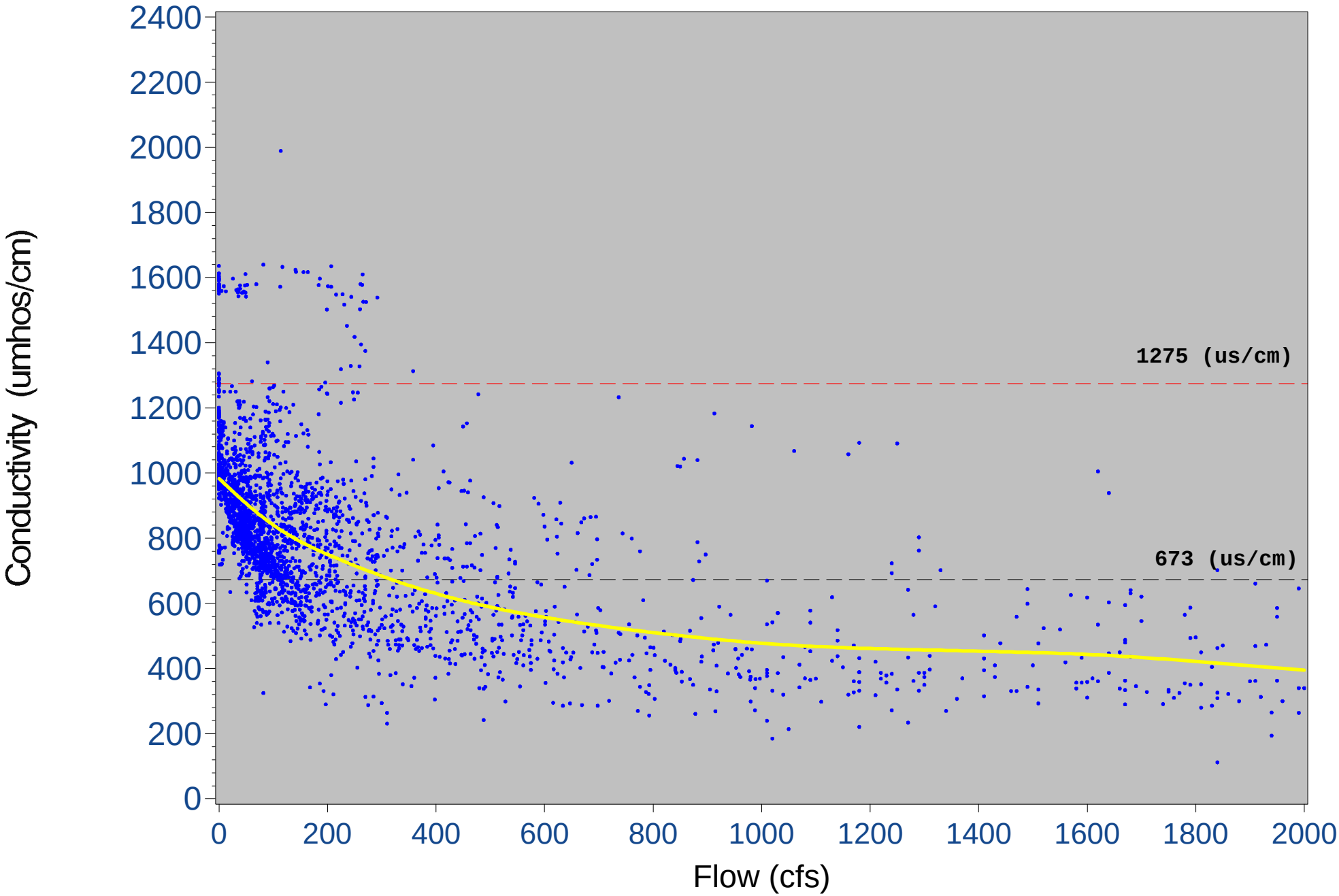


Figure 3.111b Conductivity from the City's intake vs. Shell Creek flow

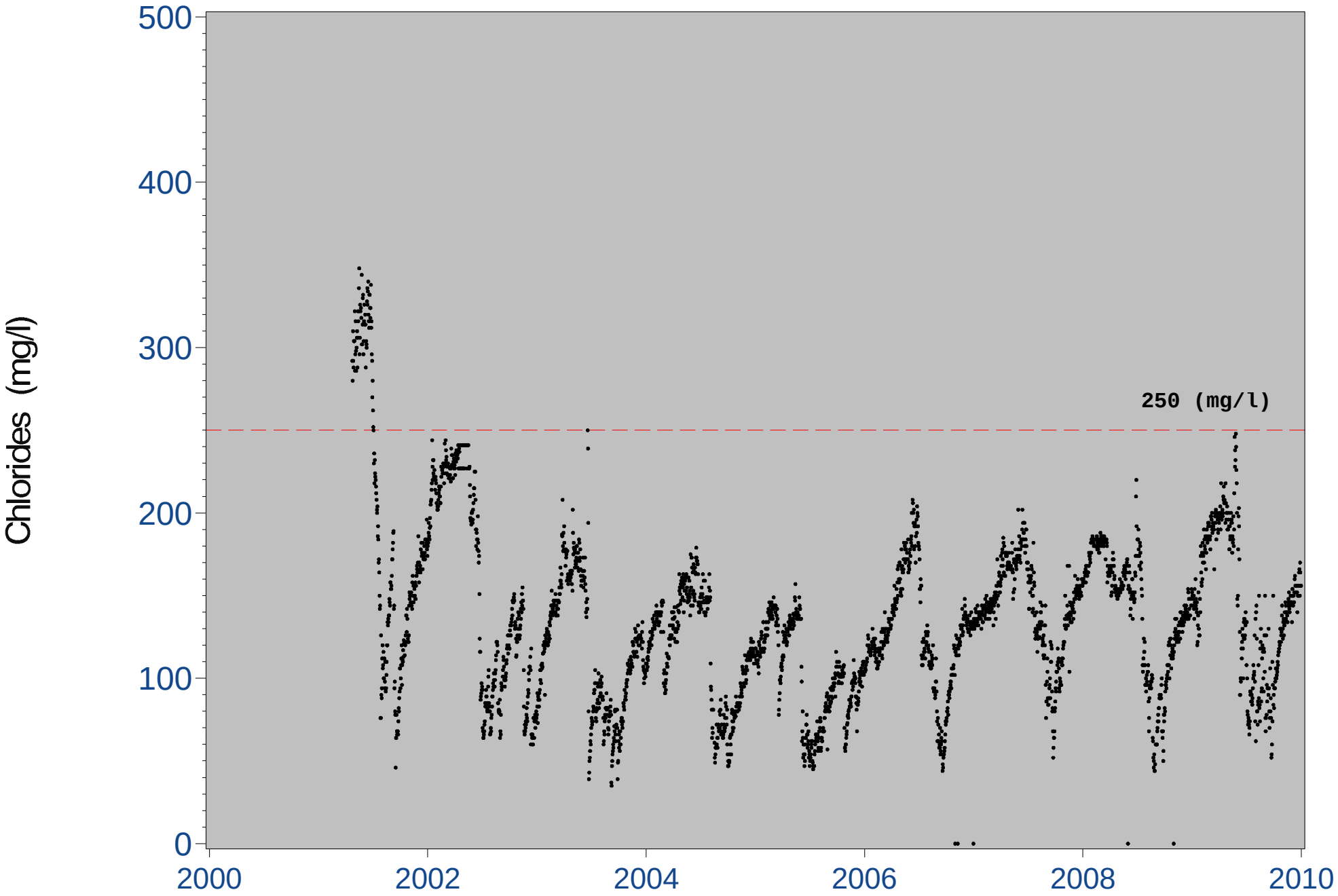


Figure 3.112a Chlorides from the City's intake

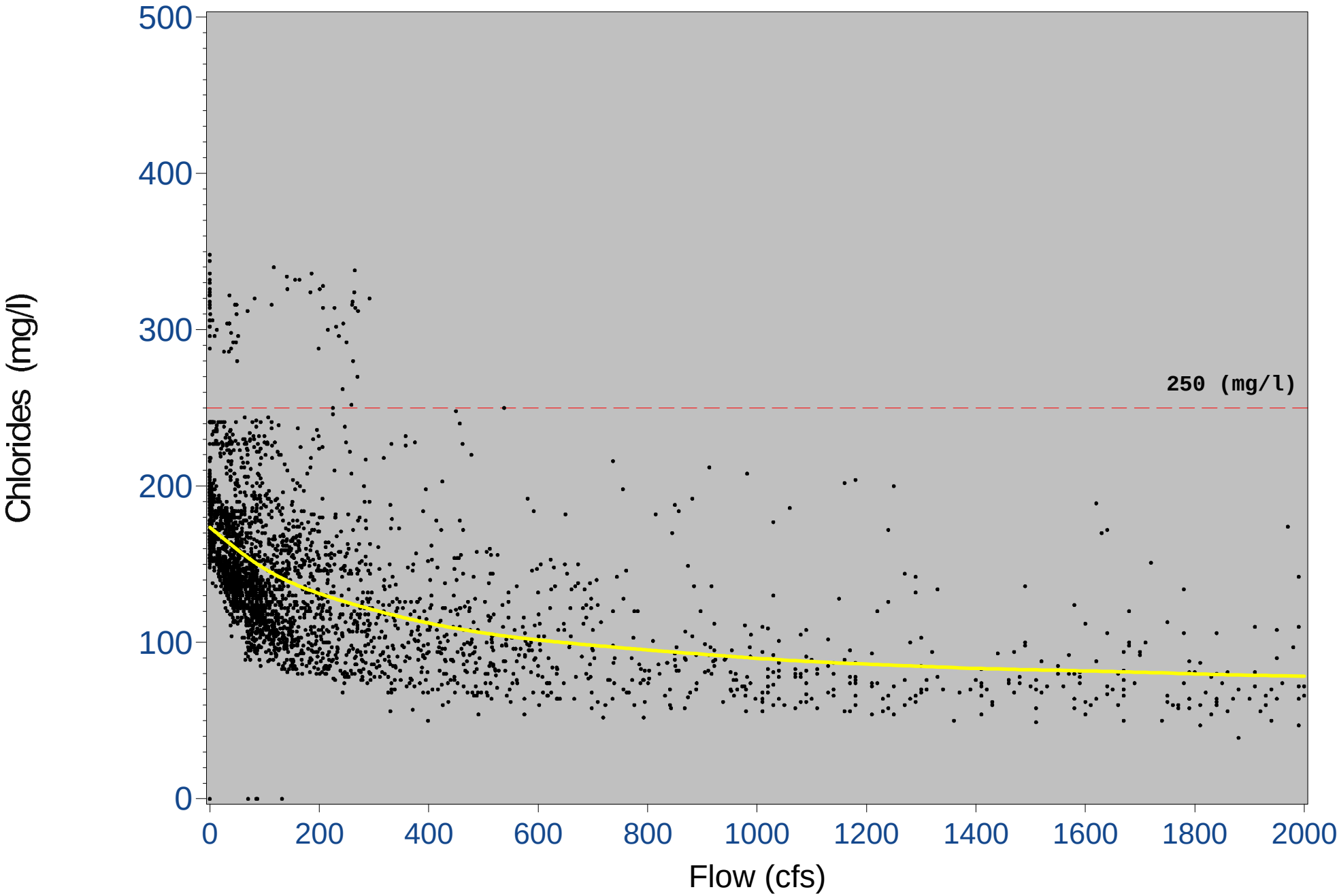


Figure 3.112b Chlorides from the City's intake vs. Shell Creek flow

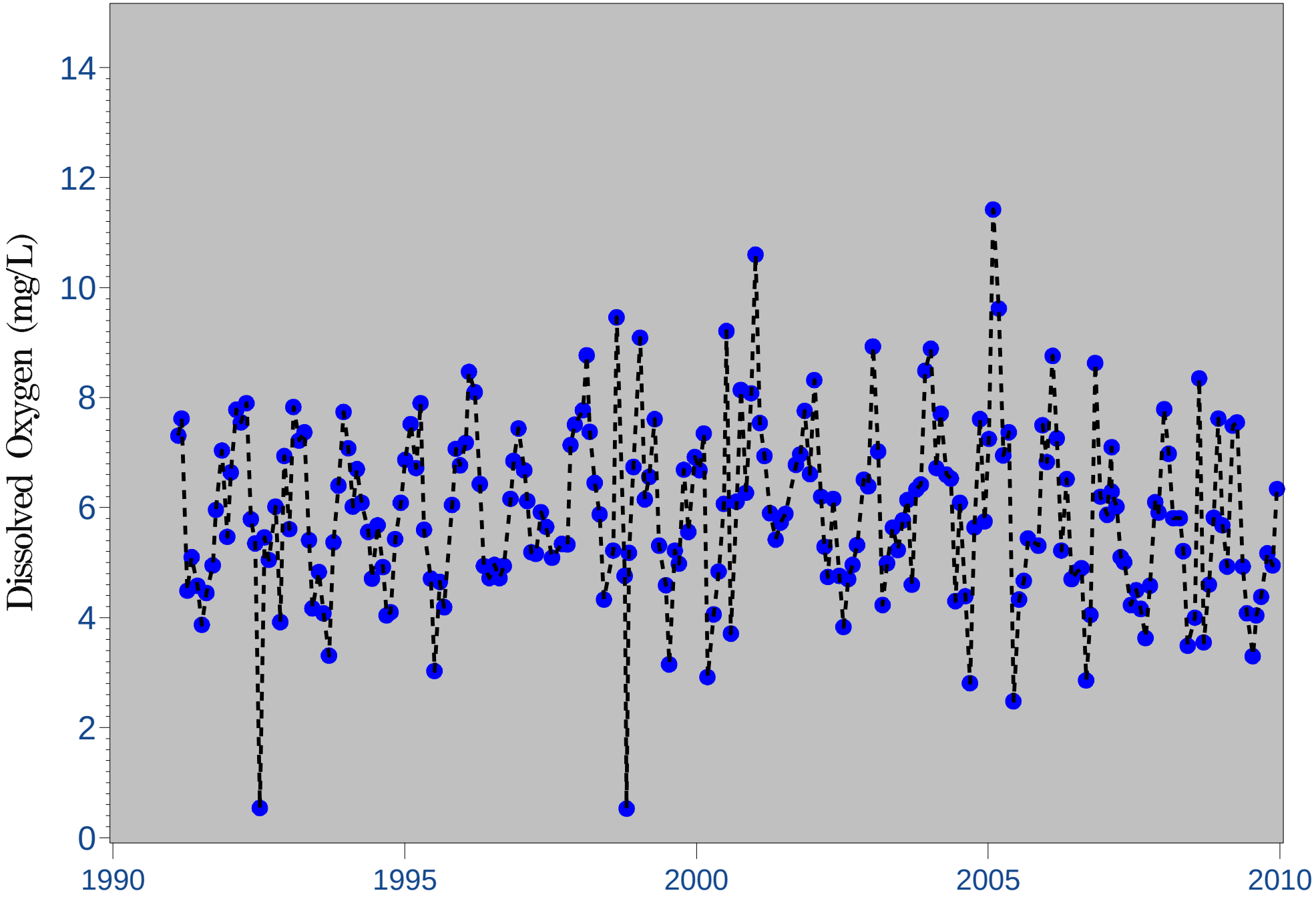


Figure 3.113a Monthly long-term dissolved oxygen - Prairie Creek at C.R. 764

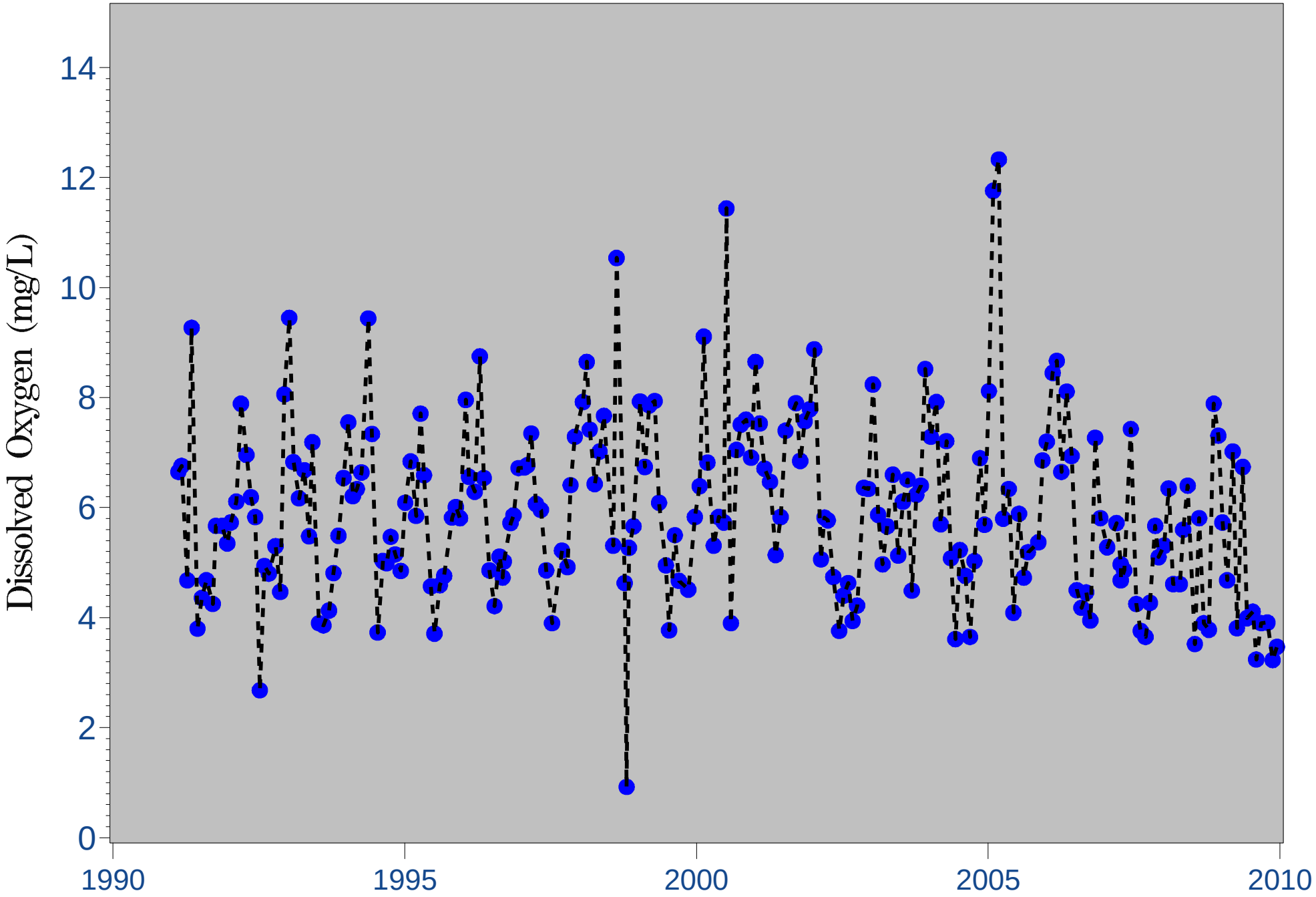


Figure 3.113b Monthly long-term dissolved oxygen - Shell Creek at C.R. 764

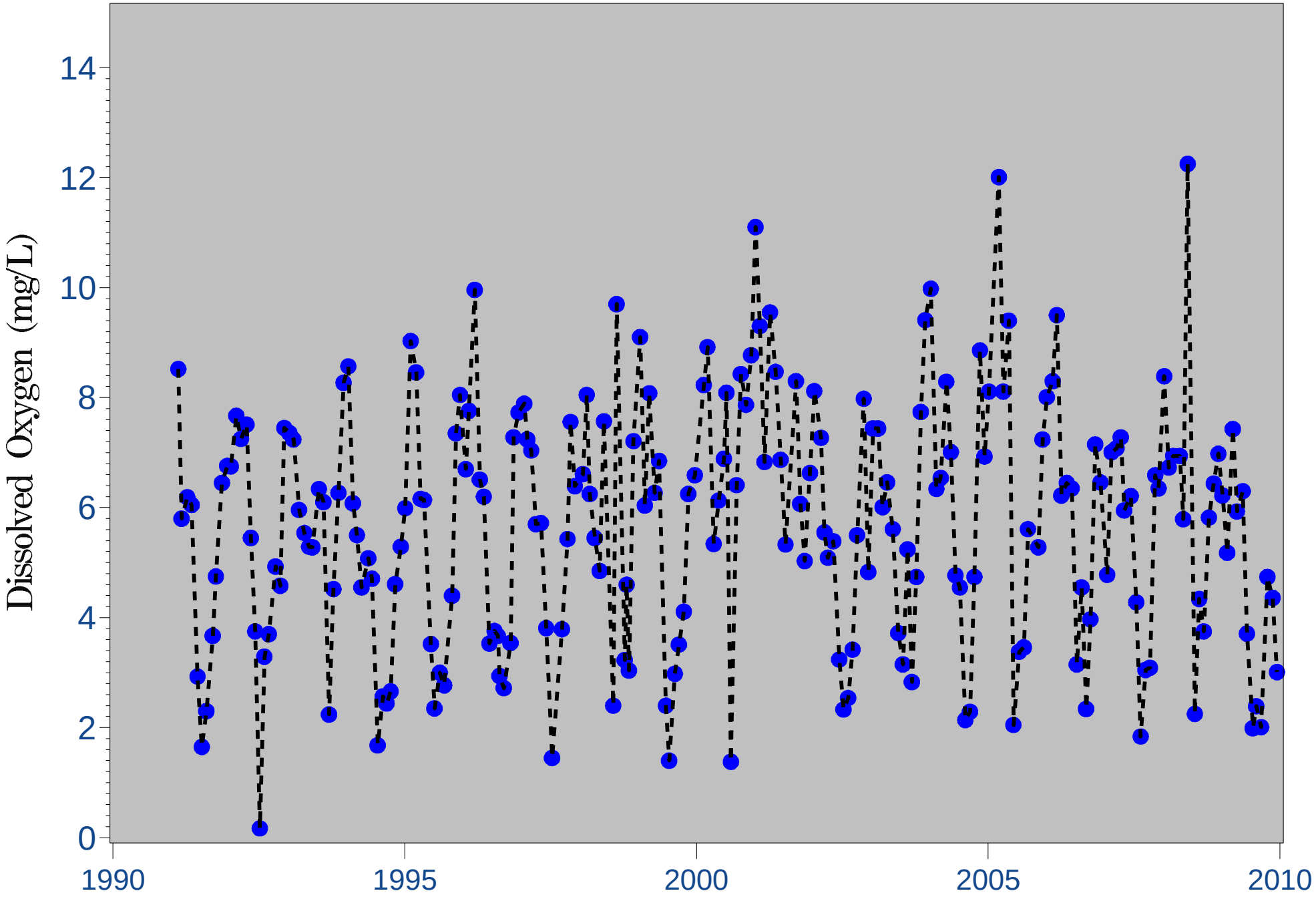


Figure 3.113c Monthly long-term dissolved oxygen - Shell Creek Reservoir just upstream of the Dam

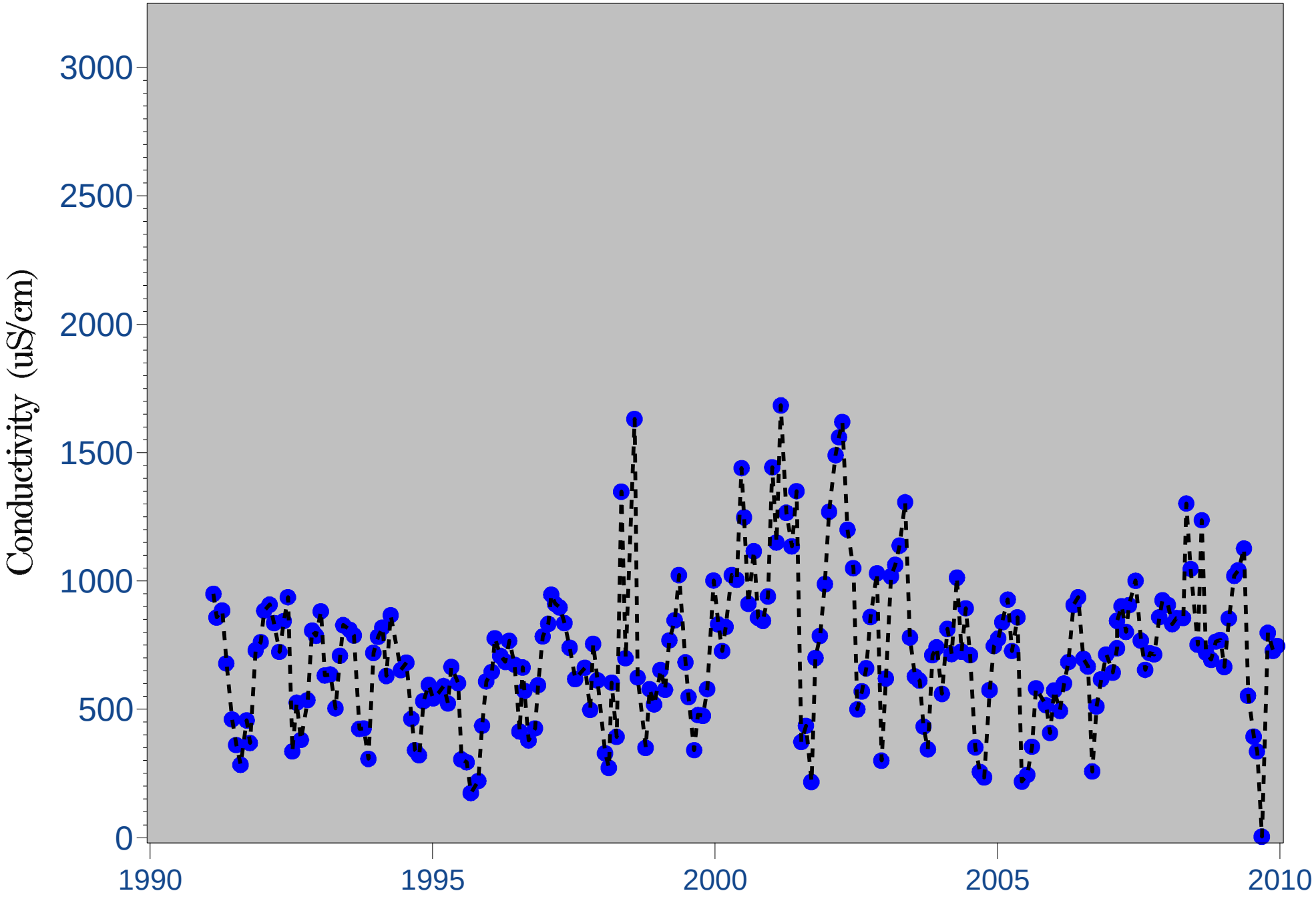


Figure 3.114a Monthly long-term conductivity - Prairie Creek at C.R. 764

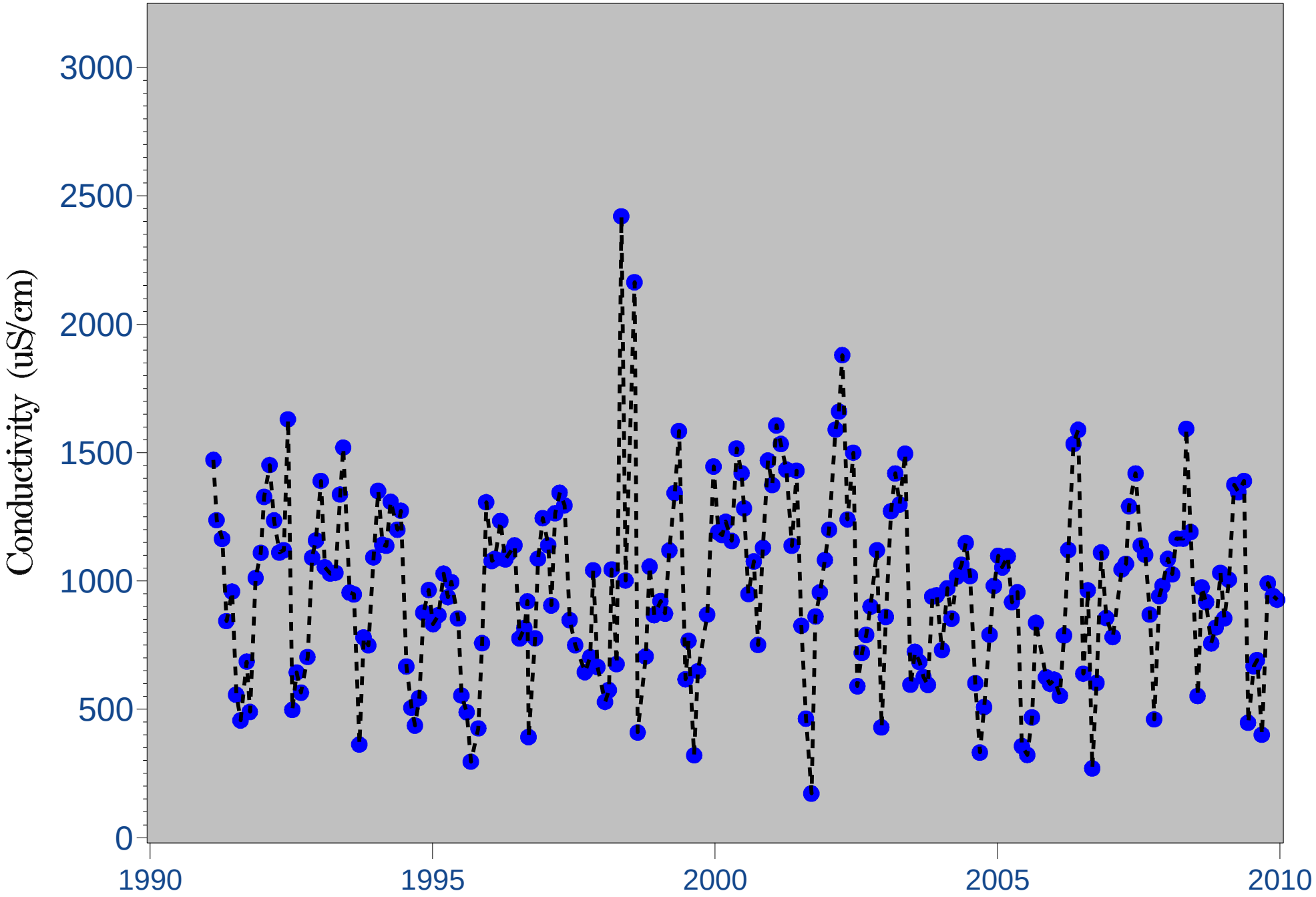


Figure 3.114b Monthly long-term conductivity - Shell Creek at C.R. 764

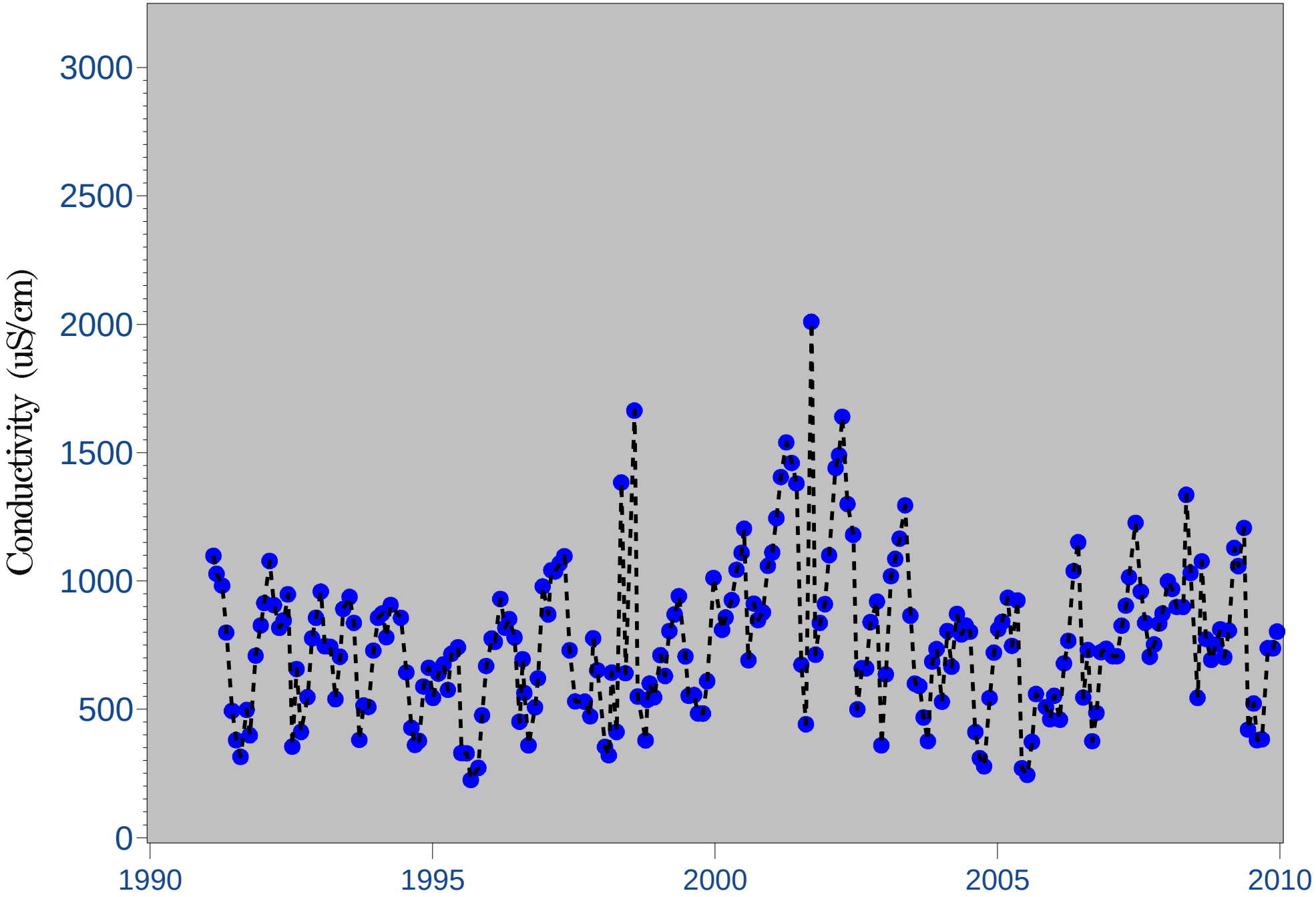


Figure 3.114c Monthly long-term conductivity - Shell Creek Reservoir just upstream of the Dam

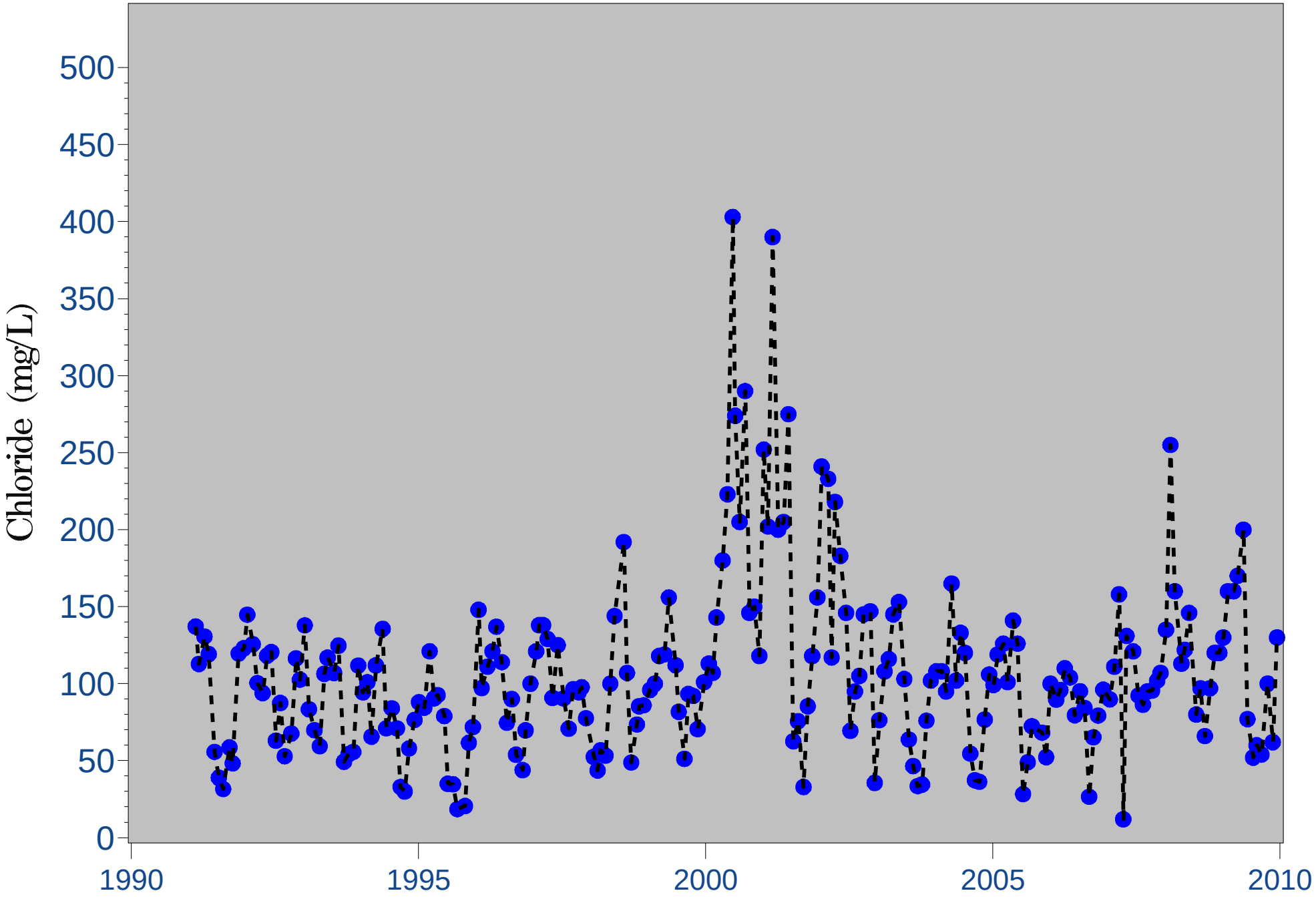


Figure 3.115a Monthly long-term chloride - Prairie Creek at C.R. 764

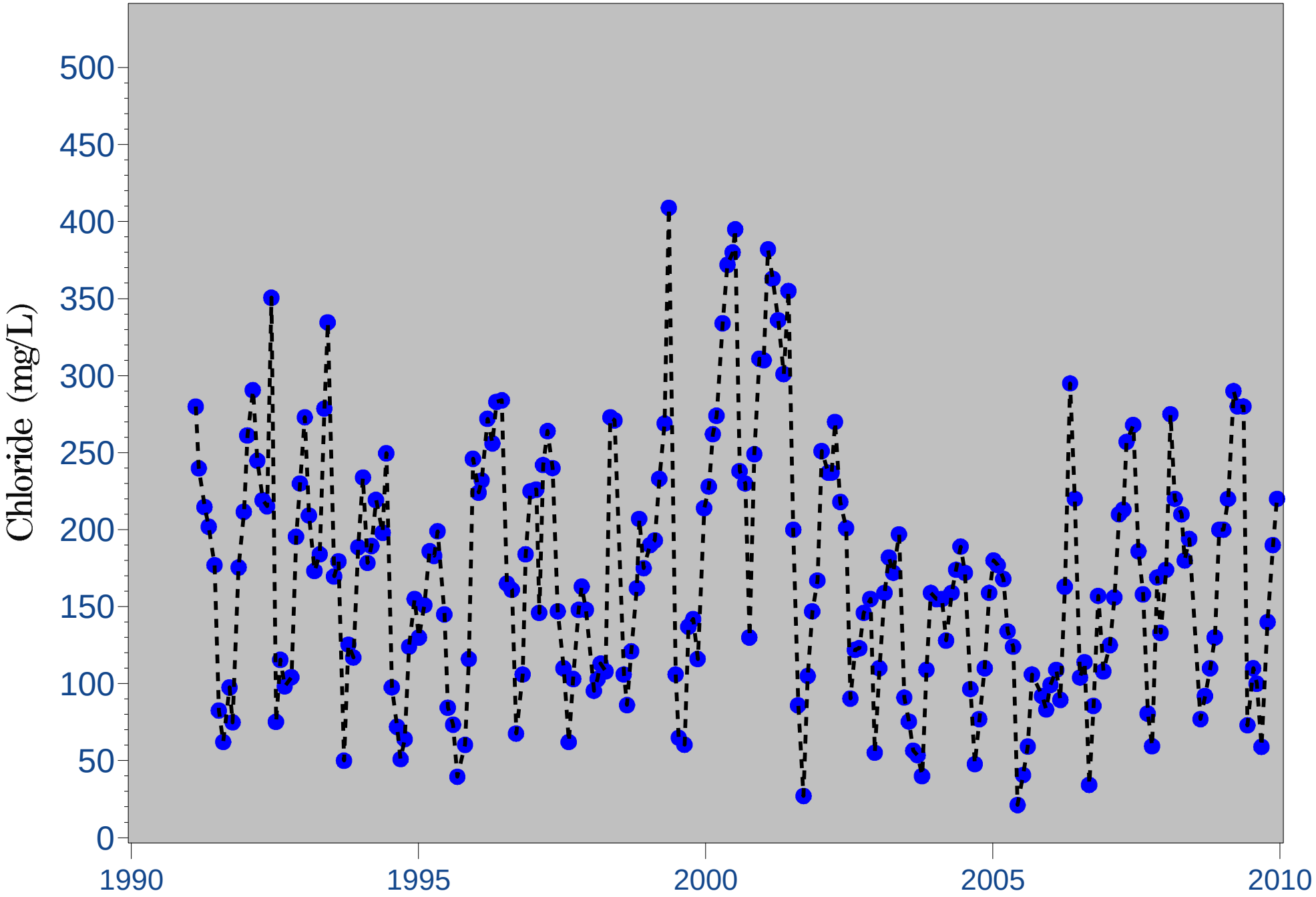


Figure 3.115b Monthly long-term chloride - Shell Creek at C.R. 764

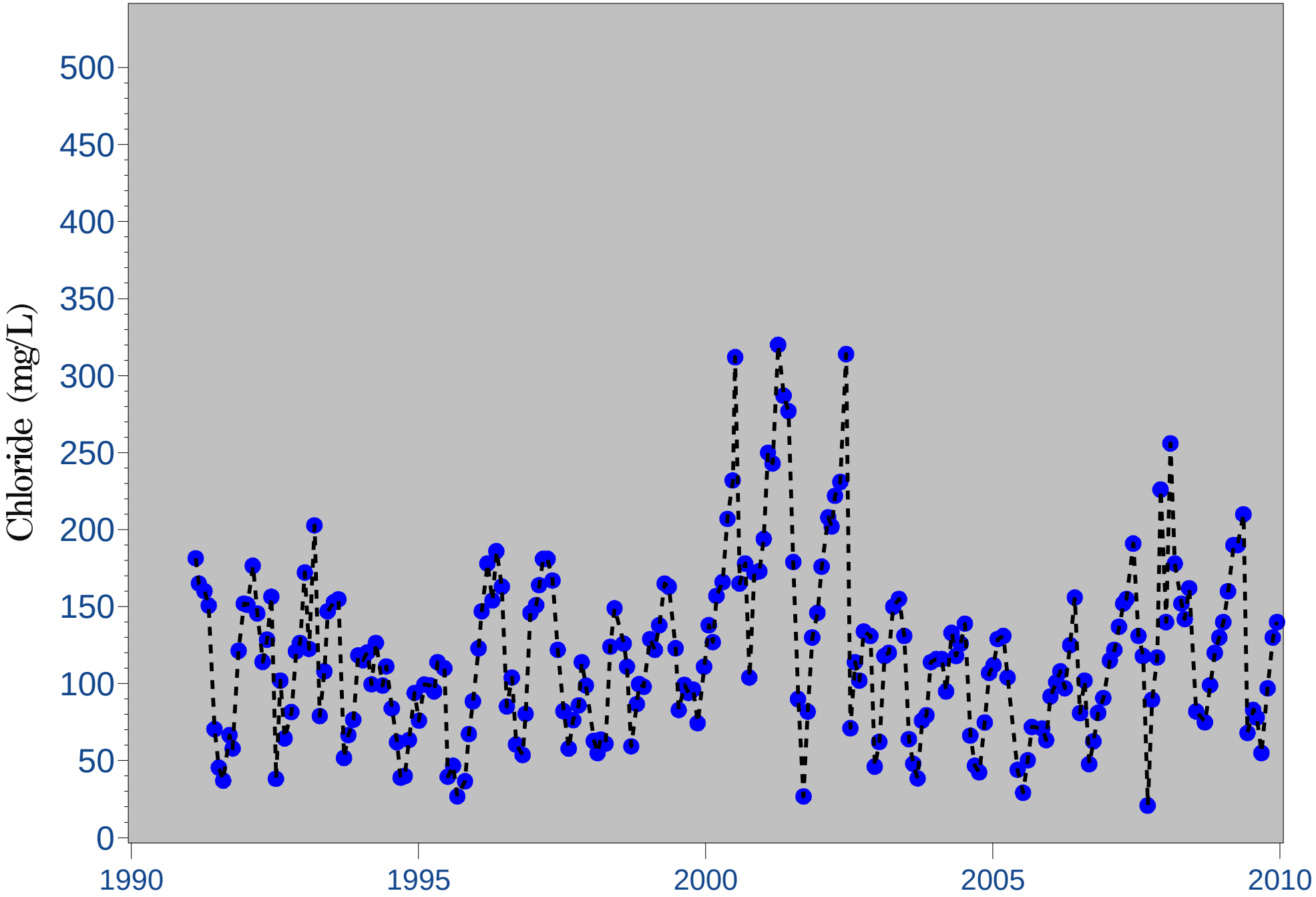


Figure 3.115c Monthly long-term chloride - Shell Creek Reservoir just upstream of the Dam

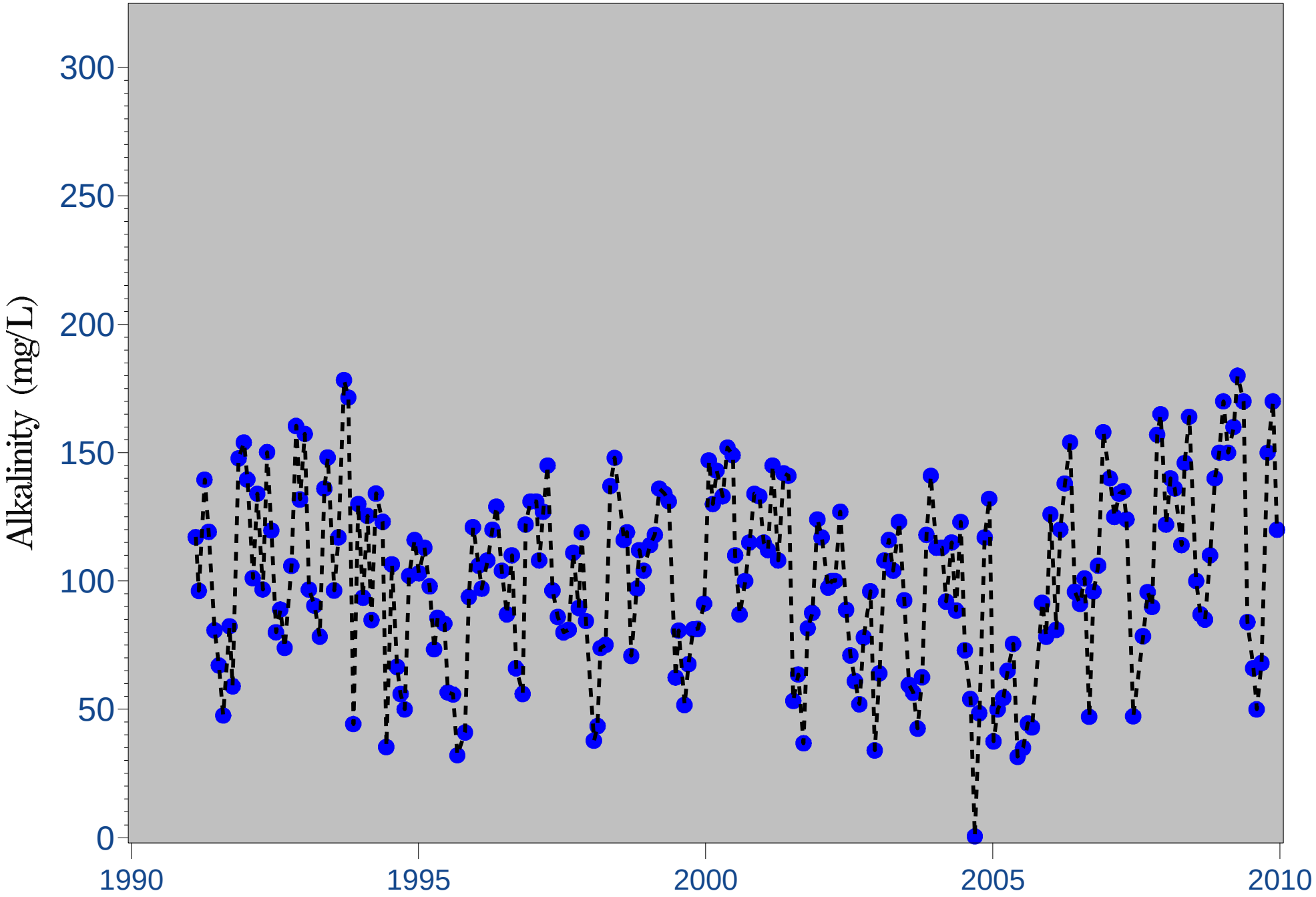


Figure 3.116a Monthly long-term alkalinity - Prairie Creek at C.R. 764

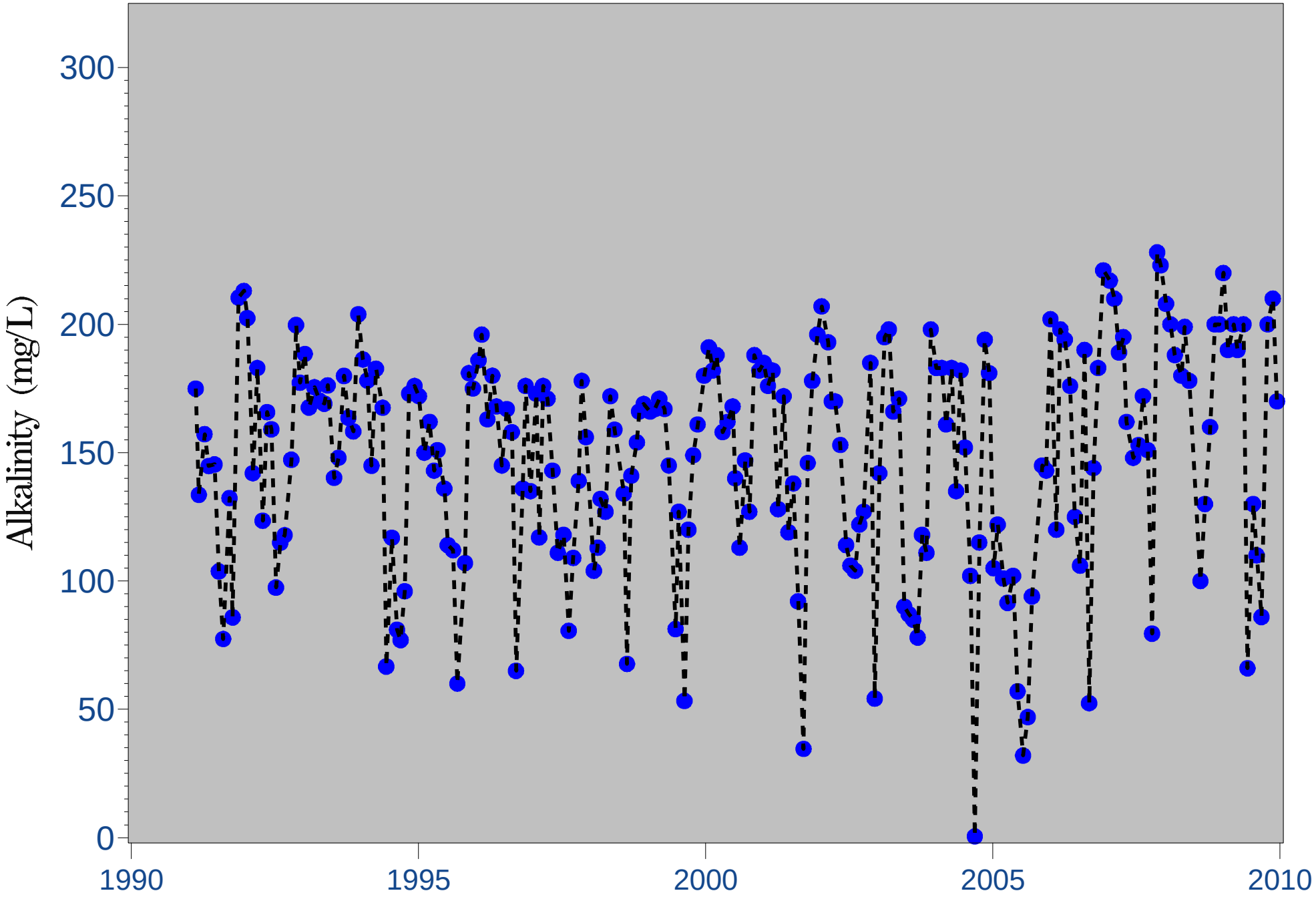


Figure 3.116b Monthly long-term alkalinity - Shell Creek at C.R. 764

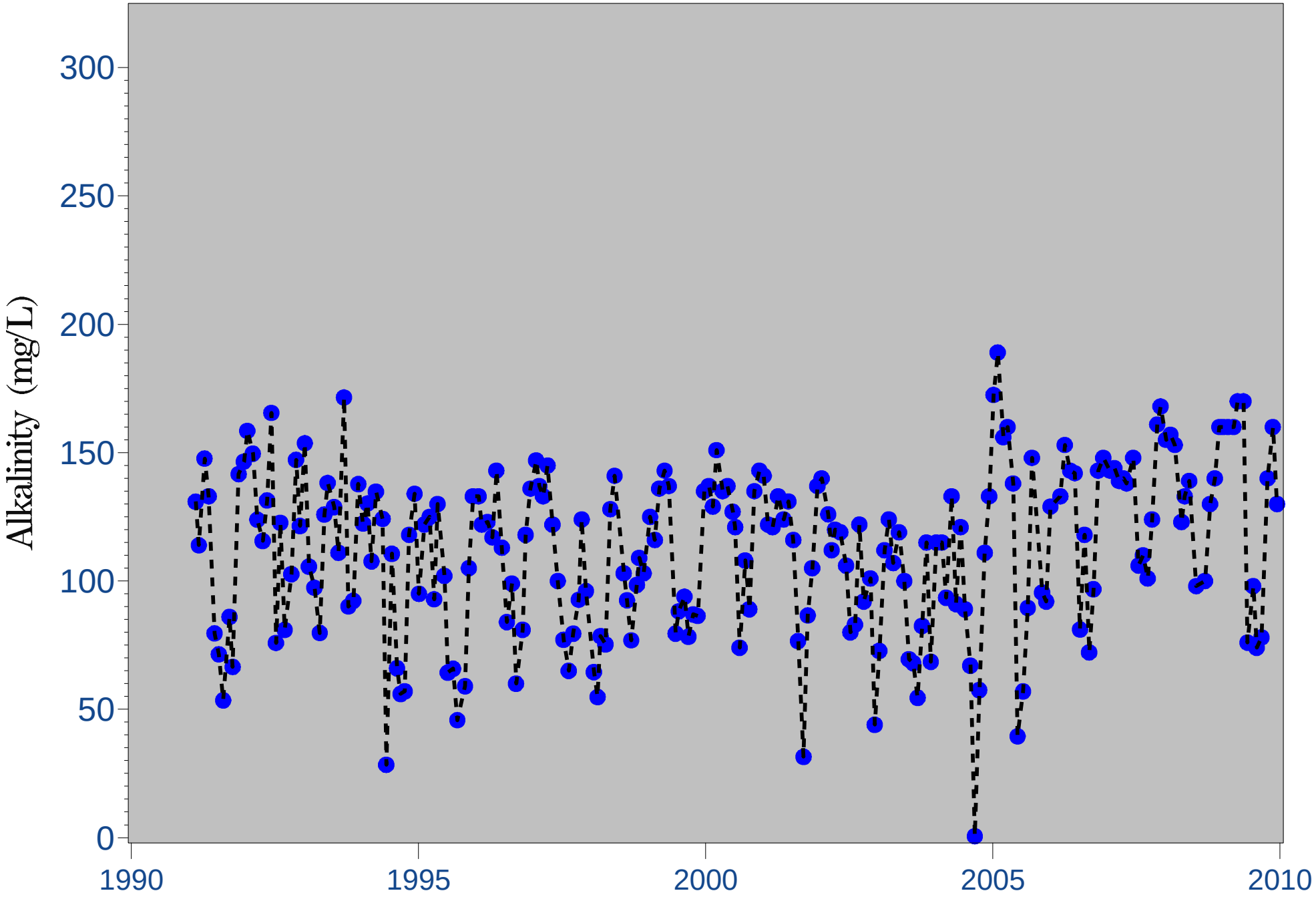


Figure 3.116c Monthly long-term alkalinity - Shell Creek Reservoir just upstream of the Dam

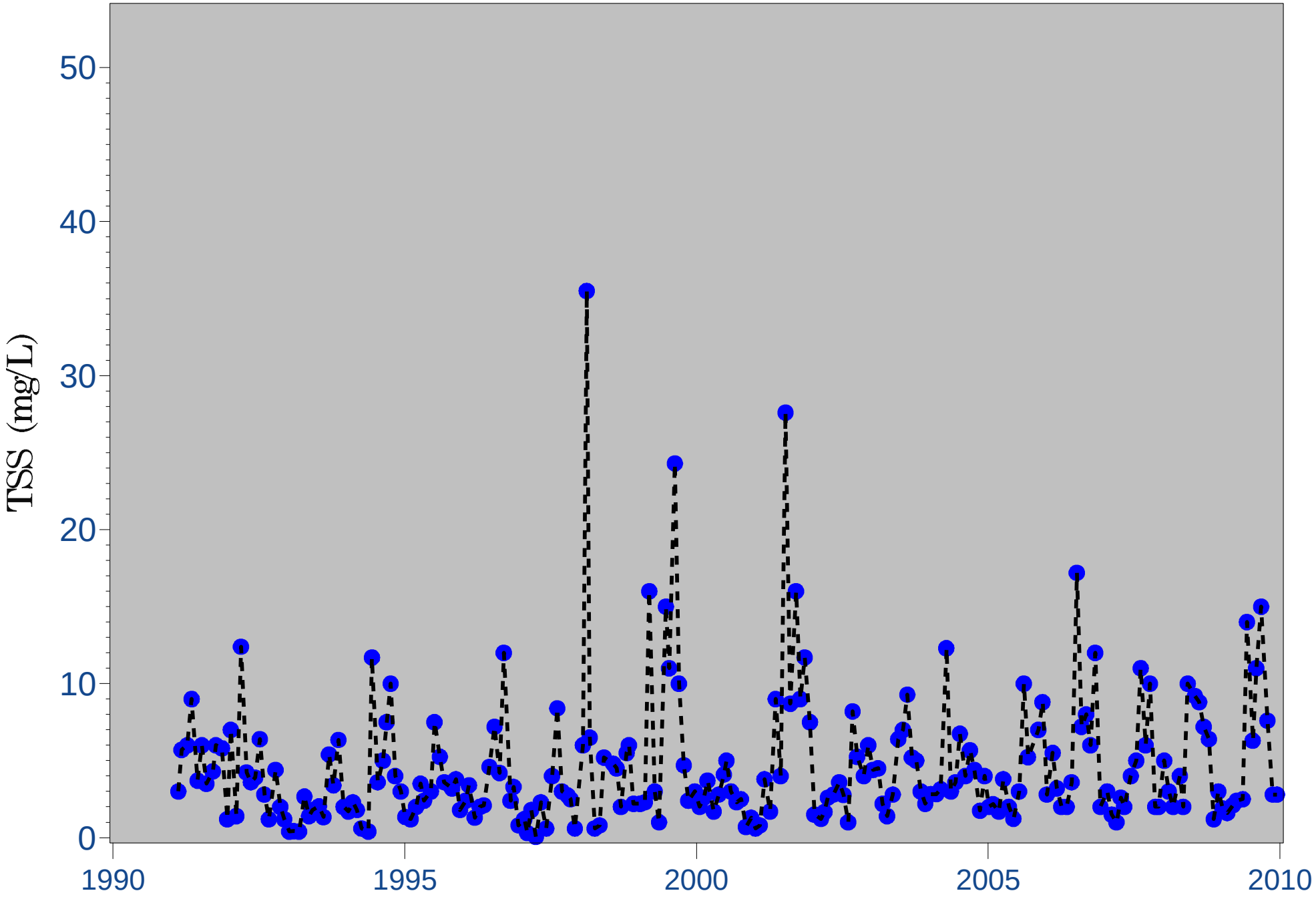


Figure 3.117a Monthly long-term total suspended solids - Prairie Creek at C.R. 764

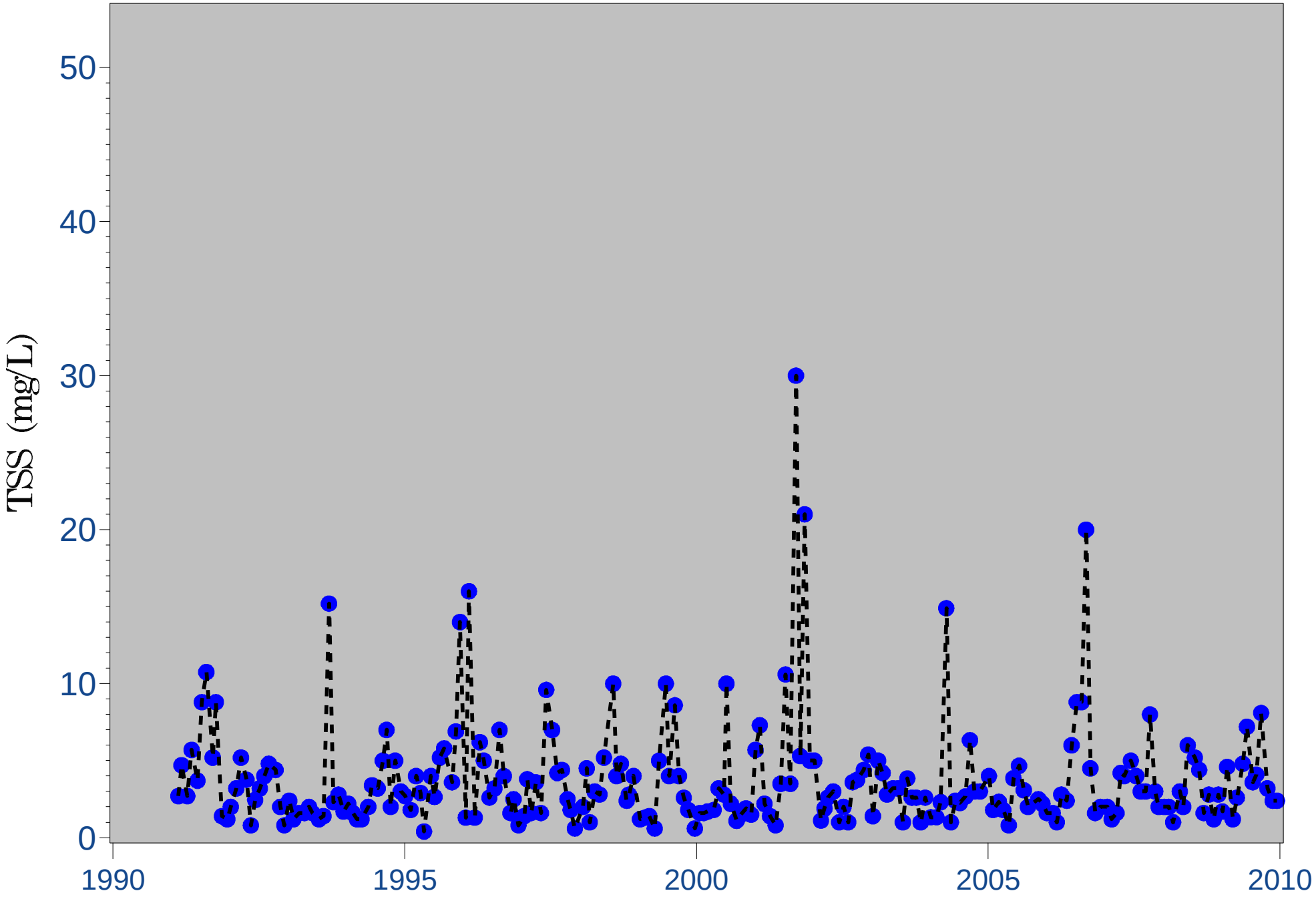


Figure 3.117b Monthly long-term total suspended solids - Shell Creek at C.R. 764

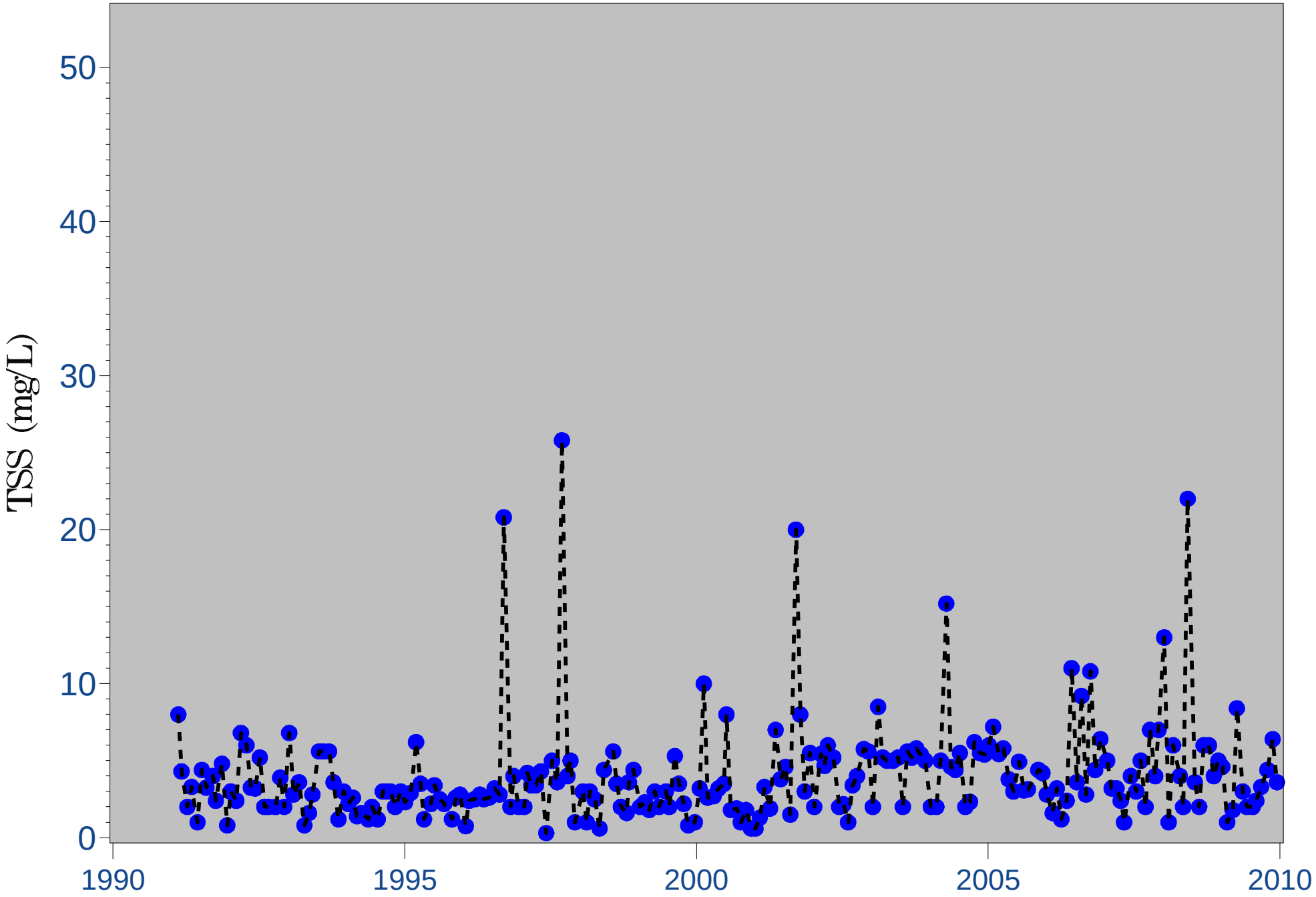


Figure 3.117c Monthly long-term total suspended solids - Shell Creek Reservoir just upstream of the Dam

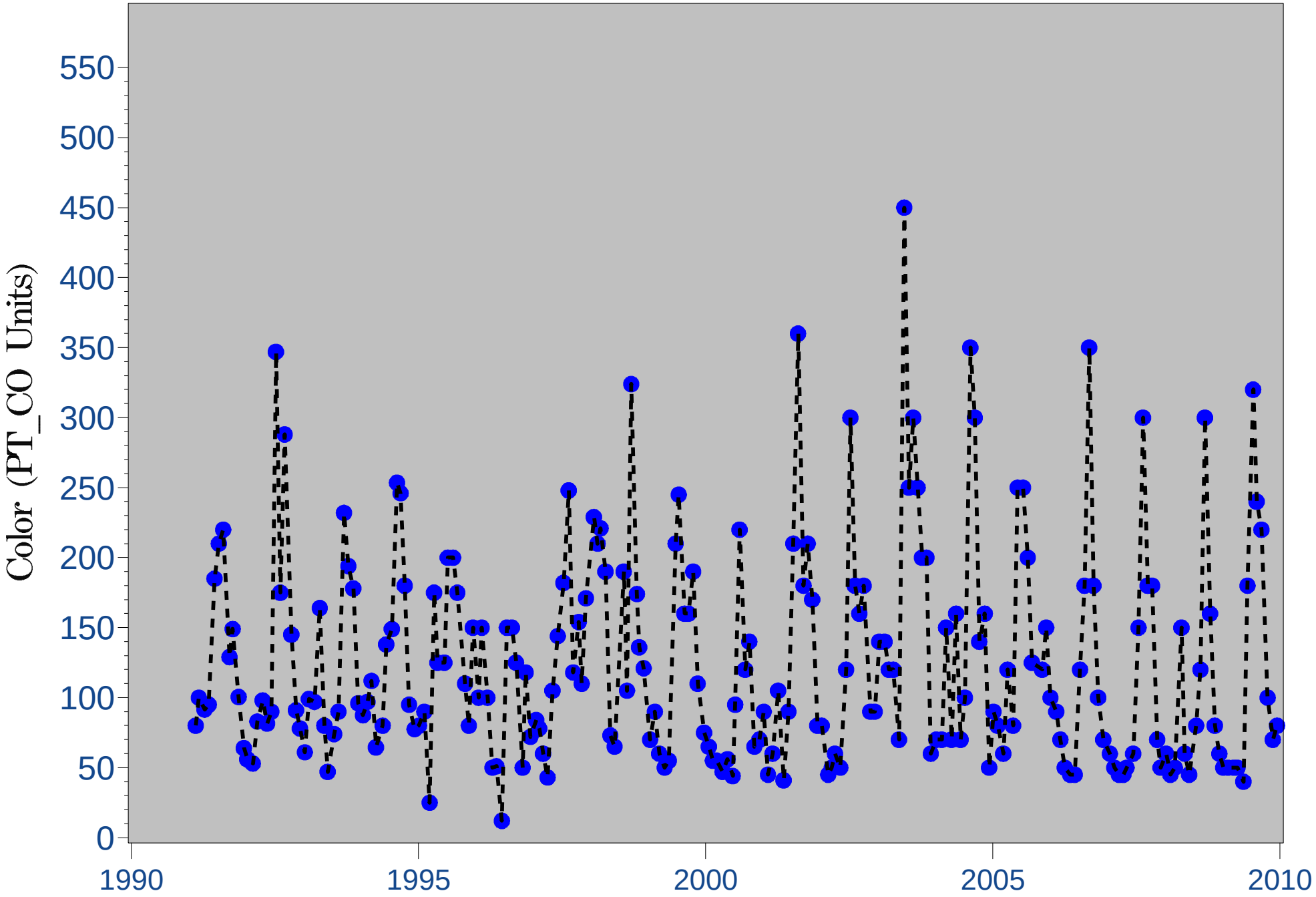


Figure 3.118a Monthly long-term water color - Prairie Creek at C.R. 764

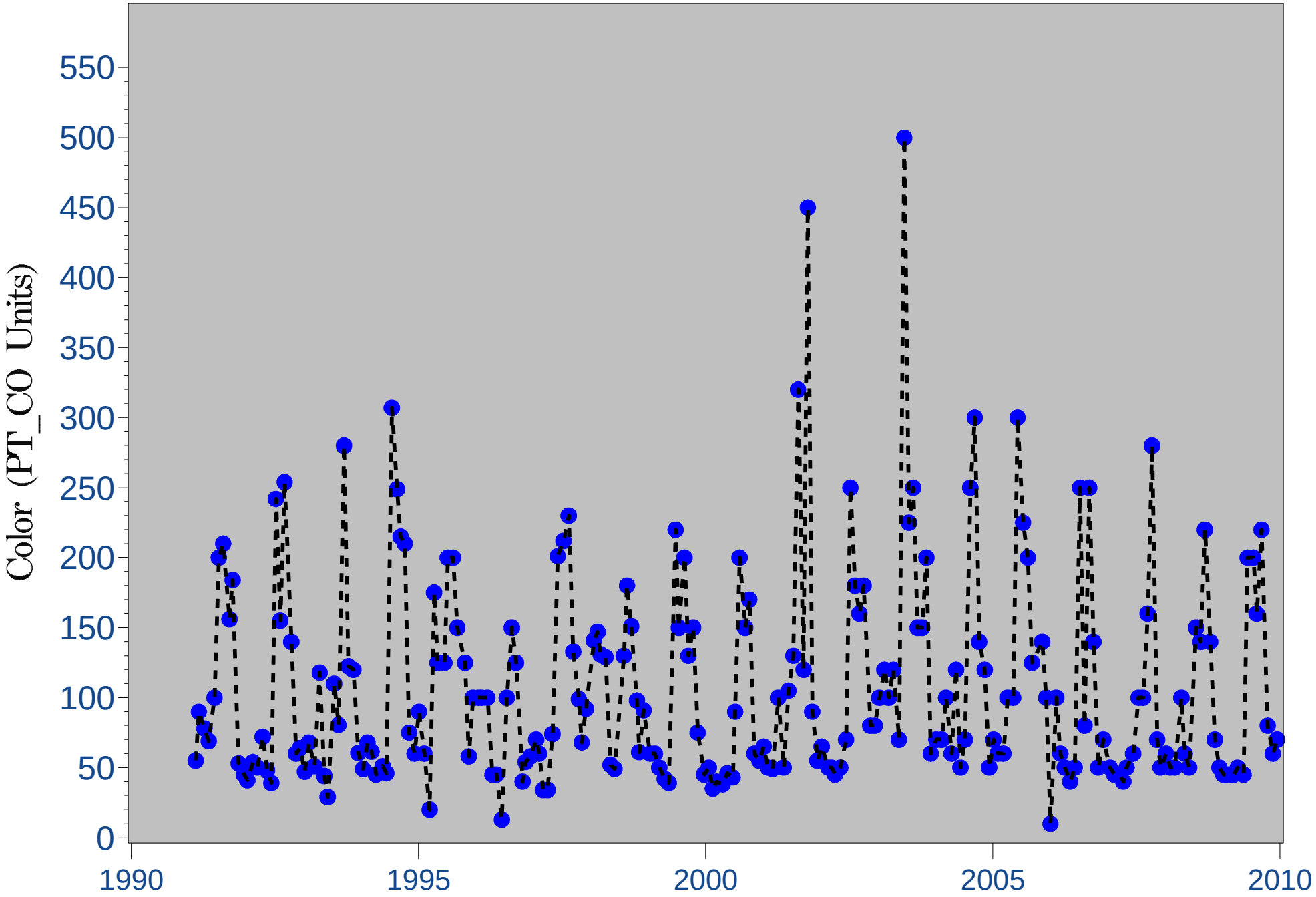


Figure 3.118b Monthly long-term water color - Shell Creek at C.R. 764

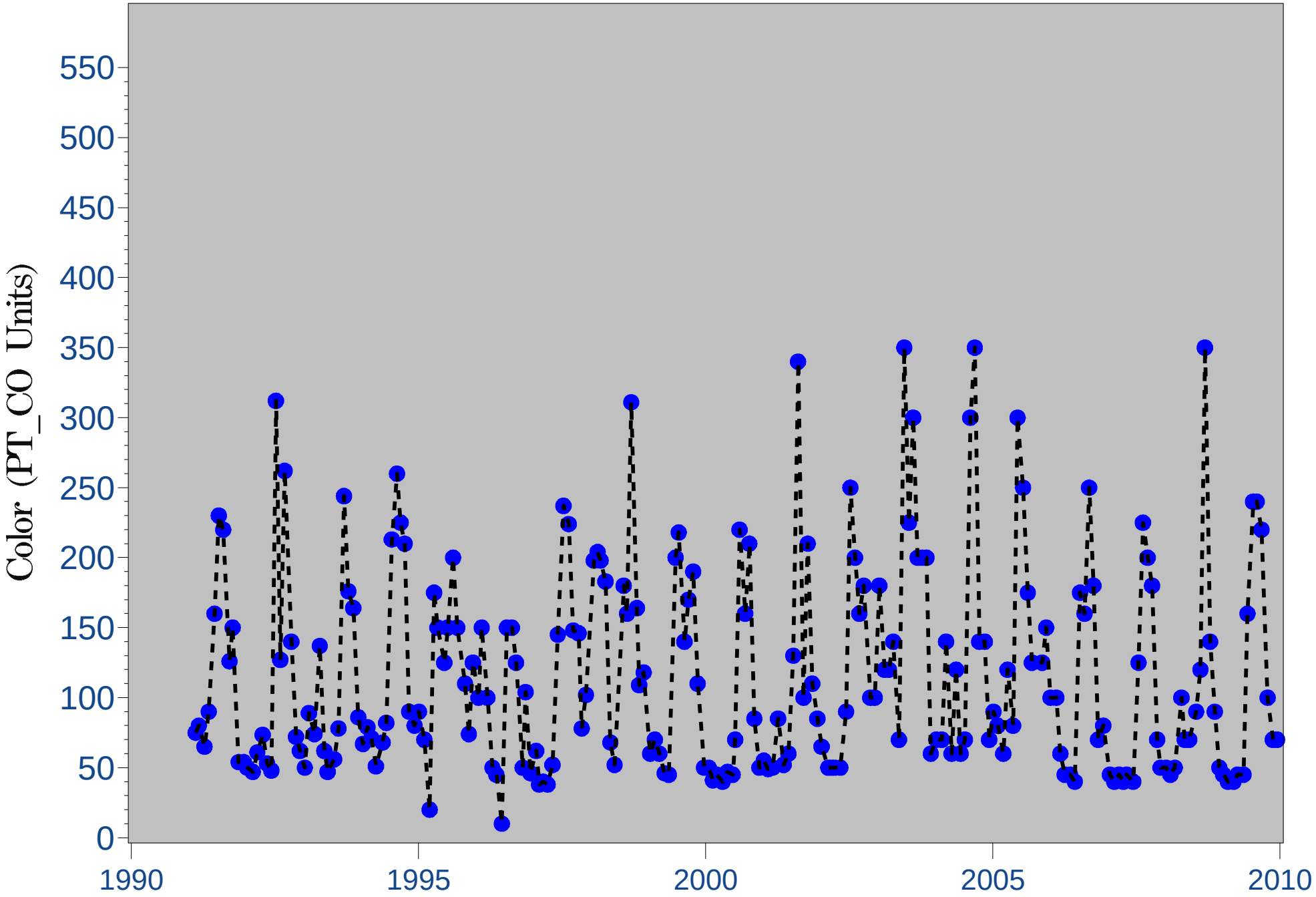


Figure 3.118c Monthly long-term water color - Shell Creek Reservoir just upstream of the Dam

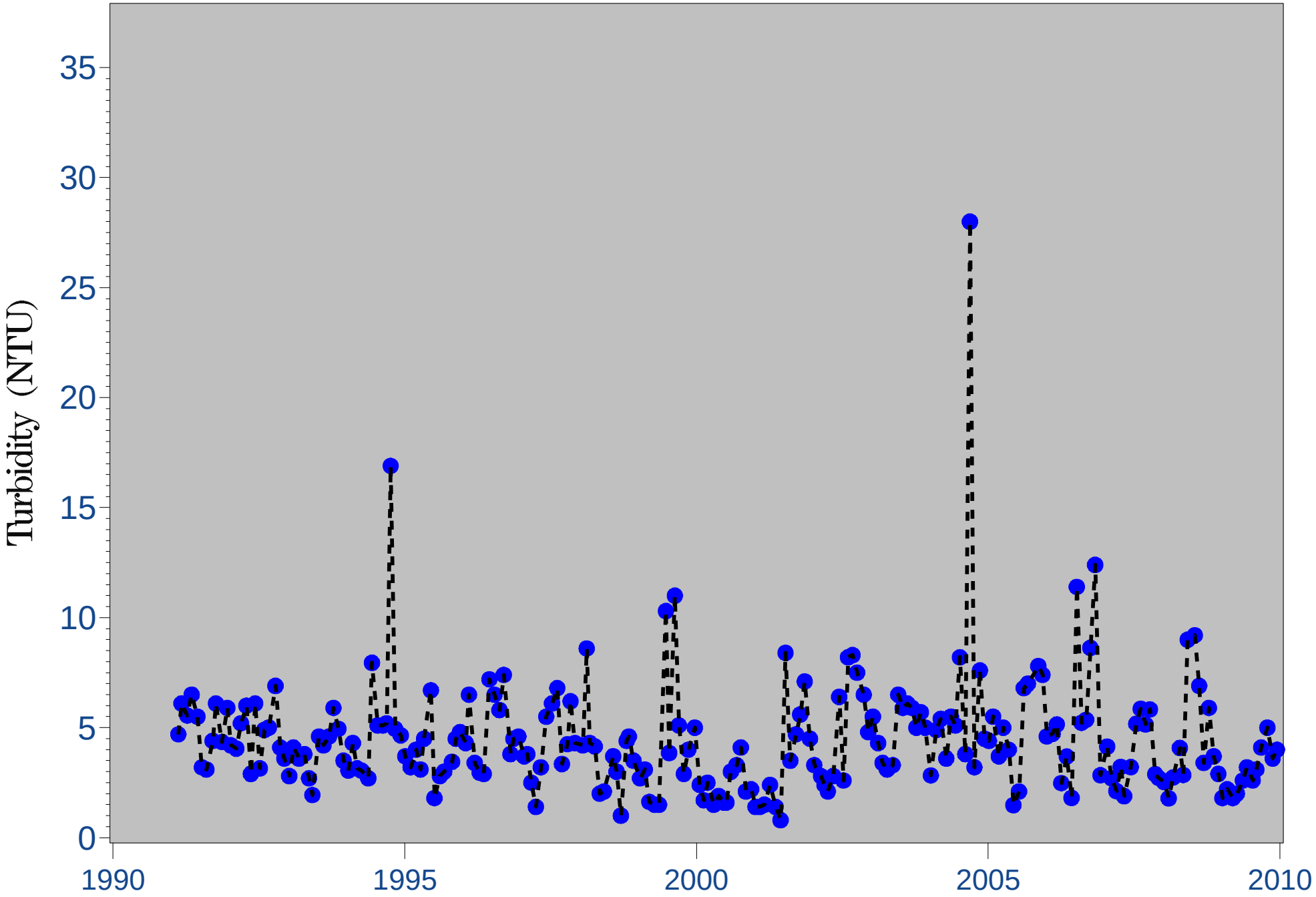


Figure 3.119a Monthly long-term turbidity - Prairie Creek at C.R. 764

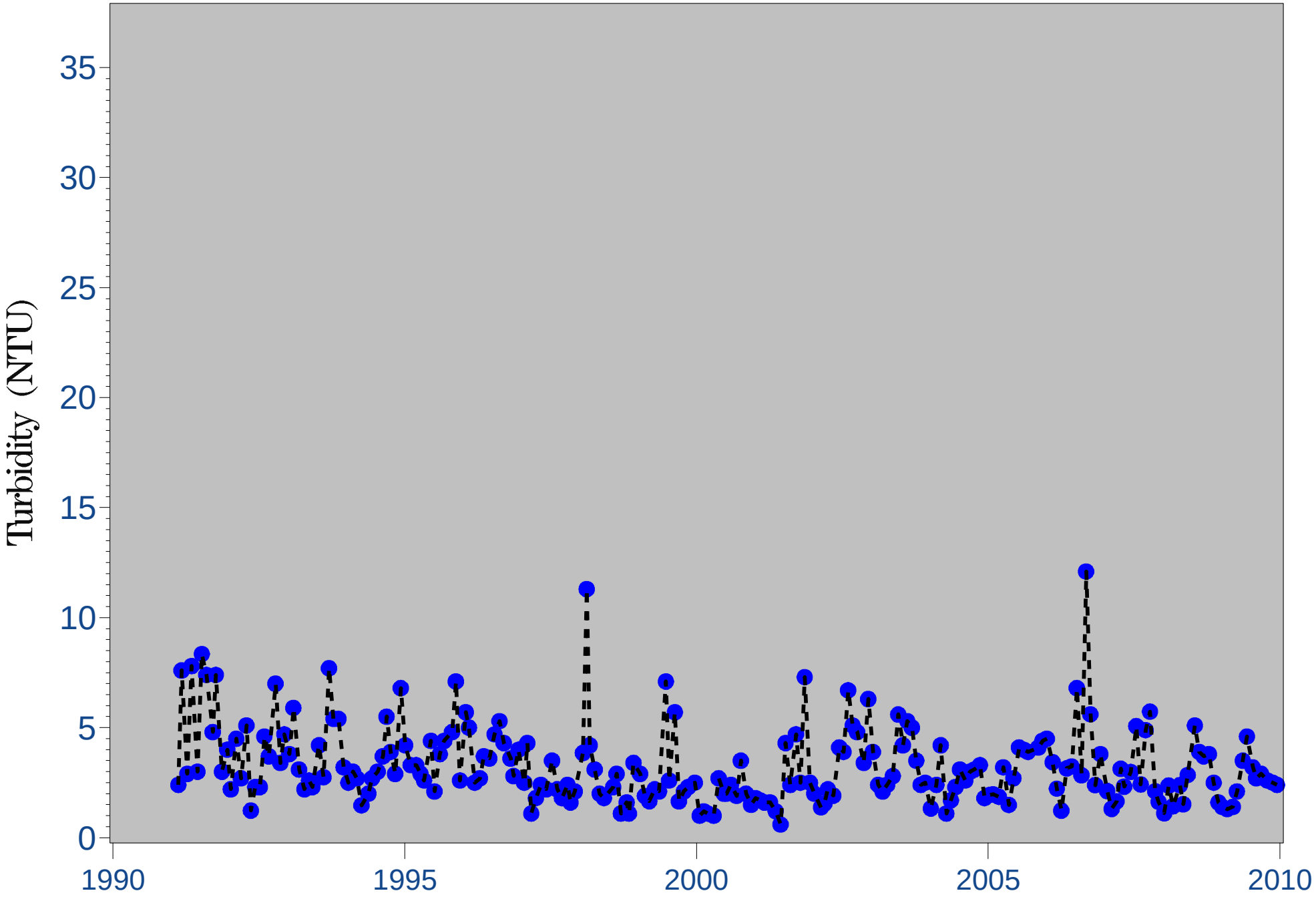


Figure 3.119b Monthly long-term turbidity - Shell Creek at C.R. 764

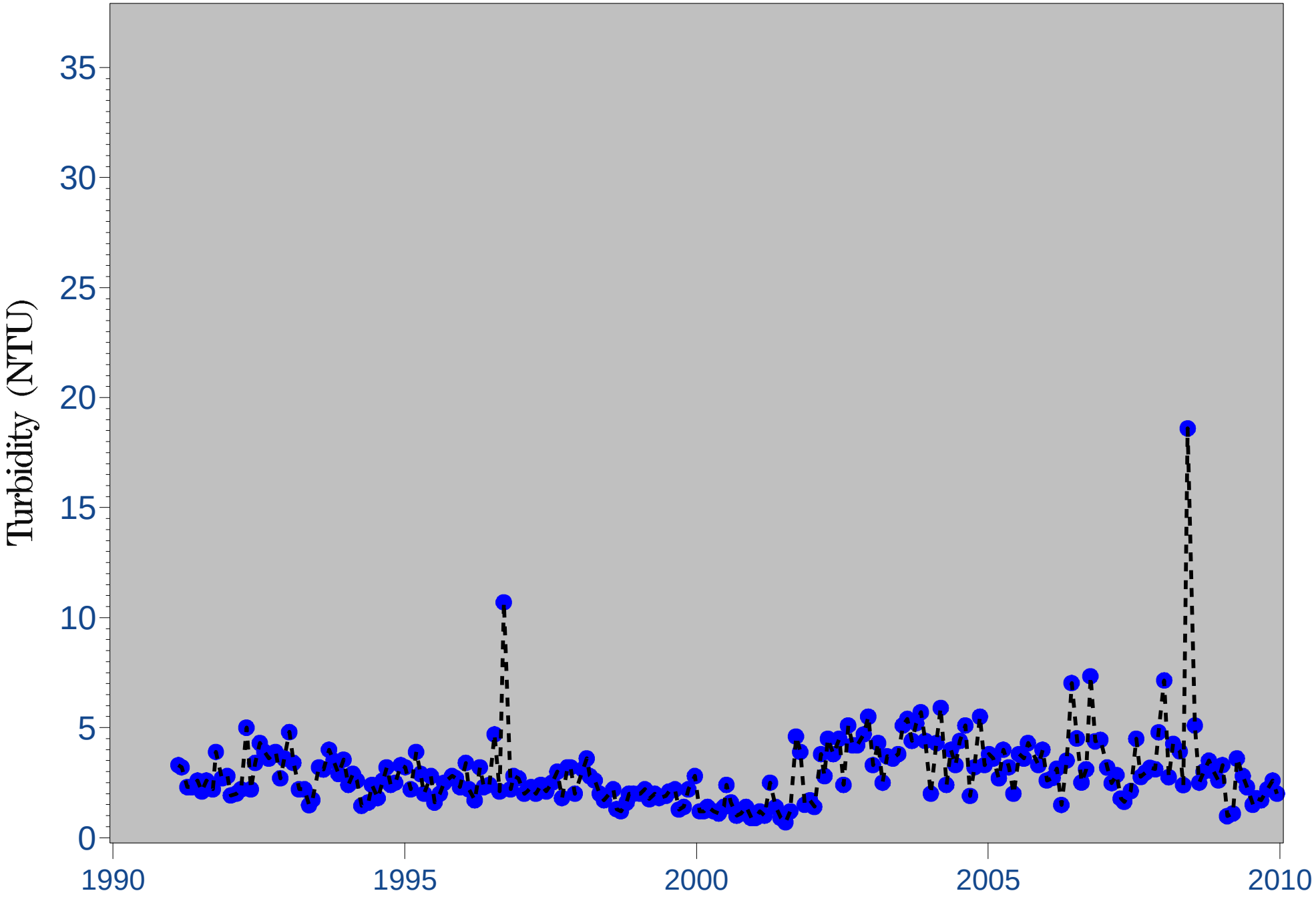


Figure 3.119c Monthly long-term turbidity - Shell Creek Reservoir just upstream of the Dam

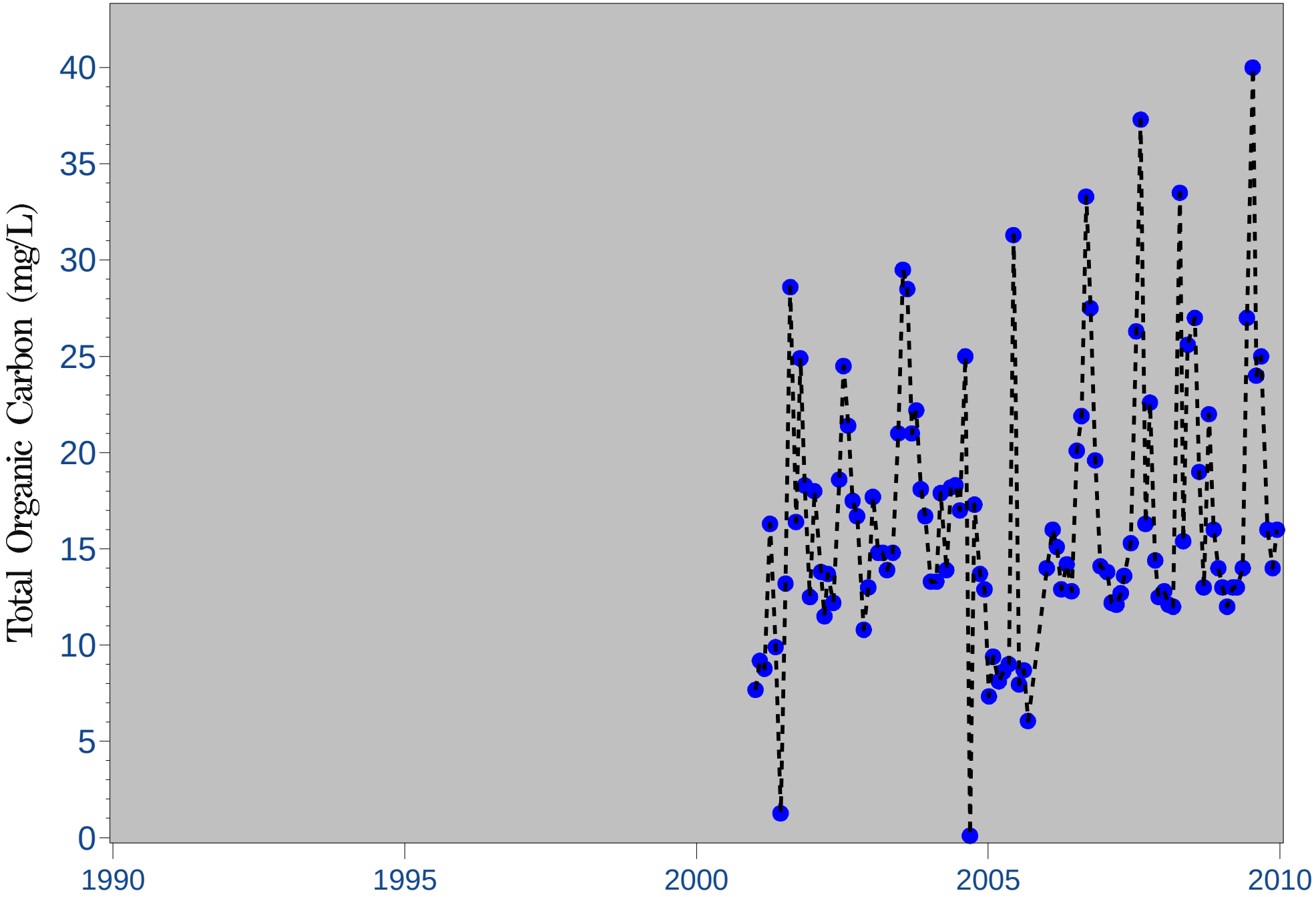


Figure 3.120a Monthly long-term toal organic carbon - Prairie Creek at C.R. 764

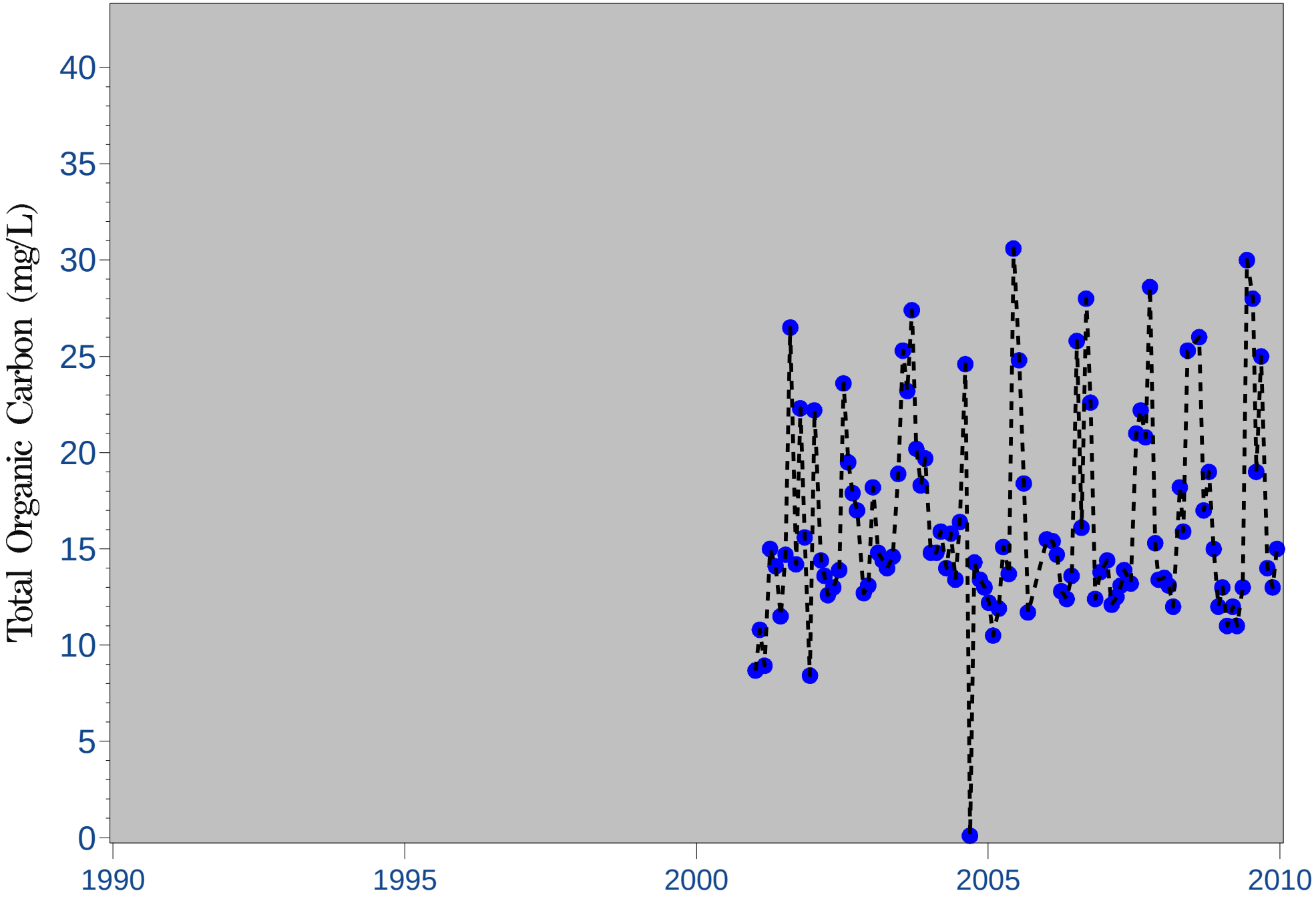


Figure 3.120b Monthly long-term total organic carbon - Shell Creek at C.R. 764

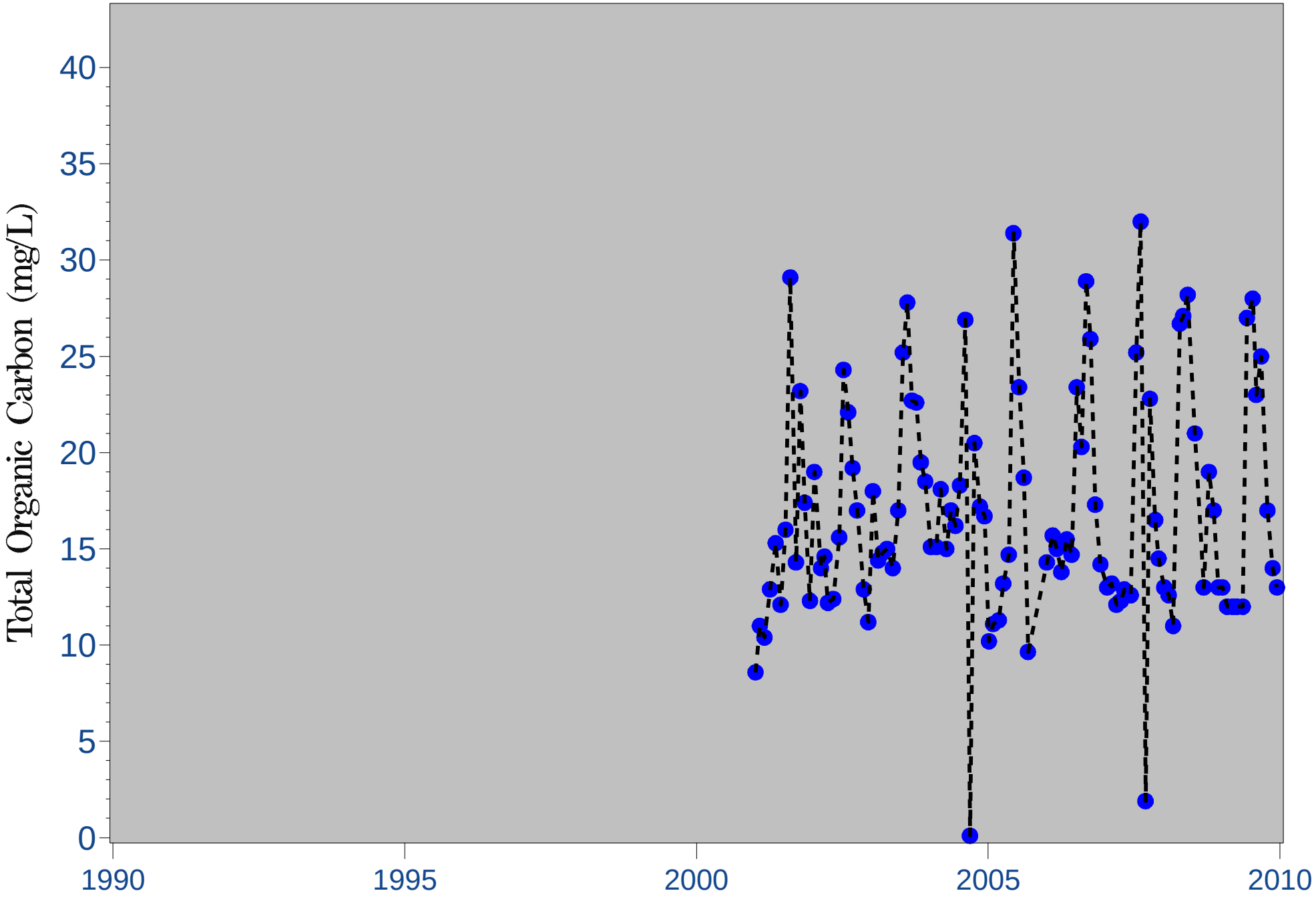


Figure 3.120c Monthly long-term total organic carbon - Shell Creek Reservoir just upstream of the Dam

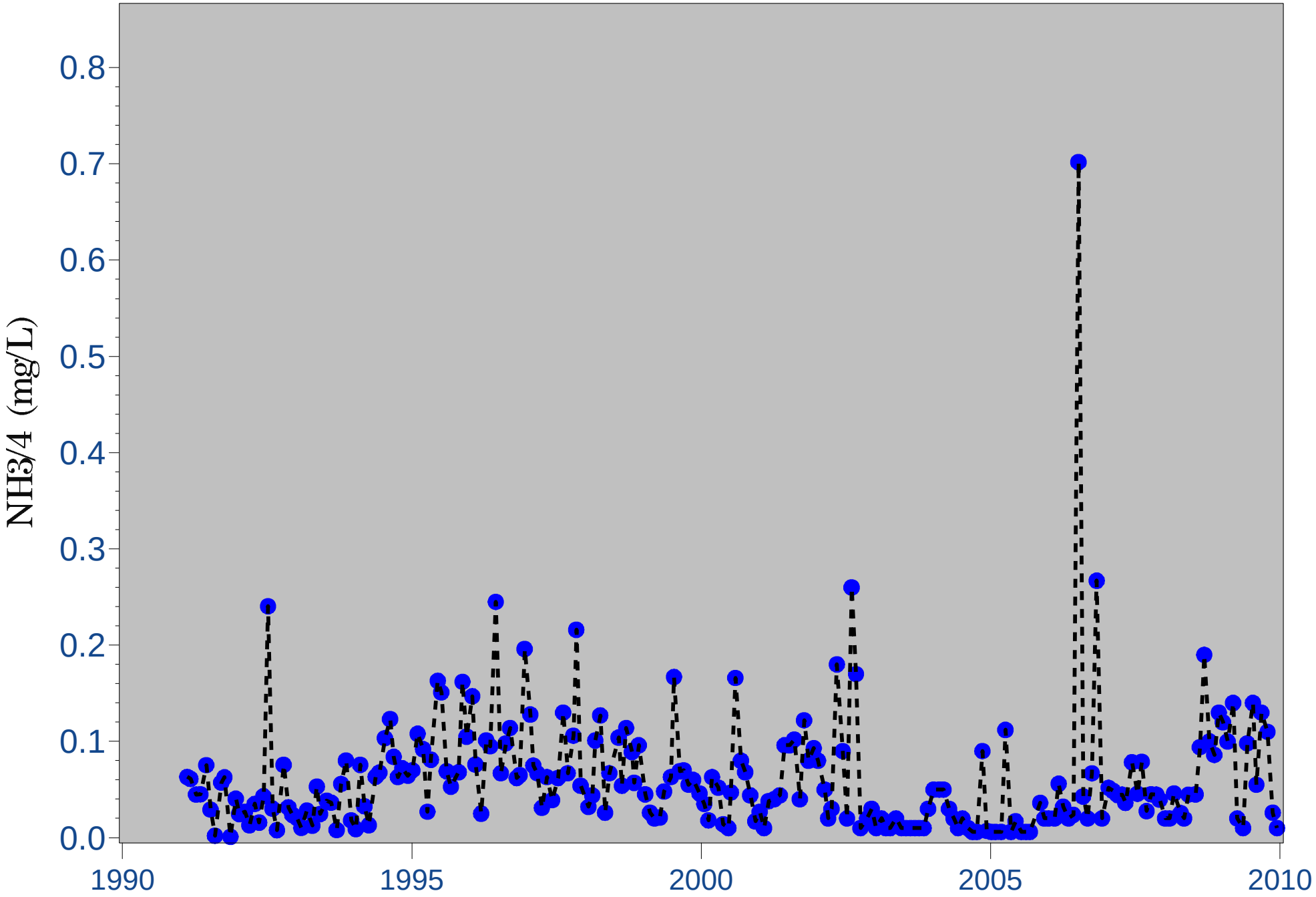


Figure 3.121a Monthly long-term ammonia/ammonium - Prairie Creek at C.R. 764

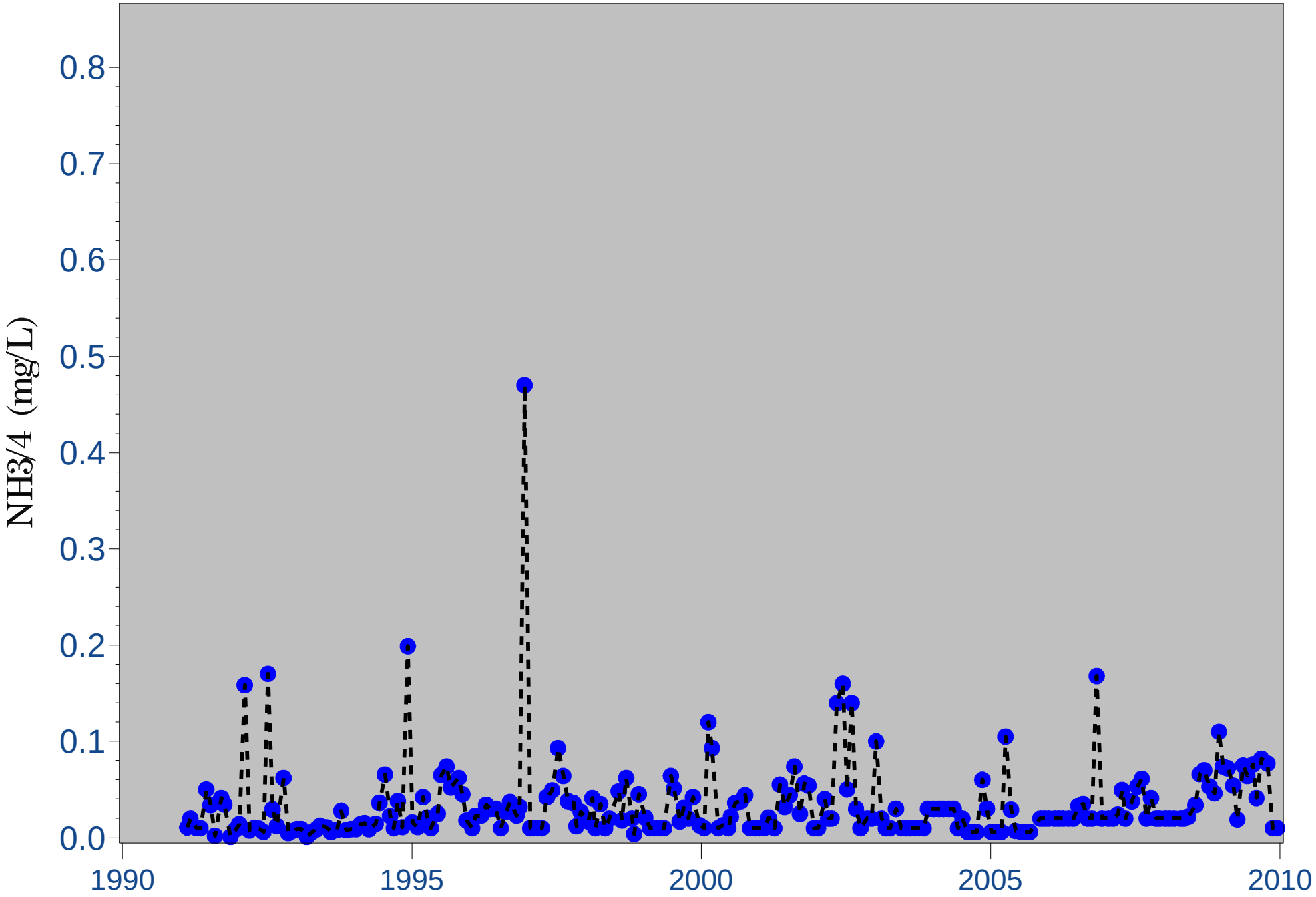


Figure 3.121b Monthly long-term ammonia/ammonium - Shell Creek at C.R. 764

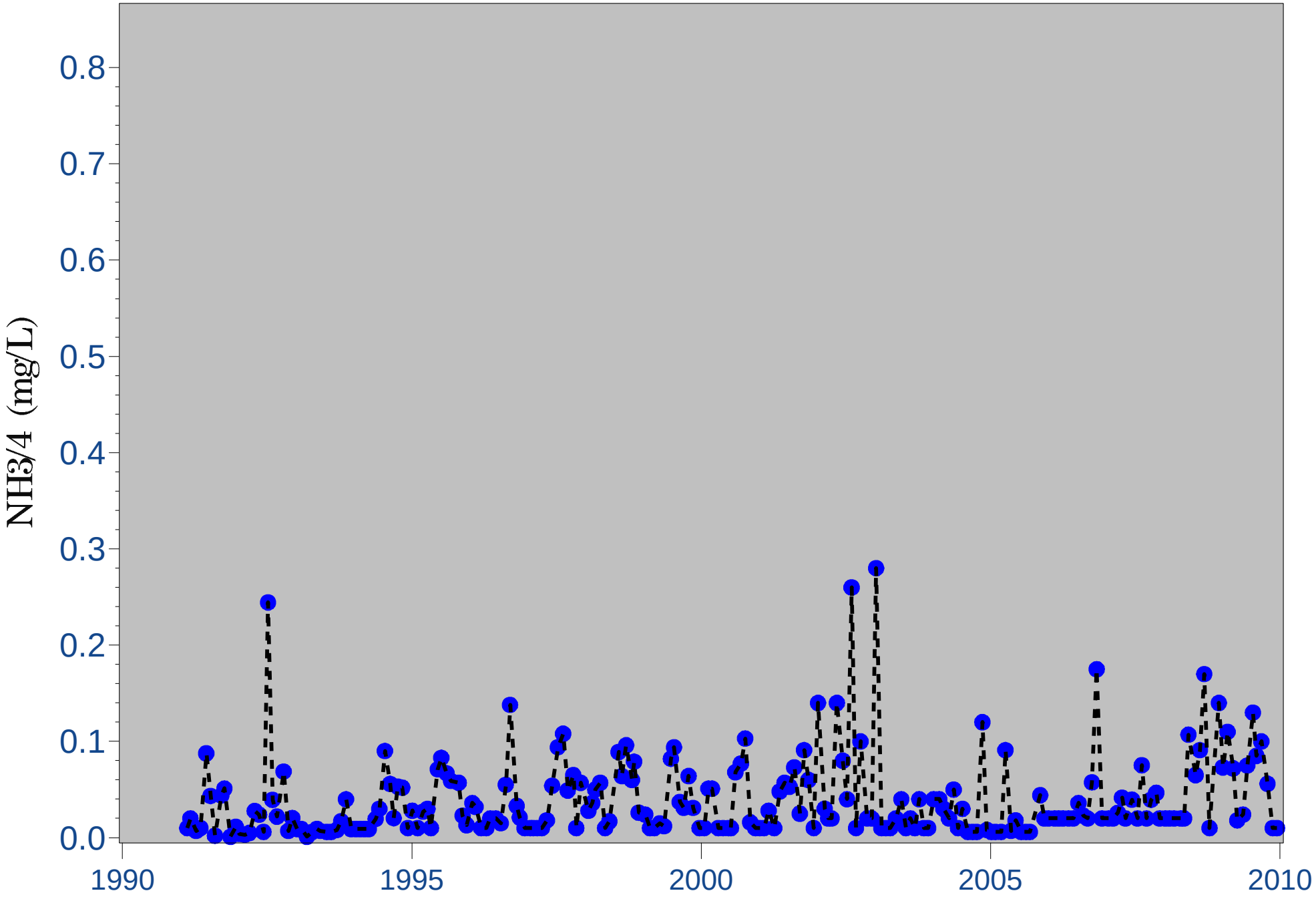


Figure 3.121c Monthly long-term ammonia/ammonium - Shell Creek Reservoir just upstream of the Dam

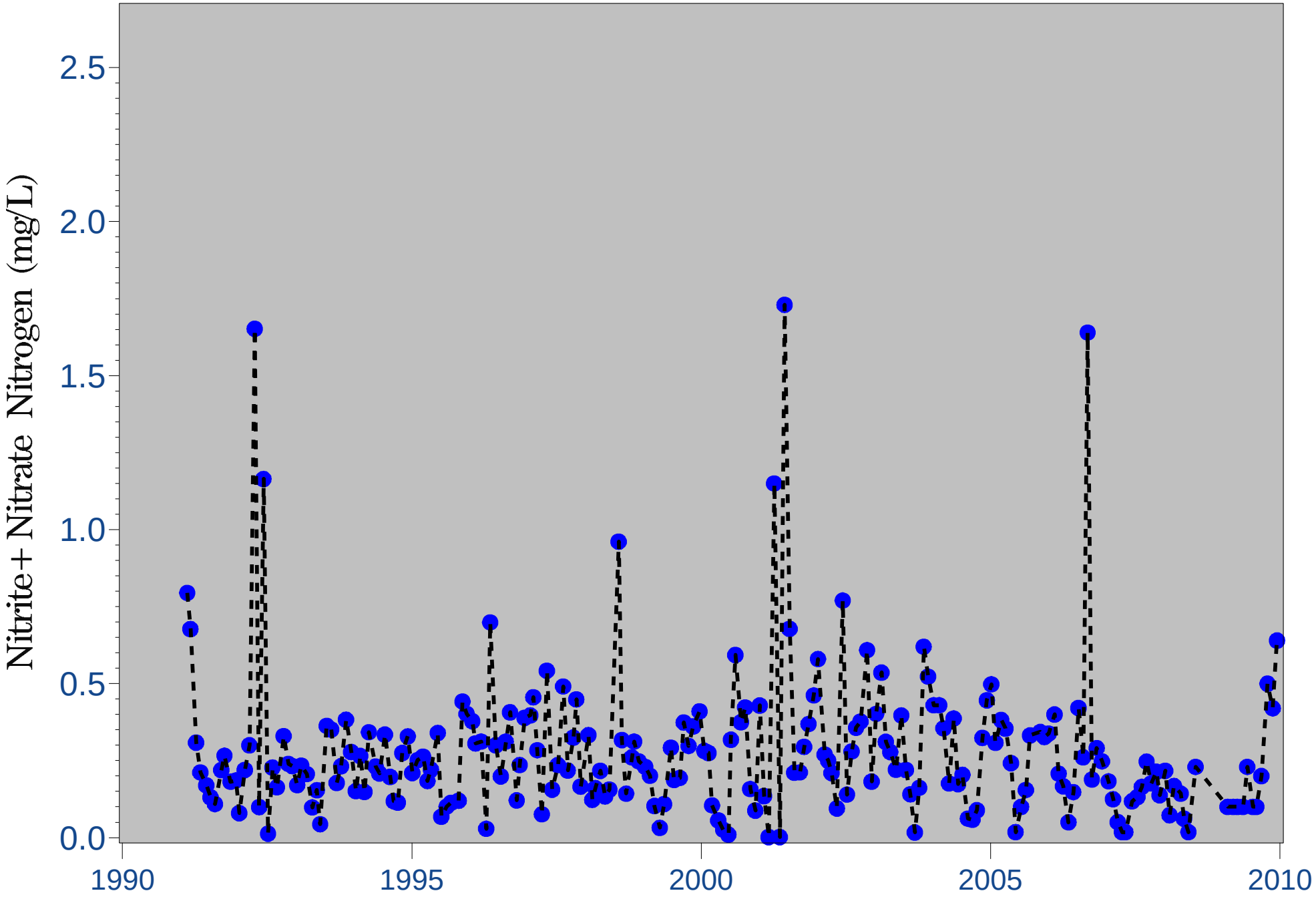


Figure 3.122a Monthly long-term nitrite+nitrate nitrogen - Prairie Creek at C.R. 764

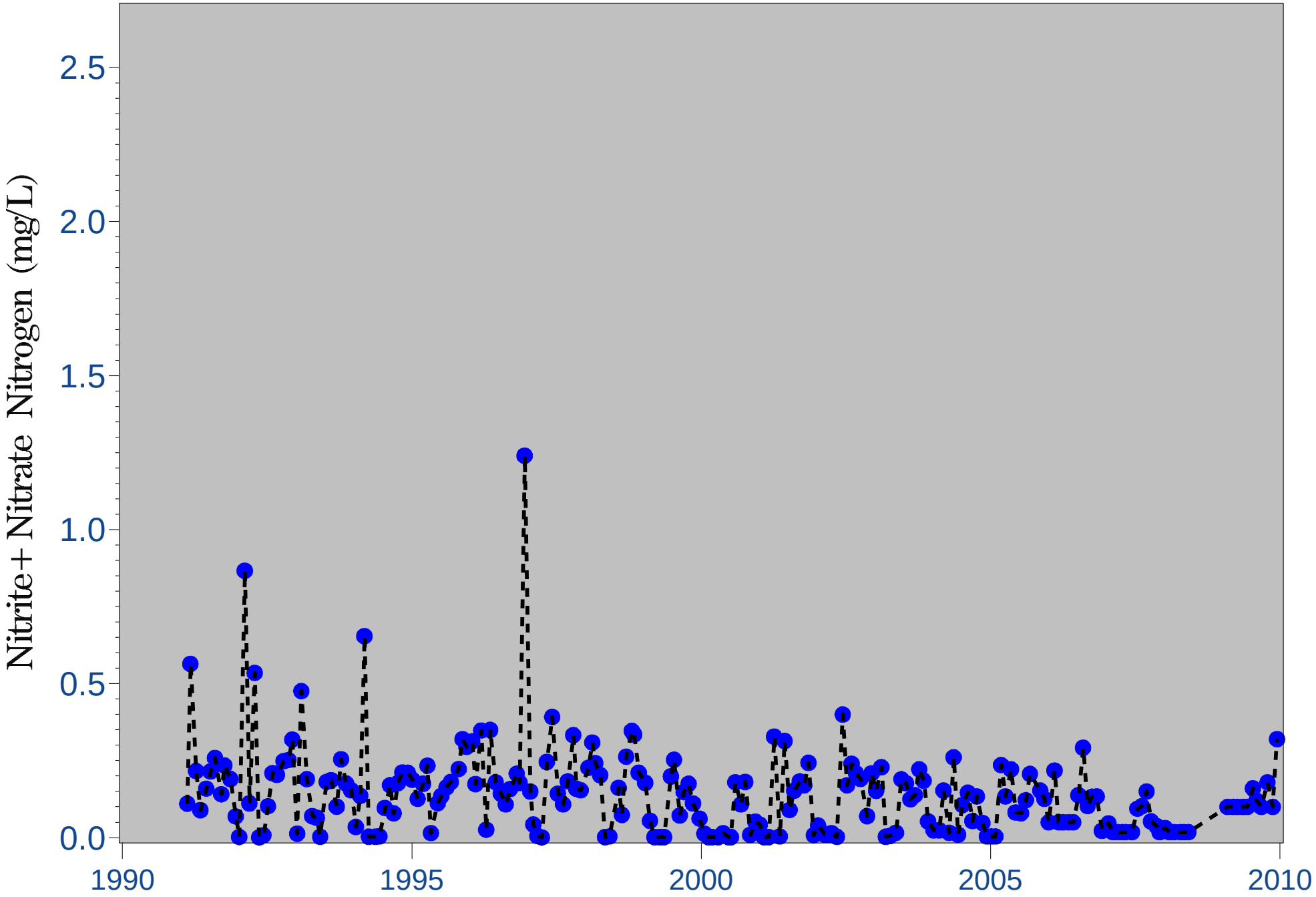


Figure 3.122b Monthly long-term nitrite+nitrate nitrogen - Shell Creek at C.R. 764

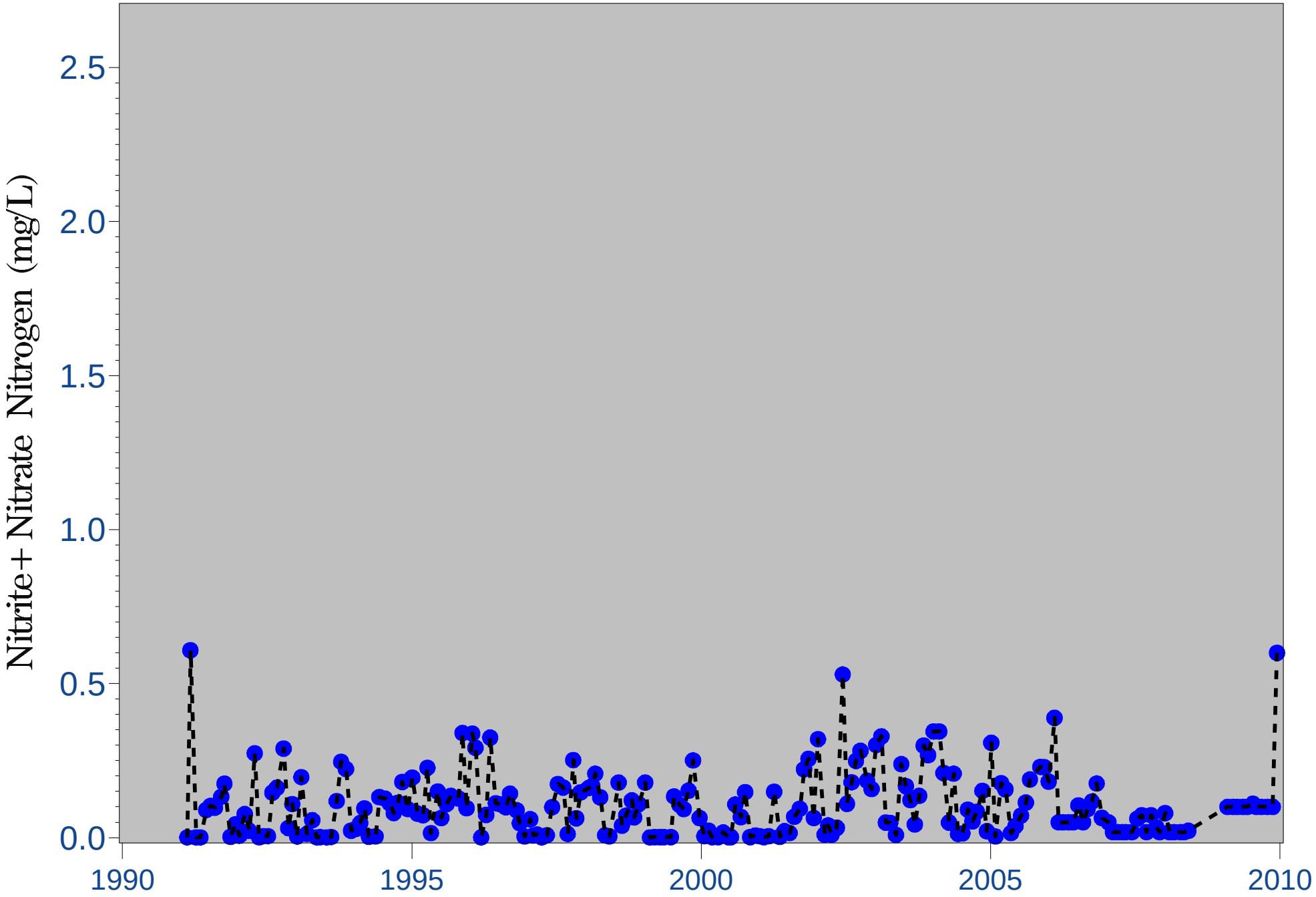


Figure 3.122c Monthly long-term nitrite+nitrate nitrogen - Shell Creek Reservoir just upstream of the Dam

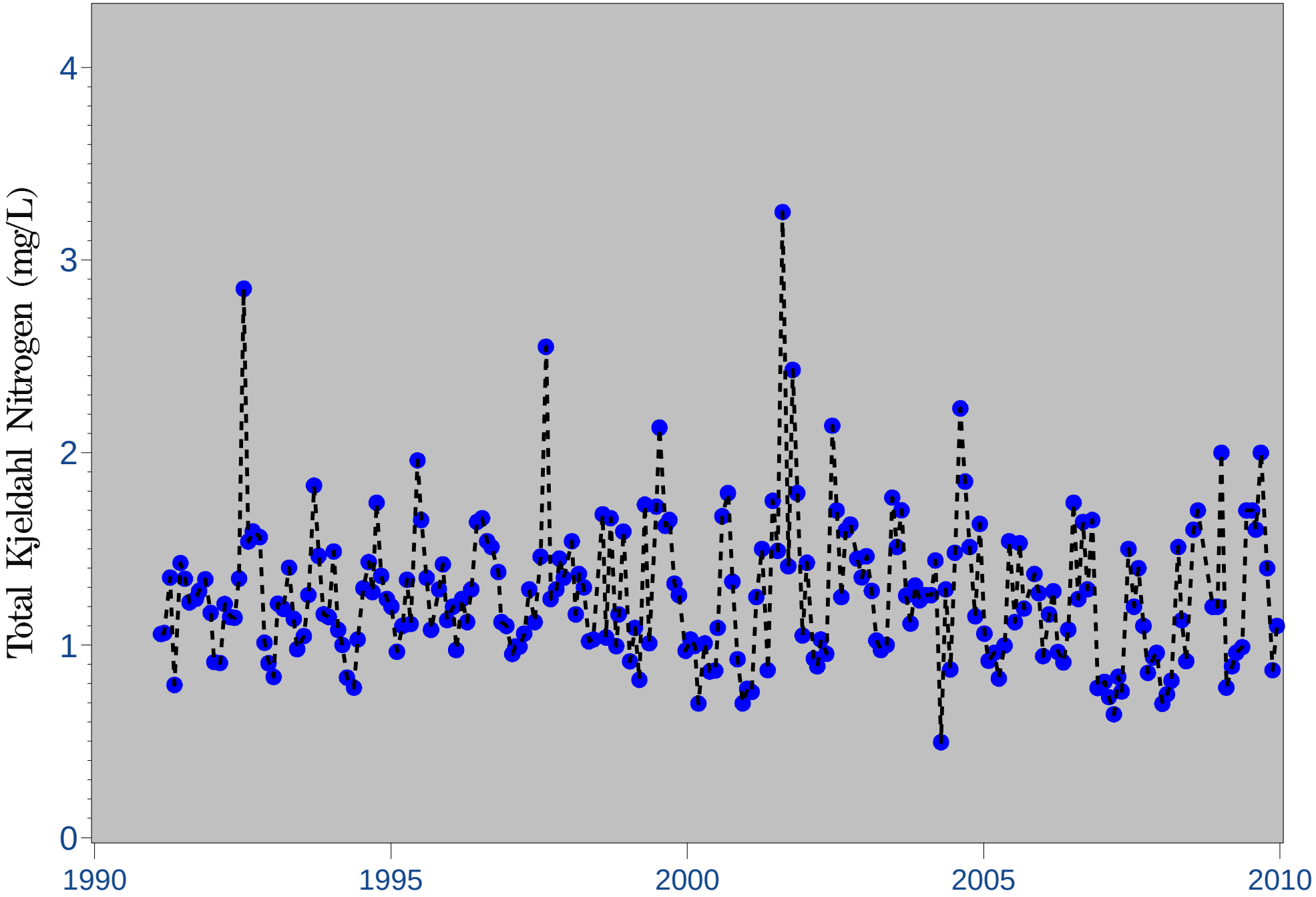


Figure 3.123a Monthly long-term total Kjeldahl nitrogen - Prairie Creek at C.R. 764

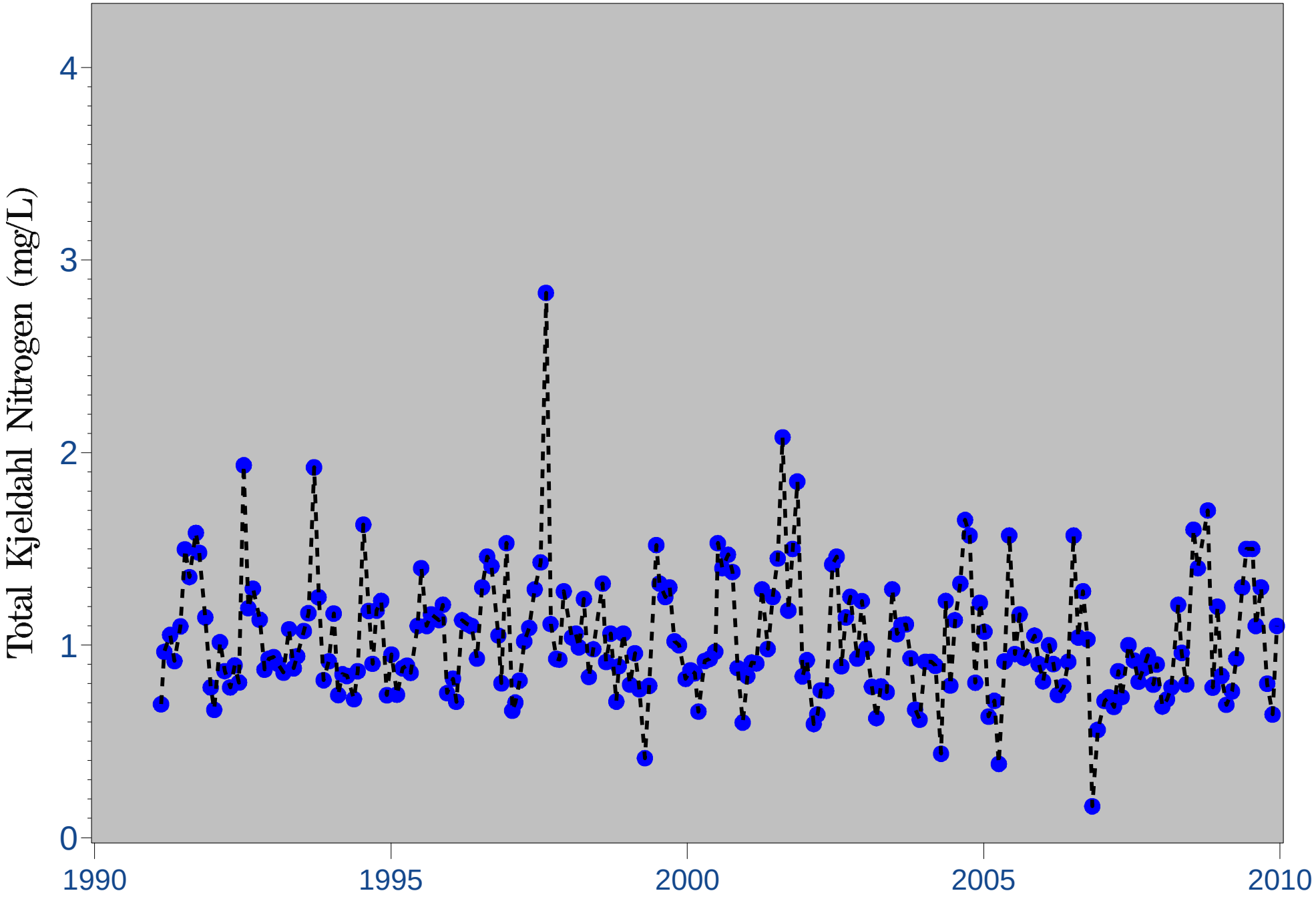


Figure 3.123b Monthly long-term total Kjeldahl nitrogen - Shell Creek at C.R. 764

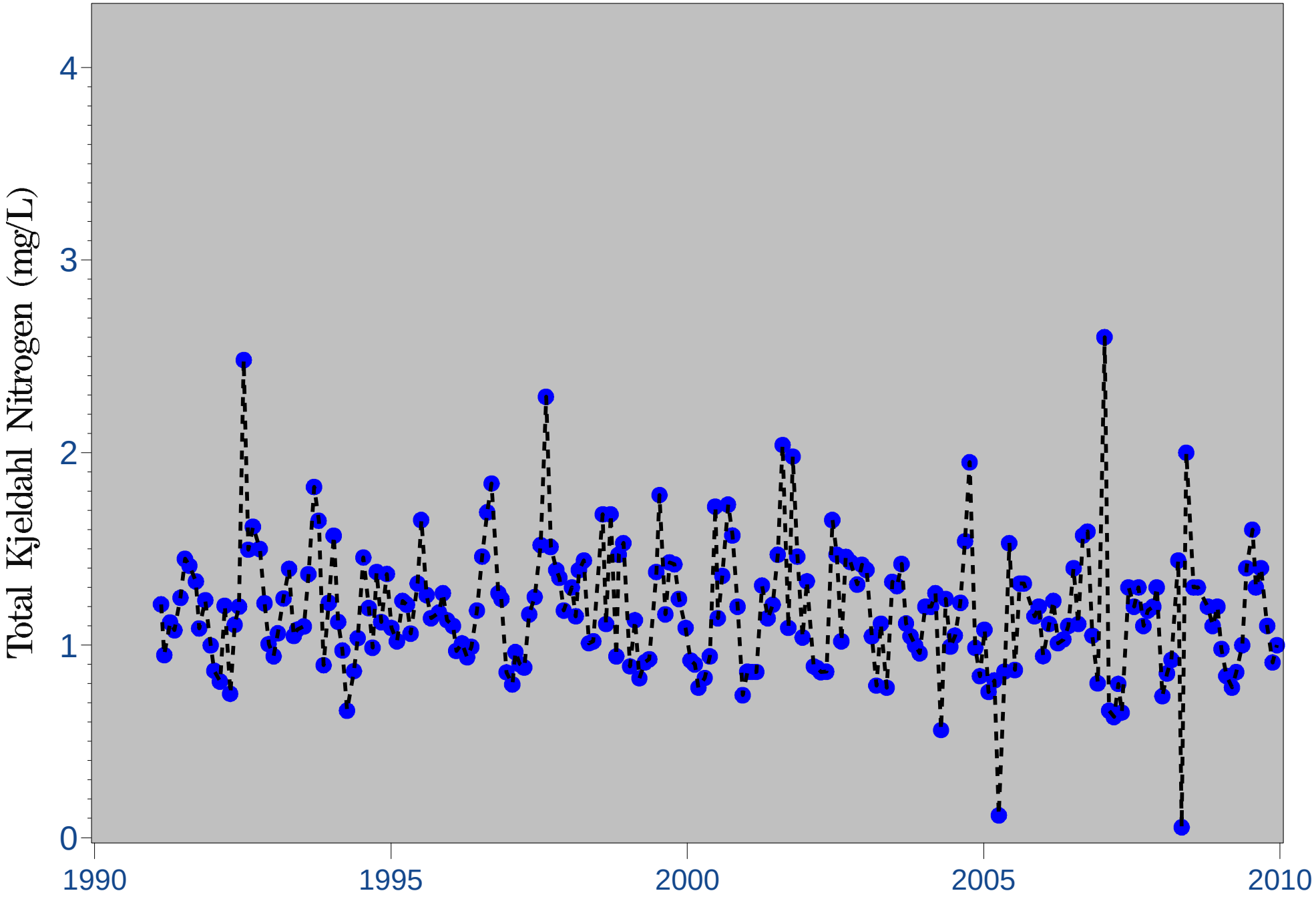


Figure 3.123c Monthly long-term total Kjeldahl nitrogen - Shell Creek Reservoir just upstream of the Dam

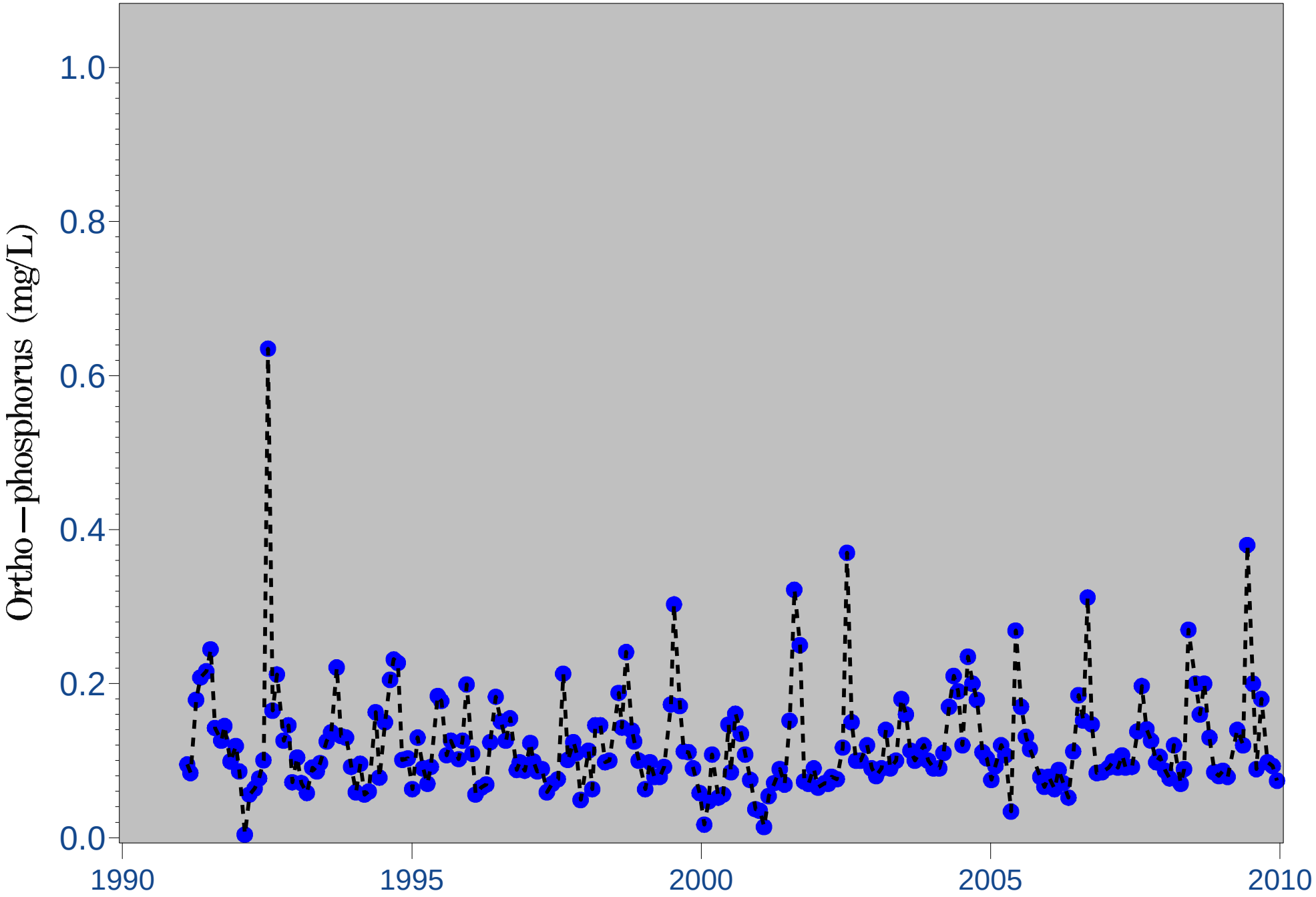


Figure 3.124a Monthly long-term ortho-phosphorus - Prairie Creek at C.R. 764

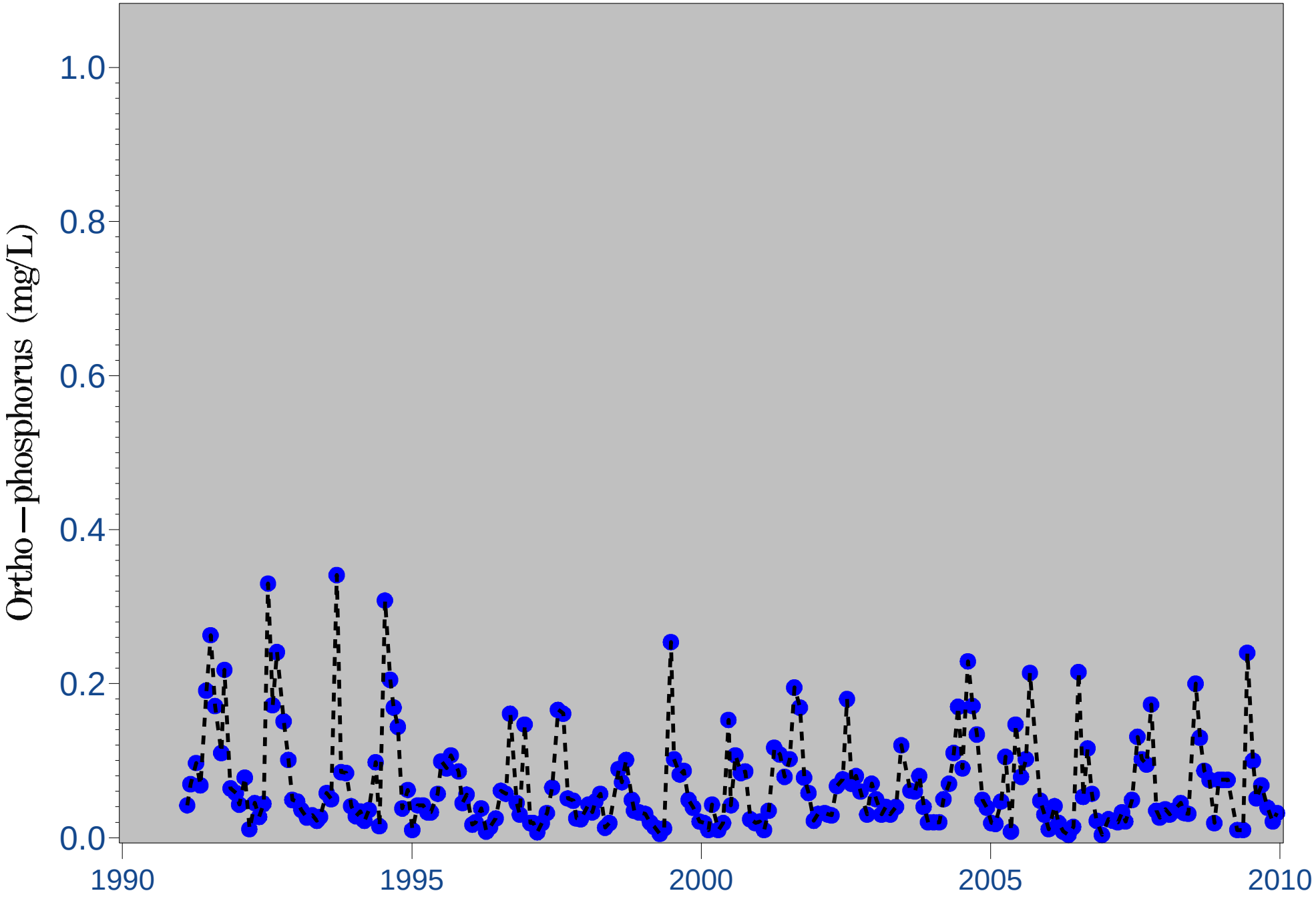


Figure 3.124b Monthly long-term ortho-phosphorus - Shell Creek at C.R. 764

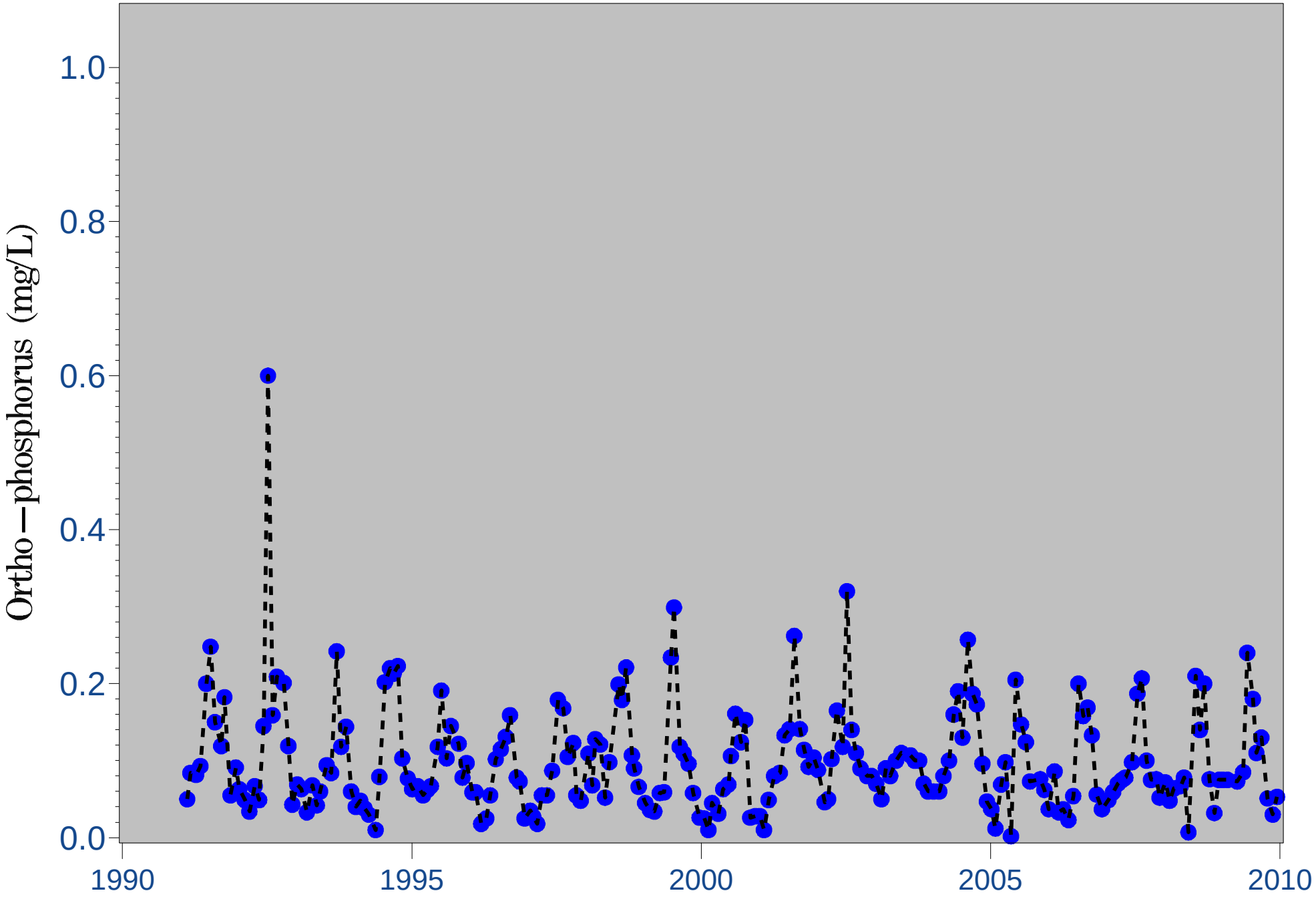


Figure 3.124c Monthly long-term ortho-phosphorus - Shell Creek Reservoir just upstream of the Dam

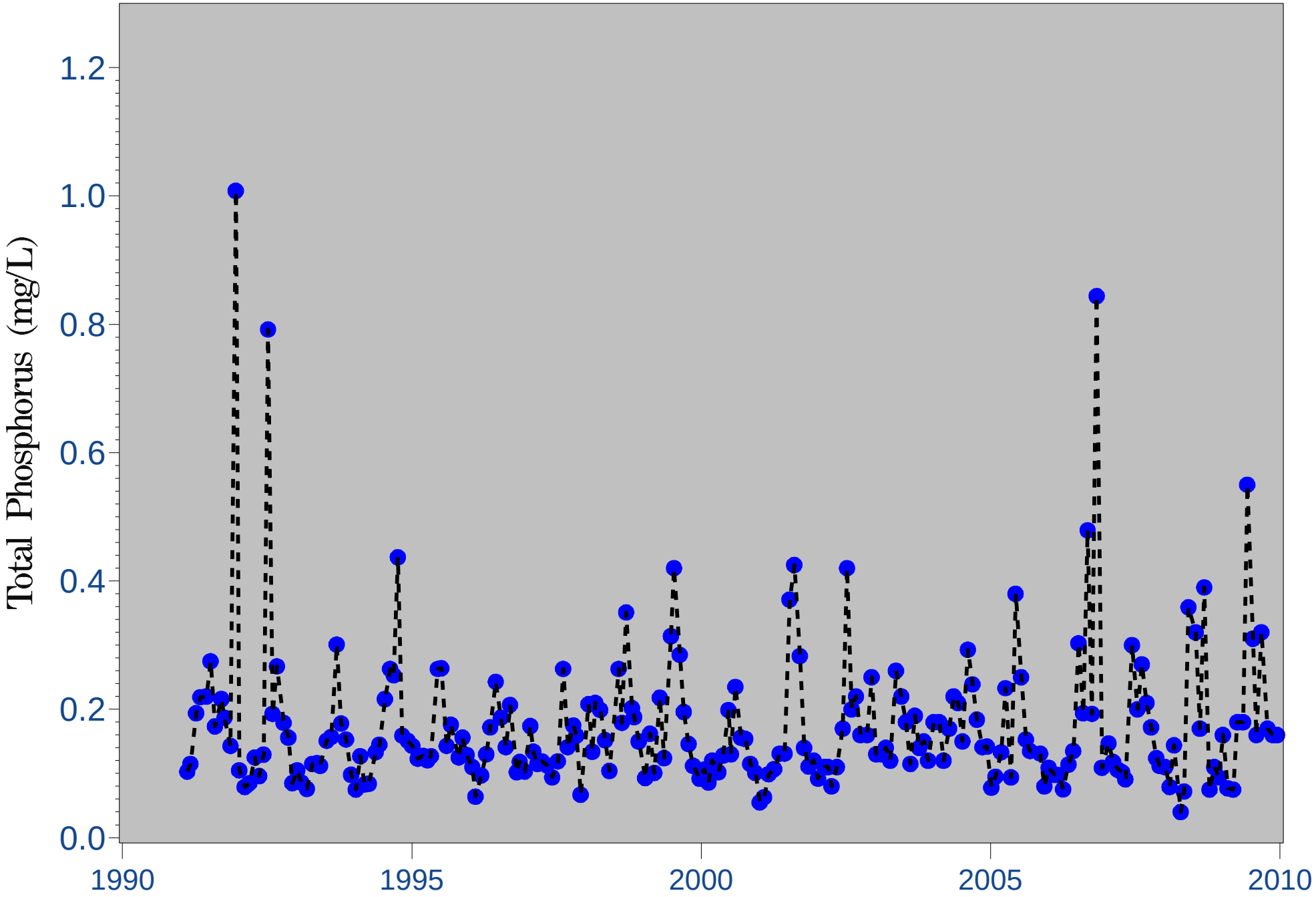


Figure 3.125a Monthly long-term total phosphorus - Prairie Creek at C.R. 764

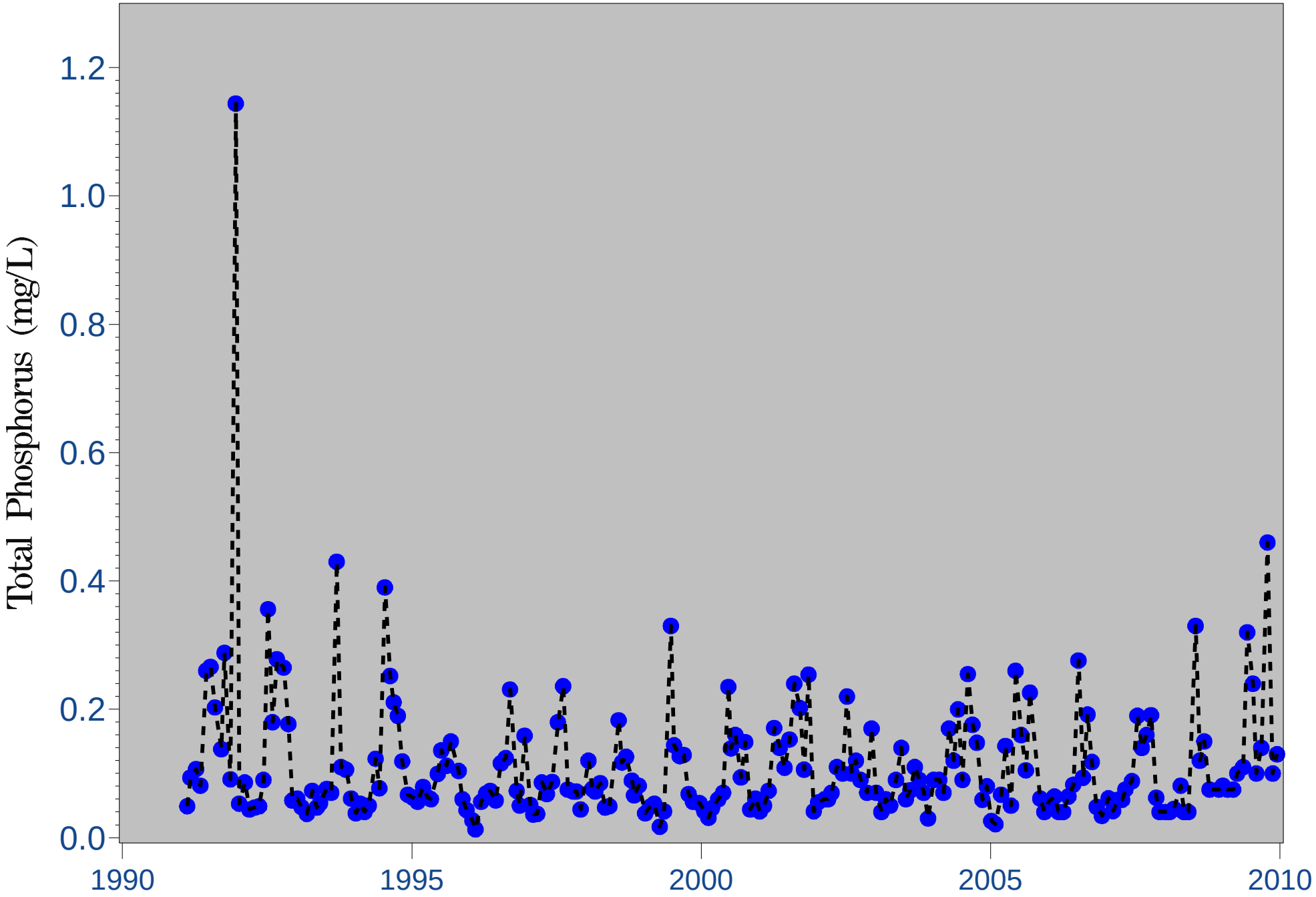


Figure 3.125b Monthly long-term total phosphorus - Shell Creek at C.R. 764

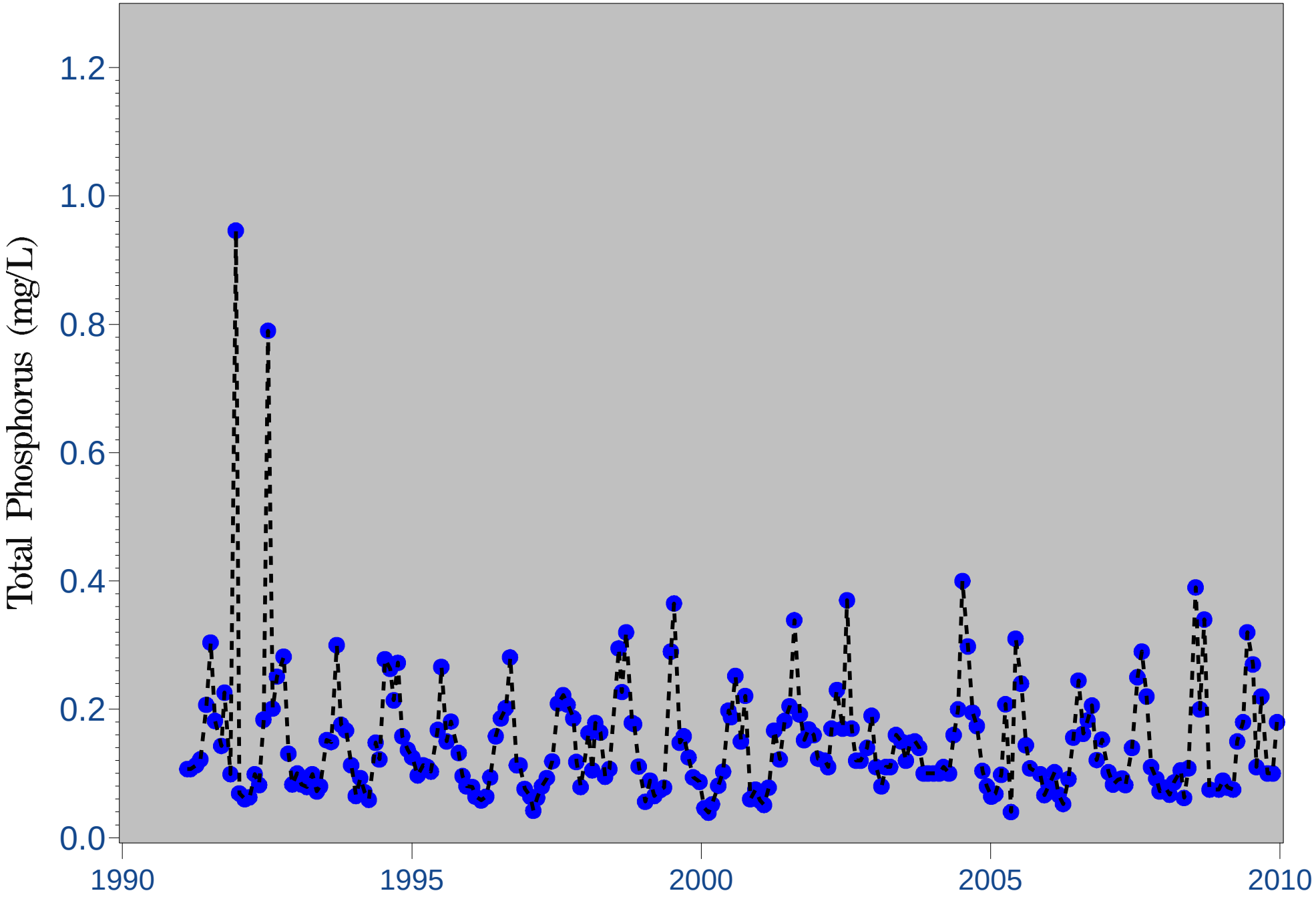


Figure 3.125c Monthly long-term total phosphorus - Shell Creek Reservoir just upstream of the Dam

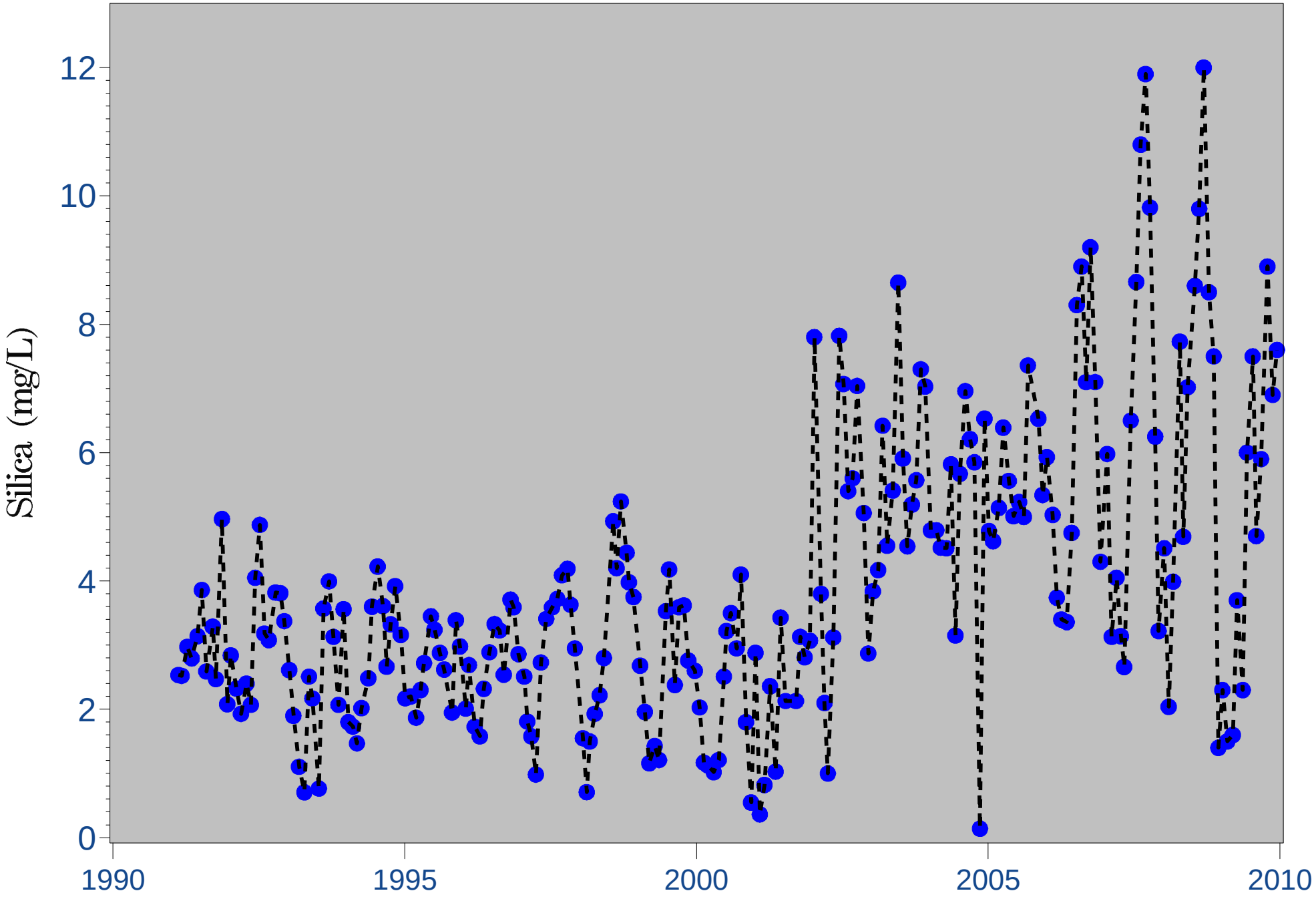


Figure 3.126a Monthly long-term silica - Prairie Creek at C.R. 764

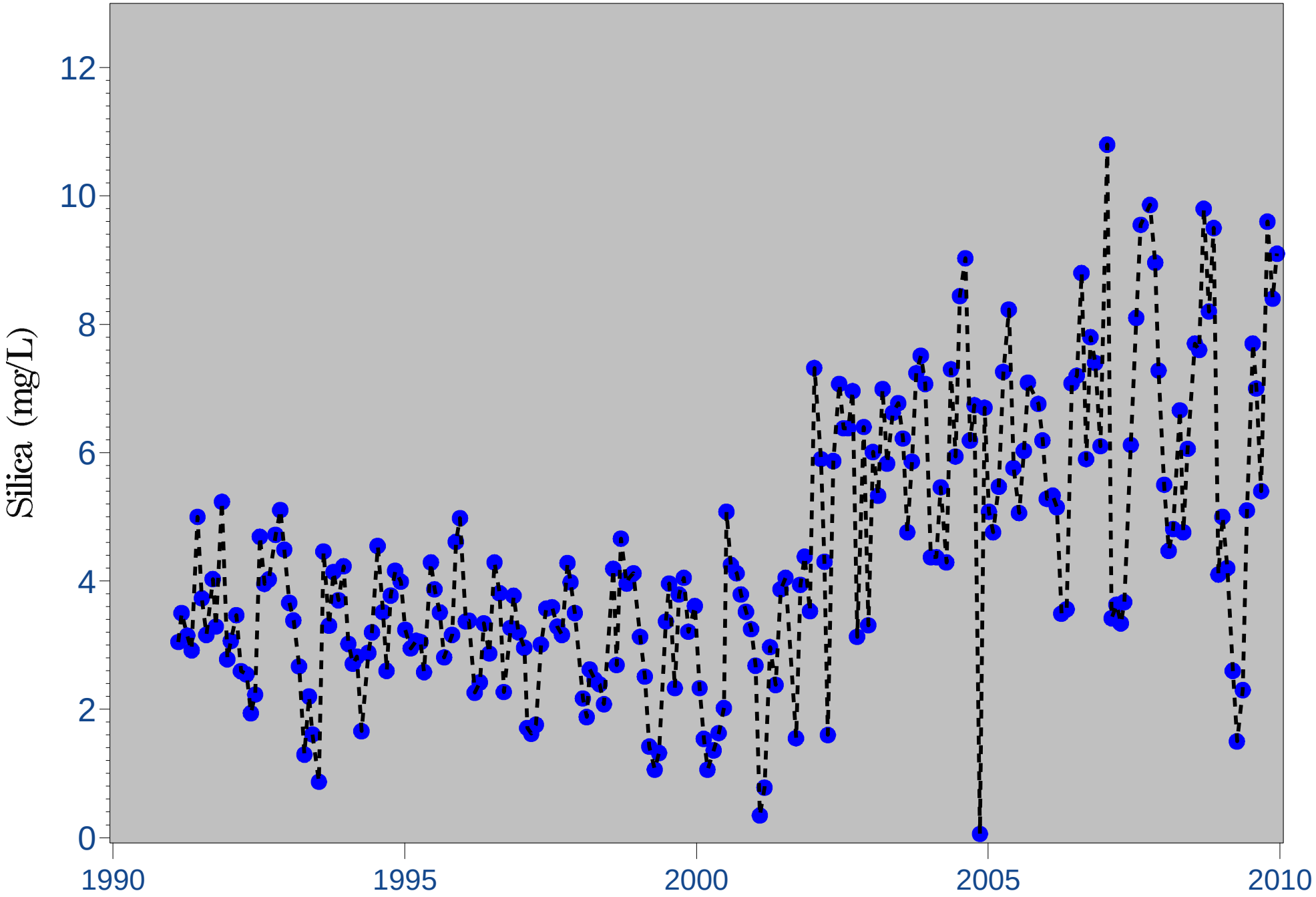


Figure 3.126b Monthly long-term silica - Shell Creek at C.R. 764

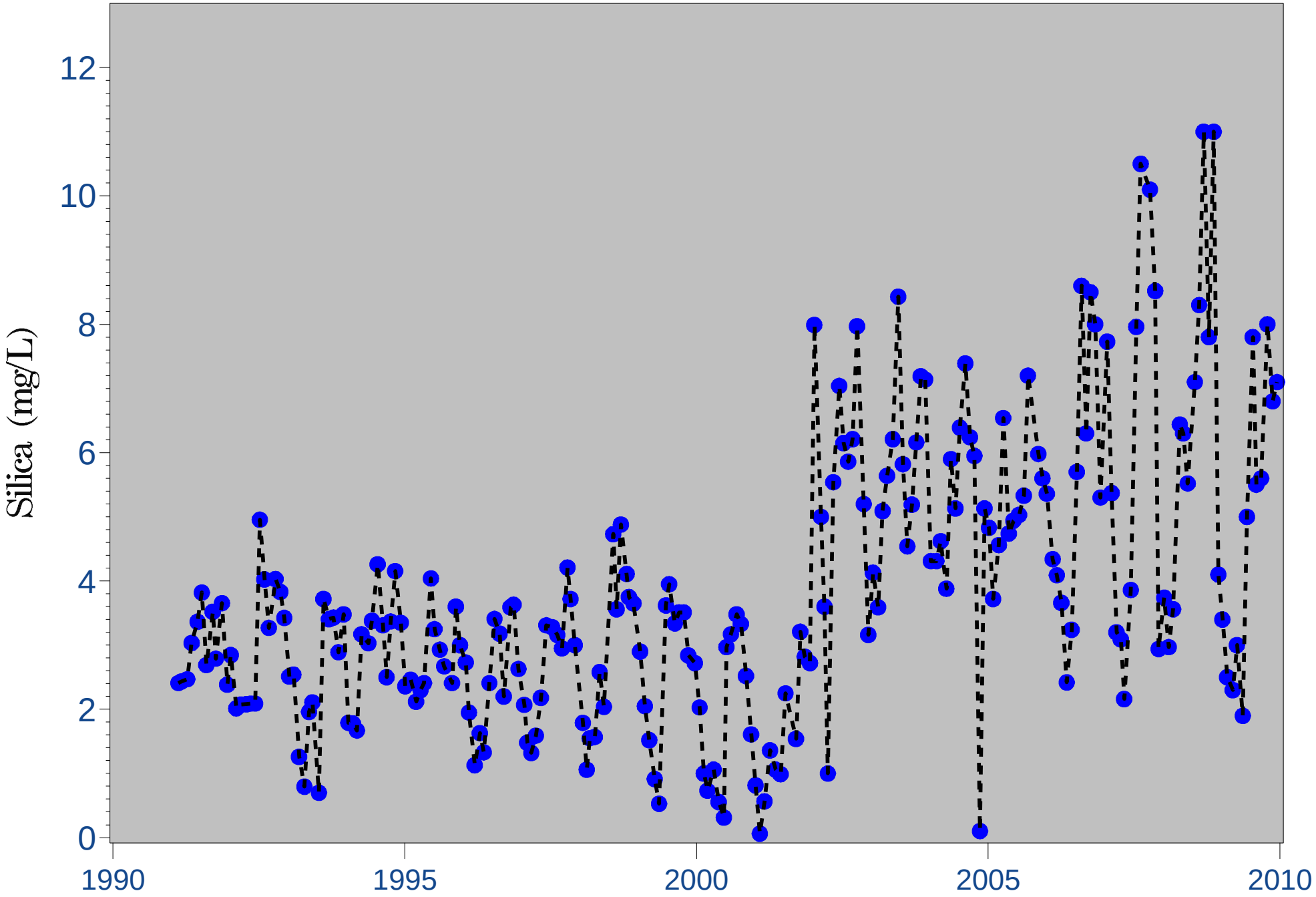


Figure 3.126c Monthly long-term silica - Shell Creek Reservoir just upstream of the Dam

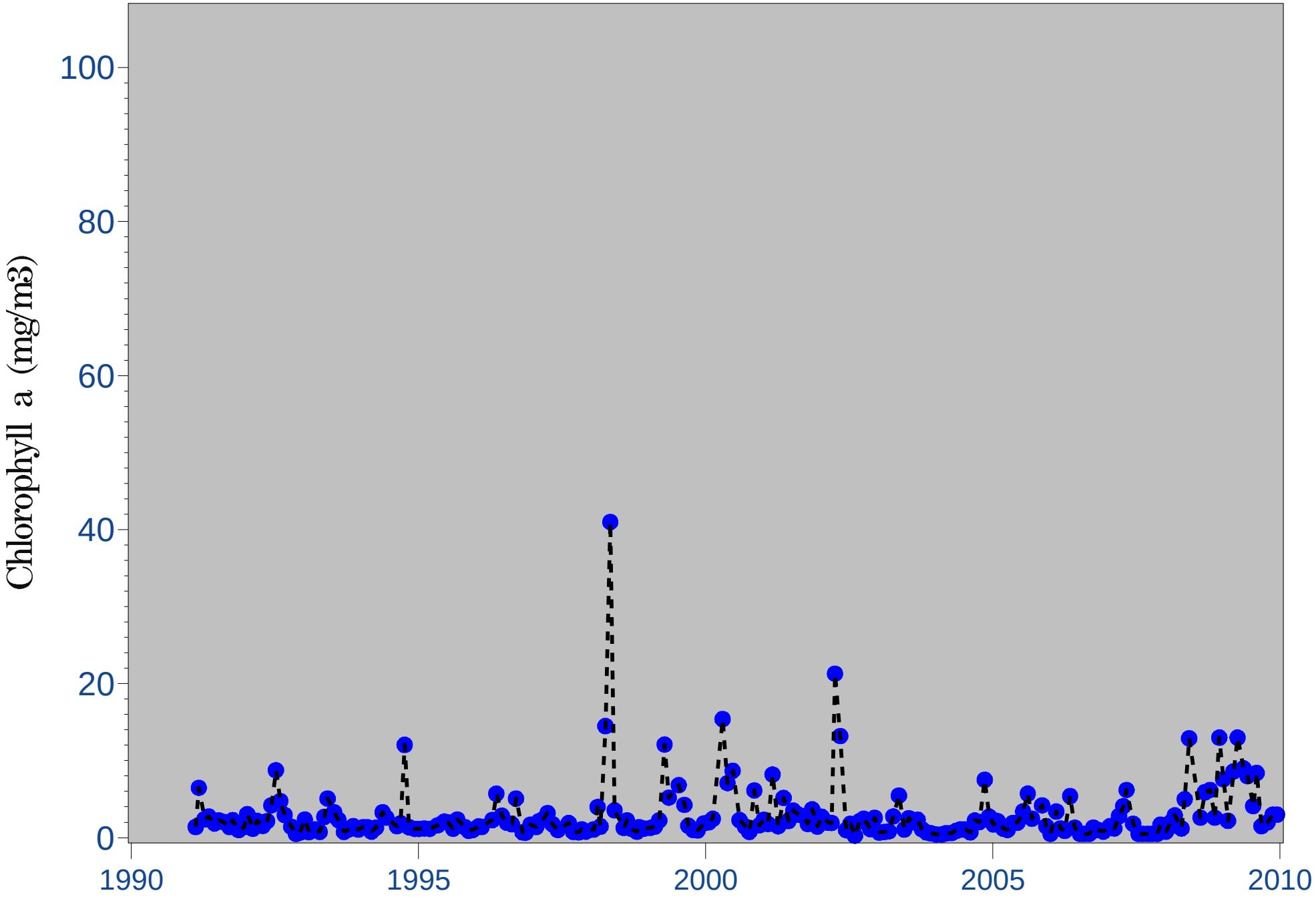


Figure 3.127a Monthly long-term chlorophyll a - Prairie Creek at C.R. 764

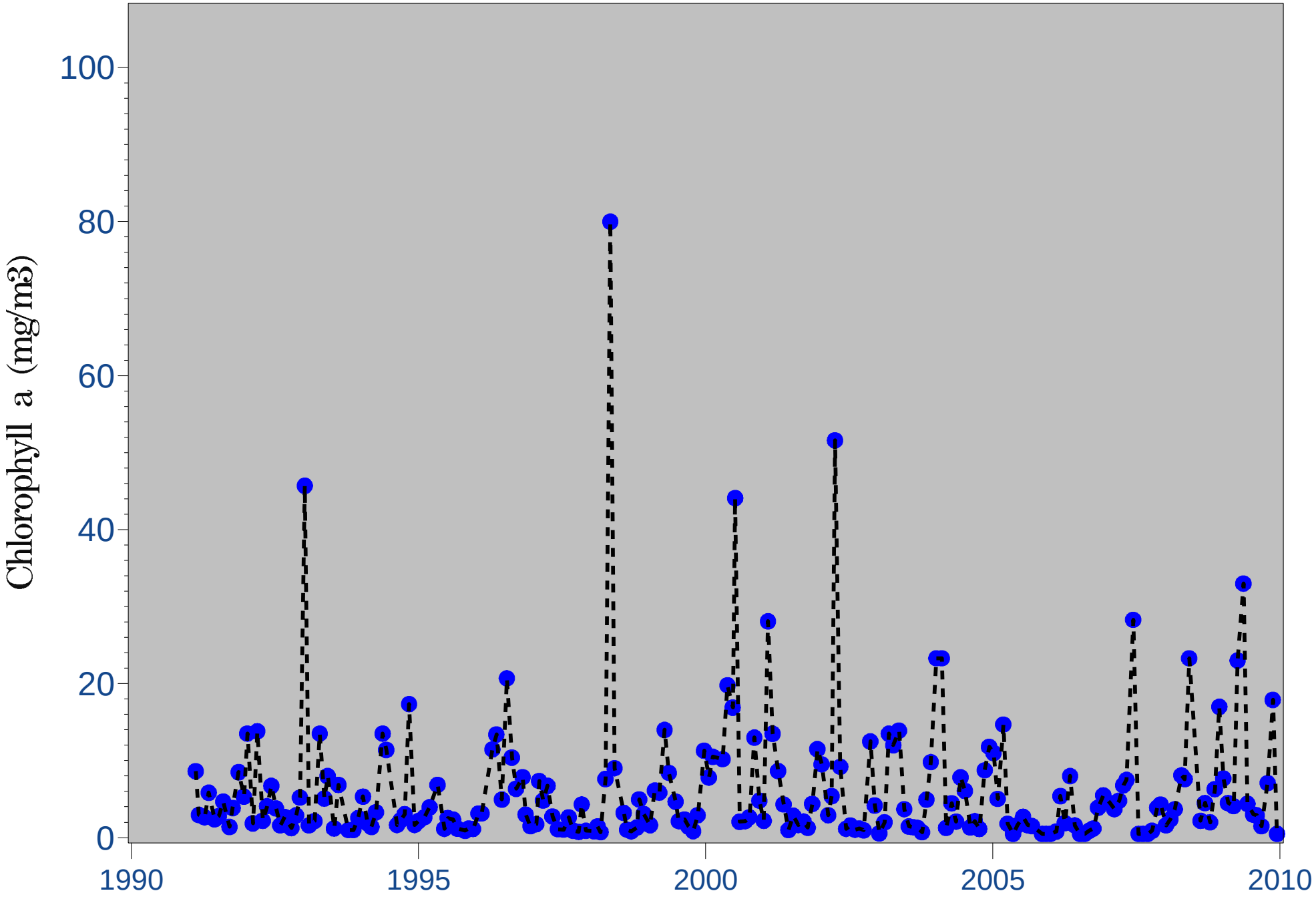


Figure 3.127b Monthly long-term chlorophyll a - Shell Creek at C.R. 764

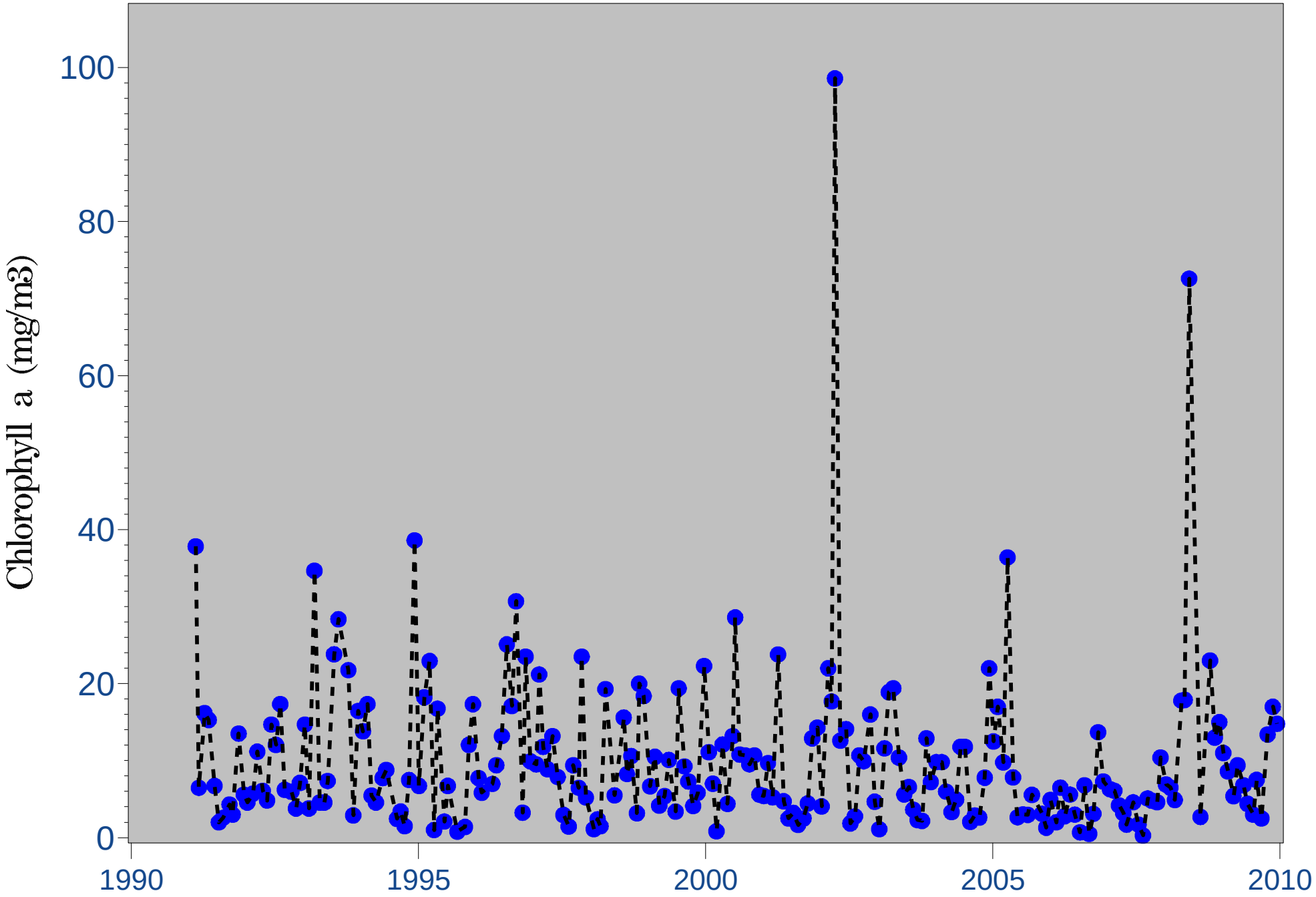


Figure 3.127c Monthly long-term chlorophyll a - Shell Creek Reservoir just upstream of the Dam

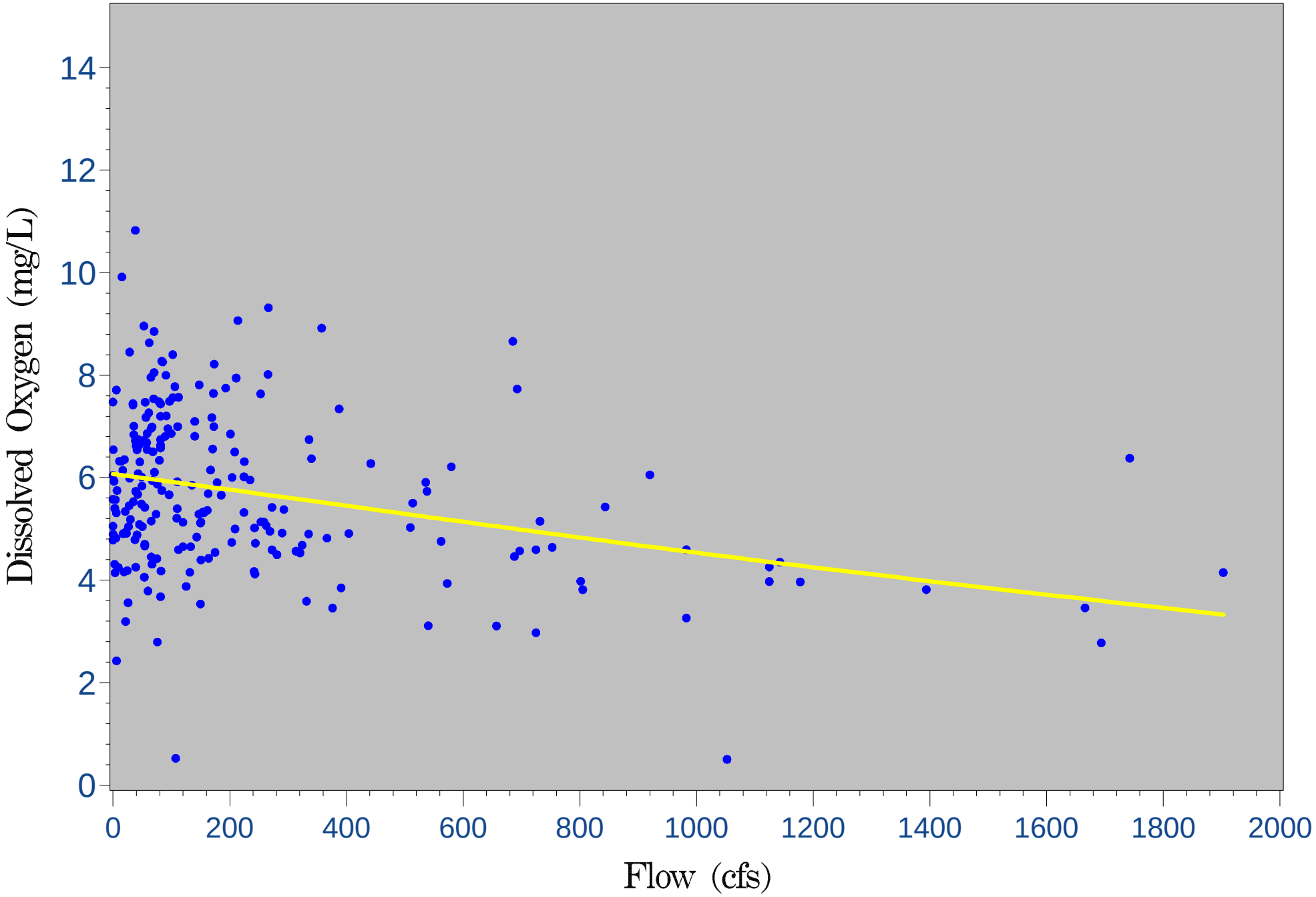


Figure 3.128a Dissolved oxygen versus flow - Prairie Creek at C.R. 764

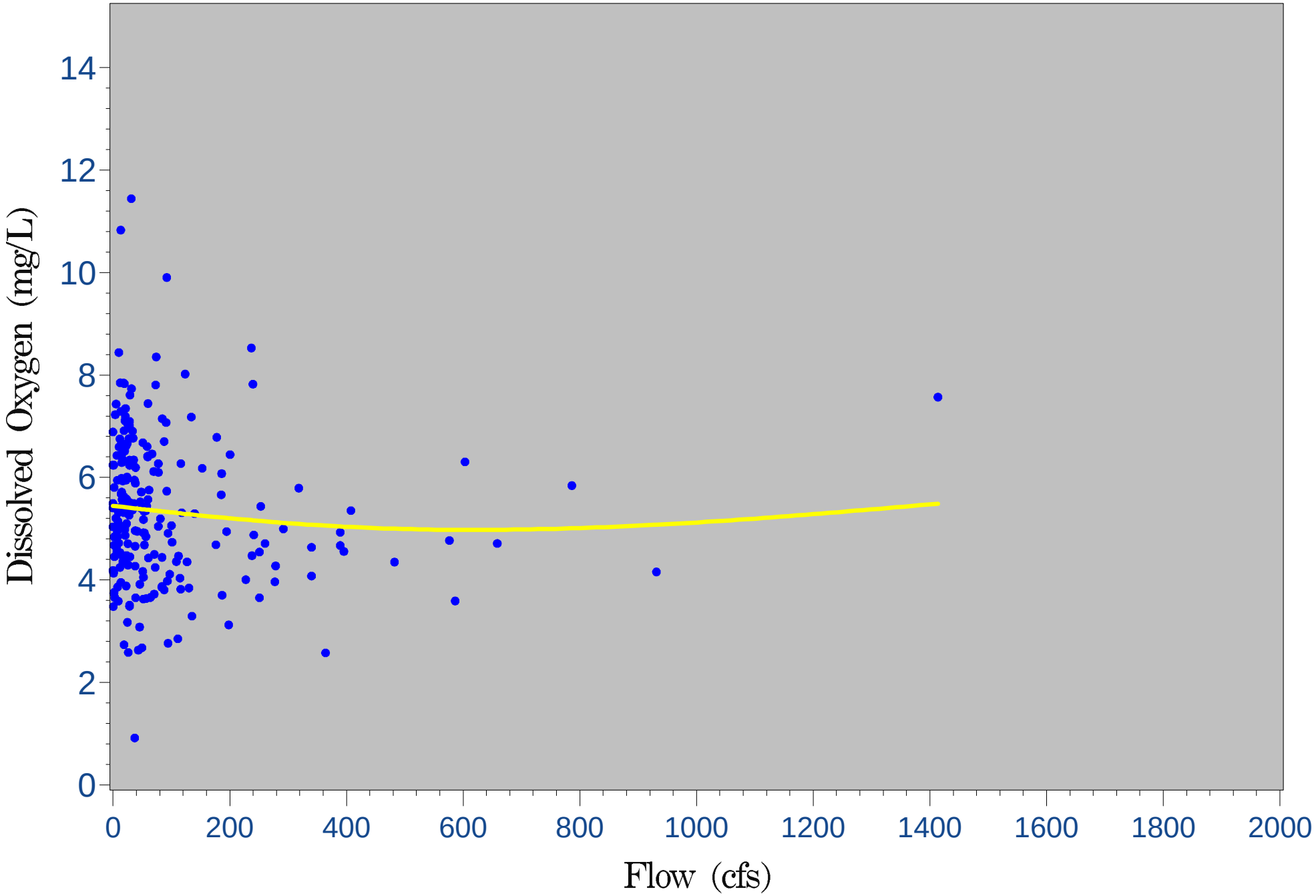


Figure 3.128b Dissolved oxygen versus flow - Shell Creek at C.R. 764

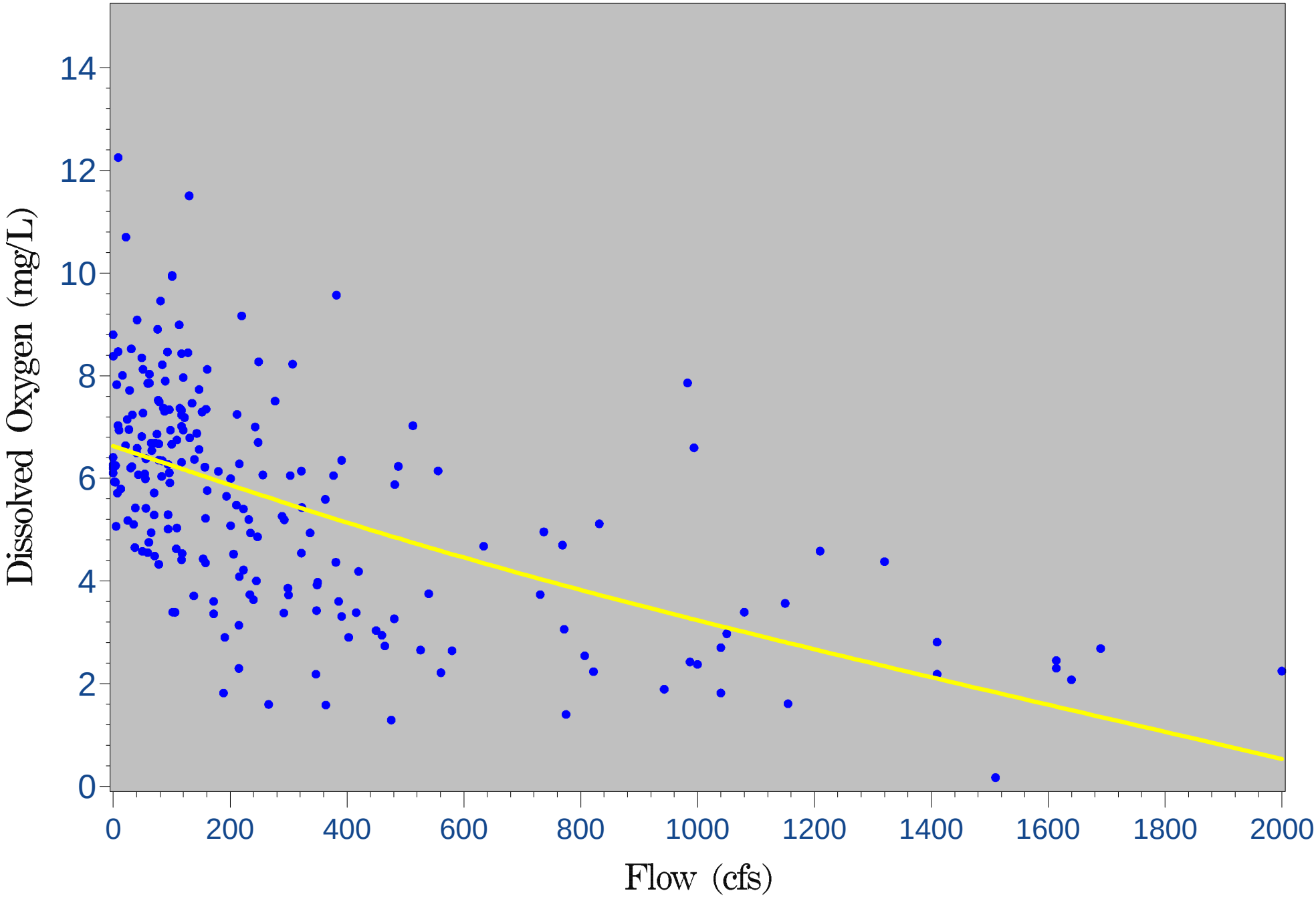


Figure 3.128c Dissolved oxygen versus flow - Shell Creek Reservoir just upstream of the Dam

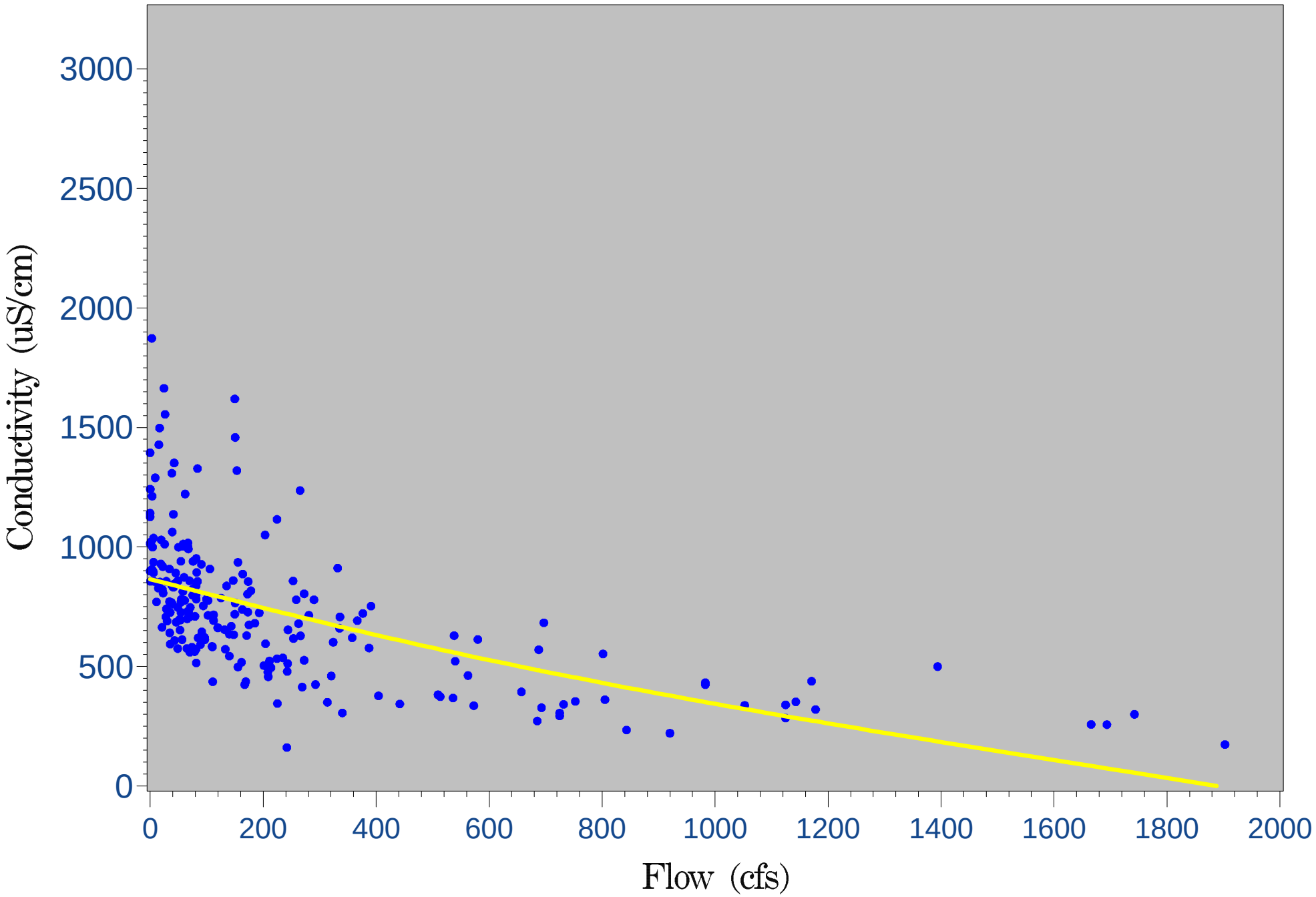


Figure 3.129a Conductivity versus flow - Prairie Creek at C.R. 764

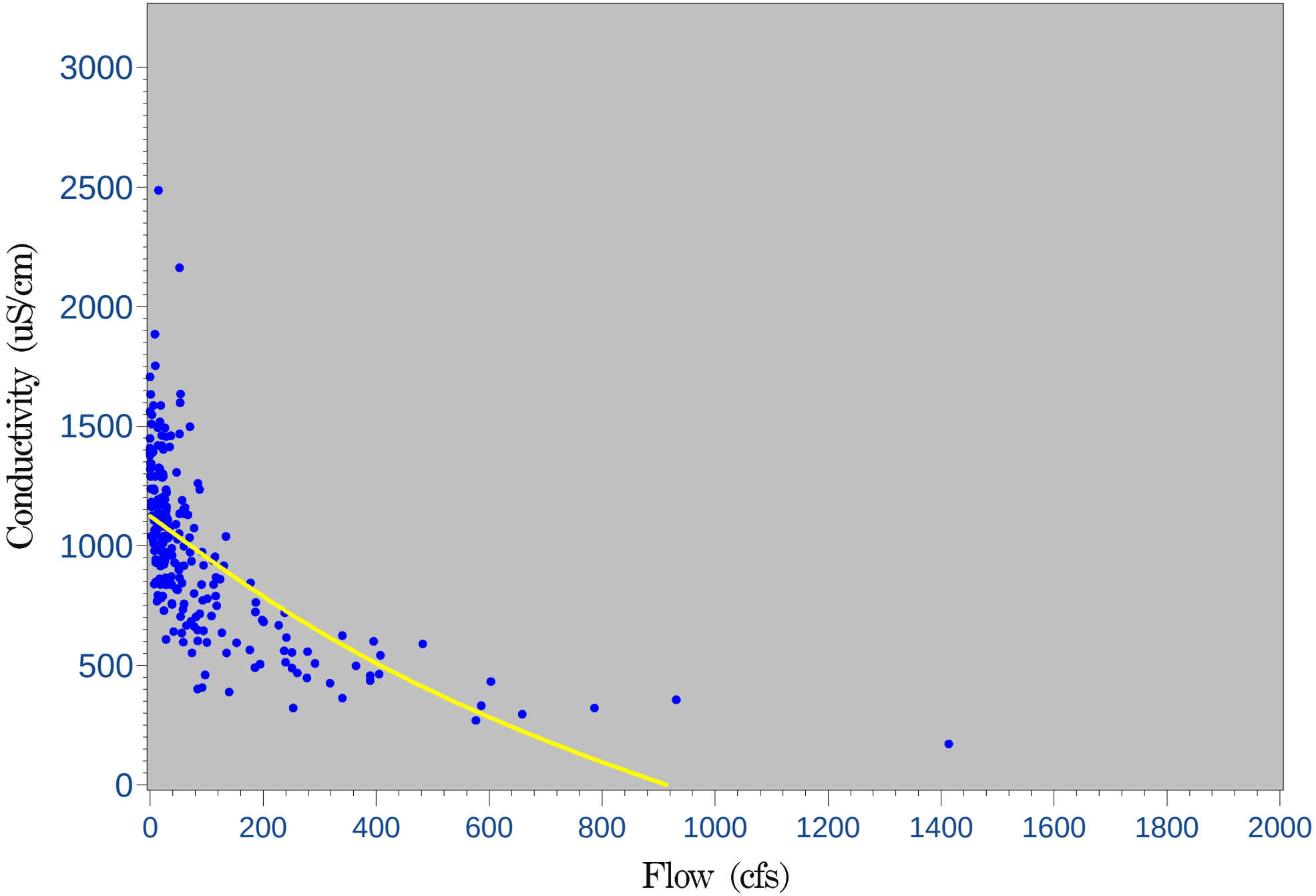


Figure 3.129b Conductivity versus flow - Shell Creek at C.R. 764

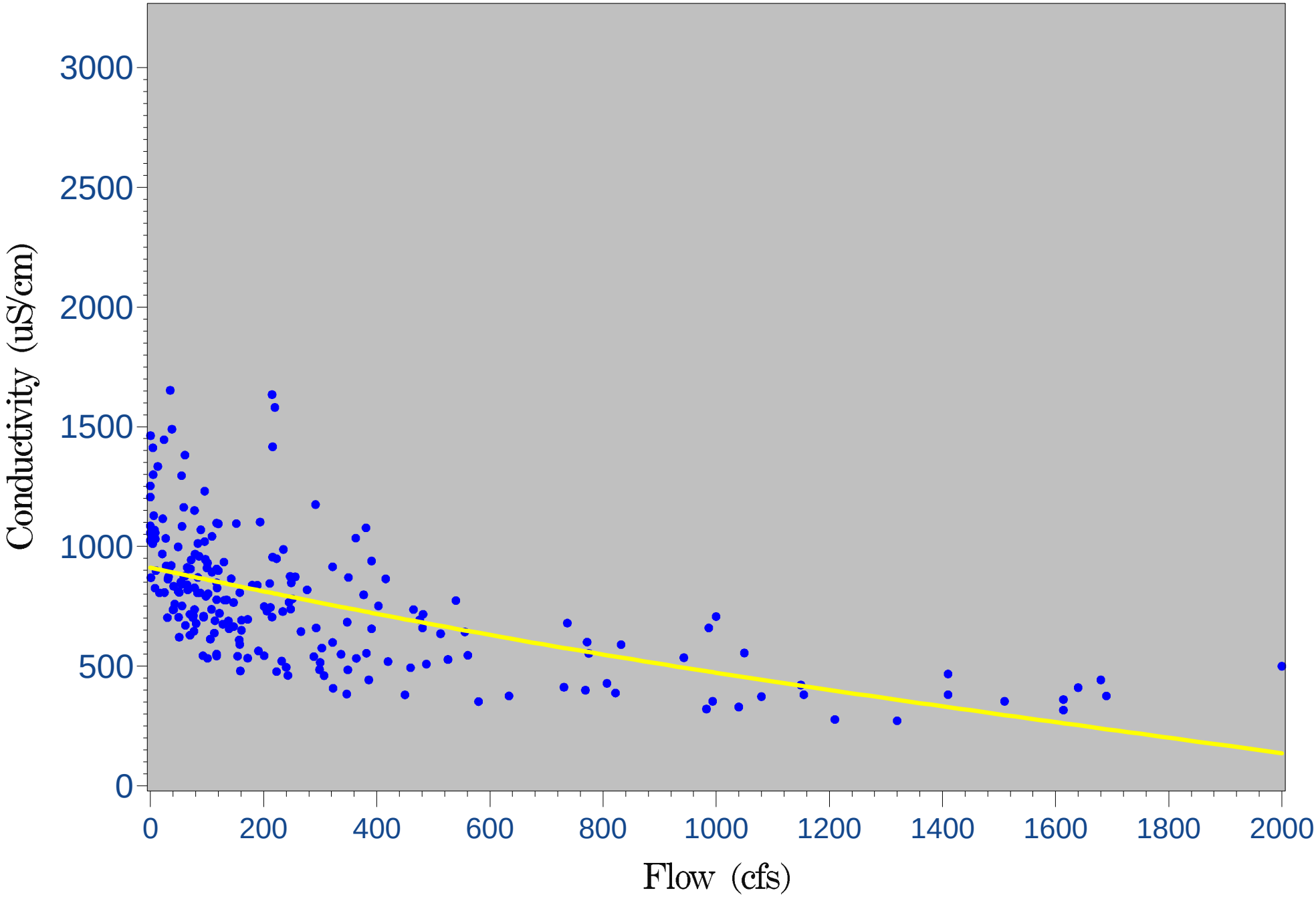


Figure 3.129c Conductivity versus flow - Shell Creek Reservoir just upstream of the Dam

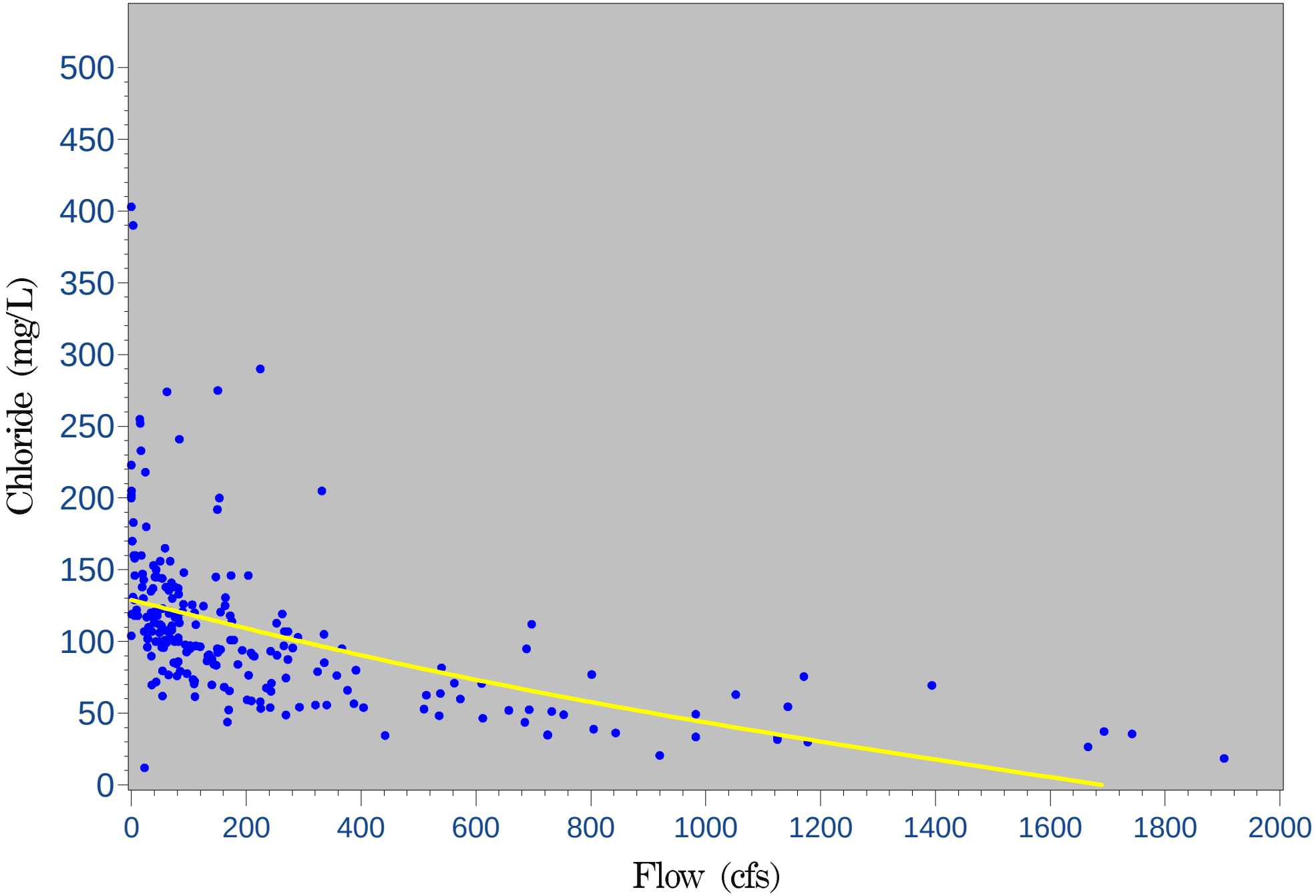


Figure 3.130a Chloride versus flow - Prairie Creek at C.R. 764

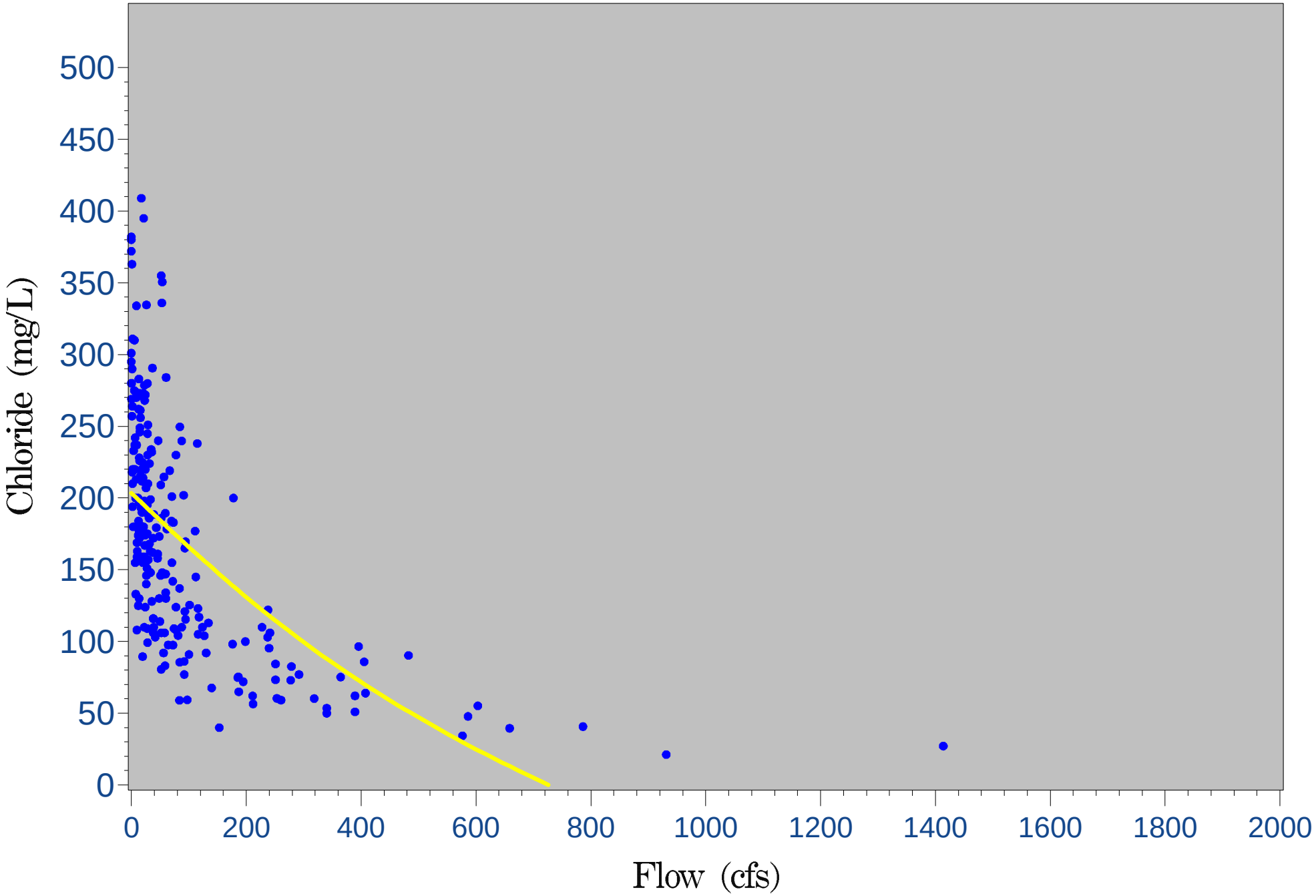


Figure 3.130b Chloride versus flow - Shell Creek at C.R. 764

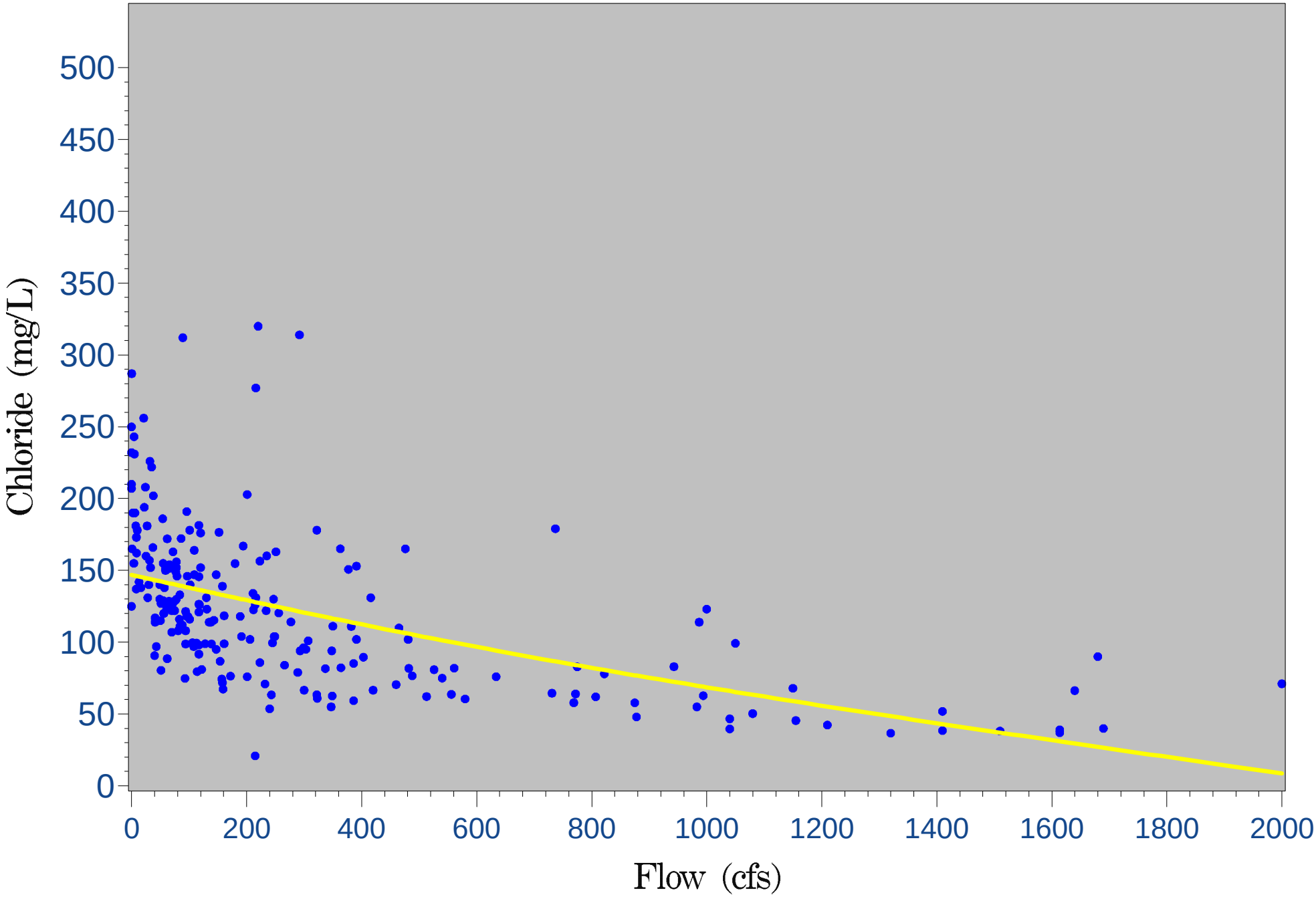


Figure 3.130c Chloride versus flow - Shell Creek Reservoir just upstream of the Dam

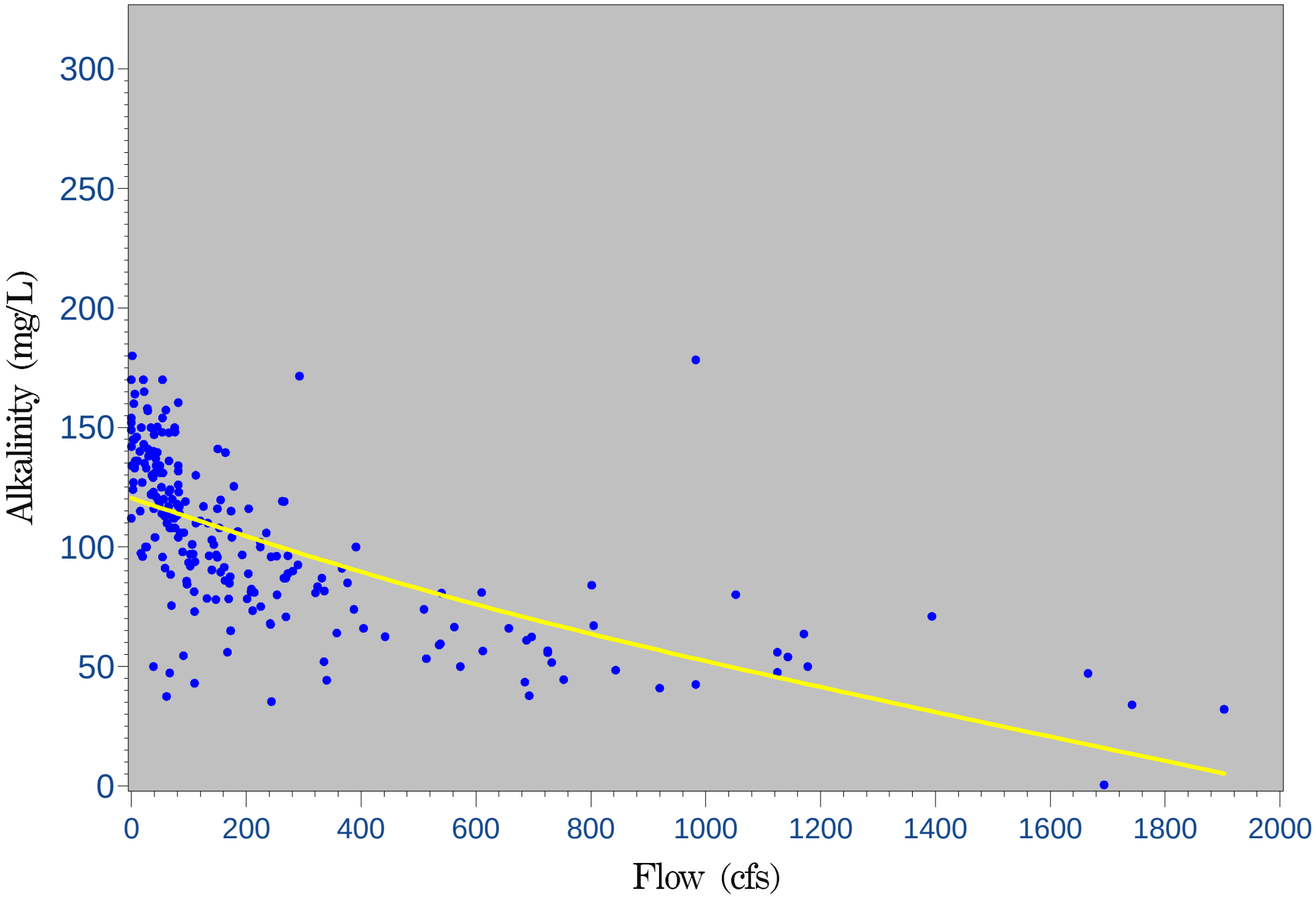


Figure 3.131a Alkalinity versus flow - Prairie Creek at C.R. 764

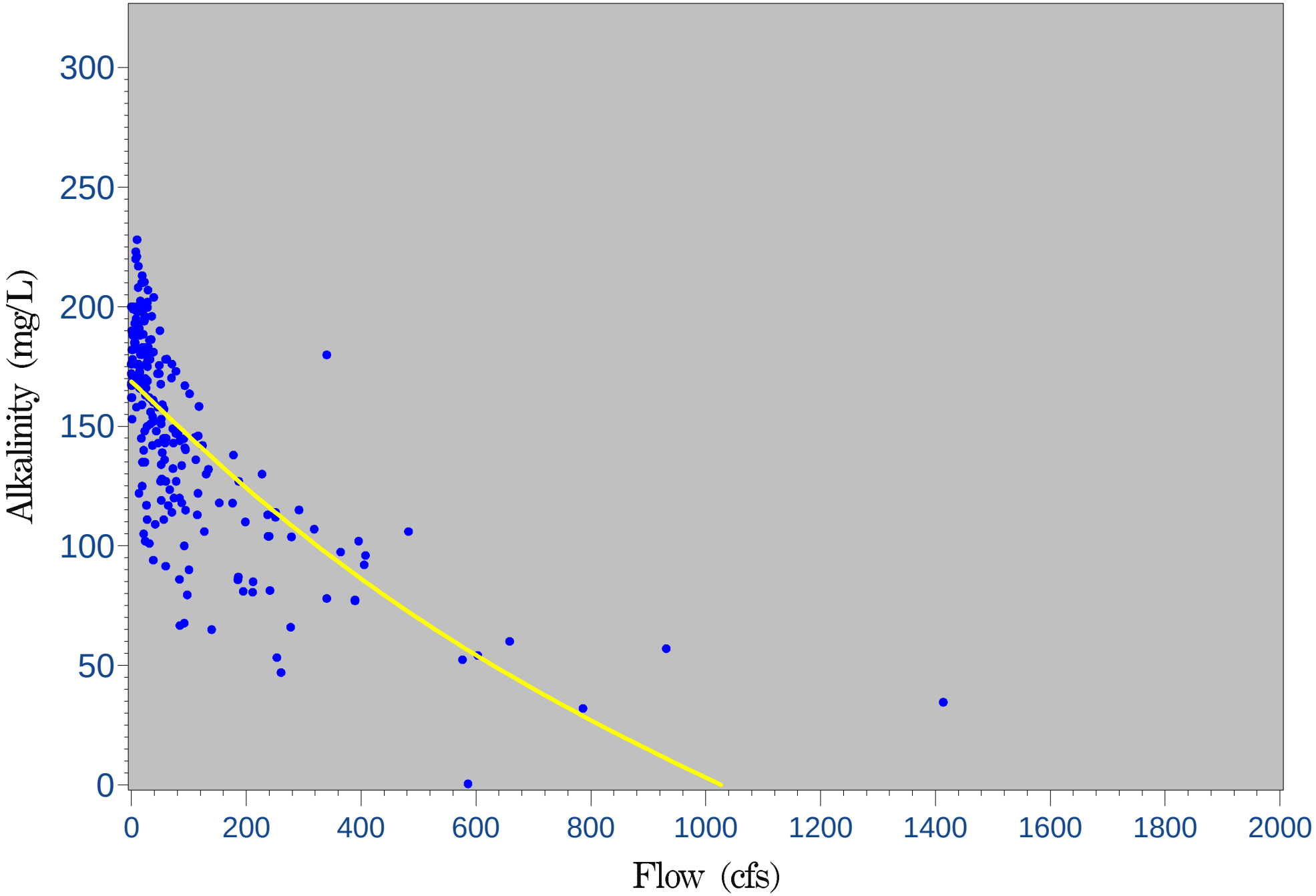


Figure 3.131b Alkalinity versus flow - Shell Creek at C.R. 764

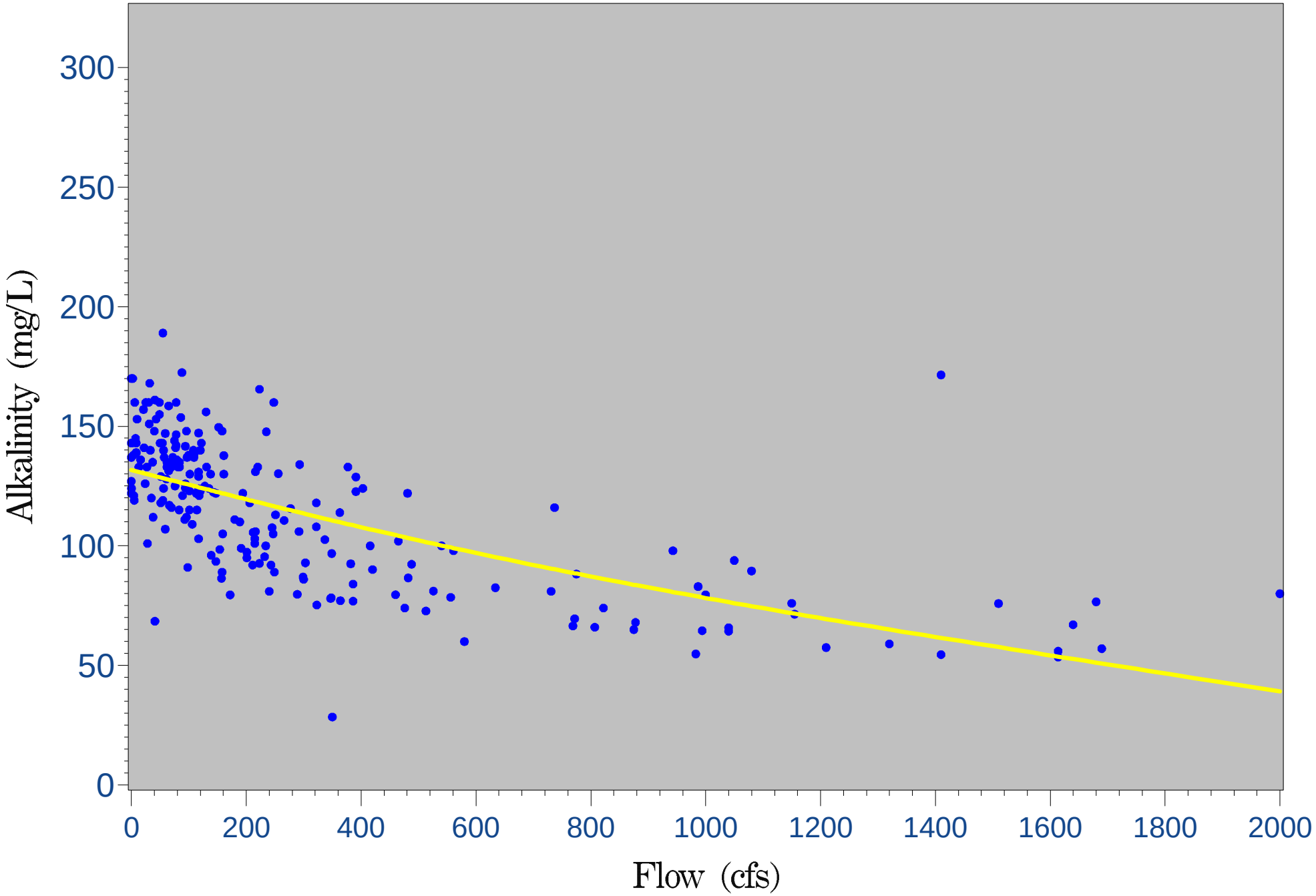


Figure 3.131c Alkalinity versus flow - Shell Creek Reservoir just upstream of the Dam

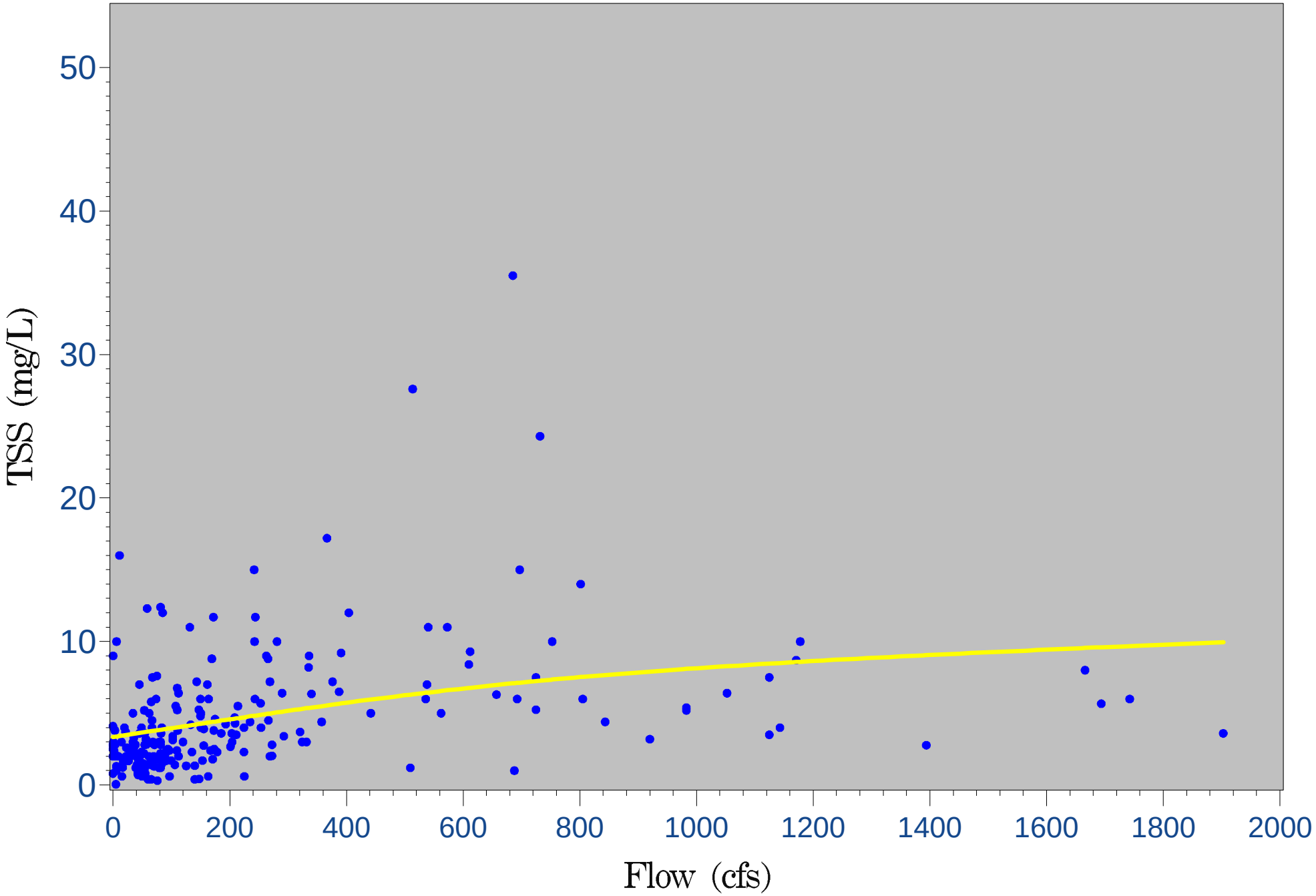


Figure 3.132a Total suspended solids versus flow - Prairie Creek at C.R. 764

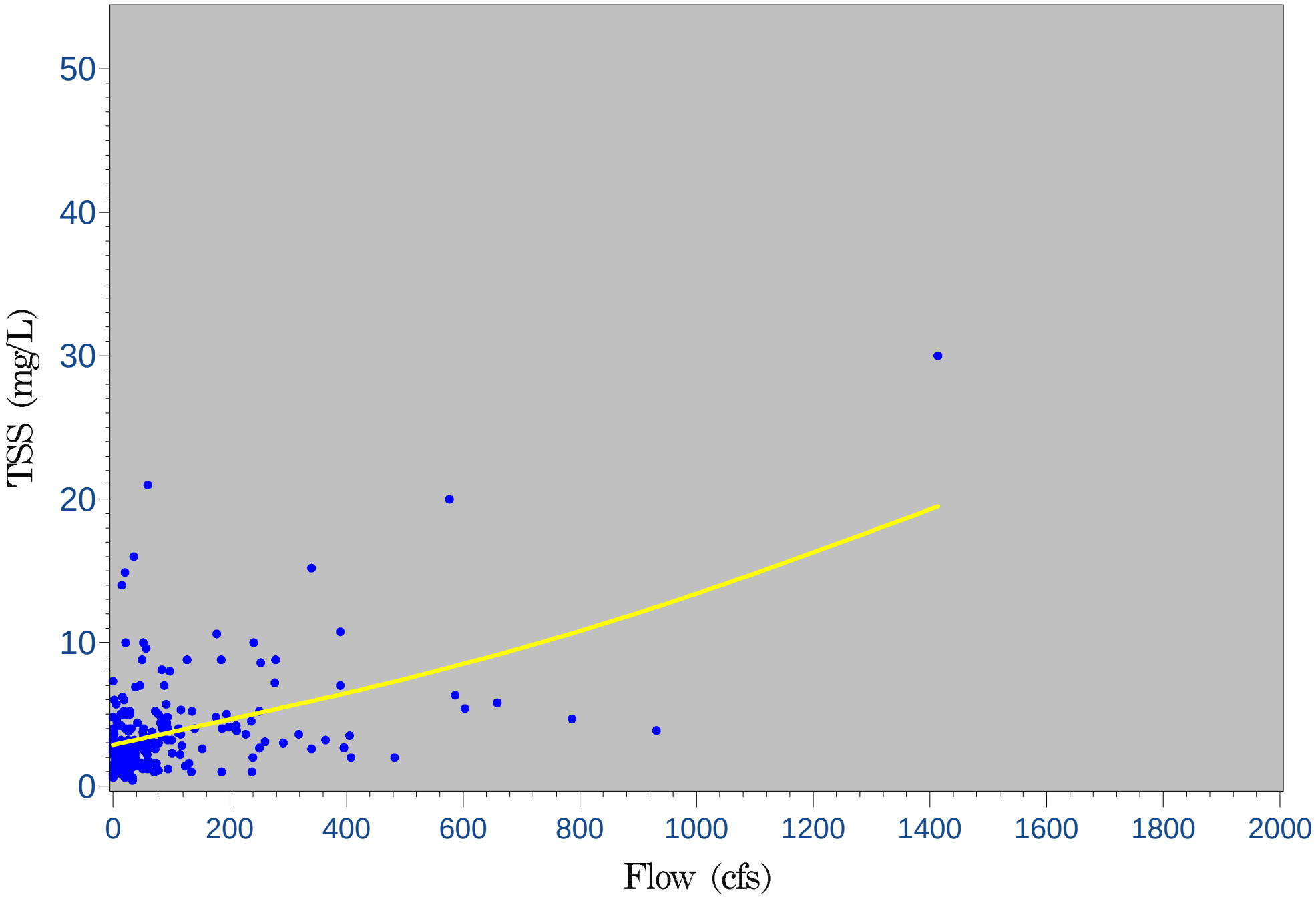


Figure 3.132b Total suspended solids versus flow - Shell Creek at C.R. 764

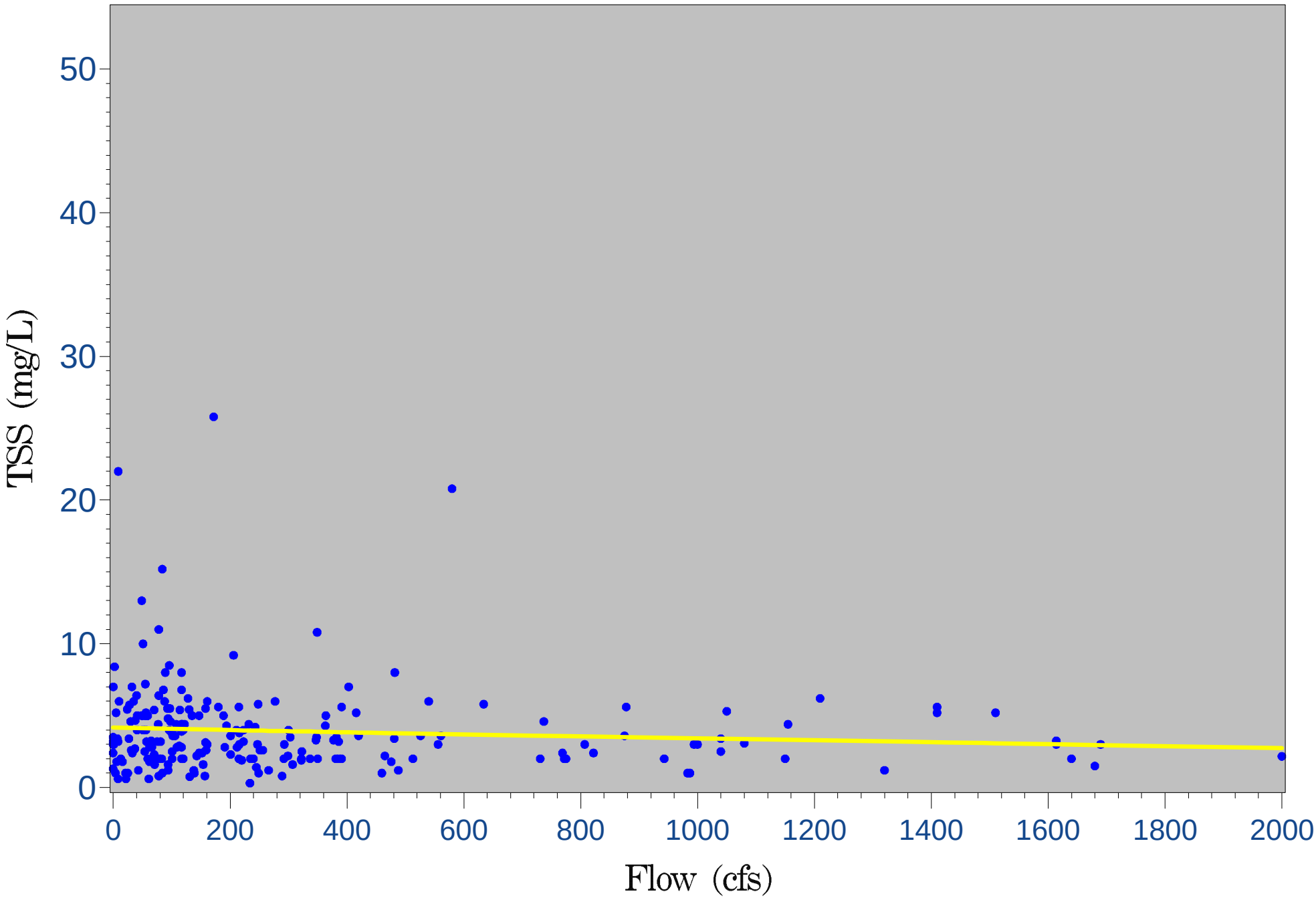


Figure 3.132c Total suspended solids versus flow - Shell Creek Reservoir just upstream of the Dam

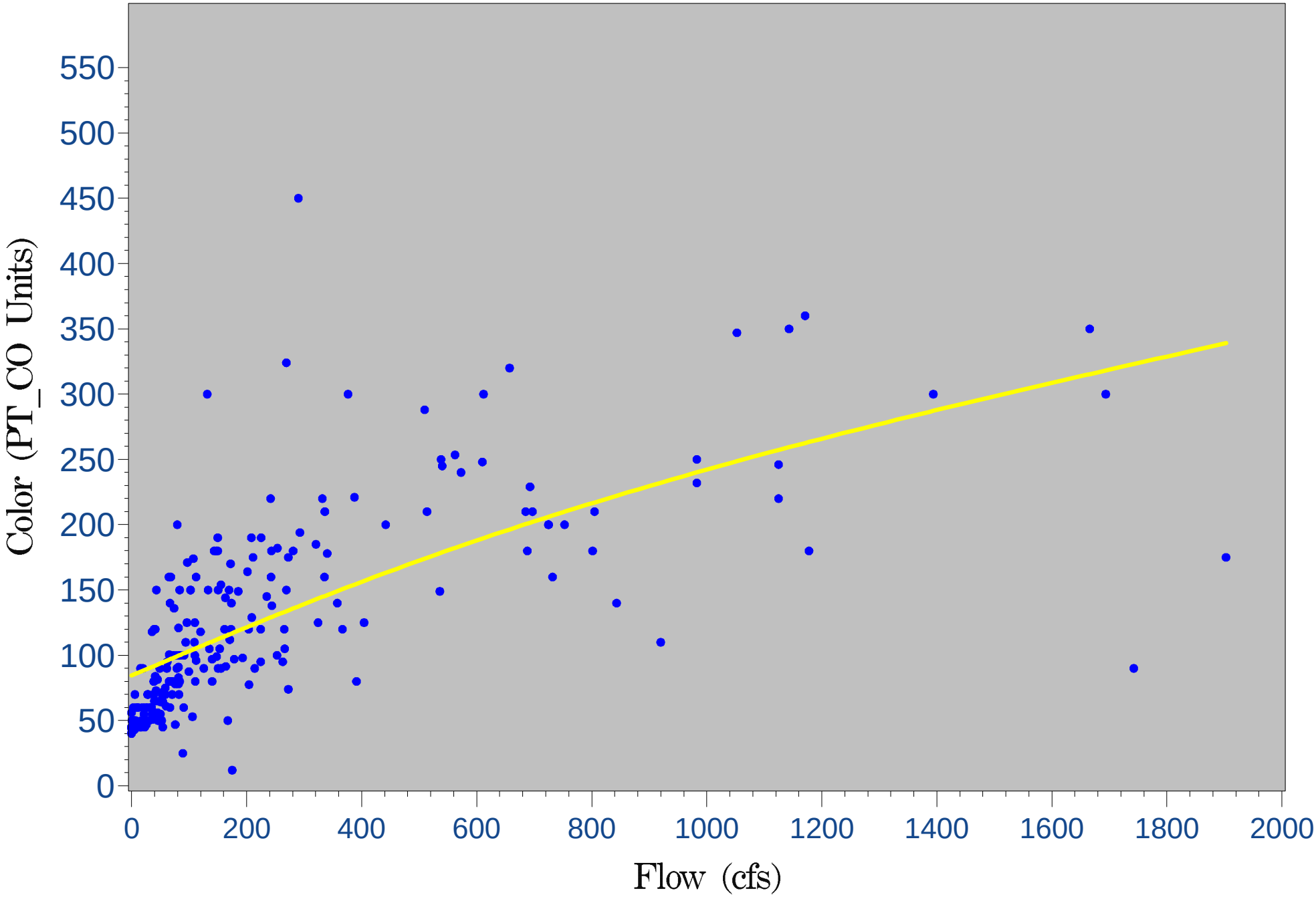


Figure 3.133a Water color versus flow - Prairie Creek at C.R. 764

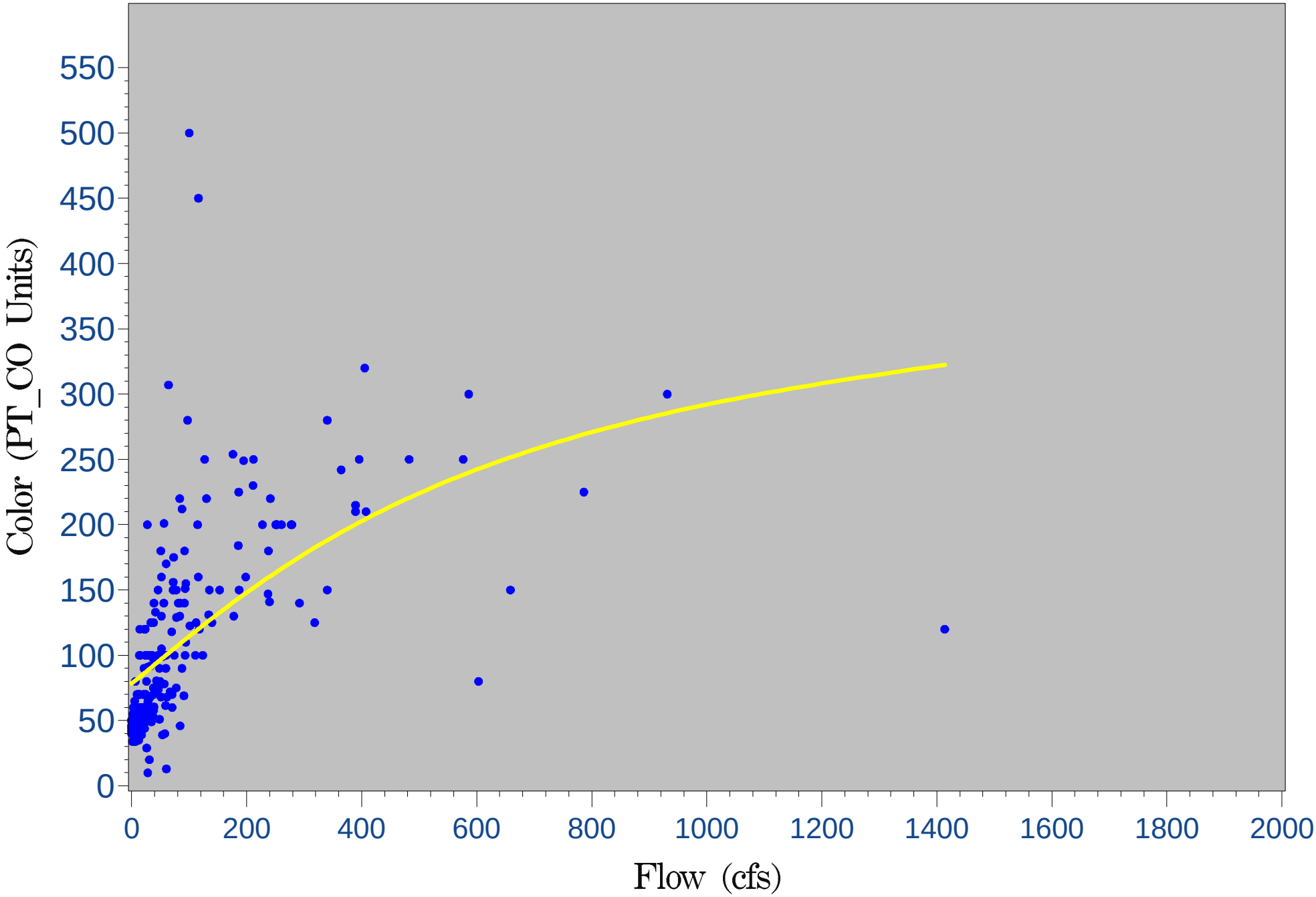


Figure 3.133b Water color versus flow - Shell Creek at C.R. 764

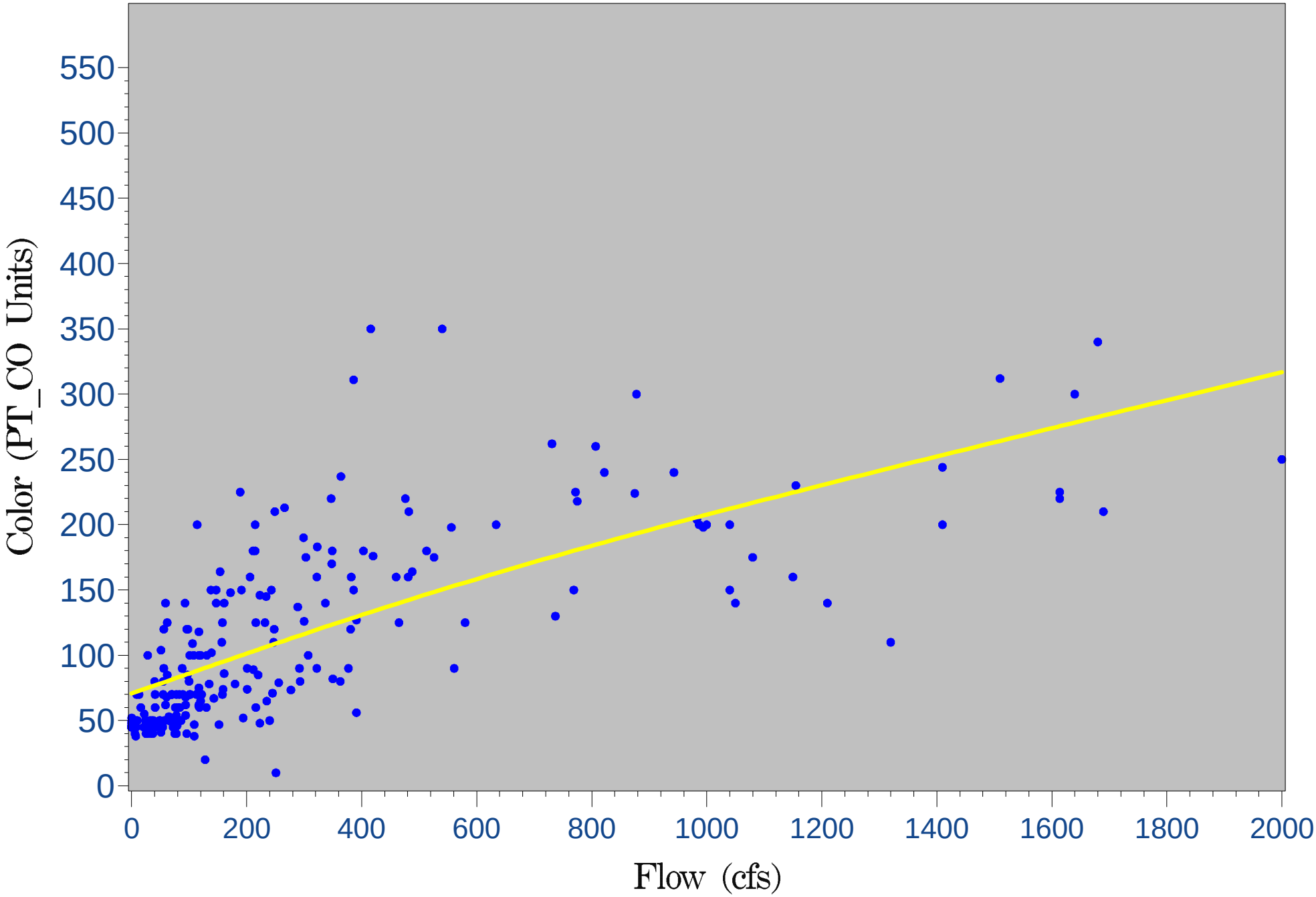


Figure 3.133c Water color versus flow - Shell Creek Reservoir just upstream of the Dam

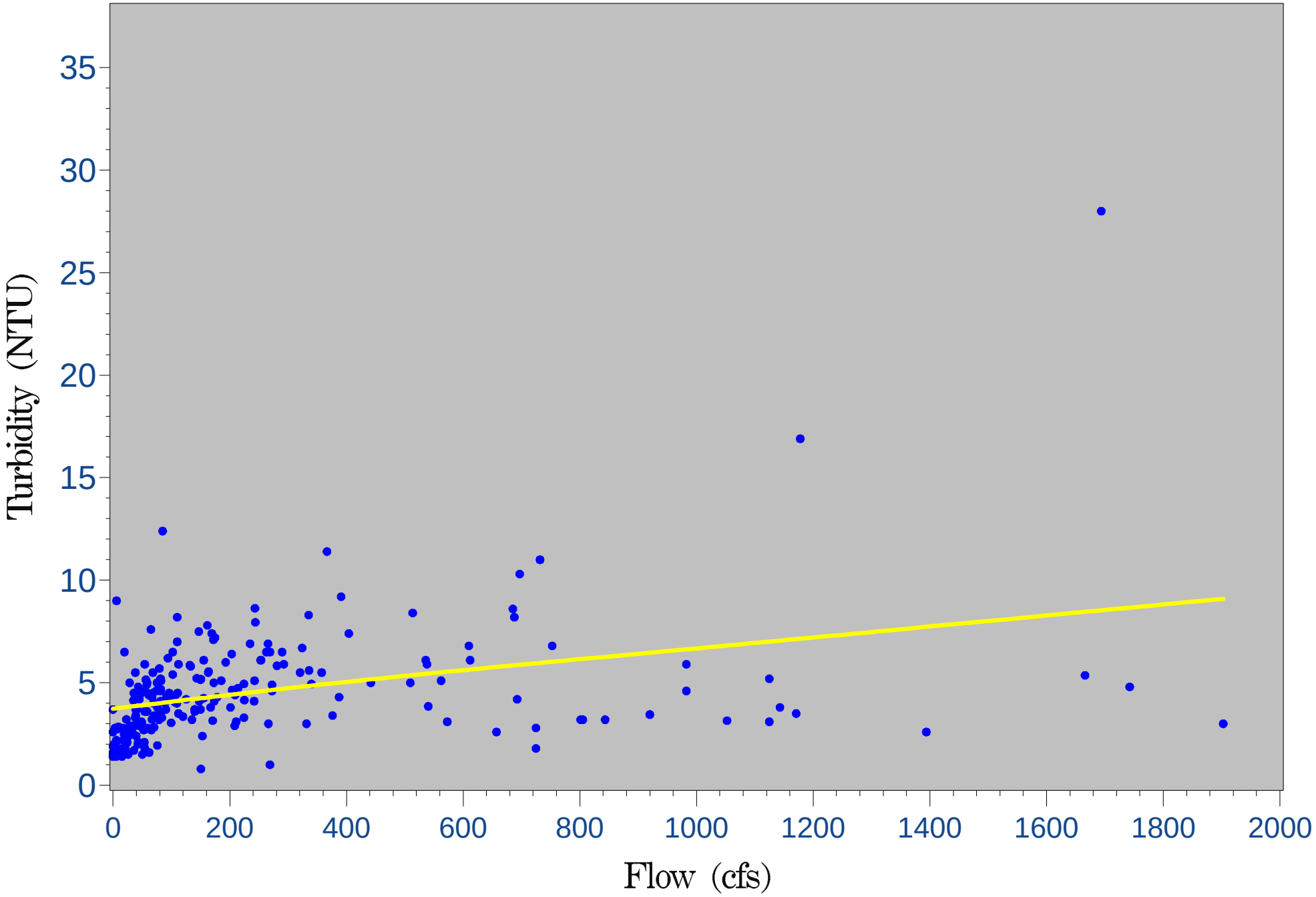


Figure 3.134a Turbidity versus flow - Prairie Creek at C.R. 764

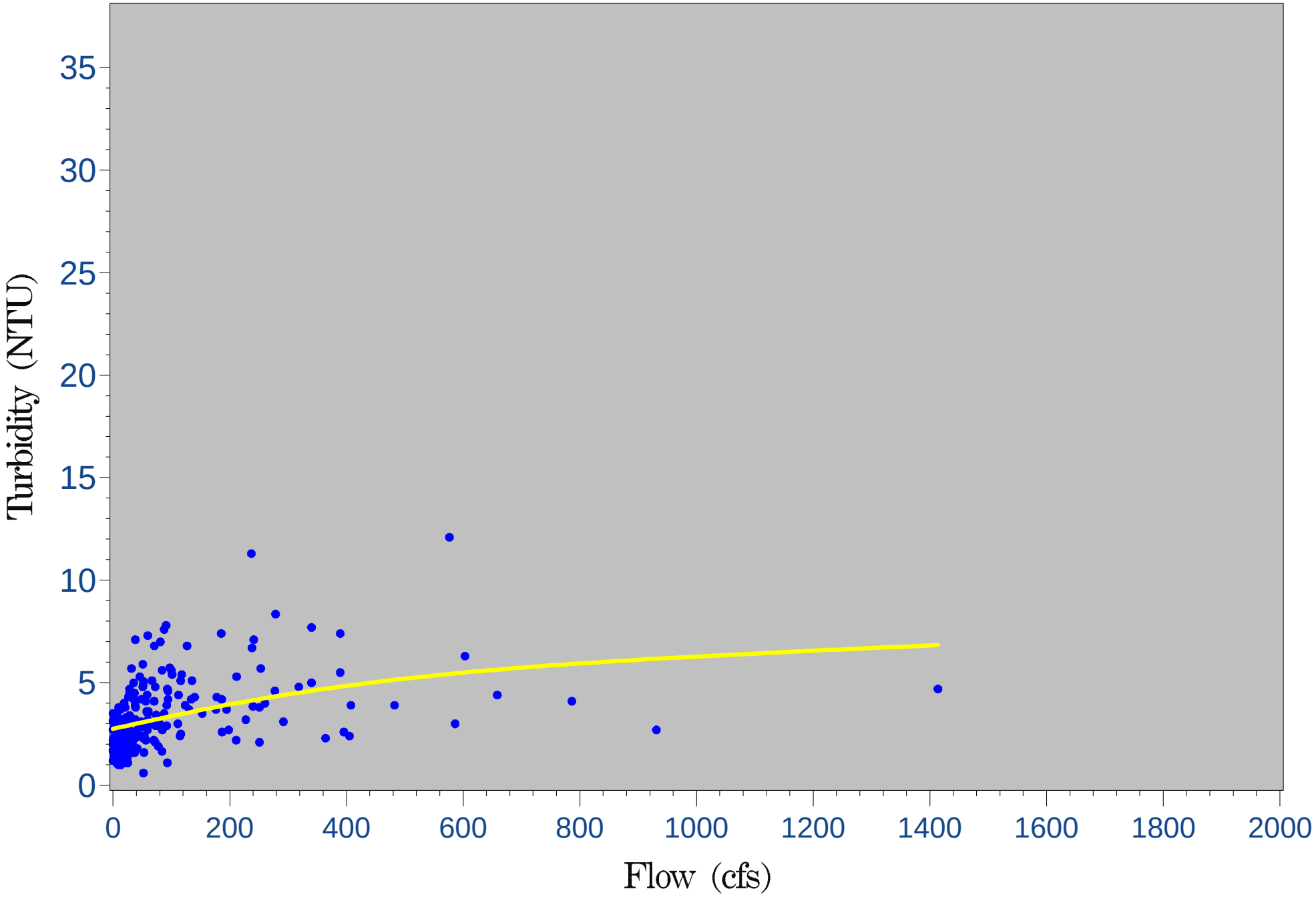


Figure 3.134b Turbidity versus flow - Shell Creek at C.R. 764

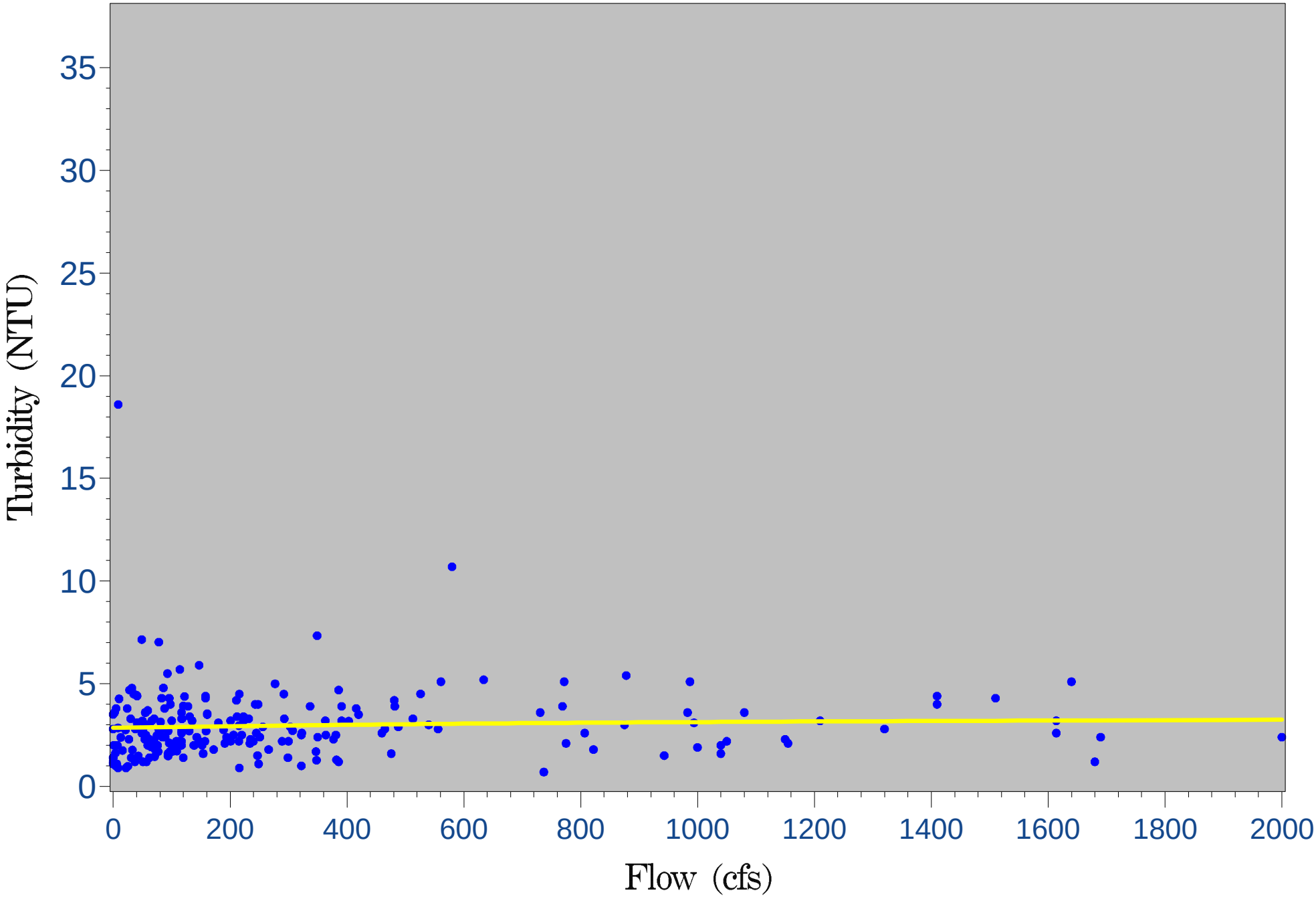


Figure 3.134c Turbidity versus flow - Shell Creek Reservoir just upstream of the Dam

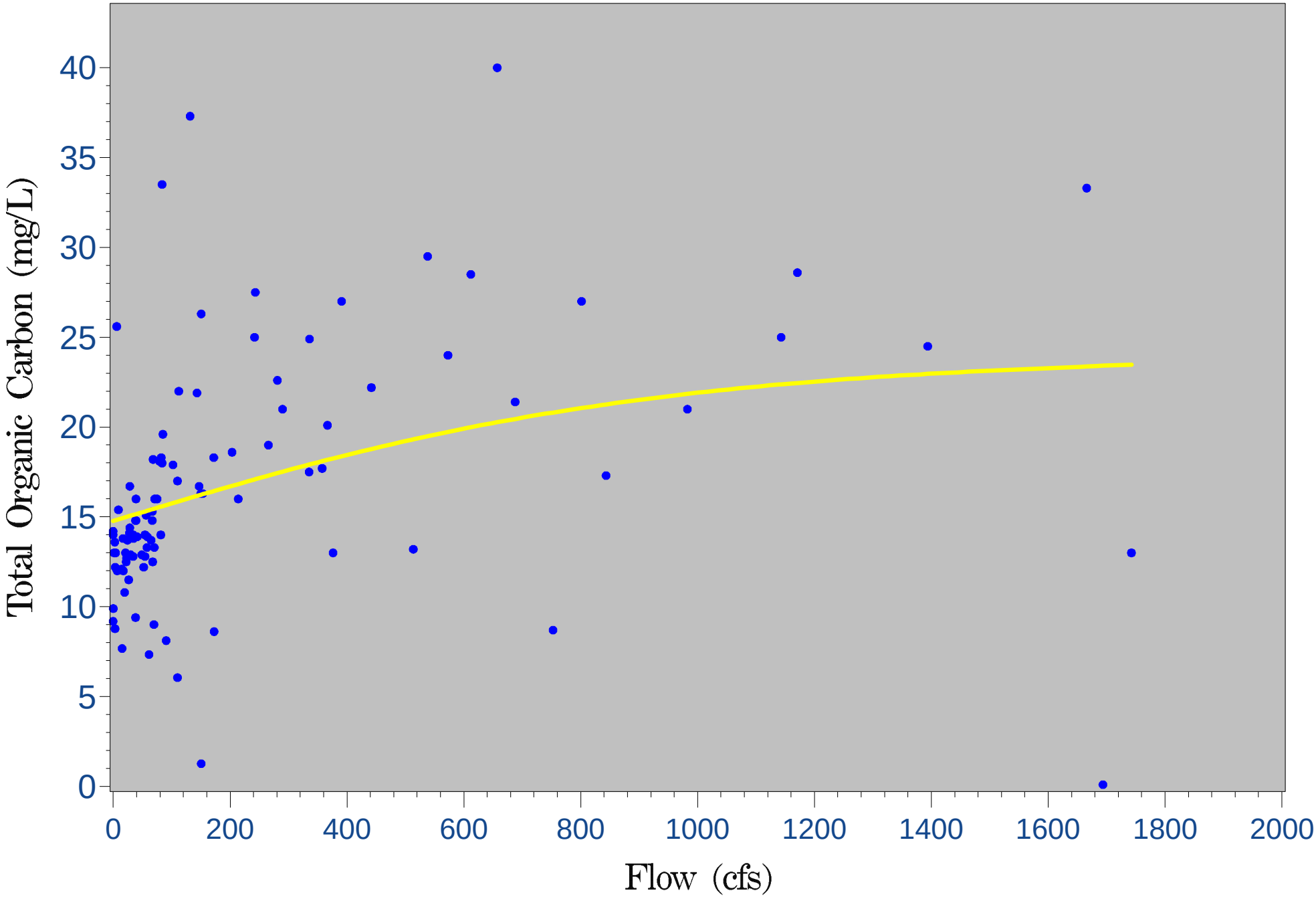


Figure 3.135a Toal organic carbon versus flow - Prairie Creek at C.R. 764

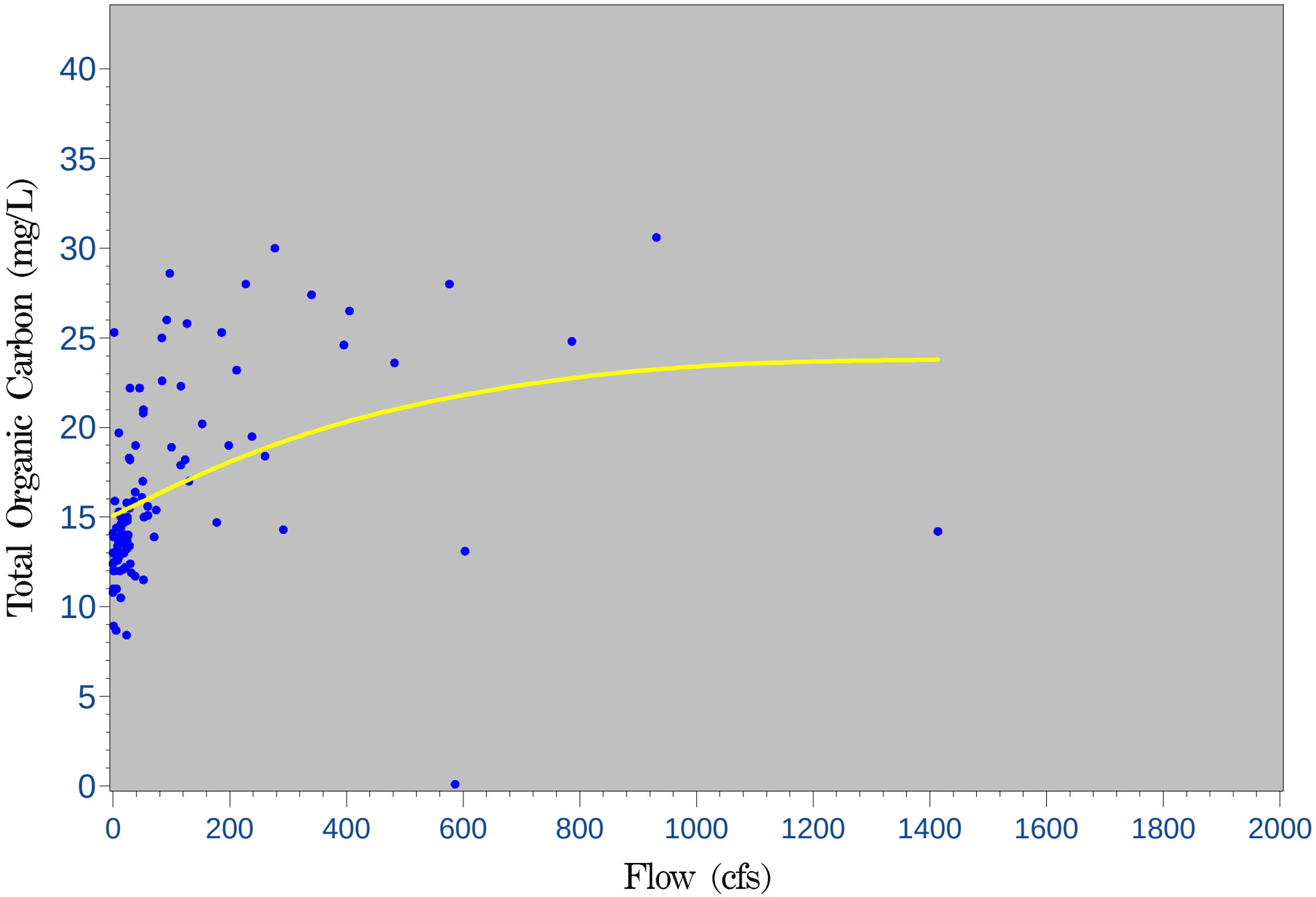


Figure 3.135b Total organic carbon versus flow - Shell Creek at C.R. 764

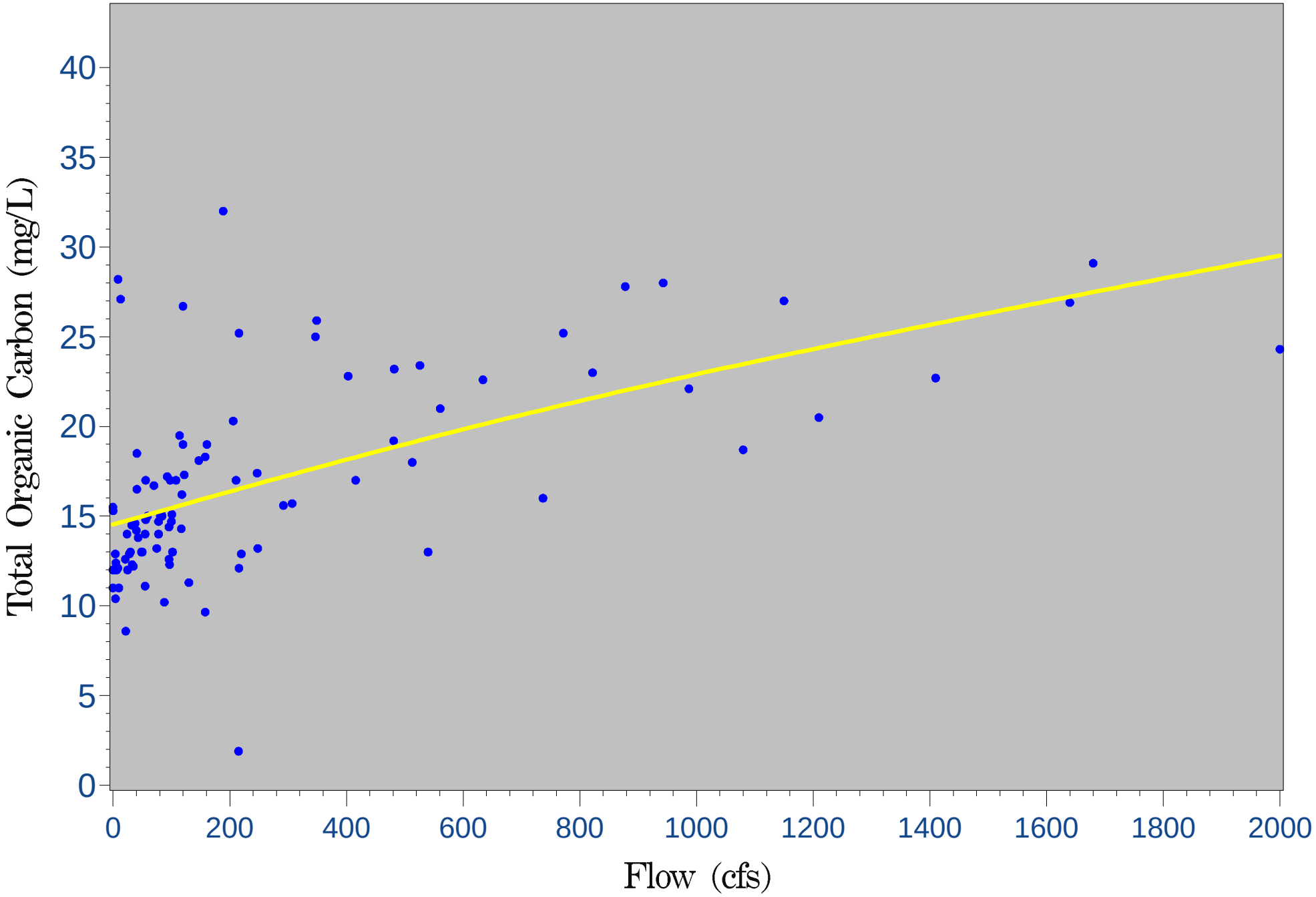


Figure 3.135c Total organic carbon versus flow - Shell Creek Reservoir just upstream of the Dam

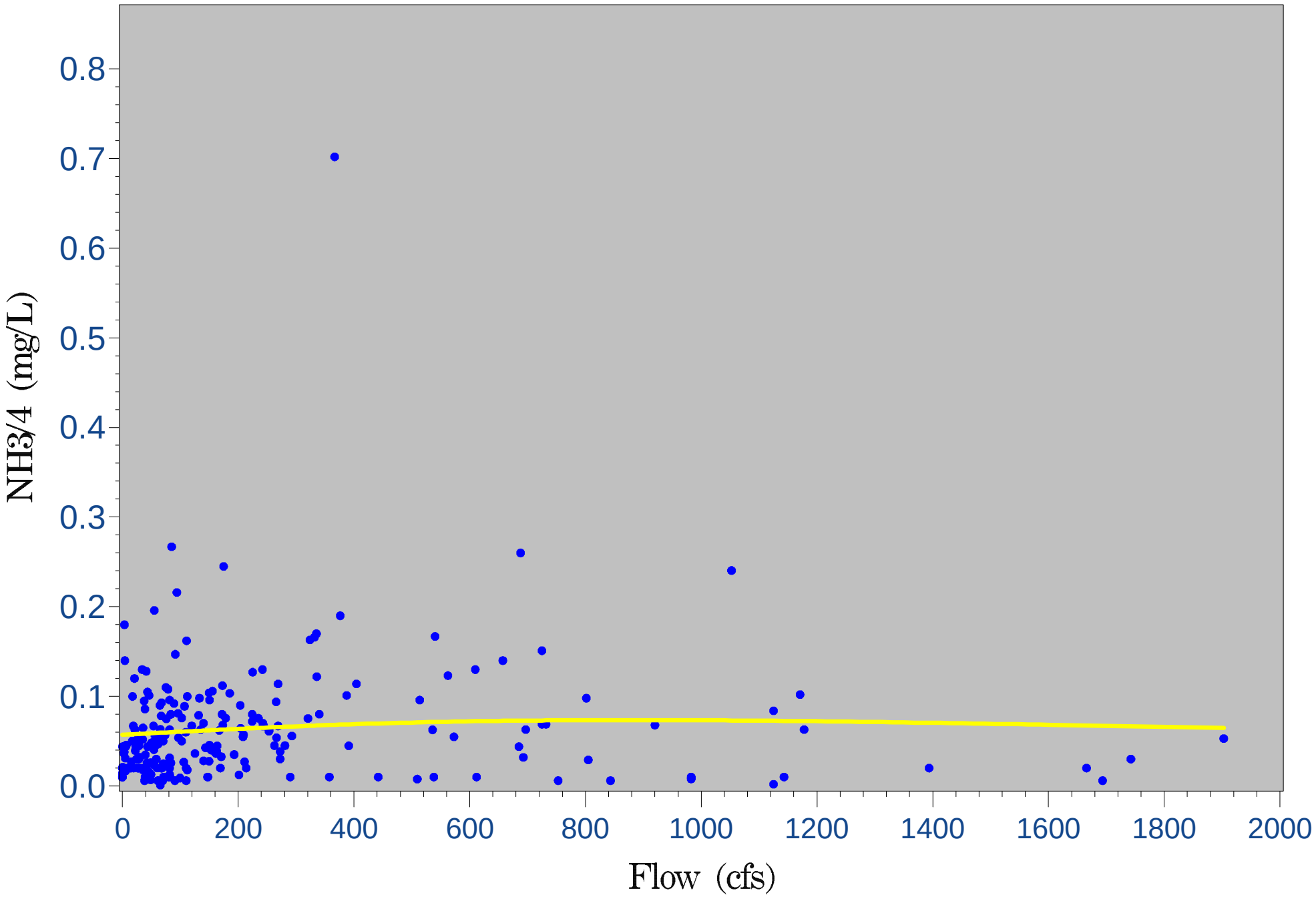


Figure 3.136a Ammonia/ammonium versus flow - Prairie Creek at C.R. 764

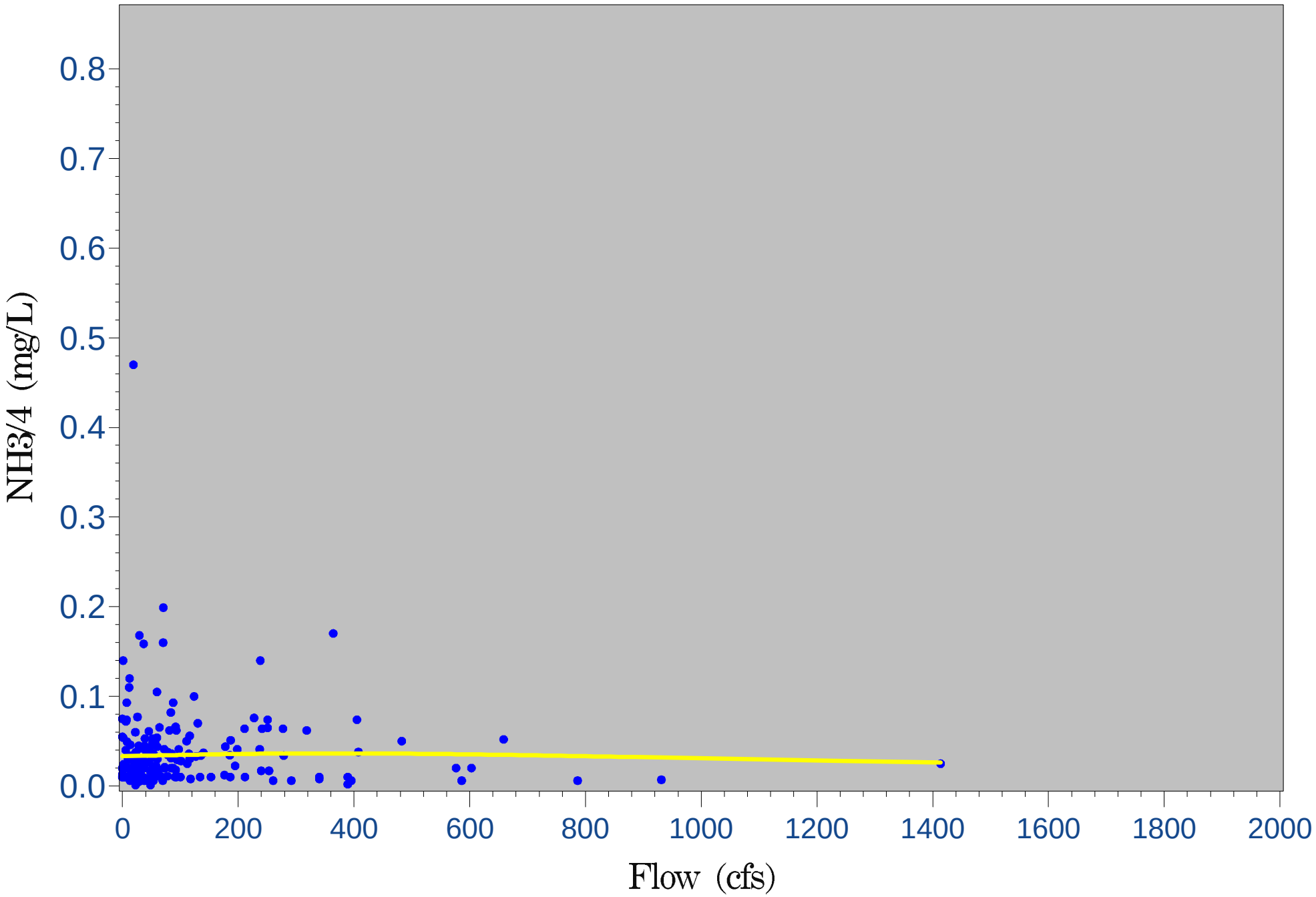


Figure 3.136b Ammonia/ammonium versus flow - Shell Creek at C.R. 764

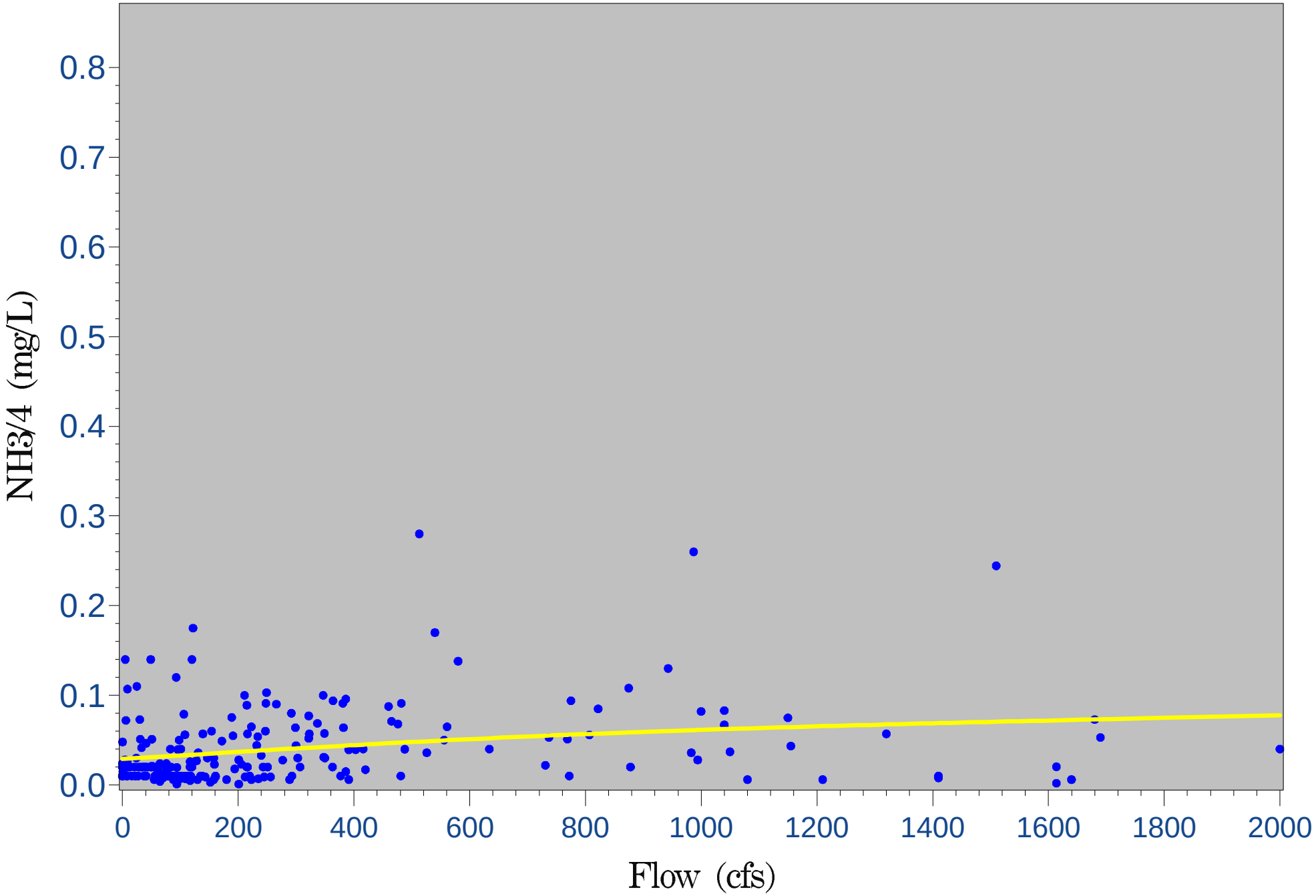


Figure 3.136c Ammonia/ammonium versus flow - Shell Creek Reservoir just upstream of the Dam

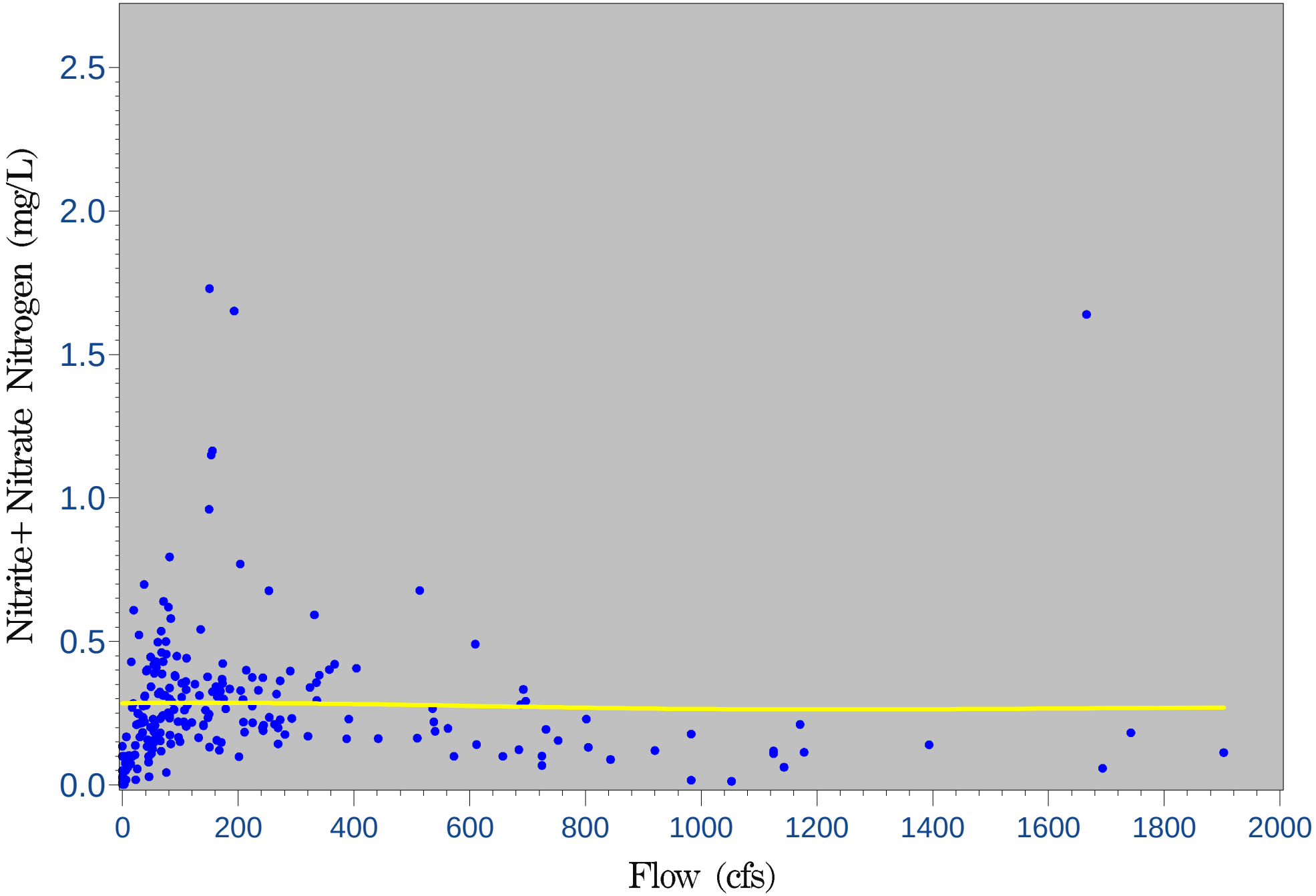


Figure 3.137a Nitrite+nitrate nitrogen versus flow - Prairie Creek at C.R. 764

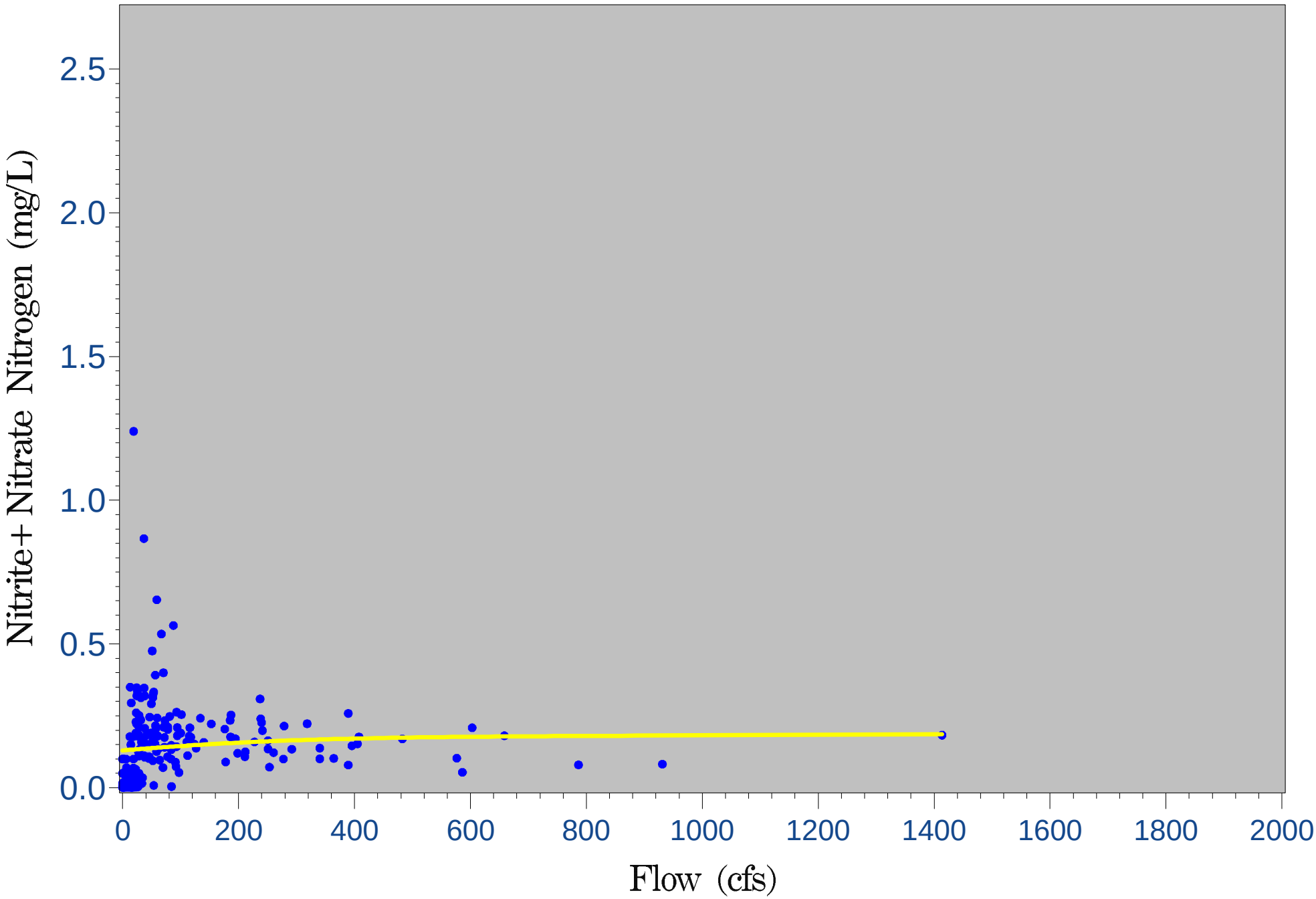


Figure 3.137b Nitrite+nitrate nitrogen versus flow - Shell Creek at C.R. 764

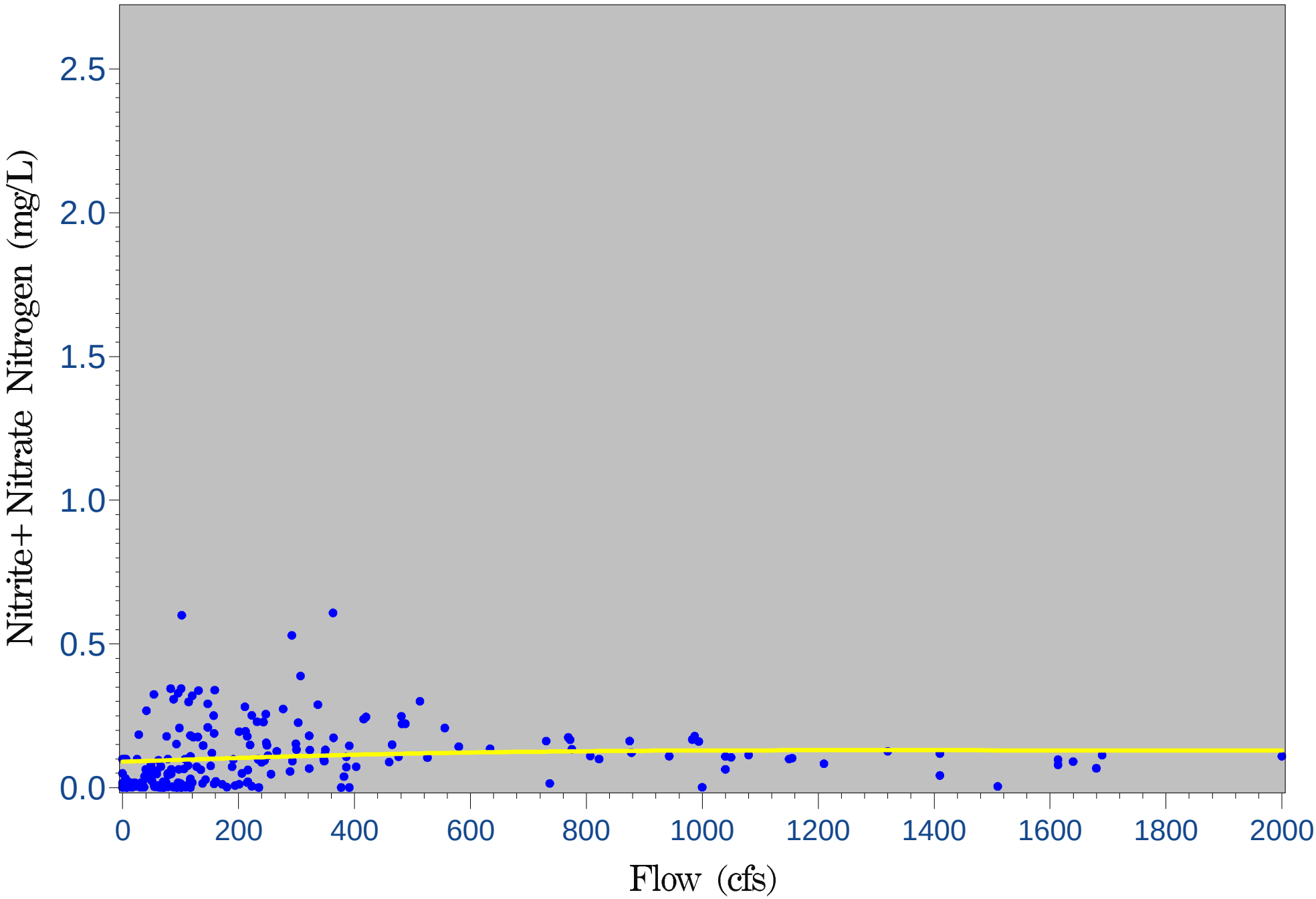


Figure 3.137c Nitrite+nitrate nitrogen versus flow - Shell Creek Reservoir just upstream of the Dam

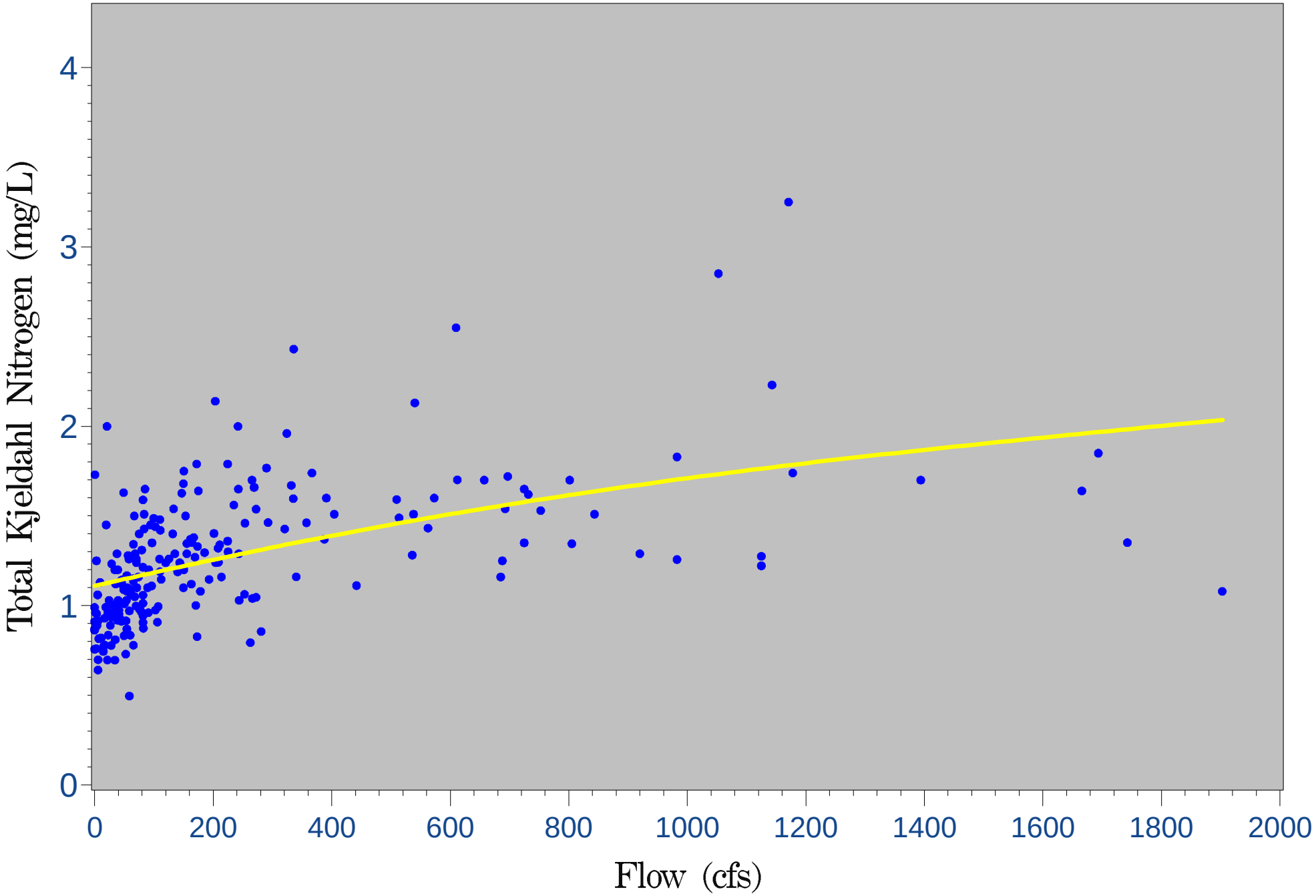


Figure 3.138a Total Kjeldahl nitrogen versus flow - Prairie Creek at C.R. 764

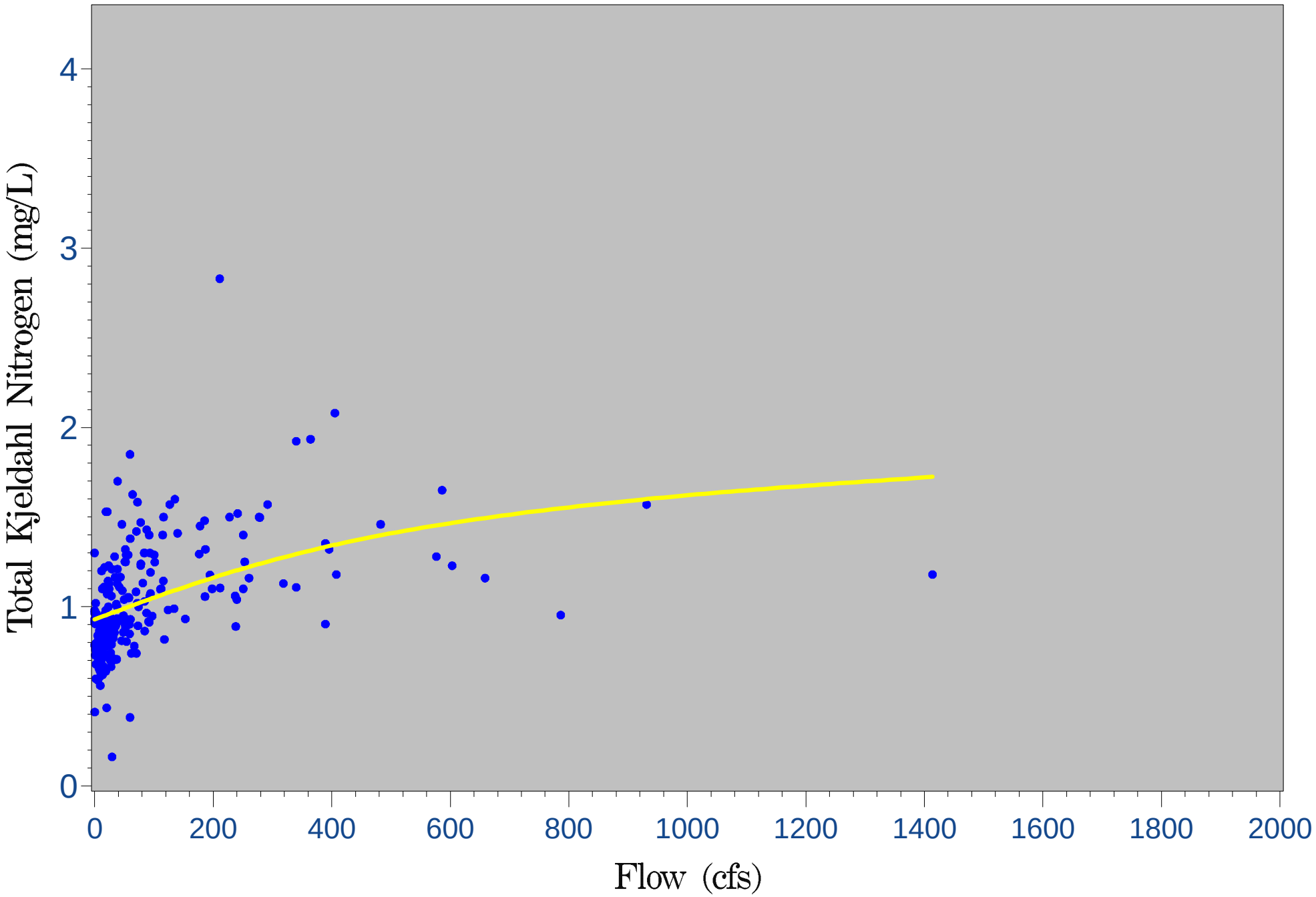


Figure 3.138b Total Kjeldahl nitrogen versus flow - Shell Creek at C.R. 764

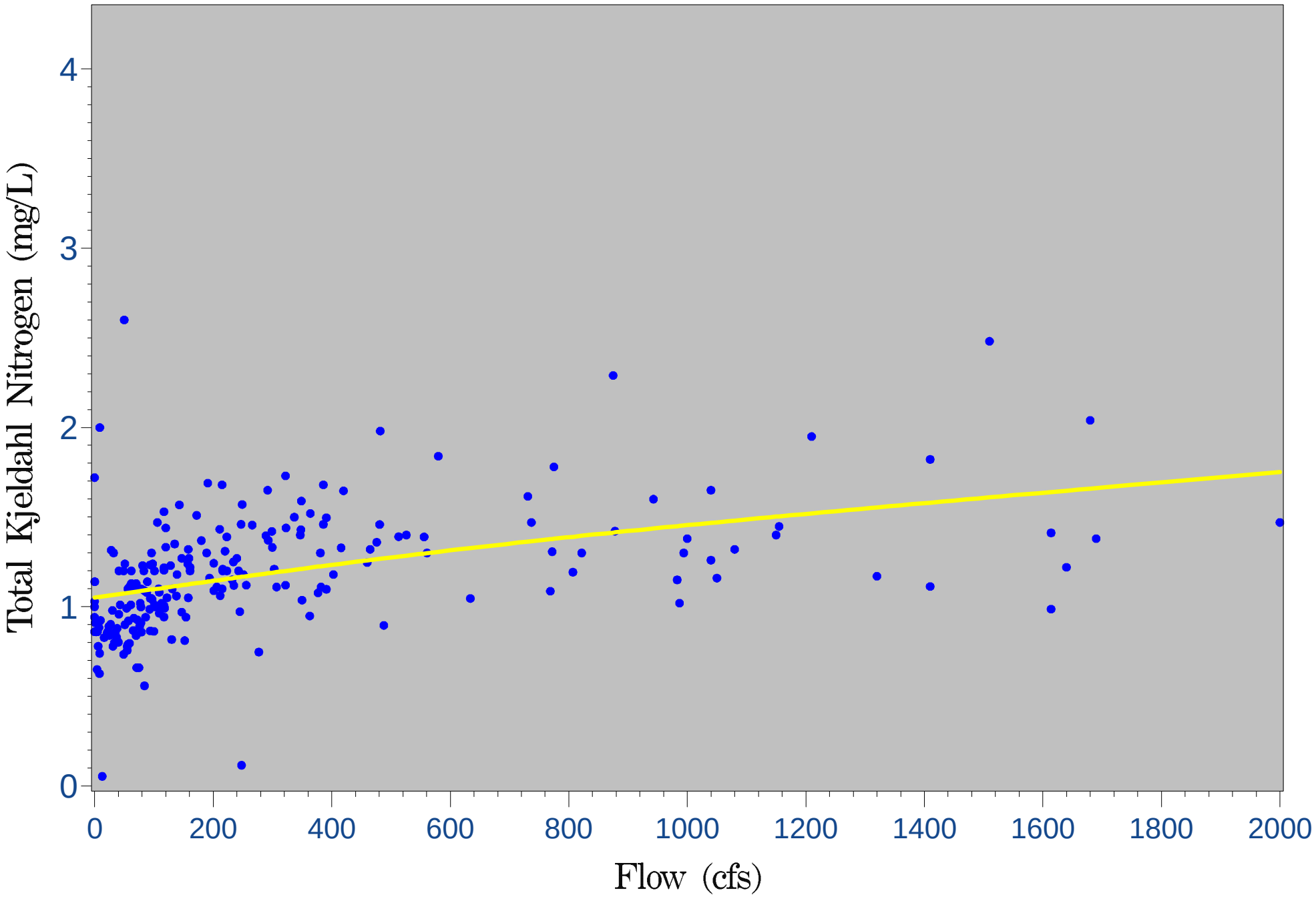


Figure 3.138c Total Kjeldahl nitrogen versus flow - Shell Creek Reservoir just upstream of the Dam

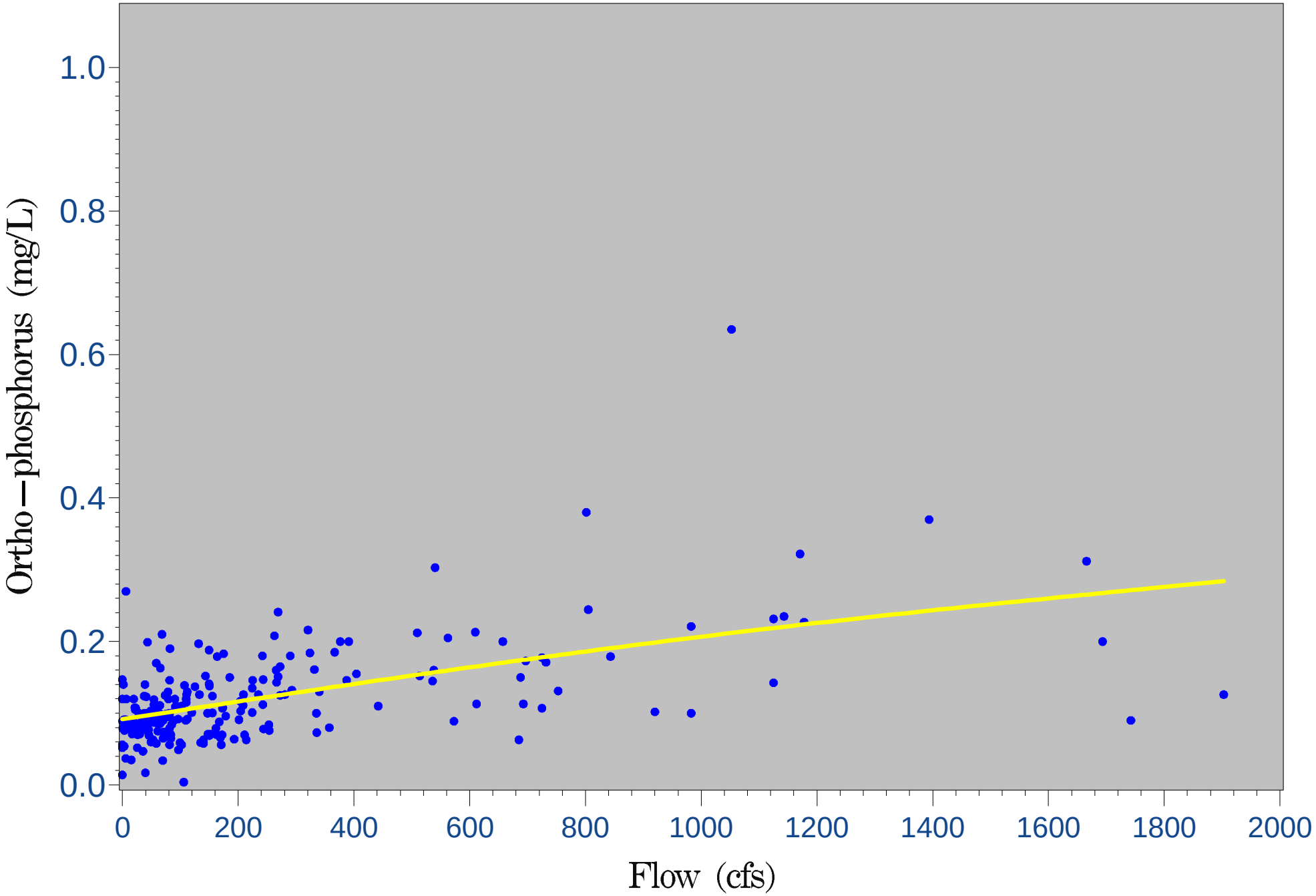


Figure 3.139a Ortho-phosphorus versus flow - Prairie Creek at C.R. 764

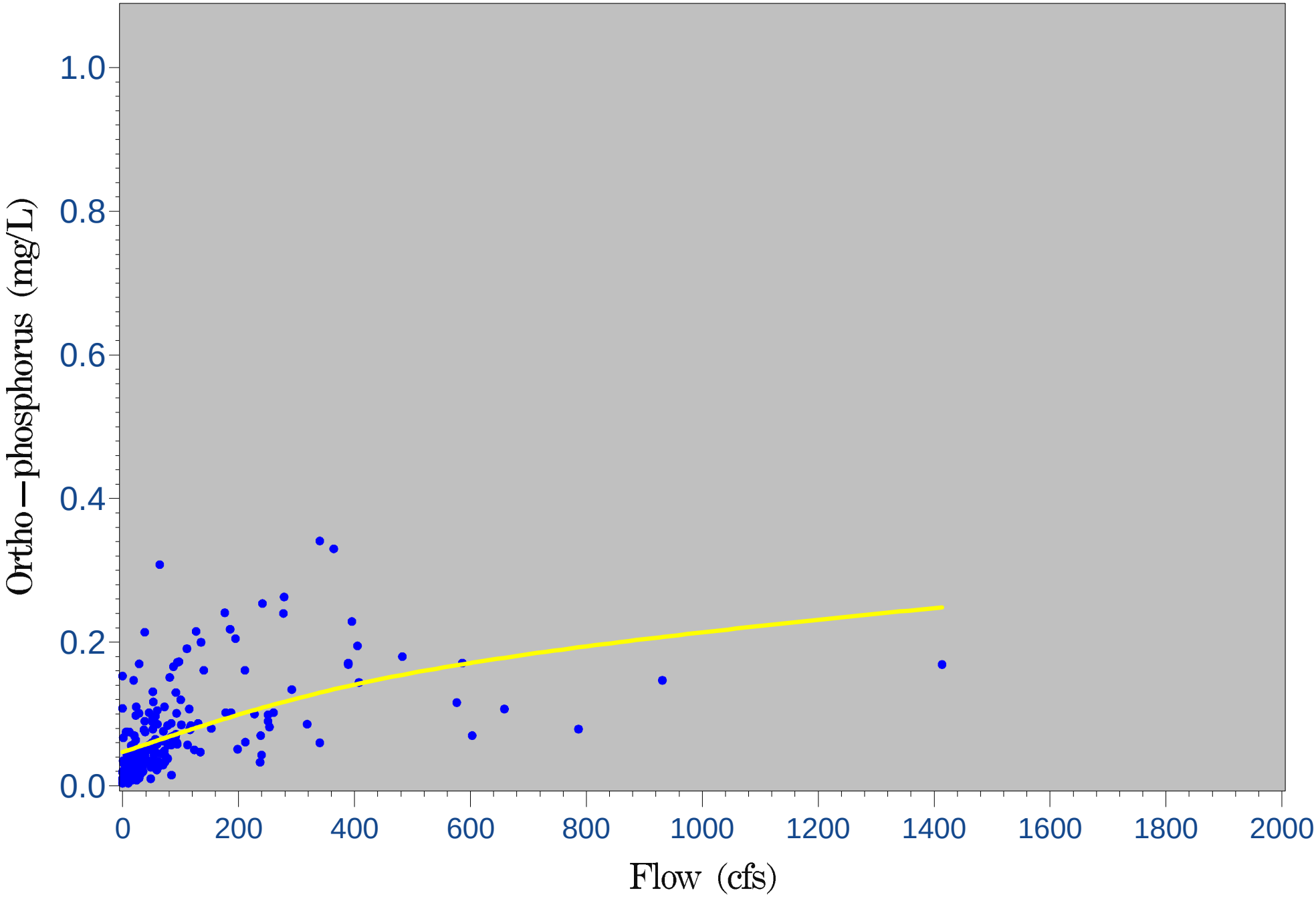


Figure 3.139b Ortho-phosphorus versus flow - Shell Creek at C.R. 764

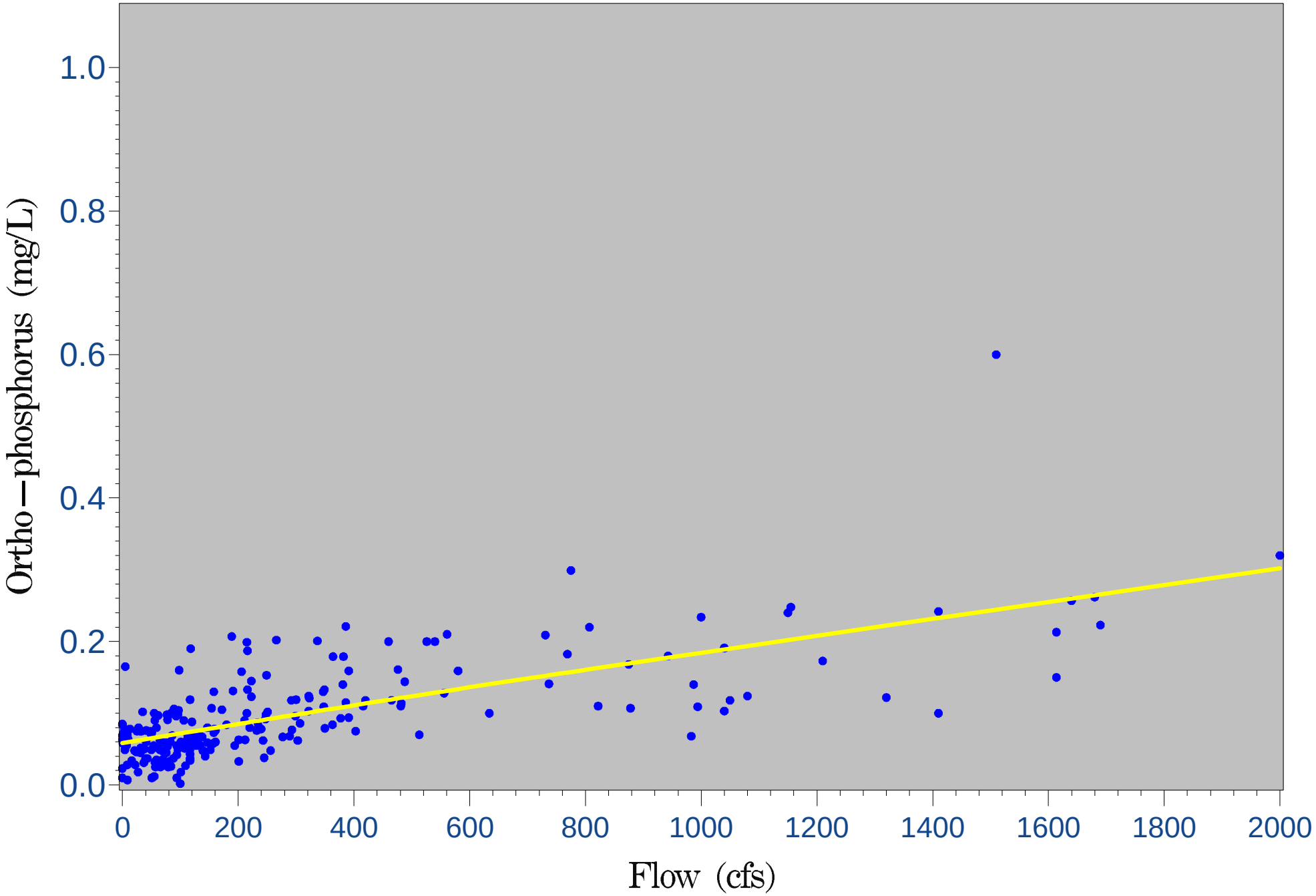


Figure 3.139c Ortho-phosphorus versus flow - Shell Creek Reservoir just upstream of the Dam

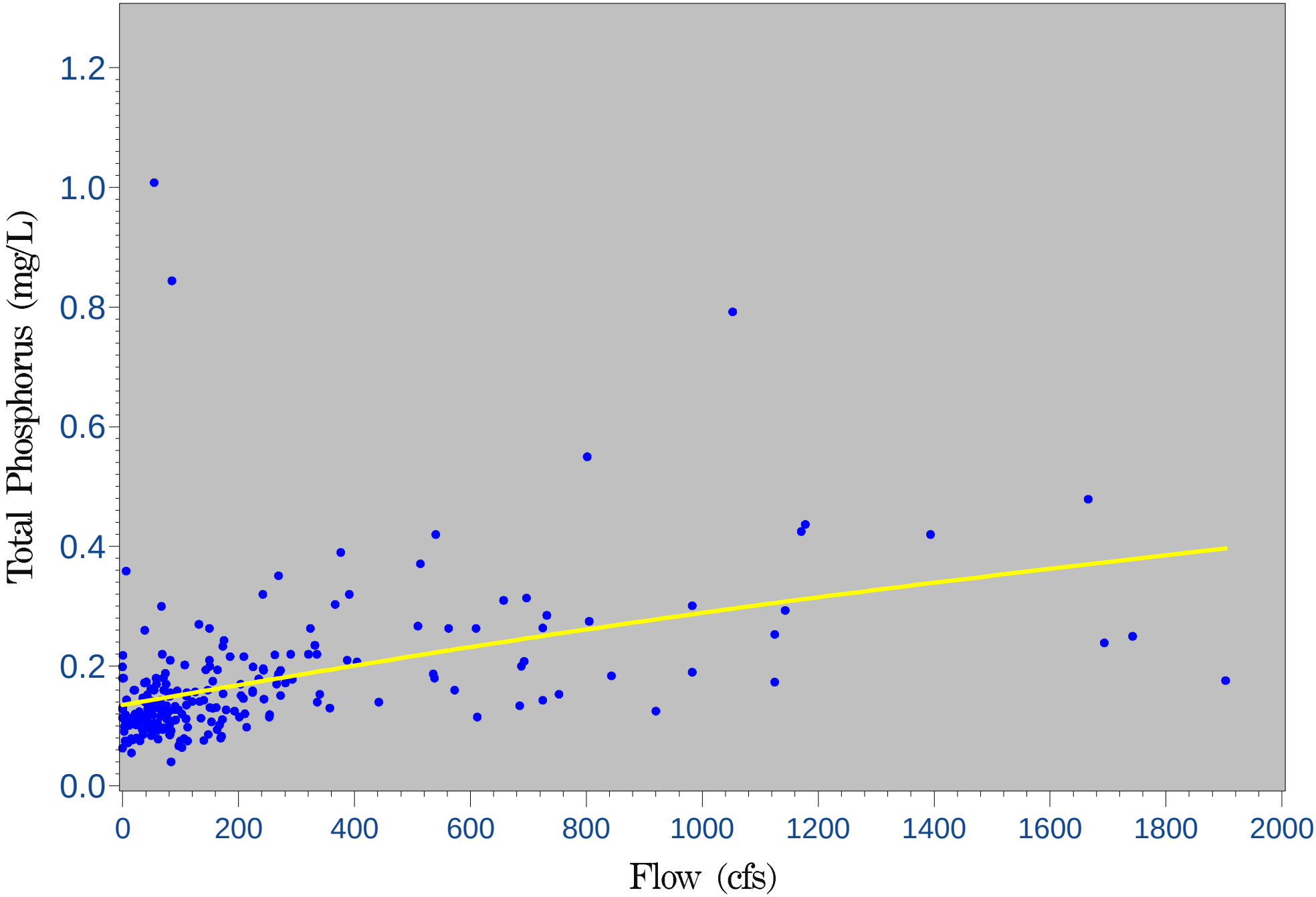


Figure 3.140a Total phosphorus versus flow - Prairie Creek at C.R. 764

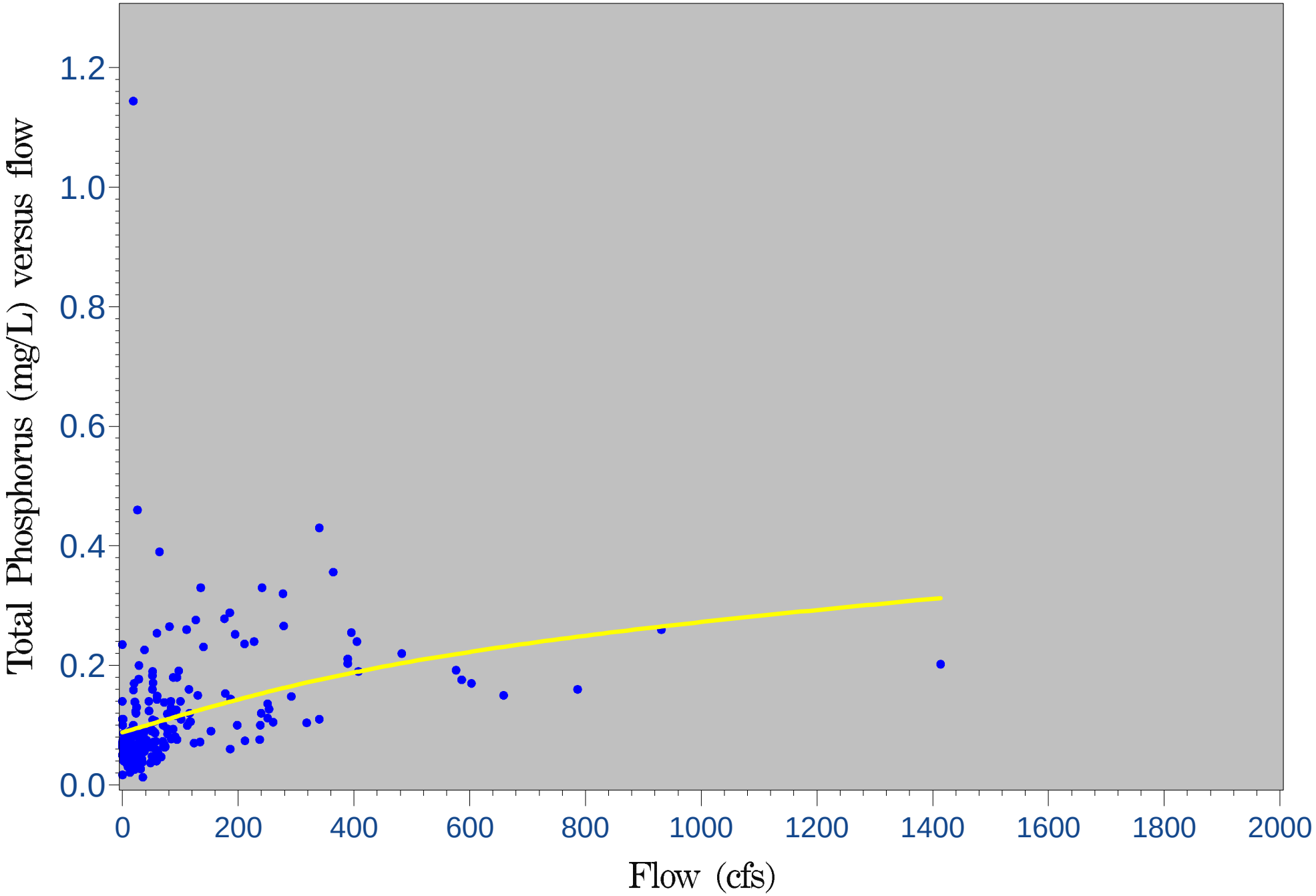


Figure 3.140b Total phosphorus - Shell Creek at C.R. 764

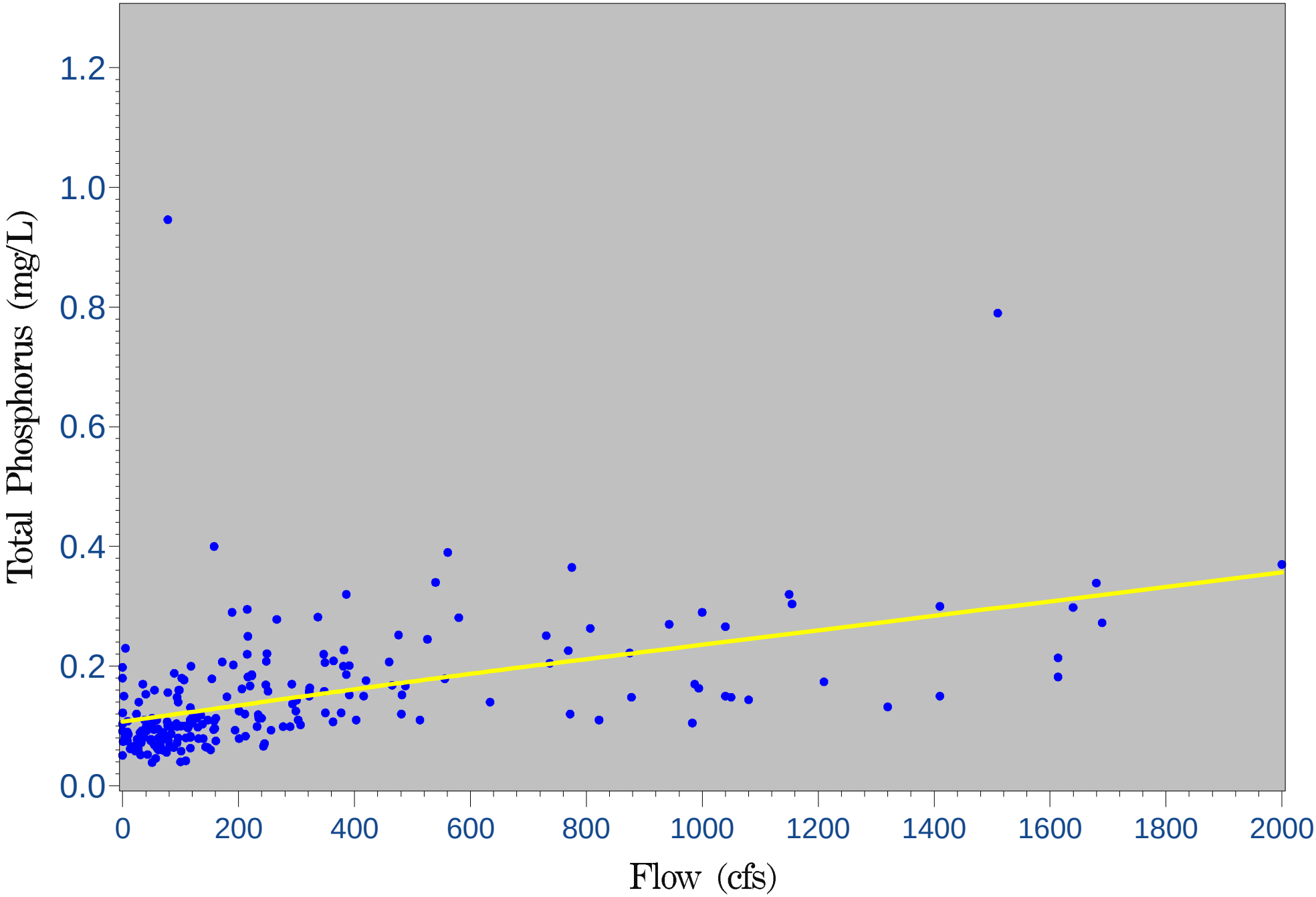


Figure 3.140c Total phosphorus versus flow - Shell Creek Reservoir just upstream of the Dam

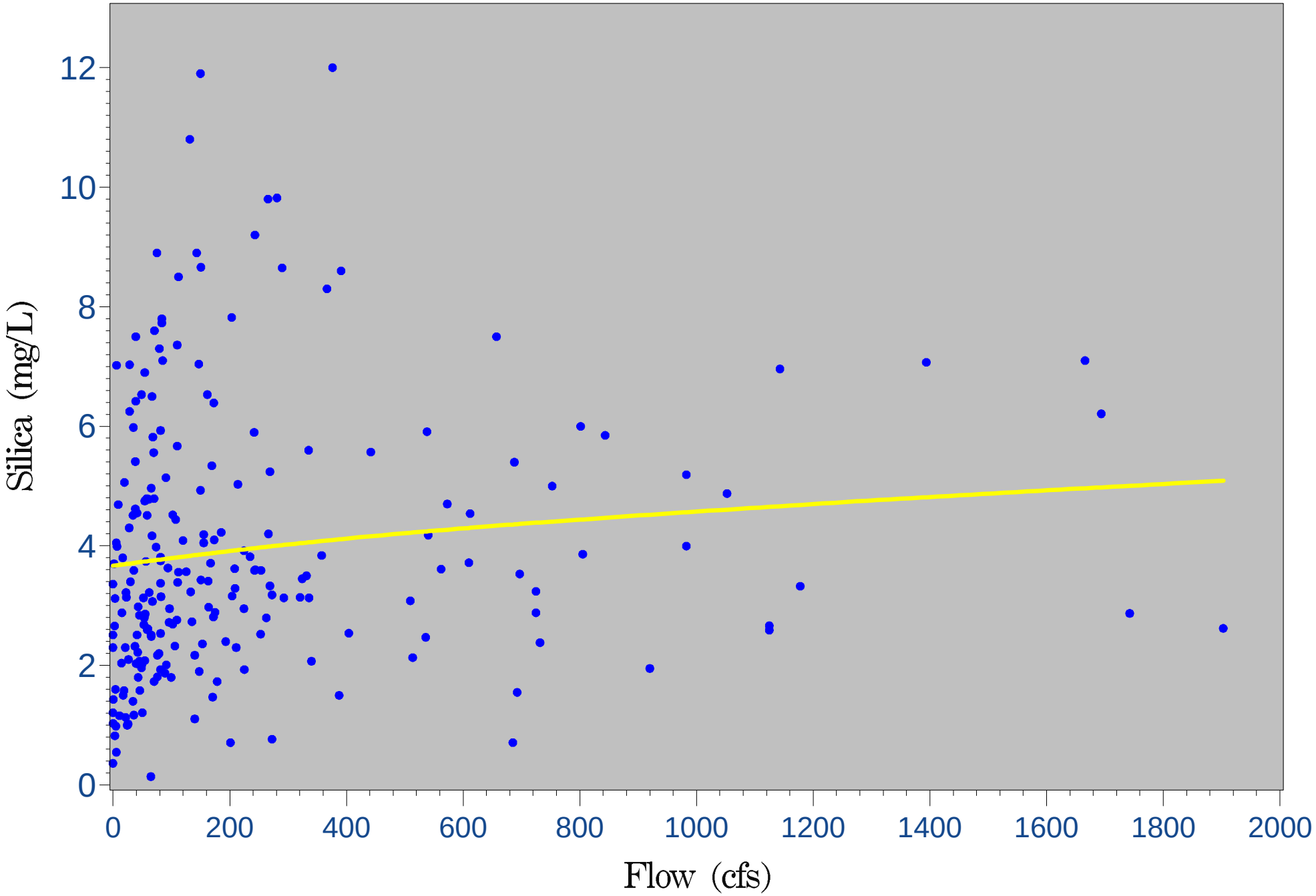


Figure 3.141a Silica versus flow - Prairie Creek at C.R. 764

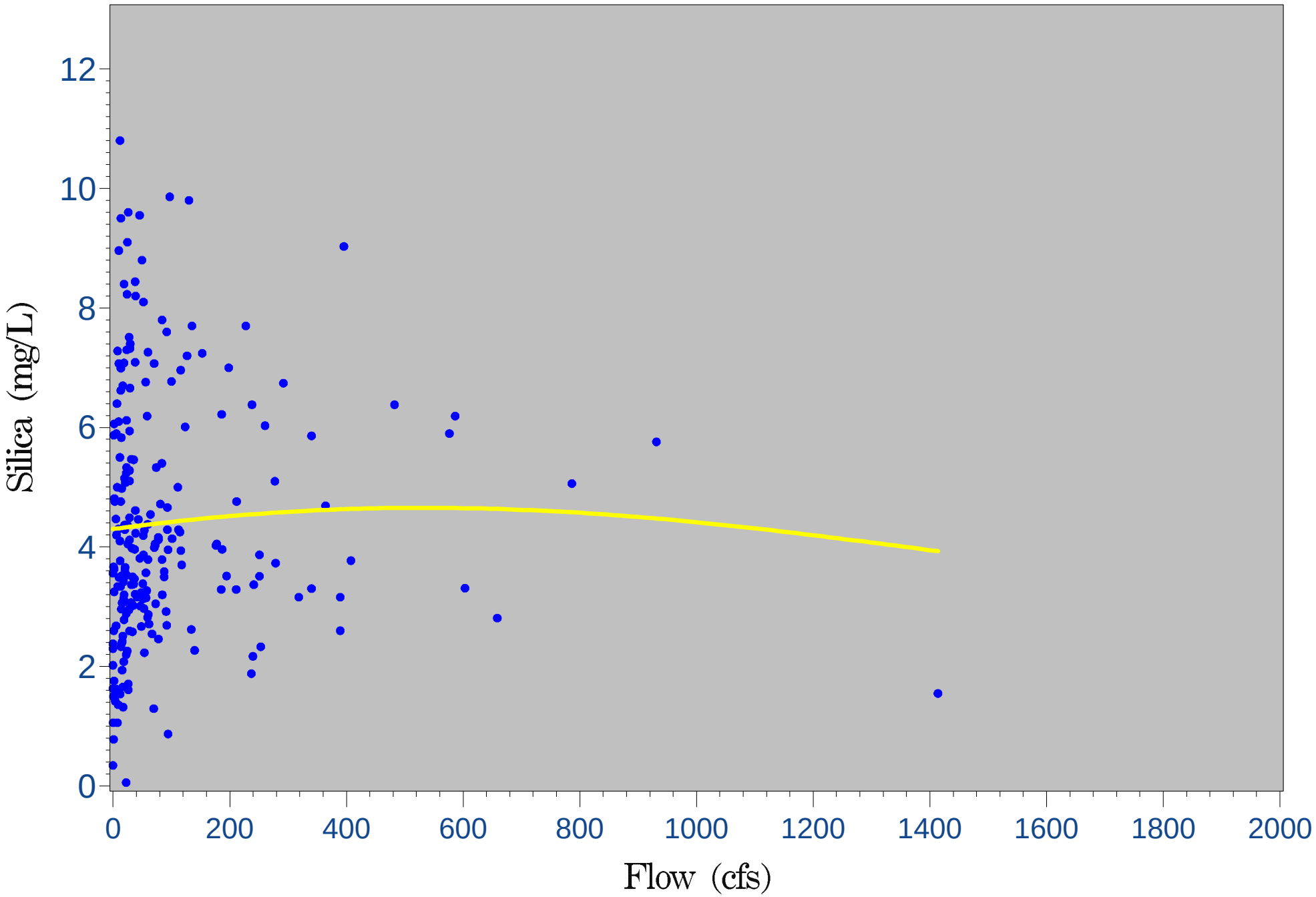


Figure 3.141b Silica versus flow - Shell Creek at C.R. 764

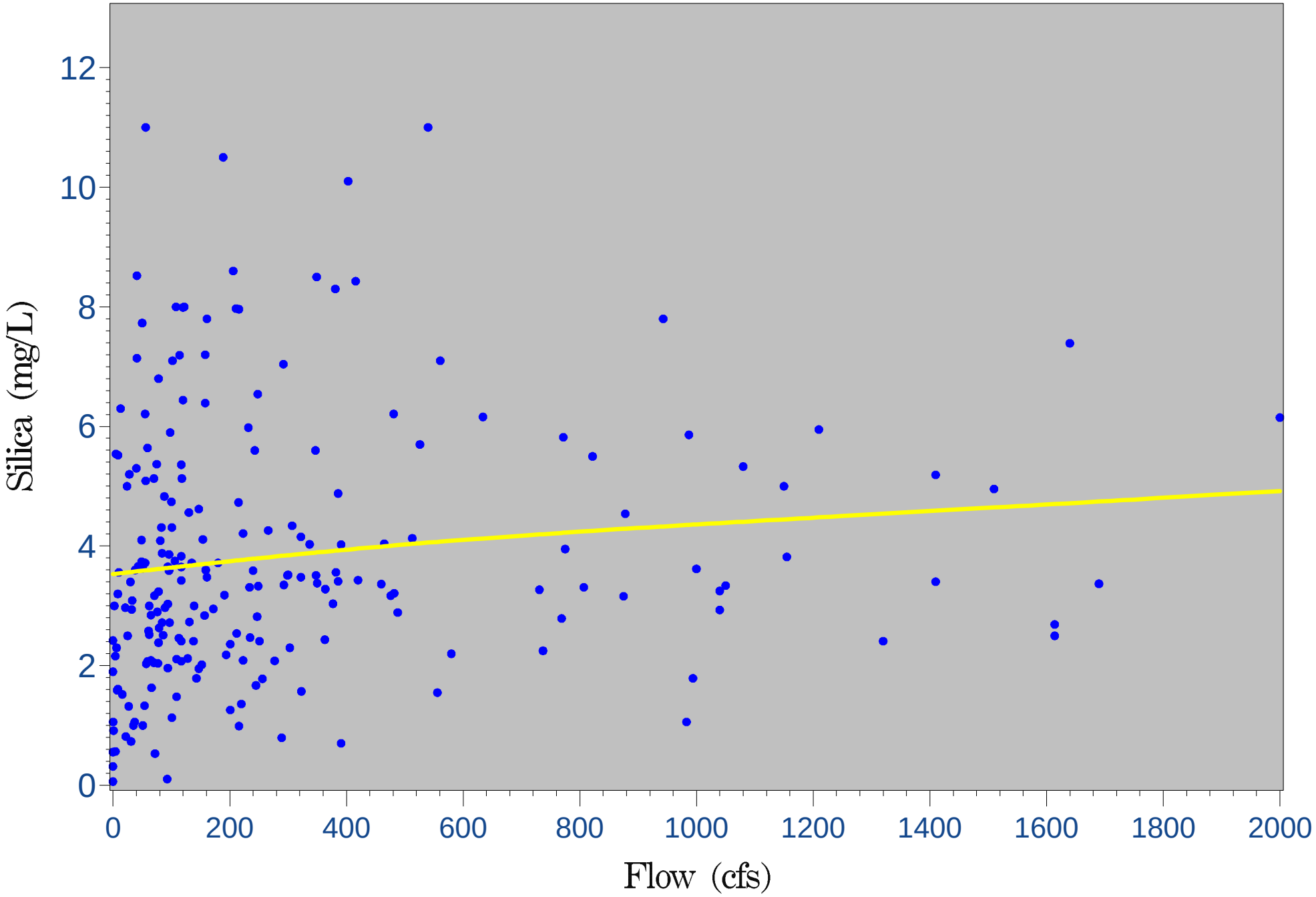


Figure 3.141c Silica versus flow - Shell Creek Reservoir just upstream of the Dam

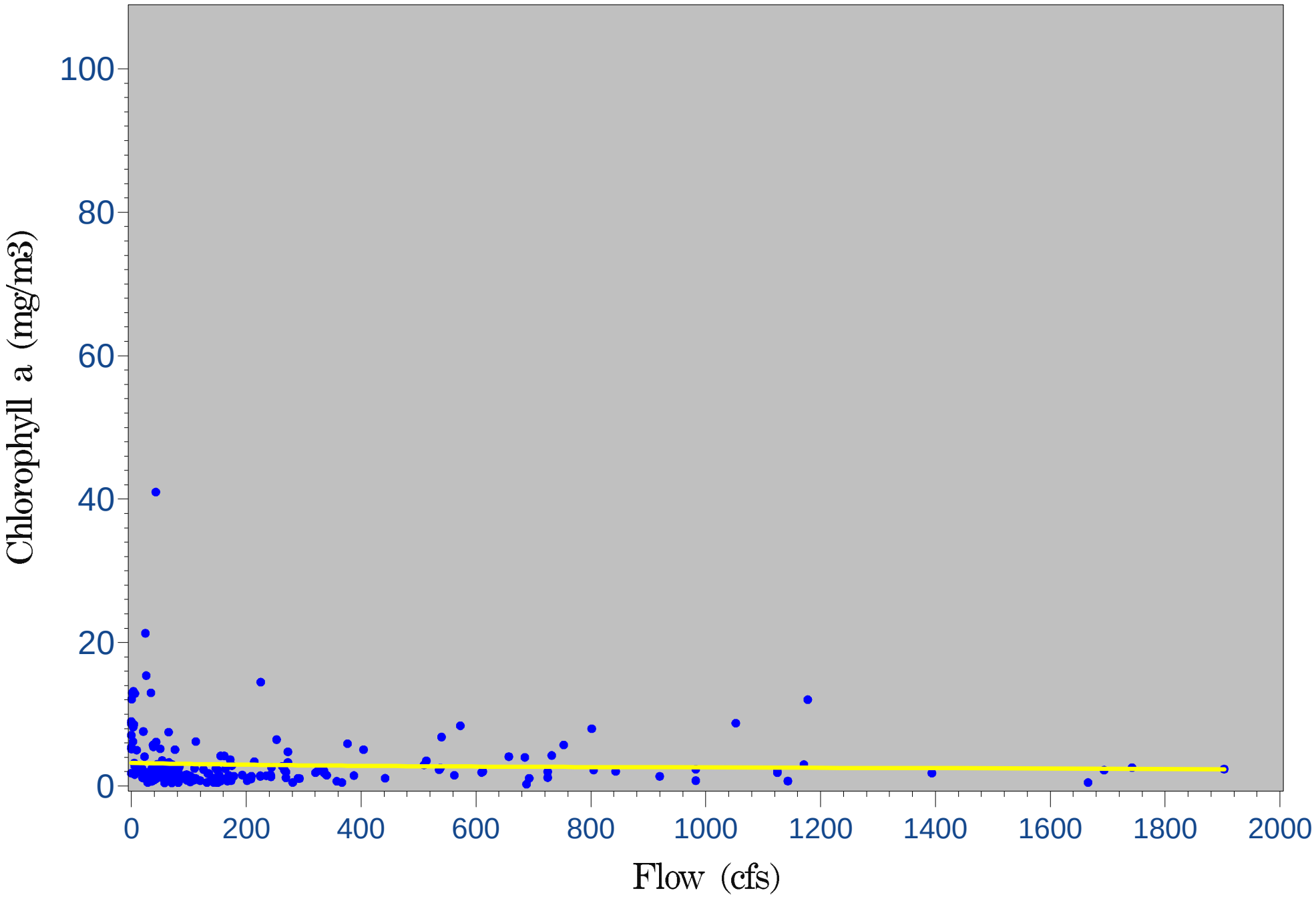


Figure 3.142a Chlorophyll a versus flow - Prairie Creek at C.R. 764

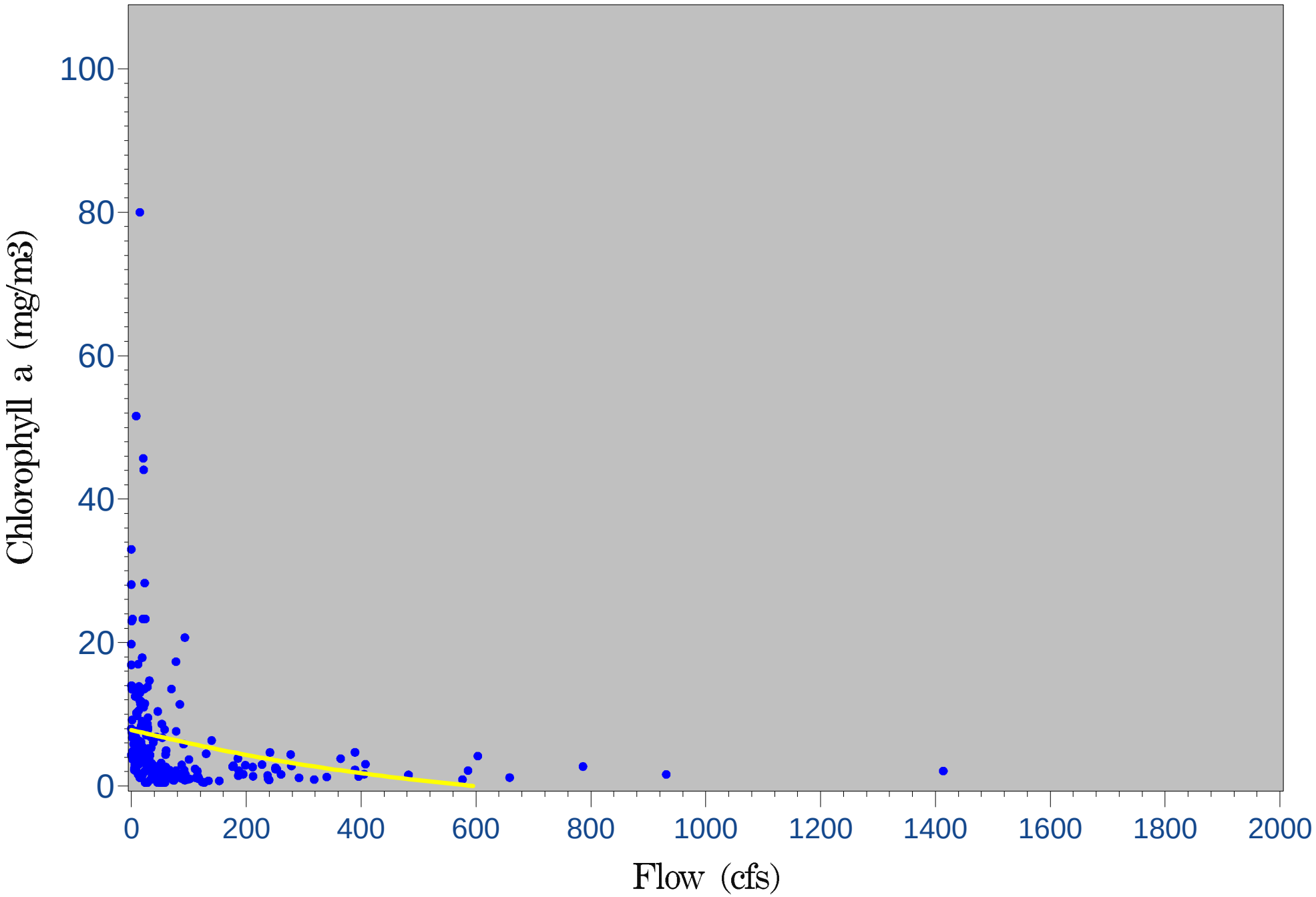


Figure 3.142b Chlorophyll a versus flow - Shell Creek at C.R. 764

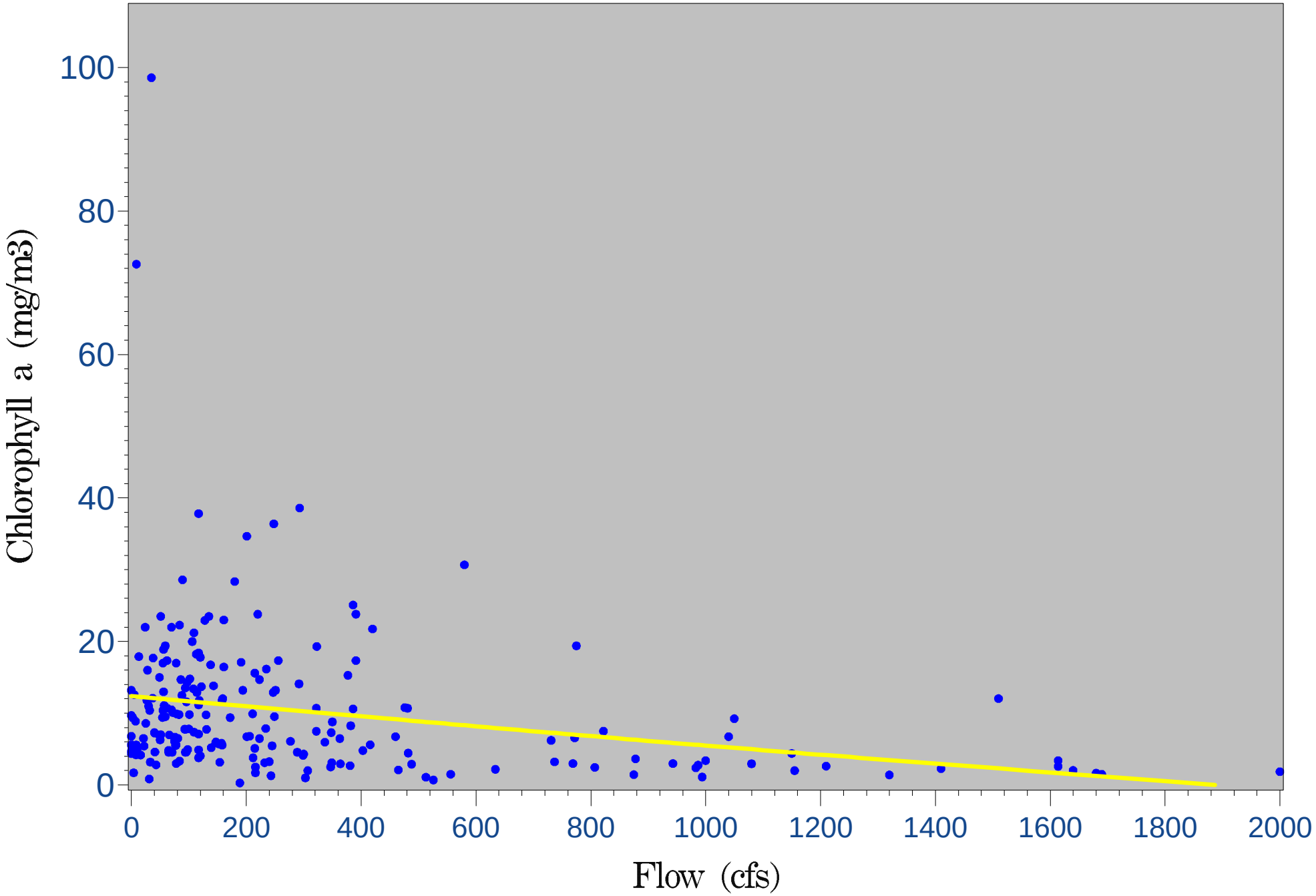


Figure 3.142c Chlorophyll a versus flow - Shell Creek Reservoir just upstream of the Dam

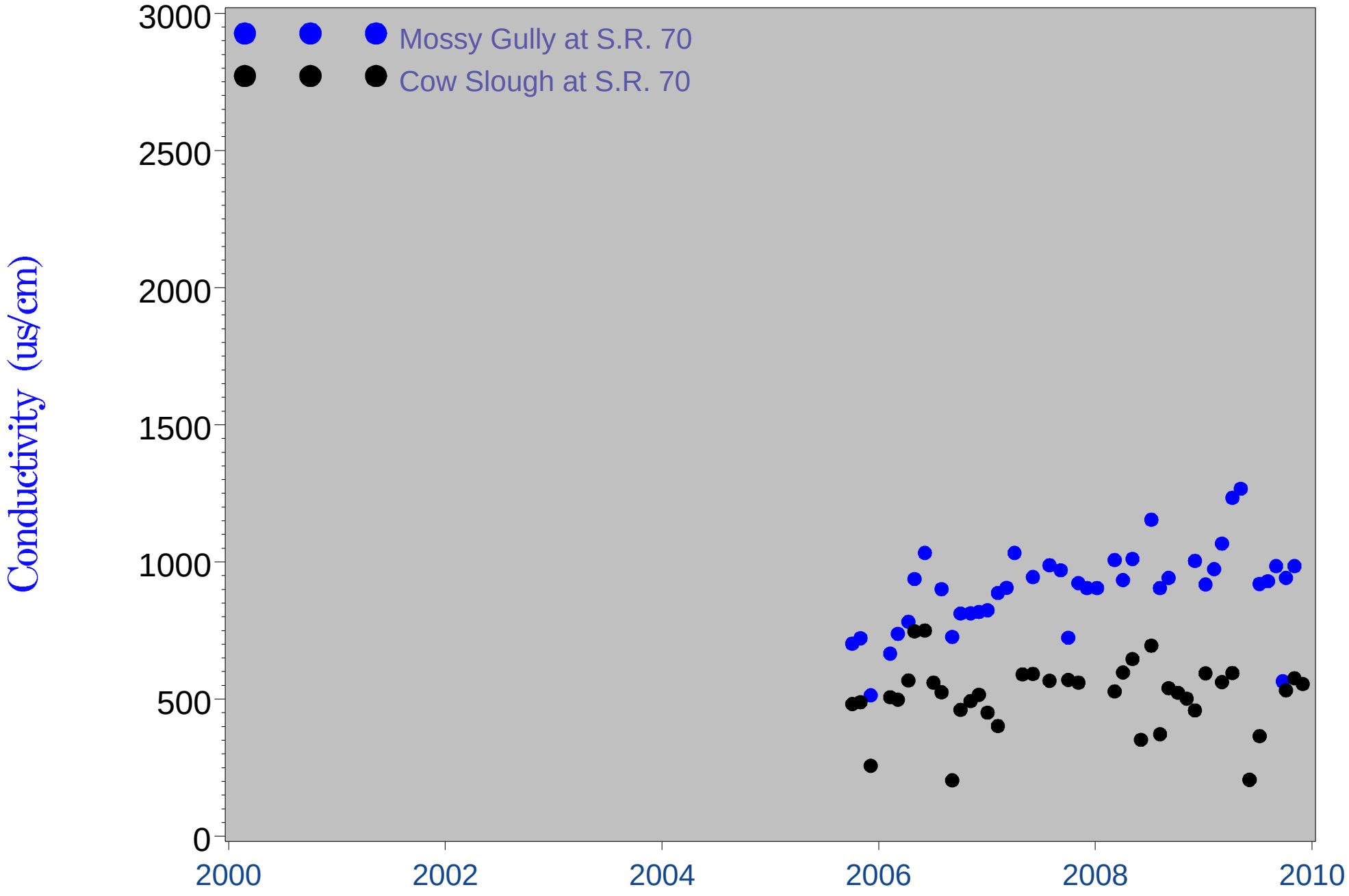


Figure 3.143a Conductivity at District's northern background sites 2000-2009

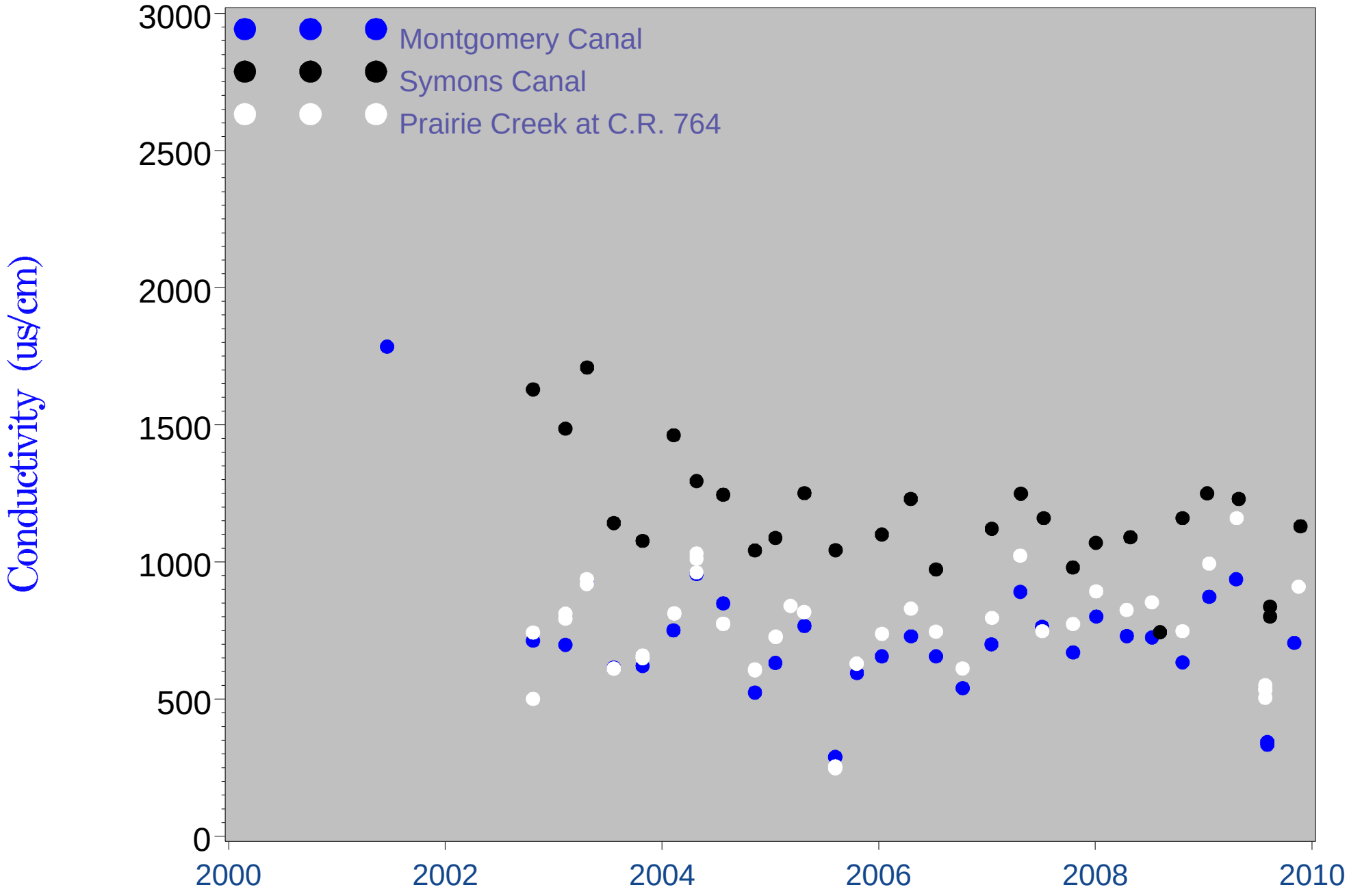


Figure 3.143b Conductivity at District's Prairie Creek sites 2000-2009

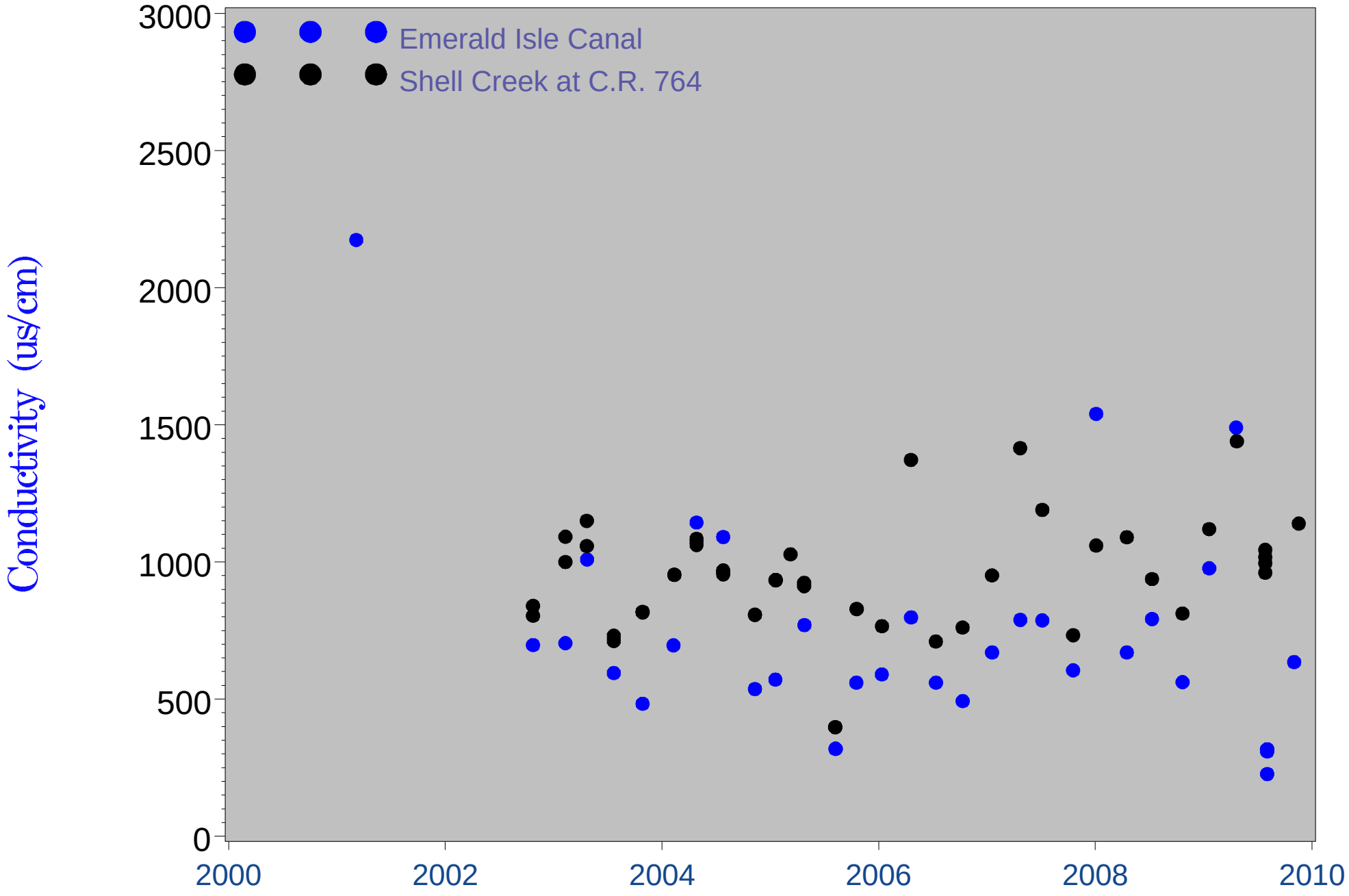


Figure 3.143c Conductivity at District's Shell Creek sites 2000-2009

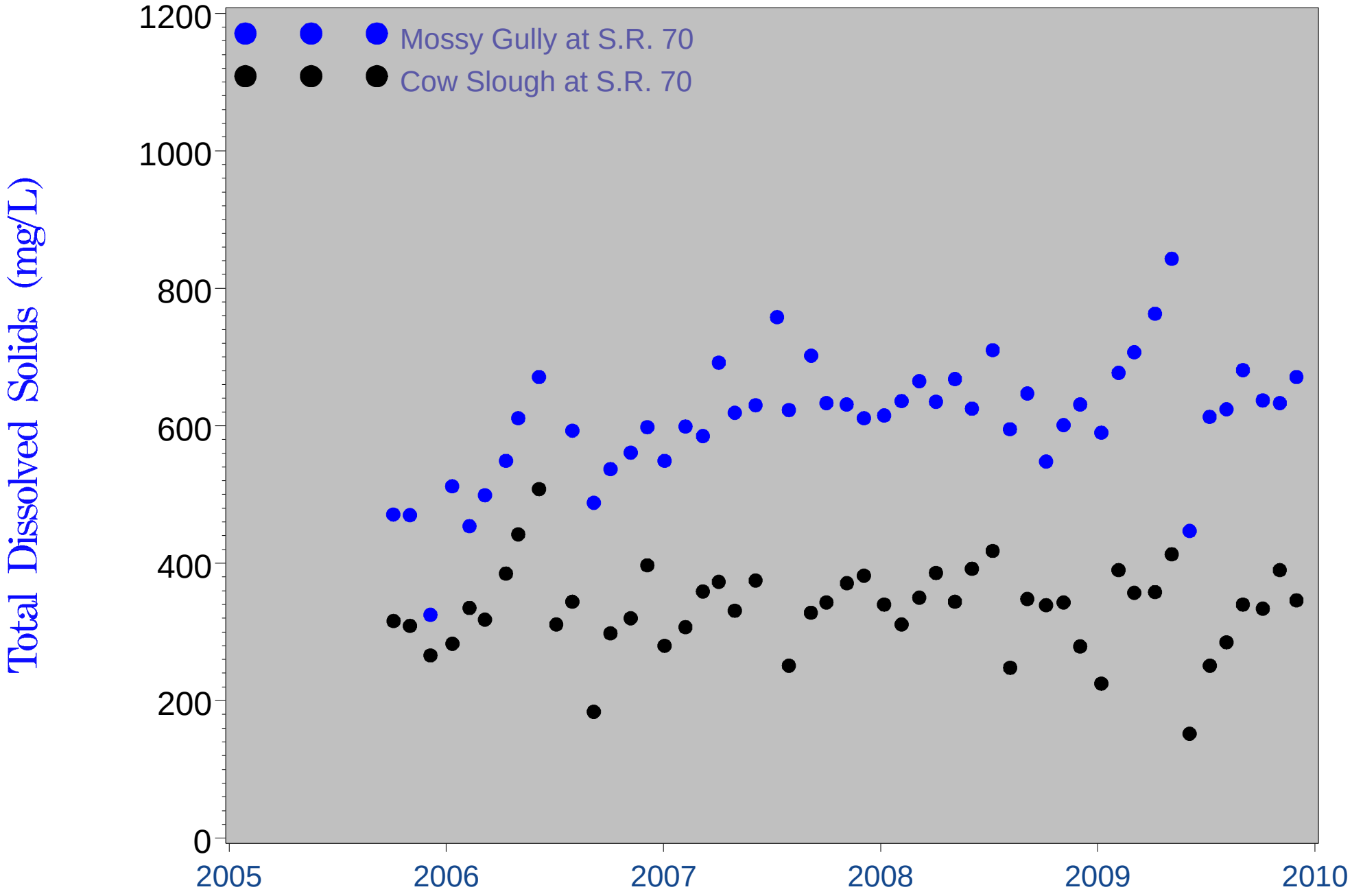


Figure 3.144a Total dissolved solid concentrations at District's northern background sites 2005-2009

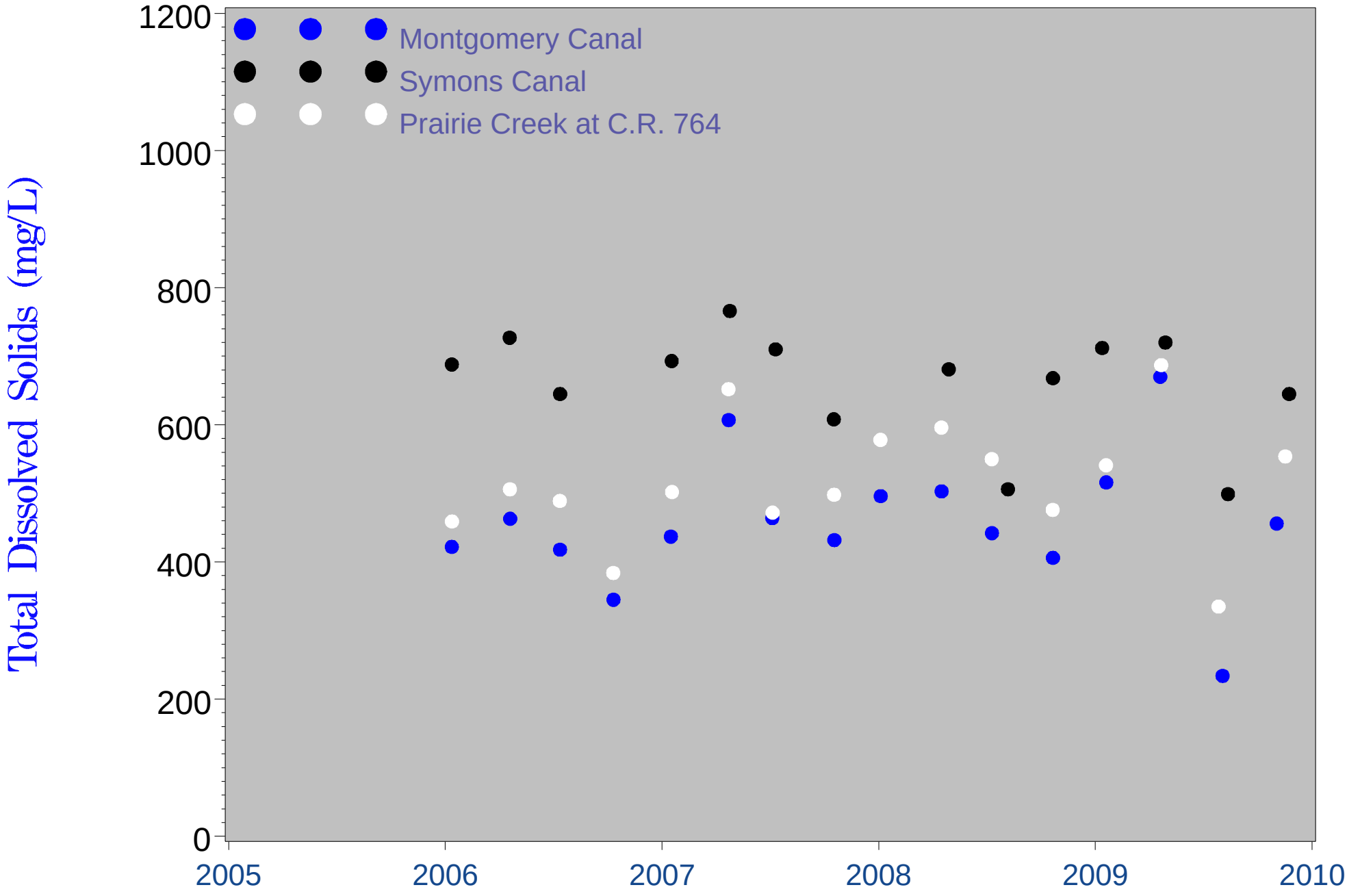


Figure 3.144b Total dissolved solid concentrations at District's Prairie Creek sites 2005-2009

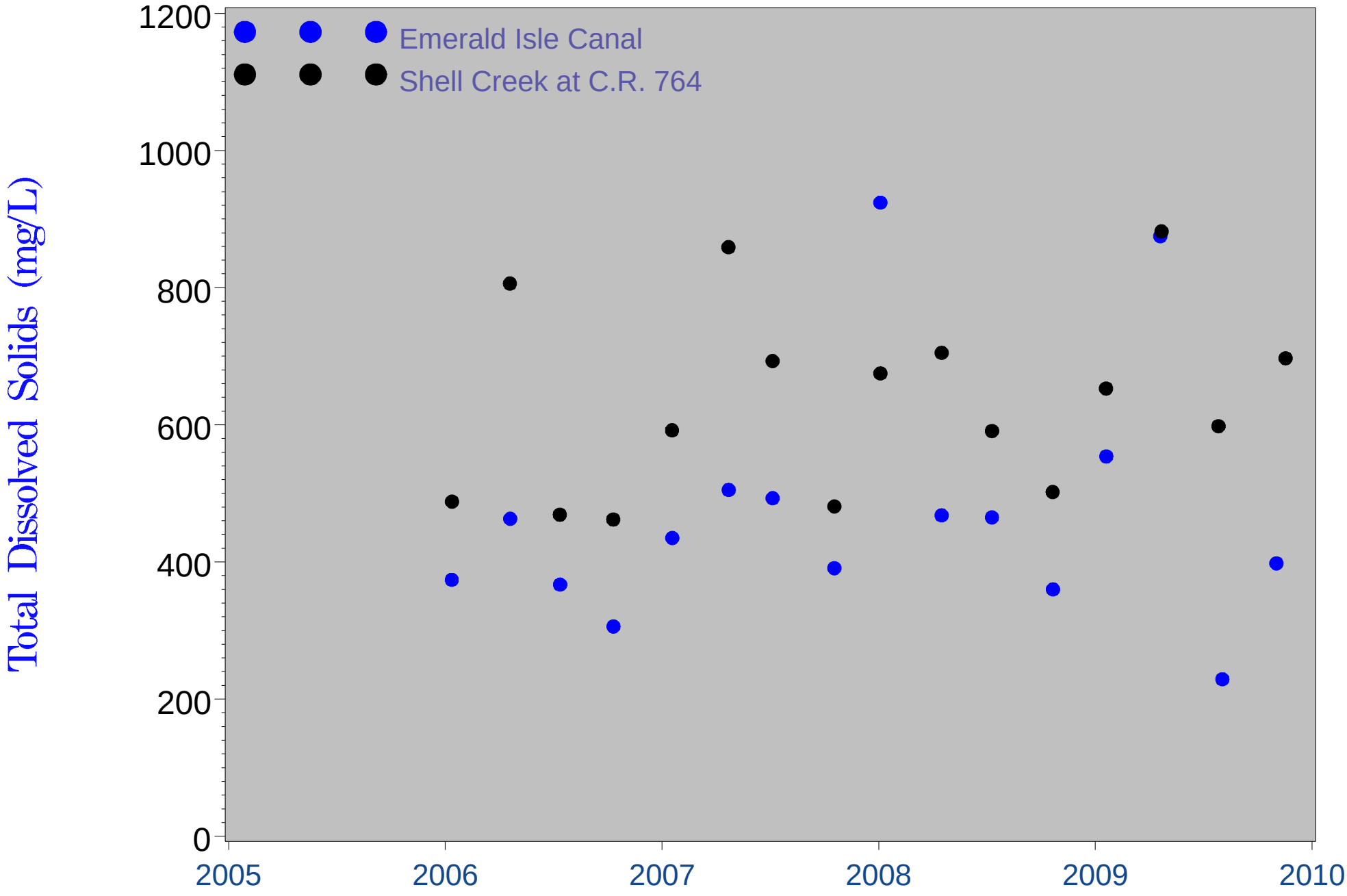


Figure 3.144c Total dissolved solid concentrations at District's Shell Creek sites 2005-2009

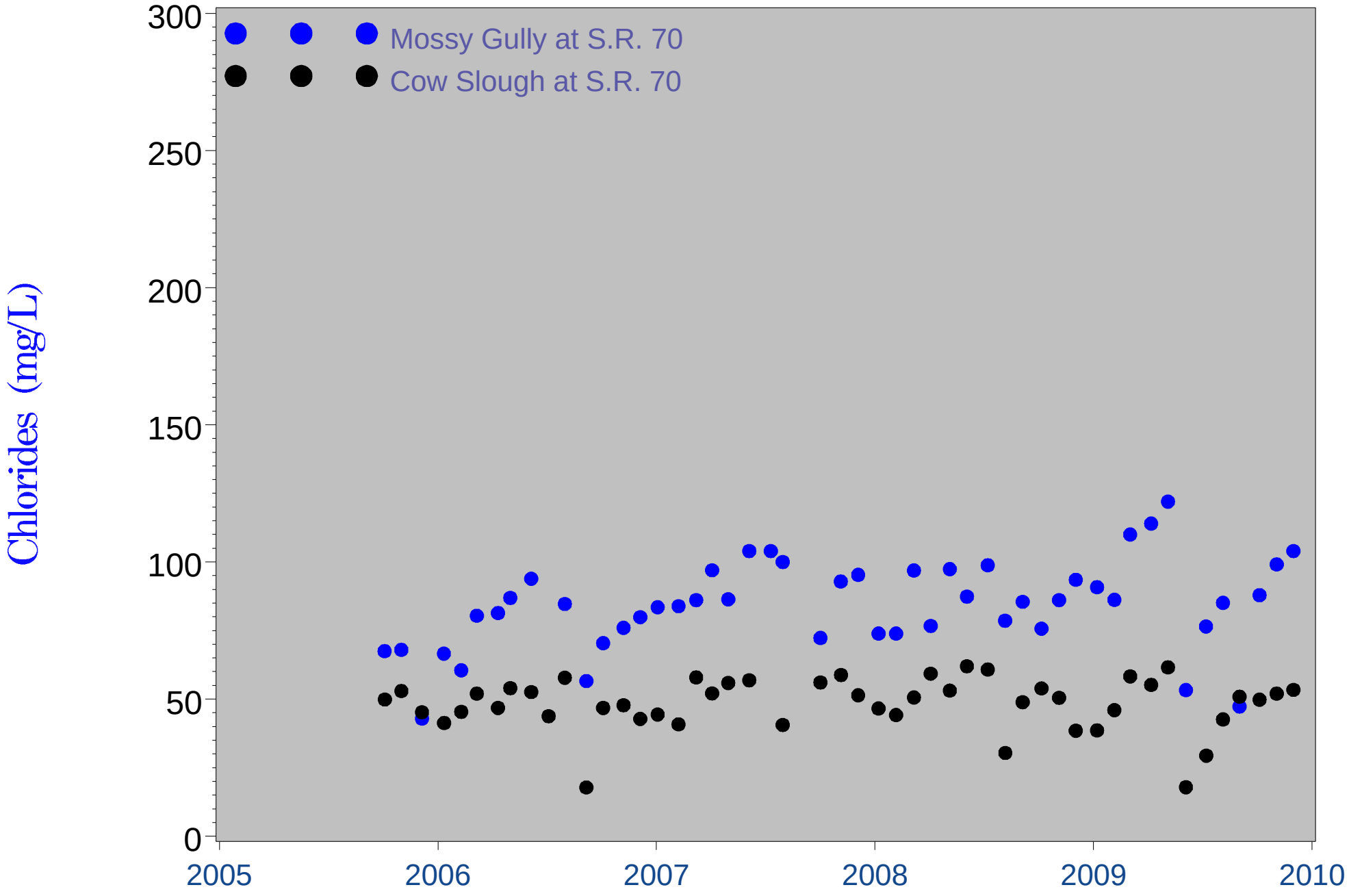


Figure 3.145a Chloride concentrations at District's northern background sites 2005-2009

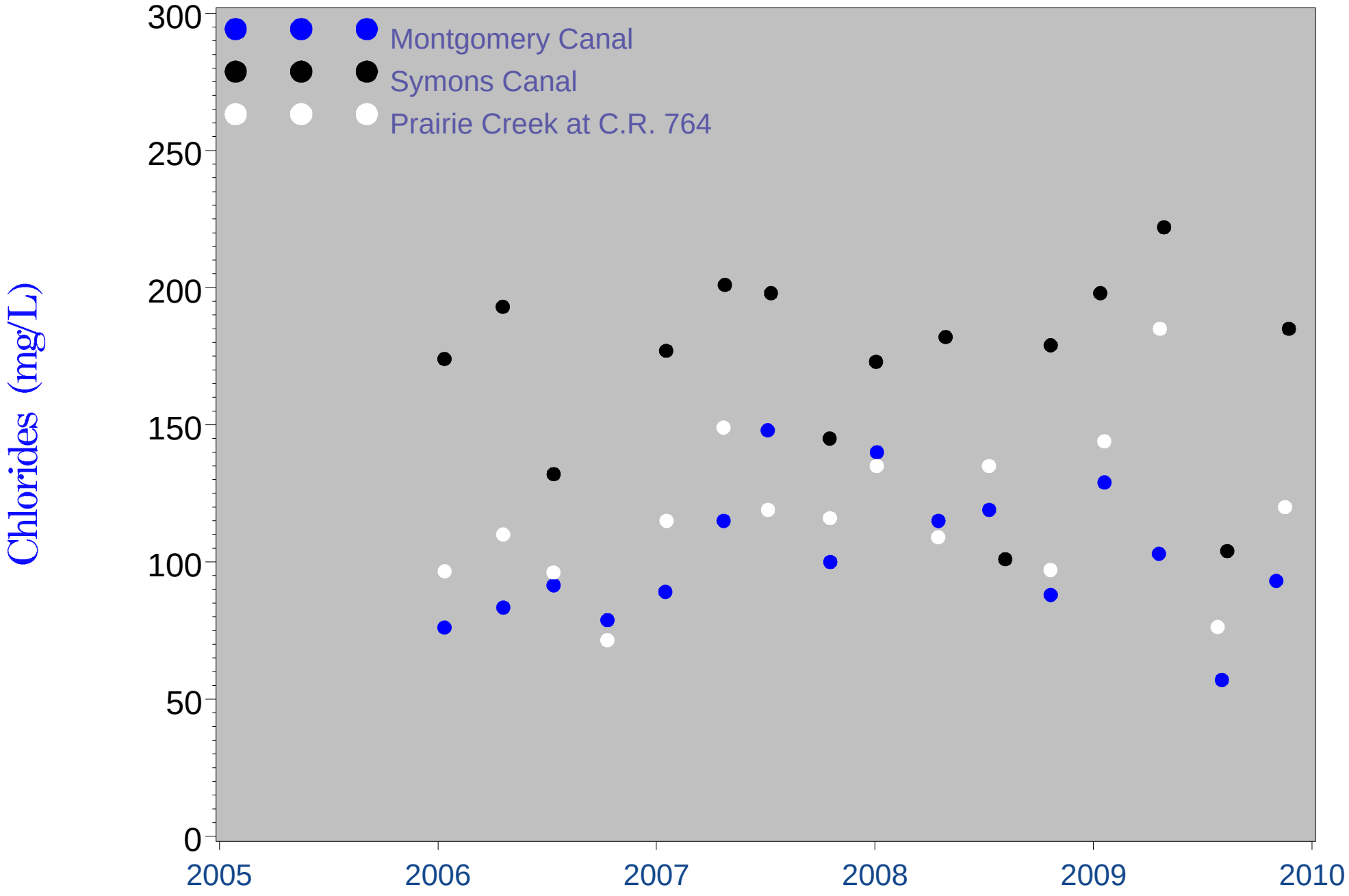


Figure 3.145b Chloride concentrations at District's Prairie Creek sites 2005-2009

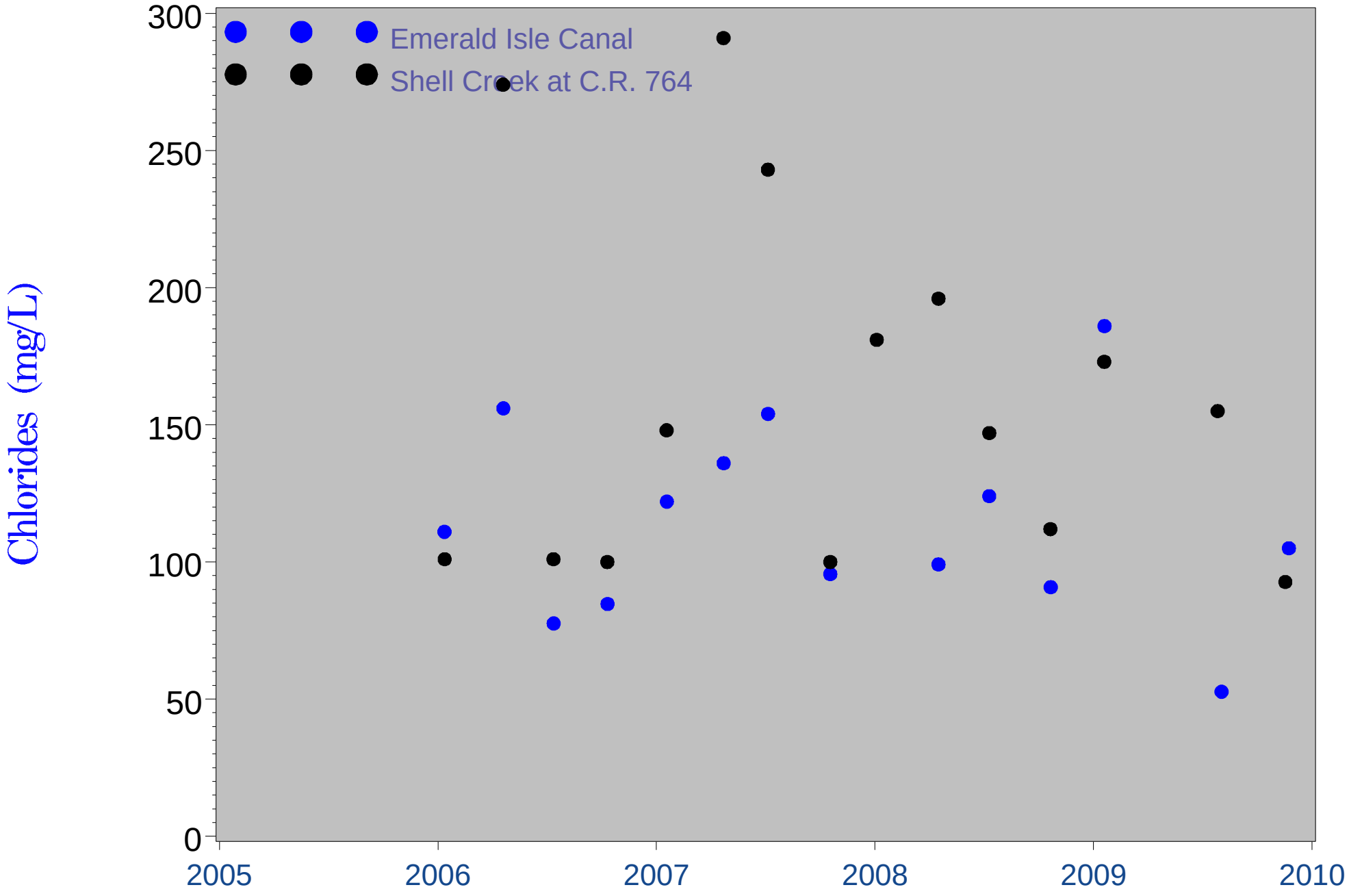


Figure 3.145c Chloride concentrations at District's Shell Creek sites 2005-2009

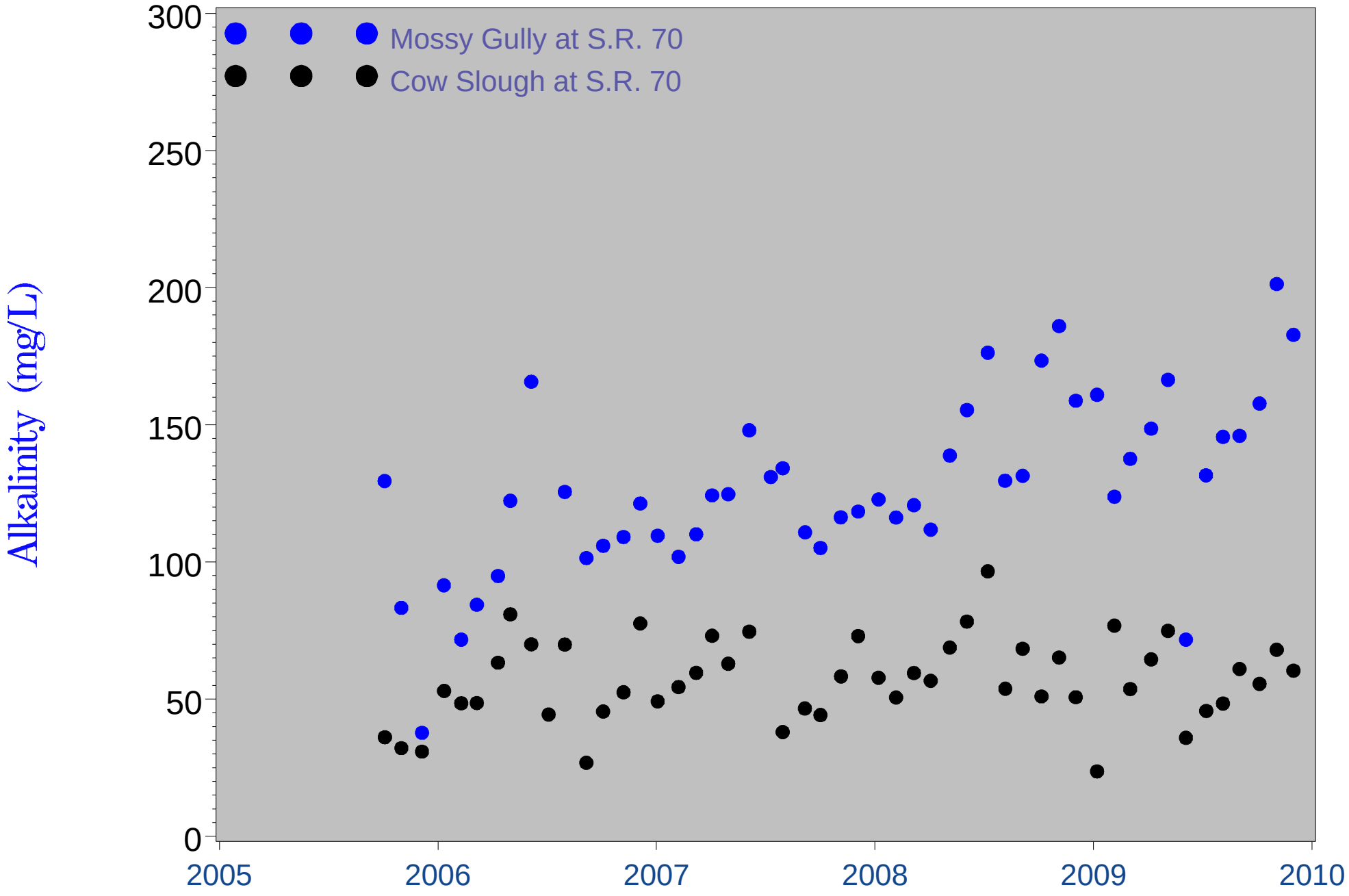


Figure 3.146a Alkalinity concentrations at District's northern background sites 2005-2009

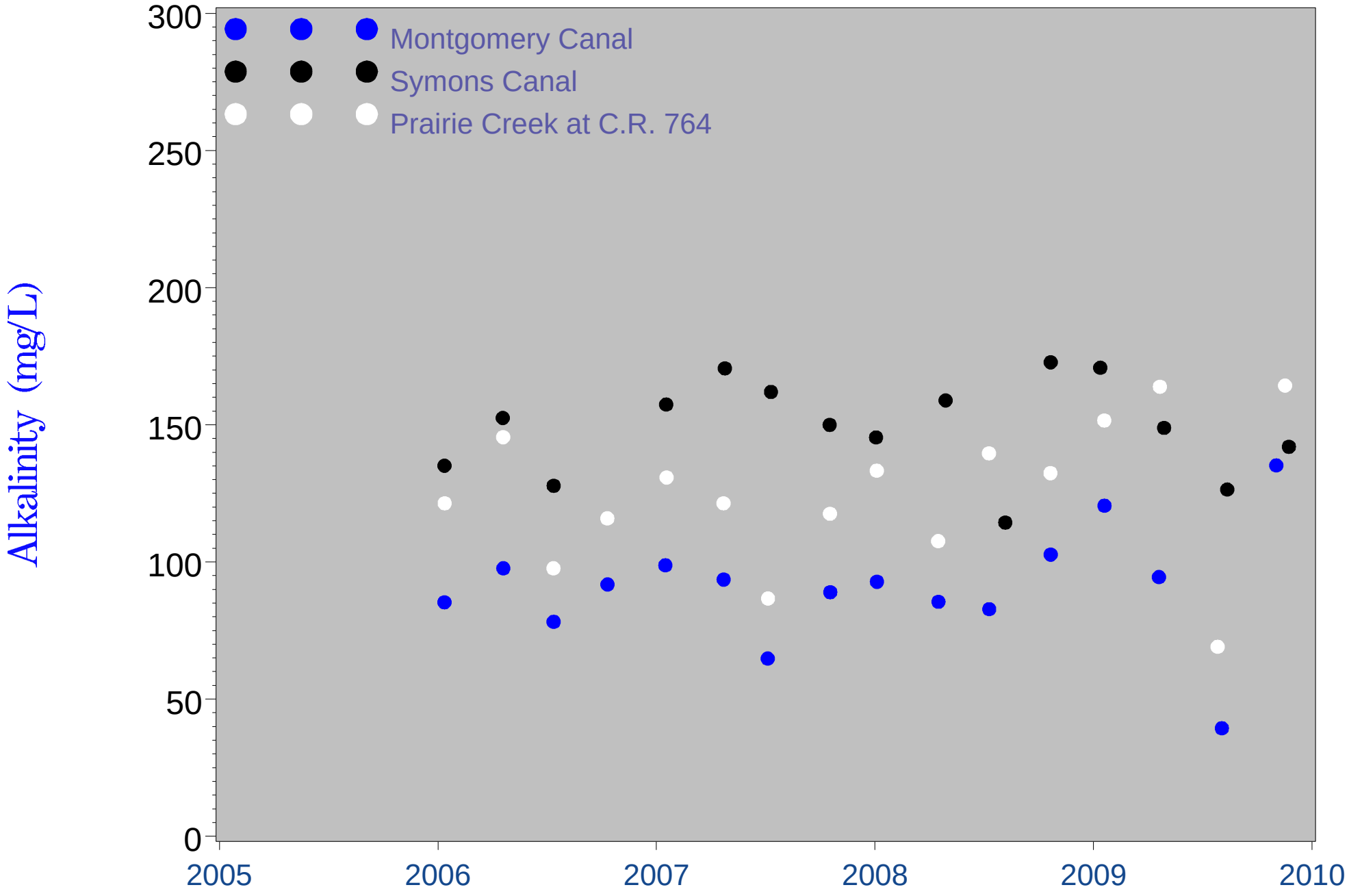


Figure 3.146b Alkalinity concentrations at District's Prairie Creek sites 2005-2009

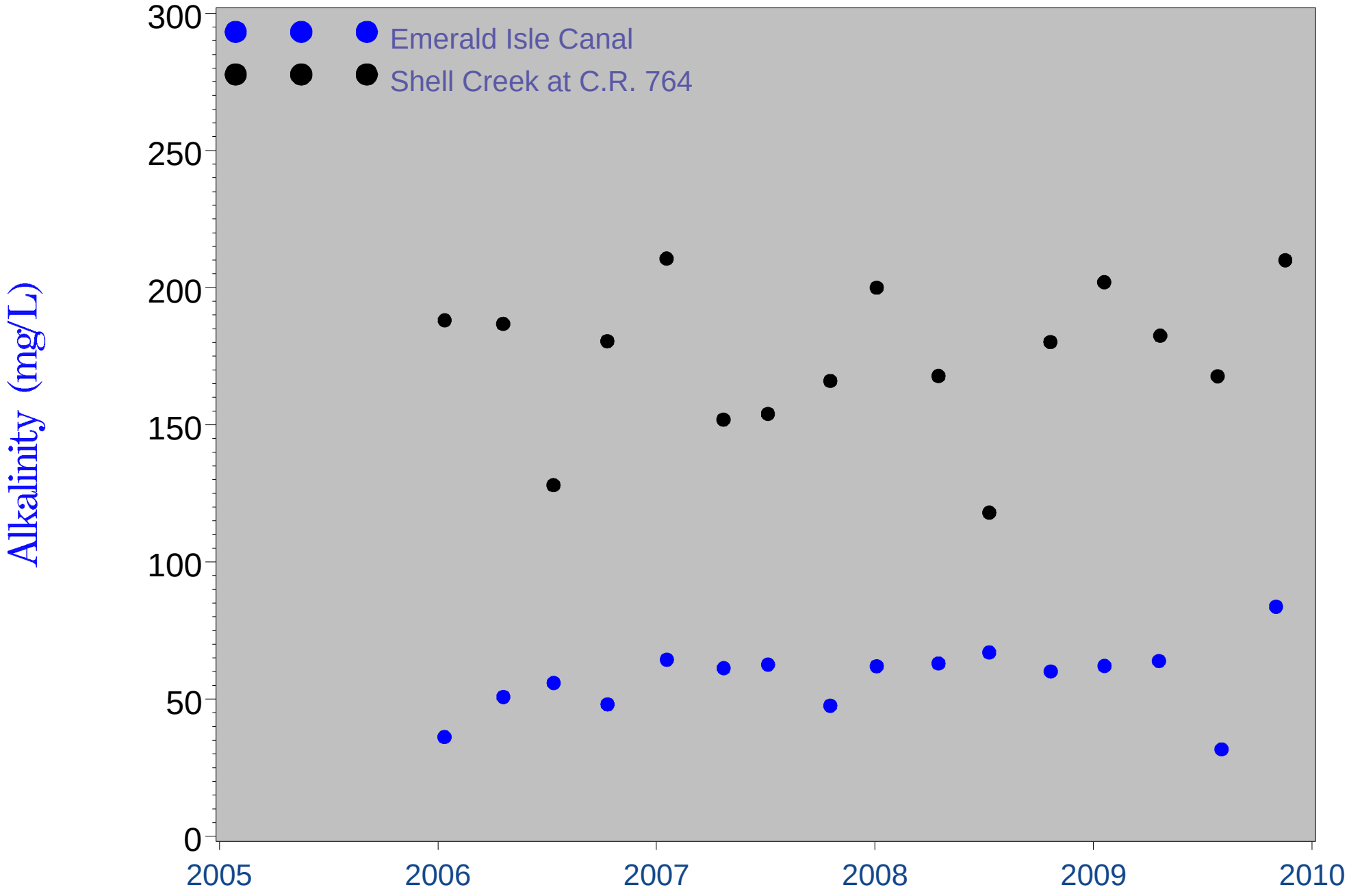


Figure 3.146c Alkalinity concentrations atDistrict's Shell Creek sites 2005-2009

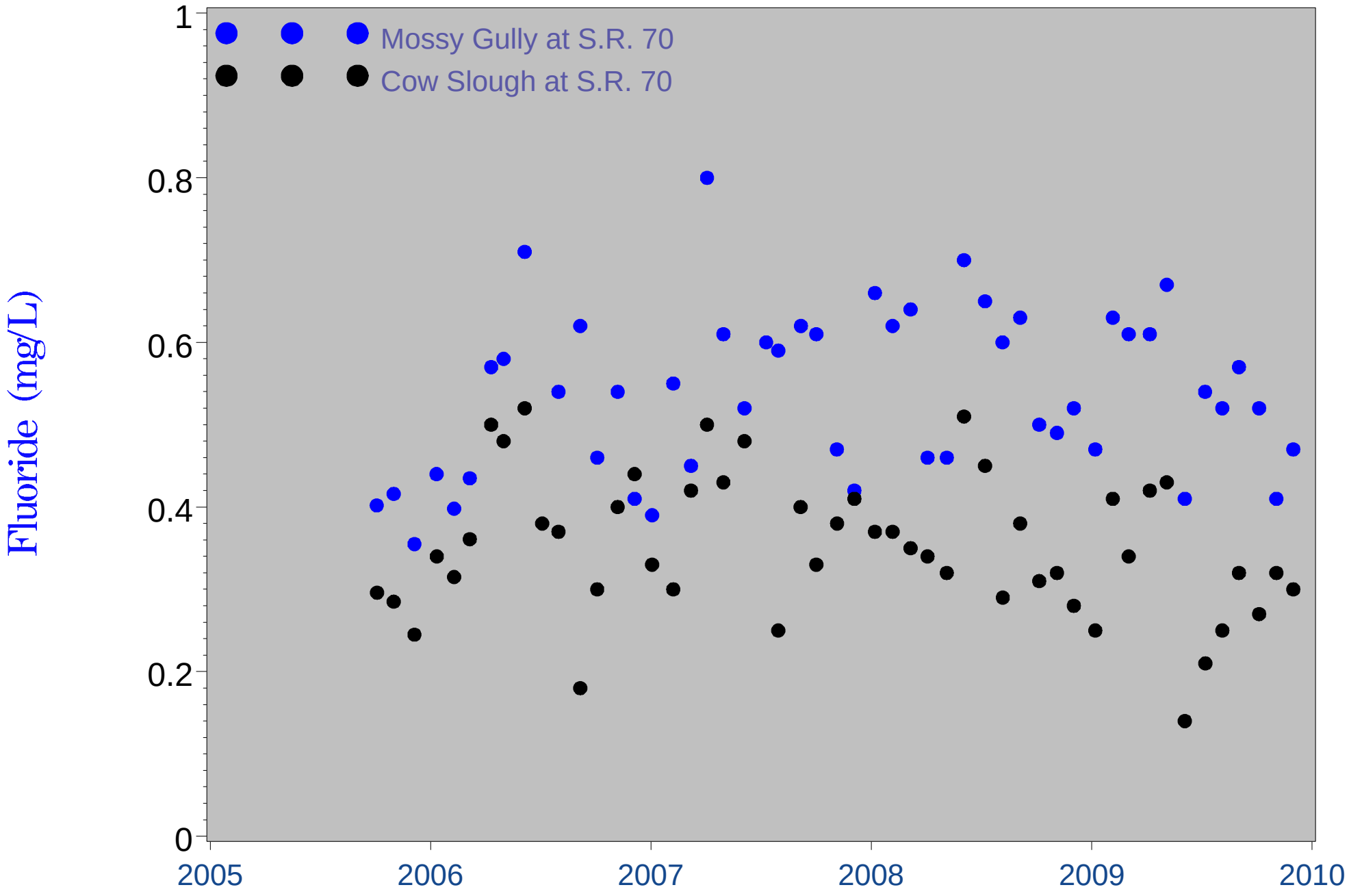


Figure 3.147a Fluoride concentrations at District's northern background sites 2005-2009

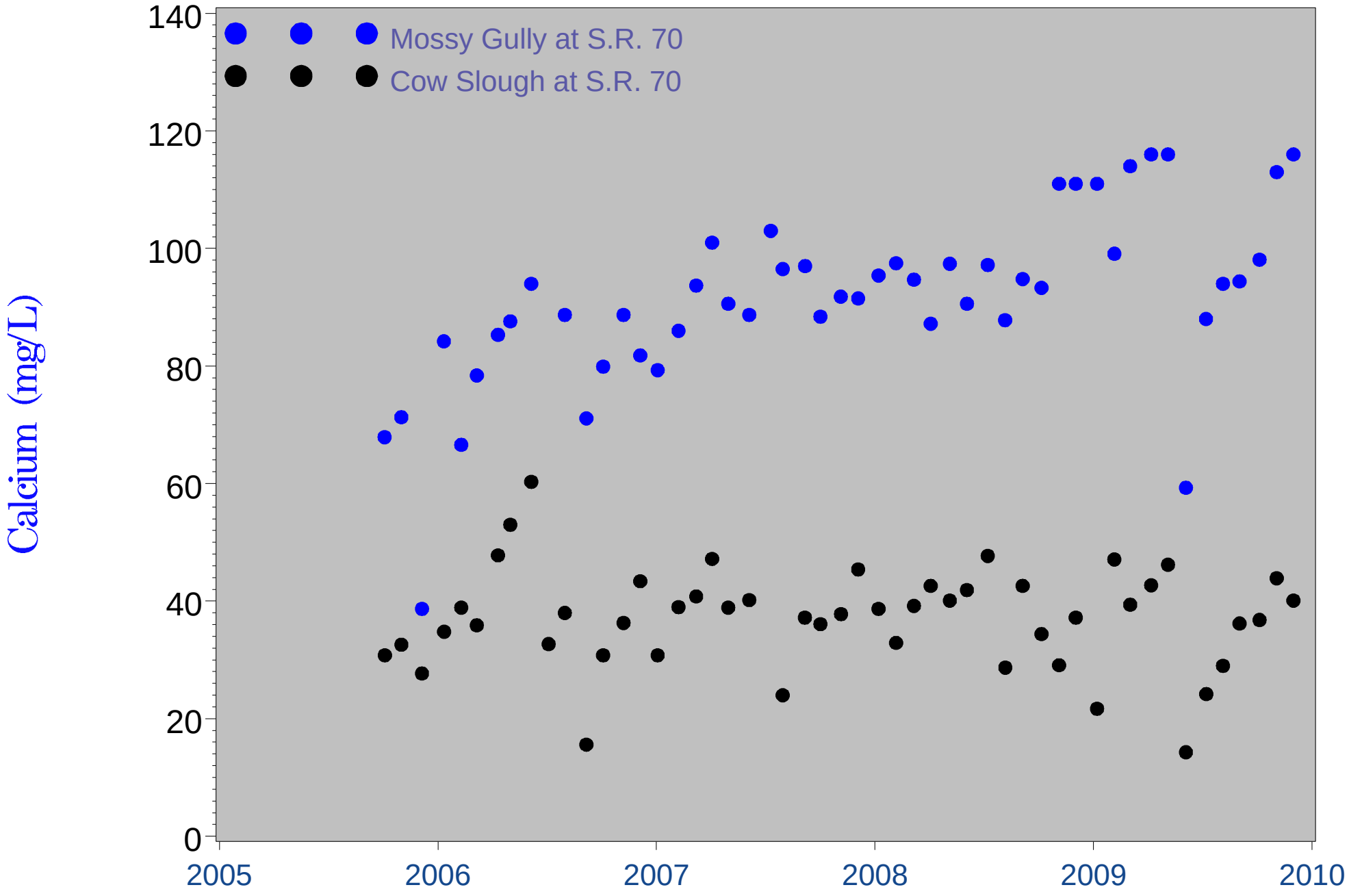


Figure 3.148a Calcium concentrations at District's northern background sites 2005-2009

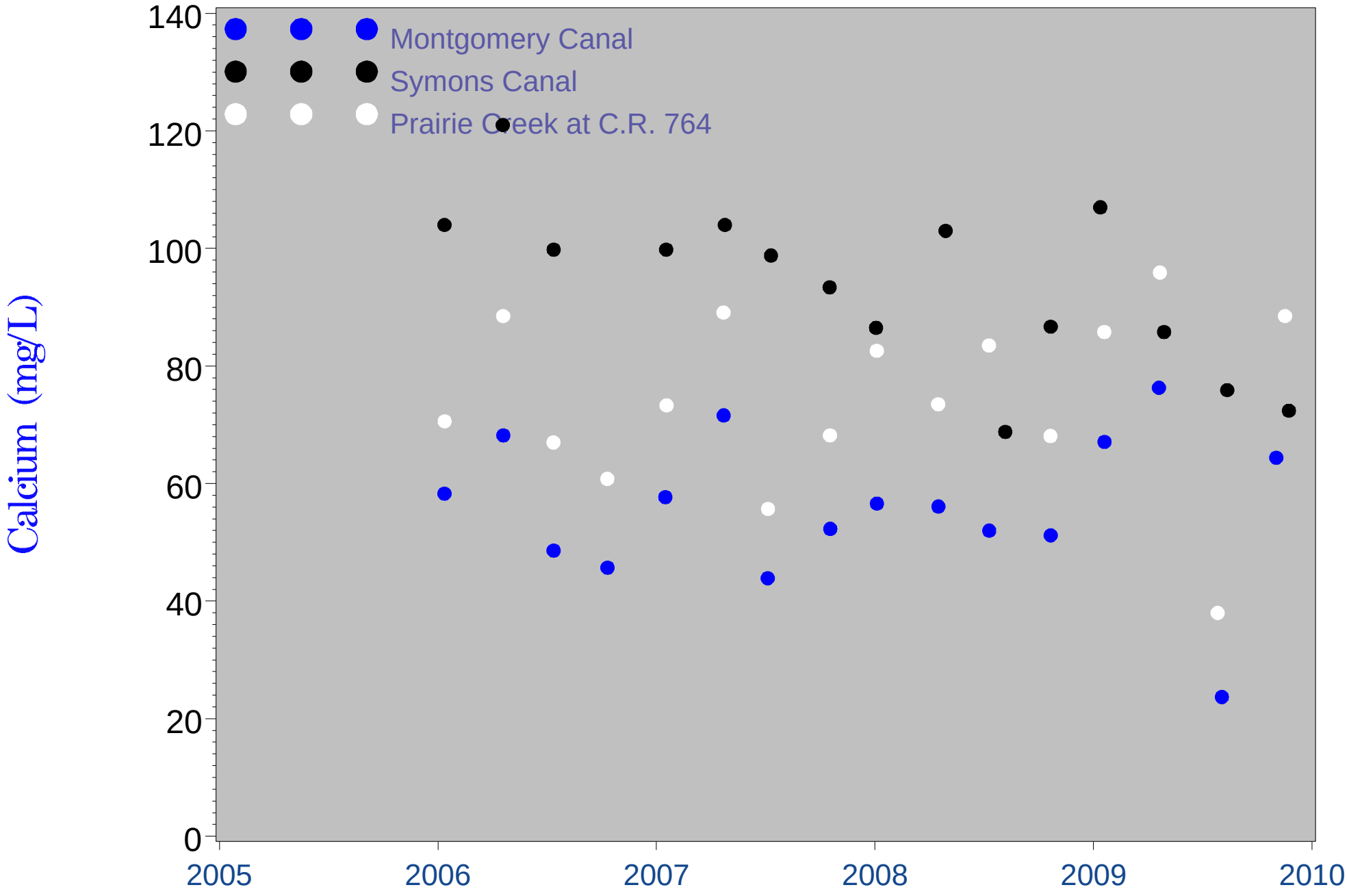


Figure 3.148b Calcium concentrations at District's Prairie Creek sites 2005-2009

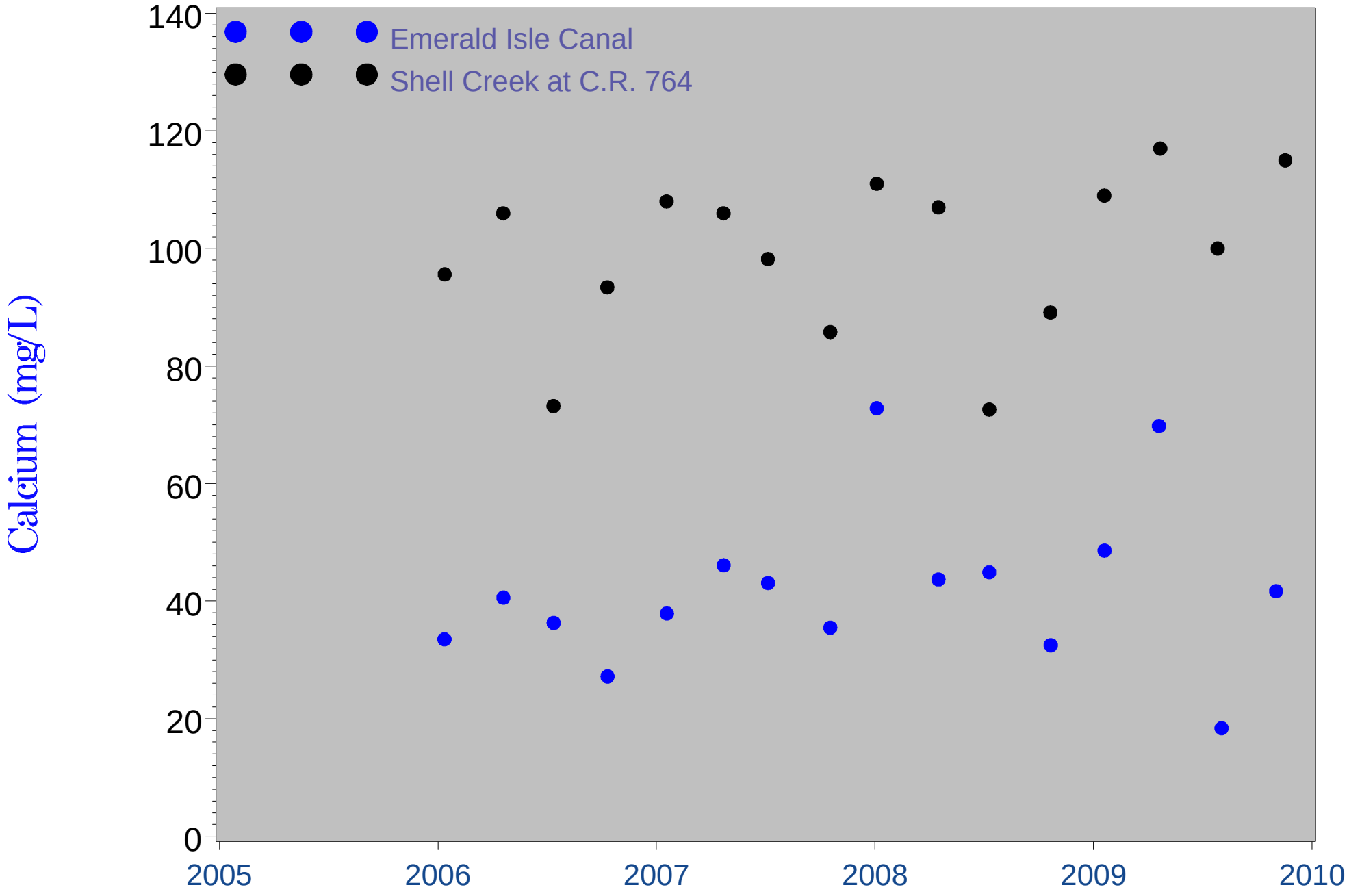


Figure 3.148c Calcium concentrations at District's Shell Creek sites 2005-2009

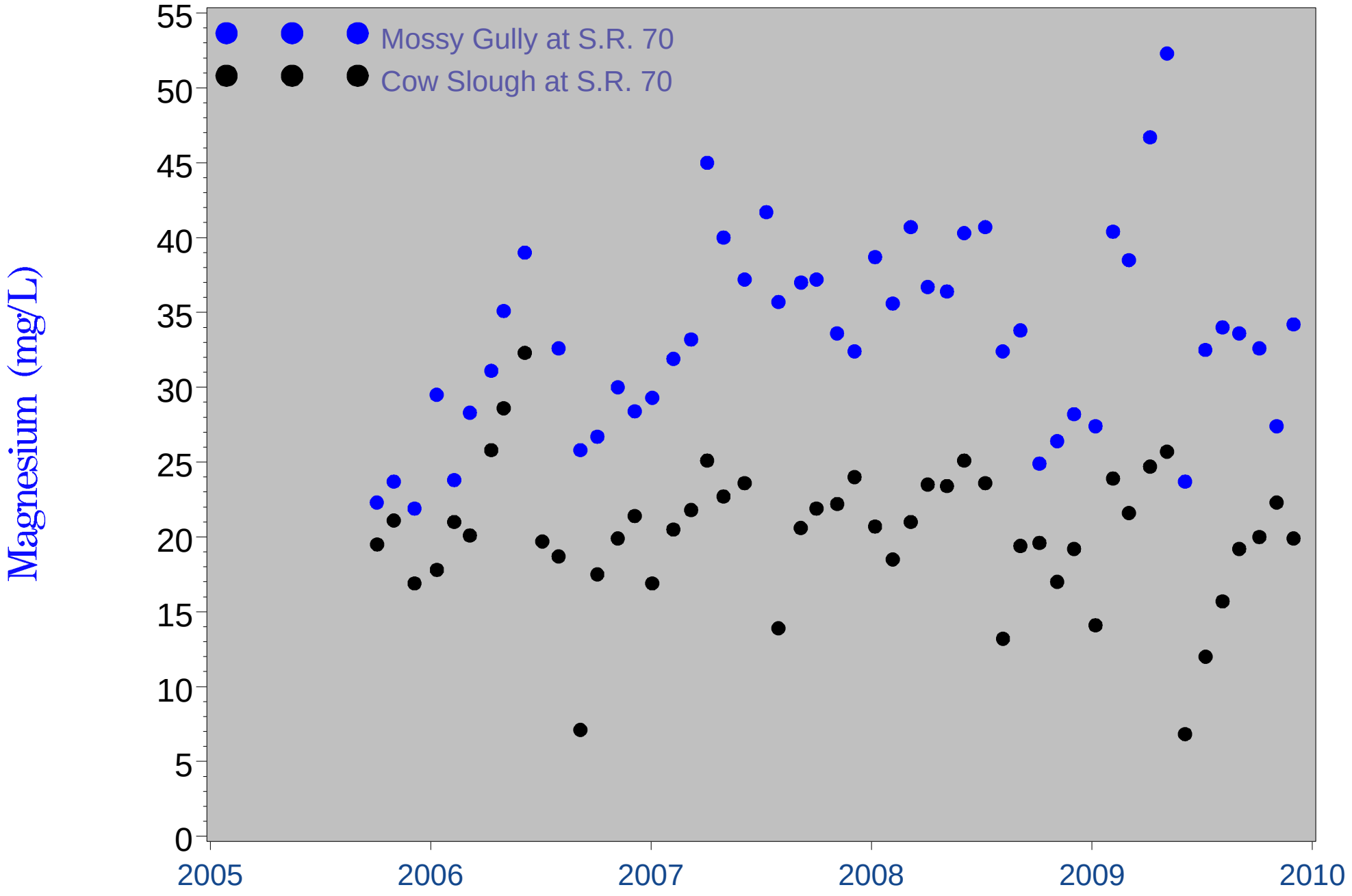


Figure 3.149a Magnesium concentrations at District's northern background sites 2005-2009

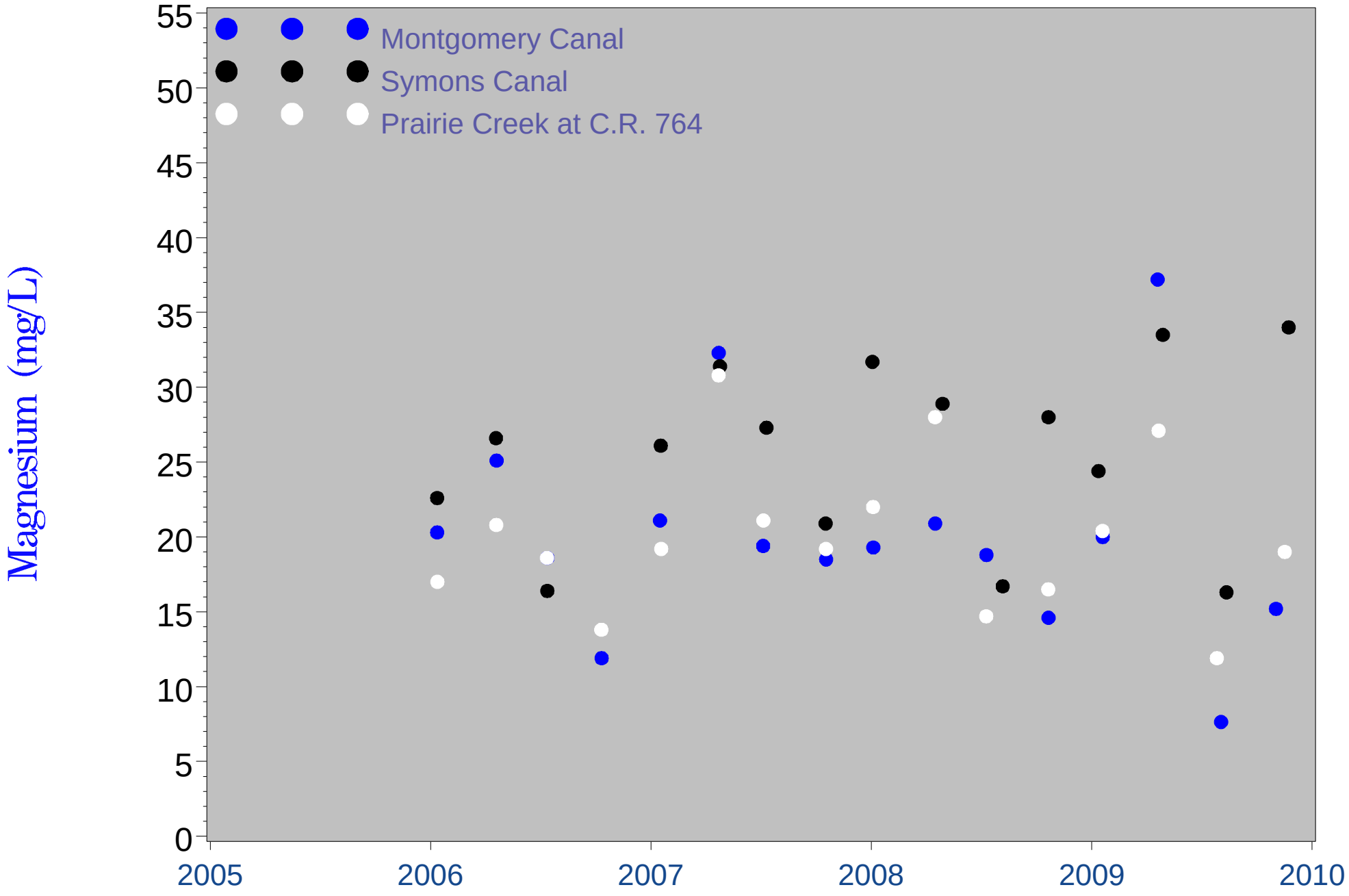


Figure 3.149b Magnesium concentrations at District's Prairie Creek sites 2005-2009

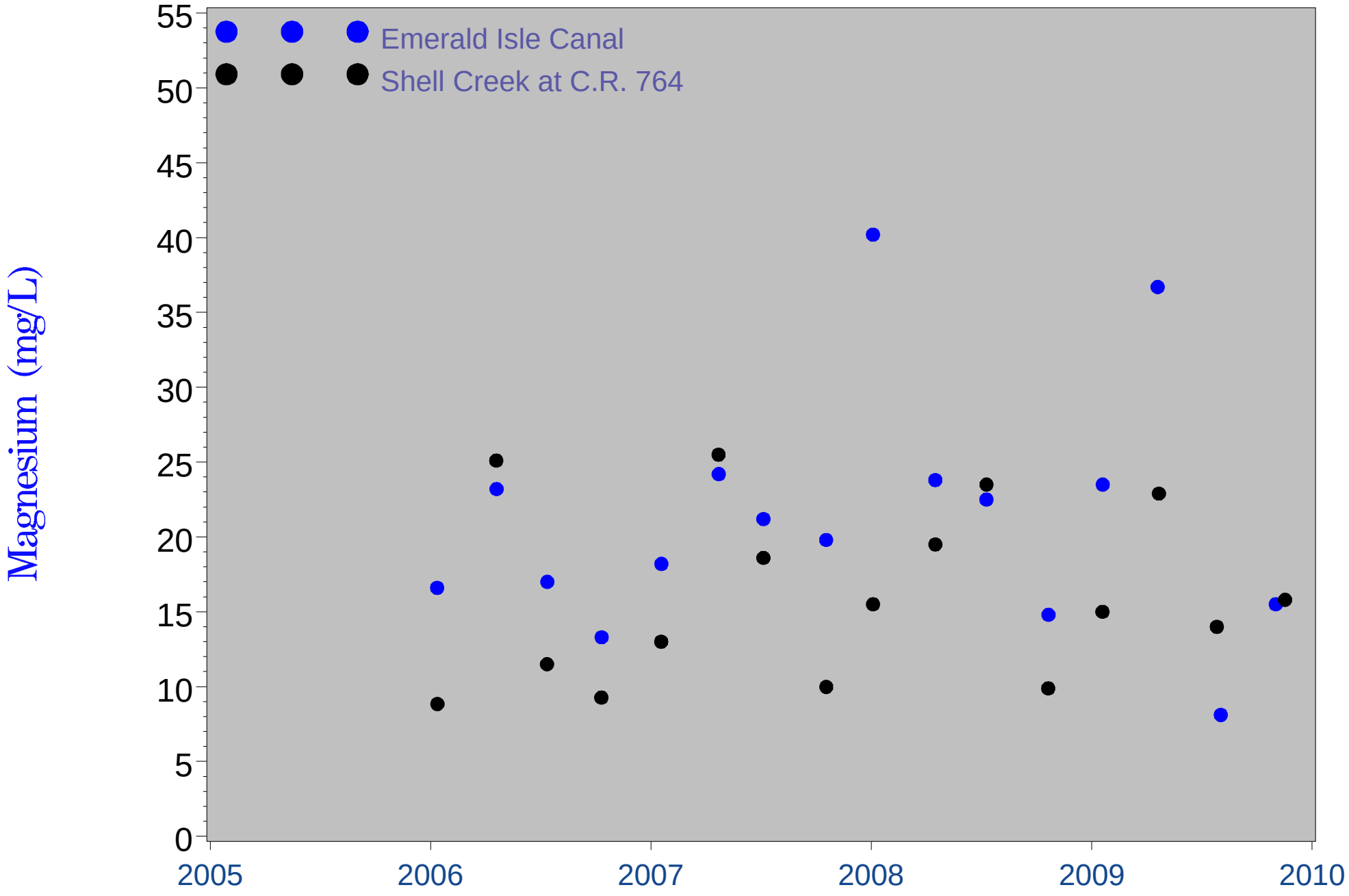


Figure 3.149c Magnesium concentrations at District's Shell Creek sites 2005-2009

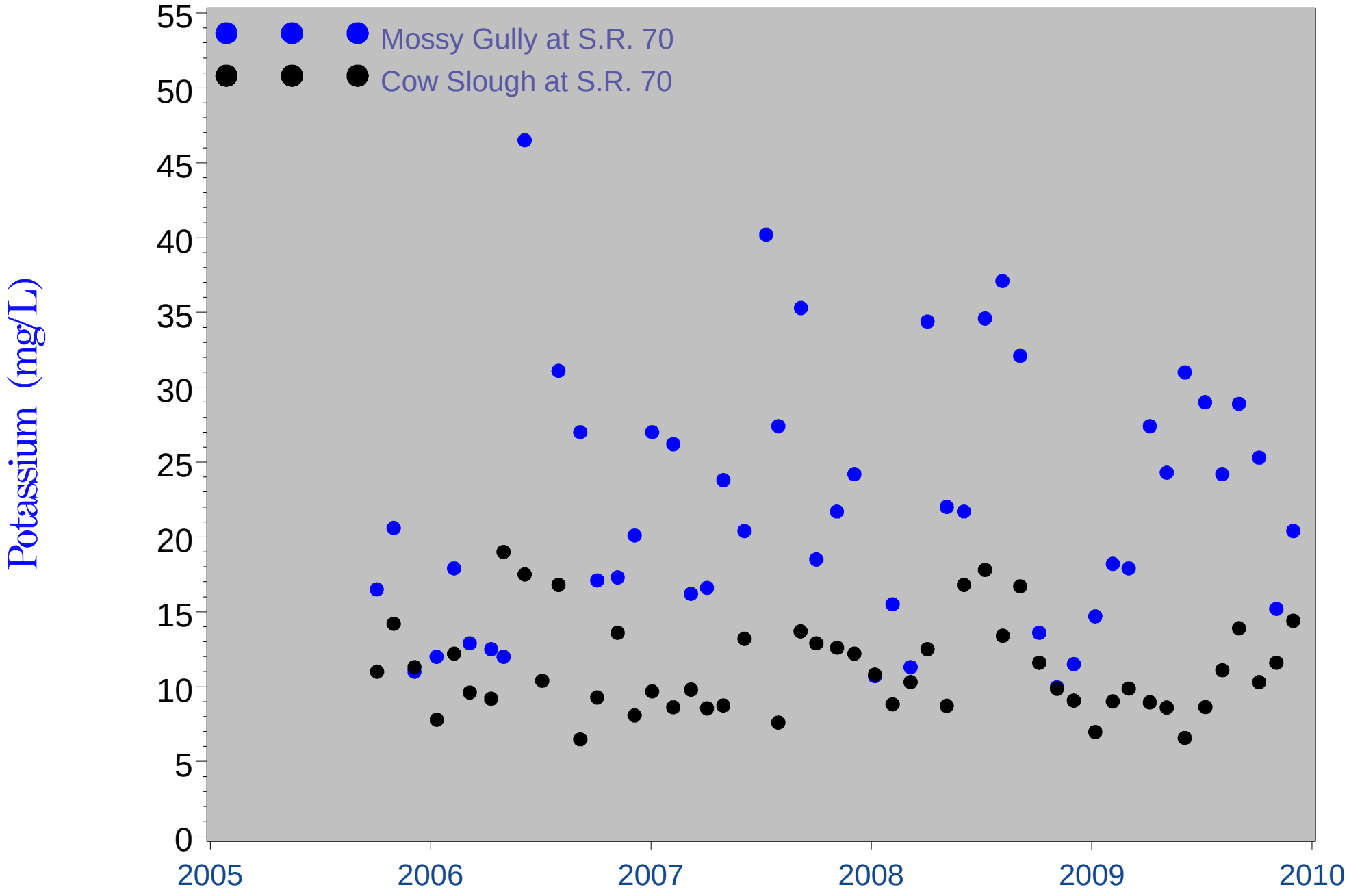


Figure 3.150a Potassium concentrations at District's northern background sites 2005-2009

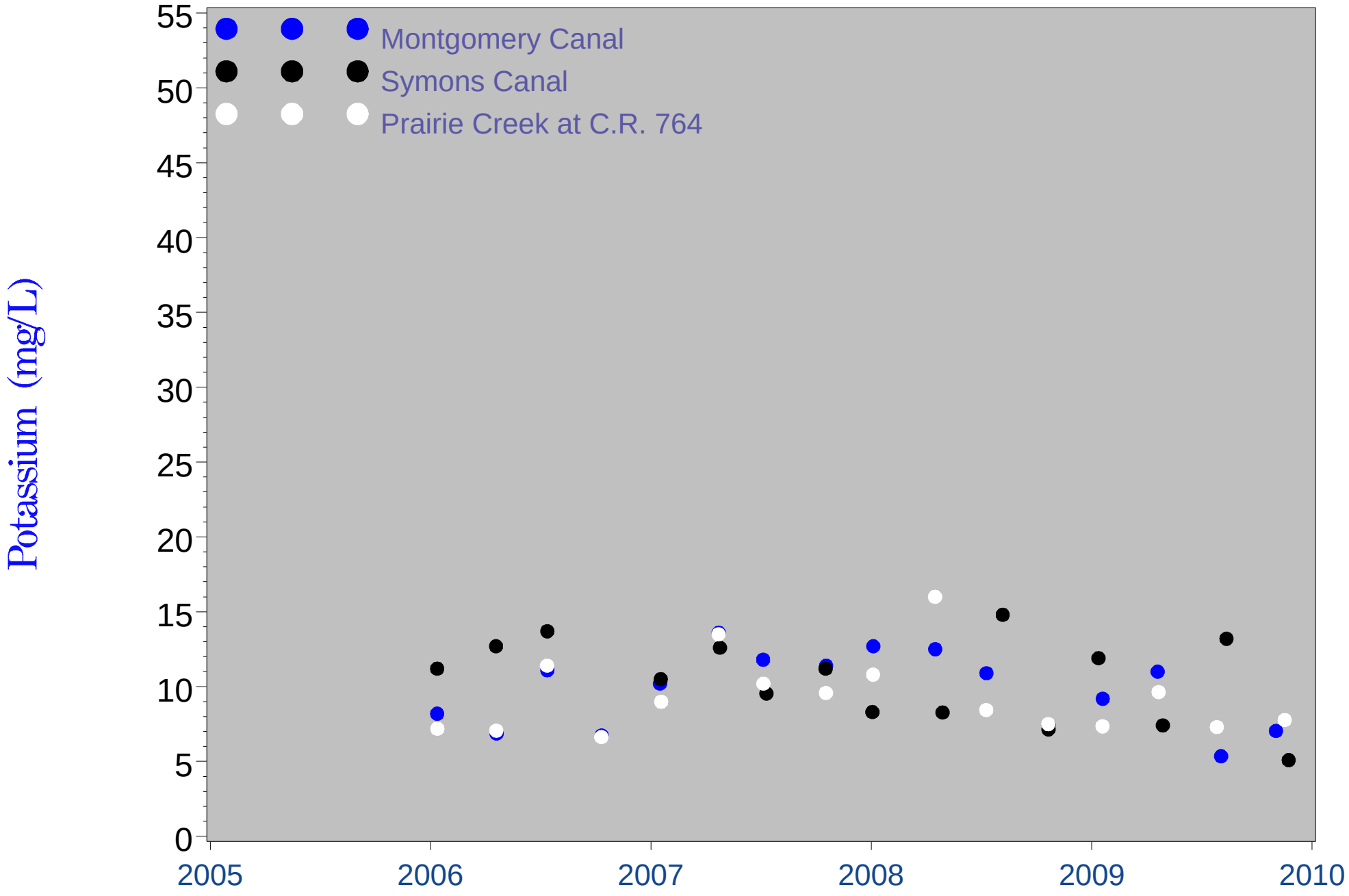


Figure 3.150b Potassium concentrations at District's Prairie Creek sites 2005-2009

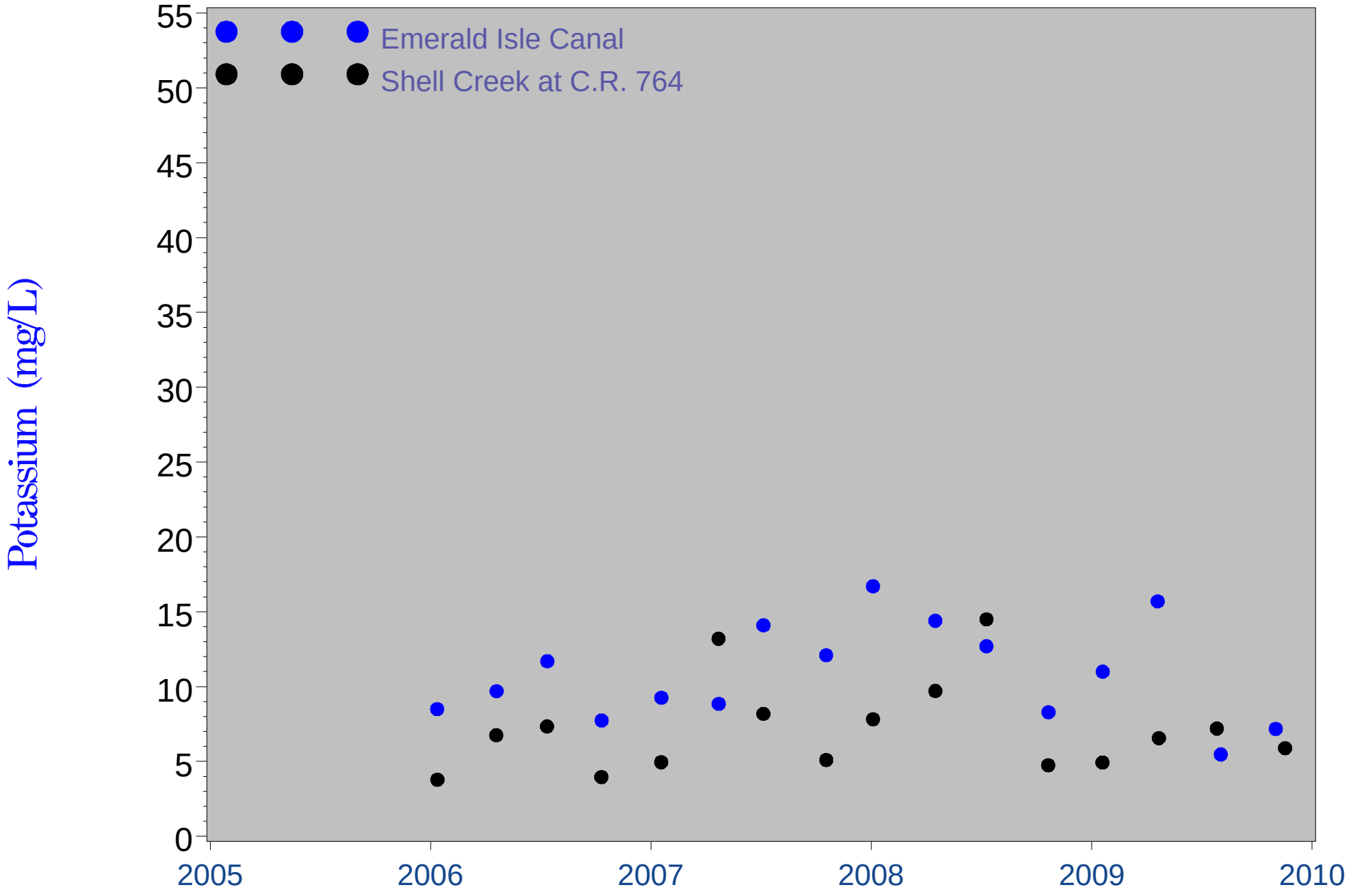


Figure 3.150c Potassium concentrations at District's Shell Creek sites 2005-2009

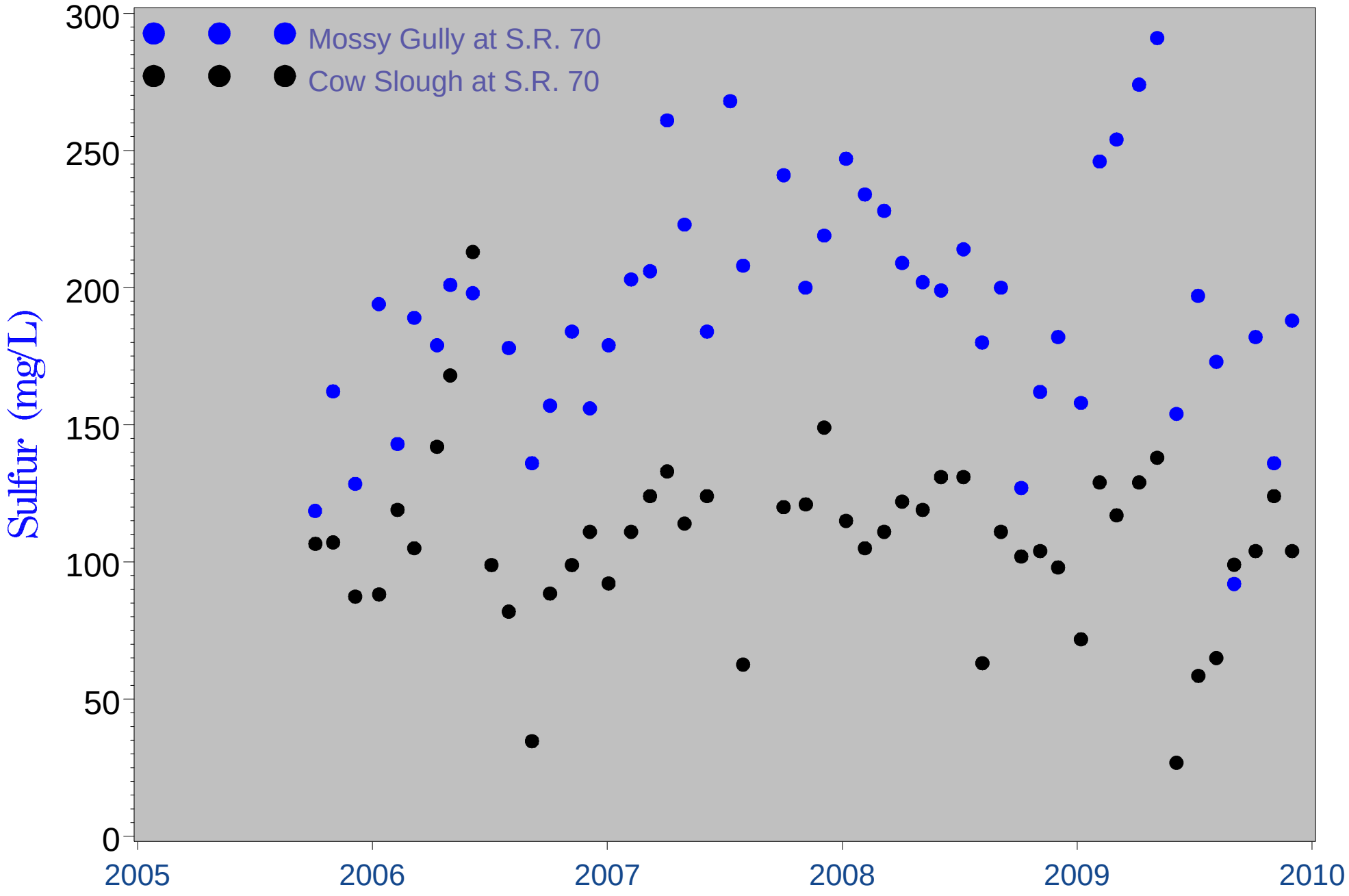


Figure 3.151a Sulfur concentrations at District's northern background sites 2005-2009

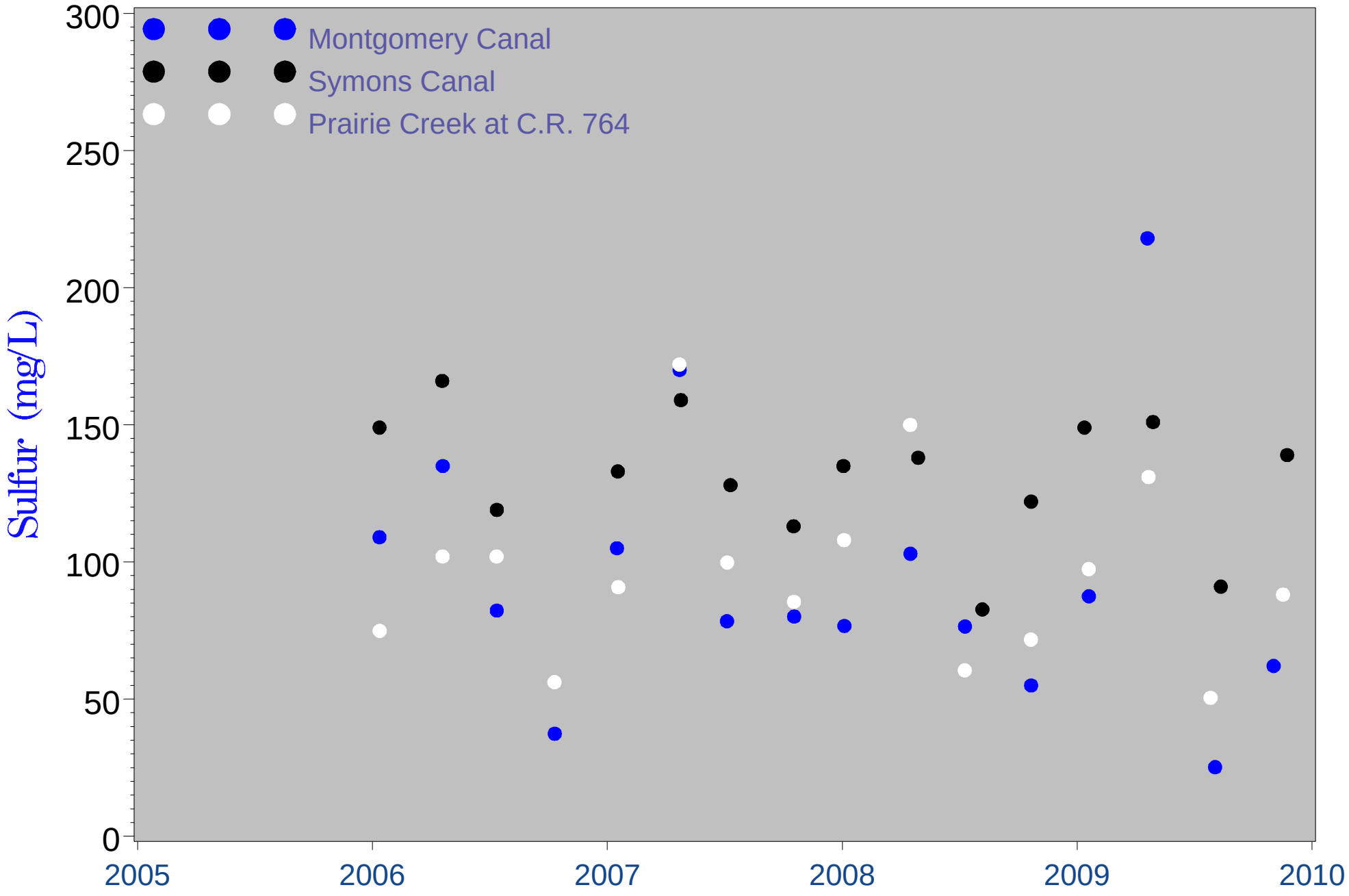


Figure 3.151b Sulfur concentrations at District's Prairie Creek sites 2005-2009

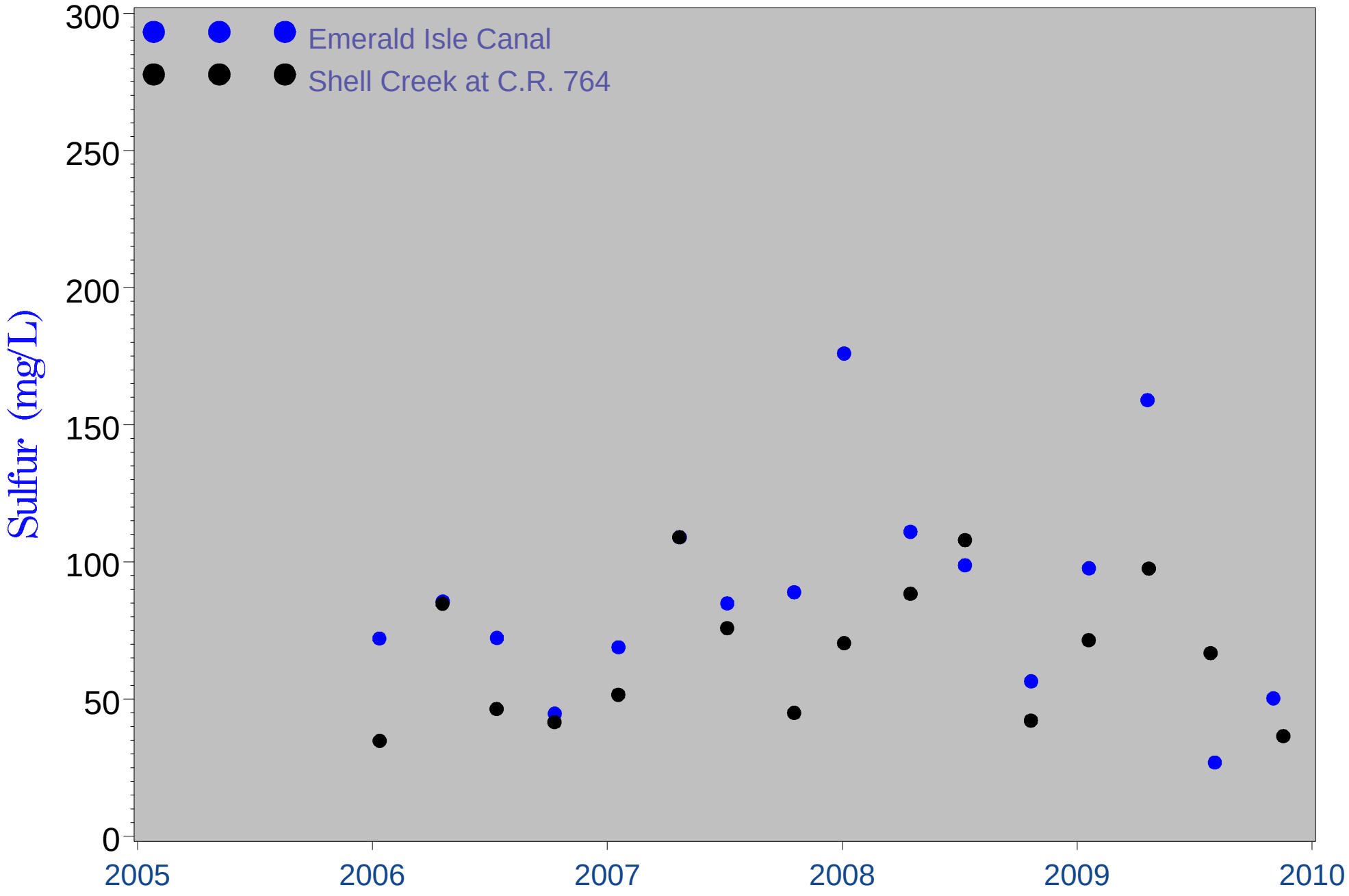


Figure 3.151c Sulfur concentrations at District's Shell Creek sites 2005-2009

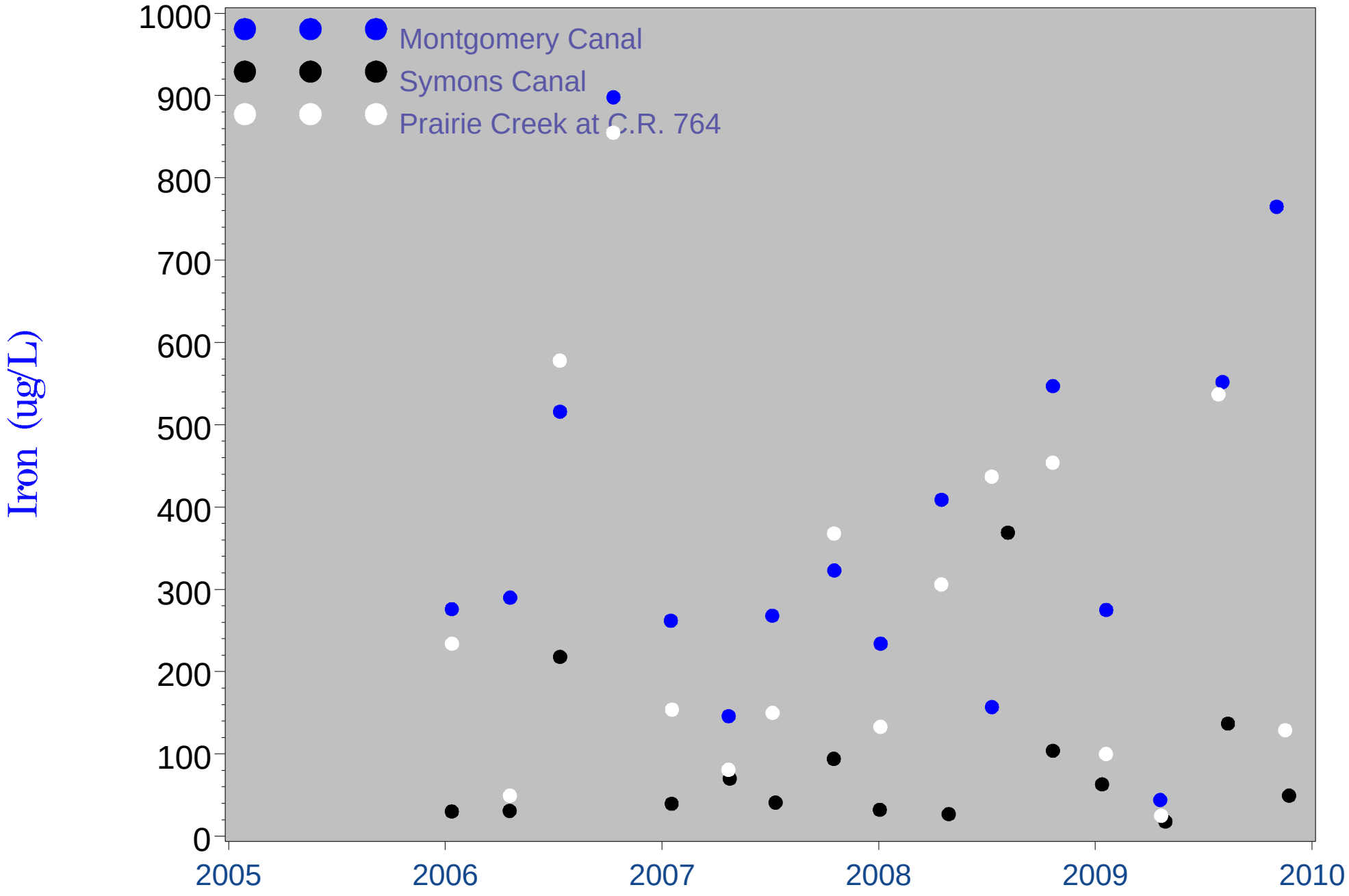


Figure 3.152b Iron concentrations at District's Prairie Creek sites 2005-2009

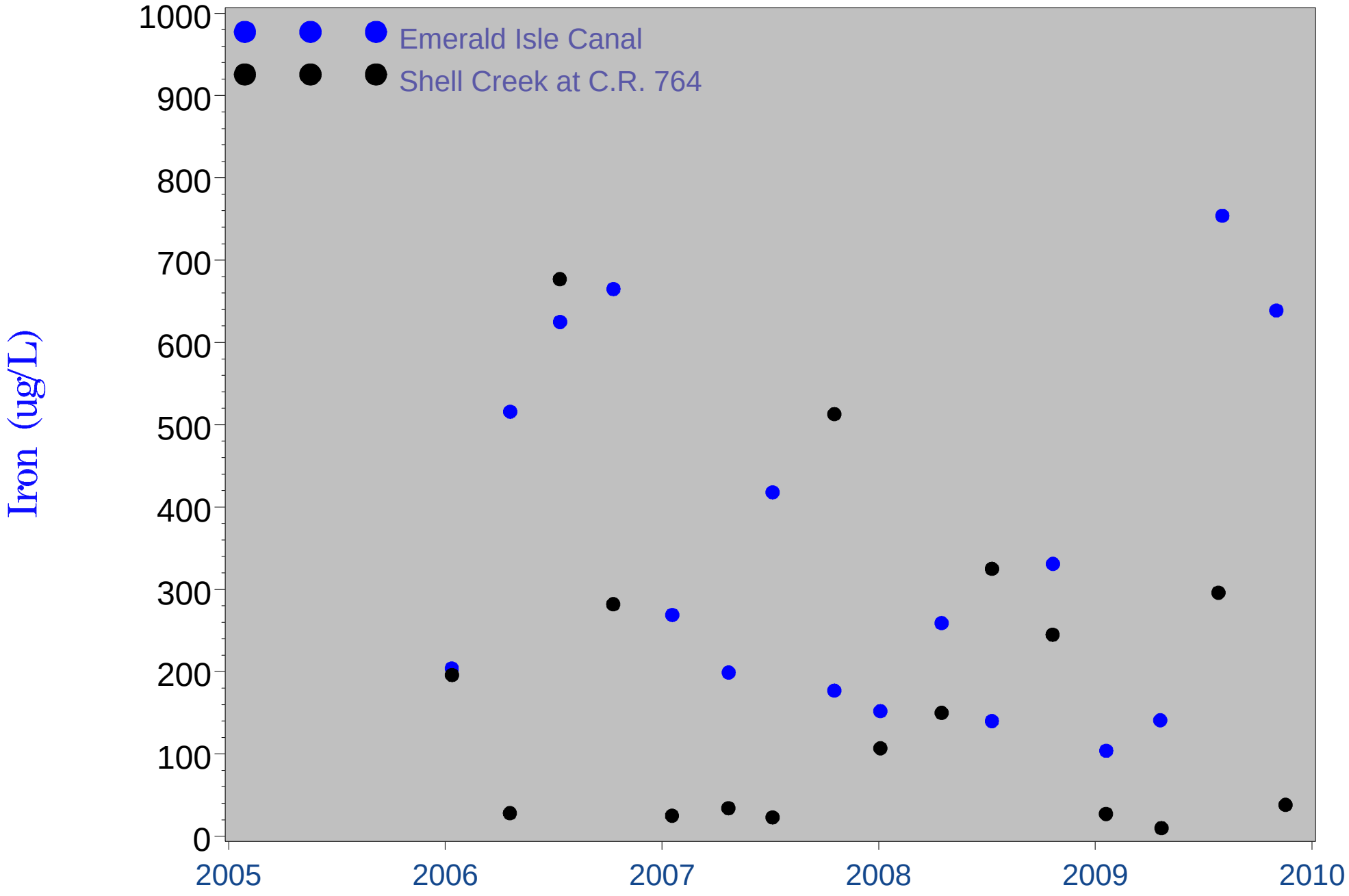


Figure 3.152c Iron concentrations at District's Shell Creek sites 2005-2009

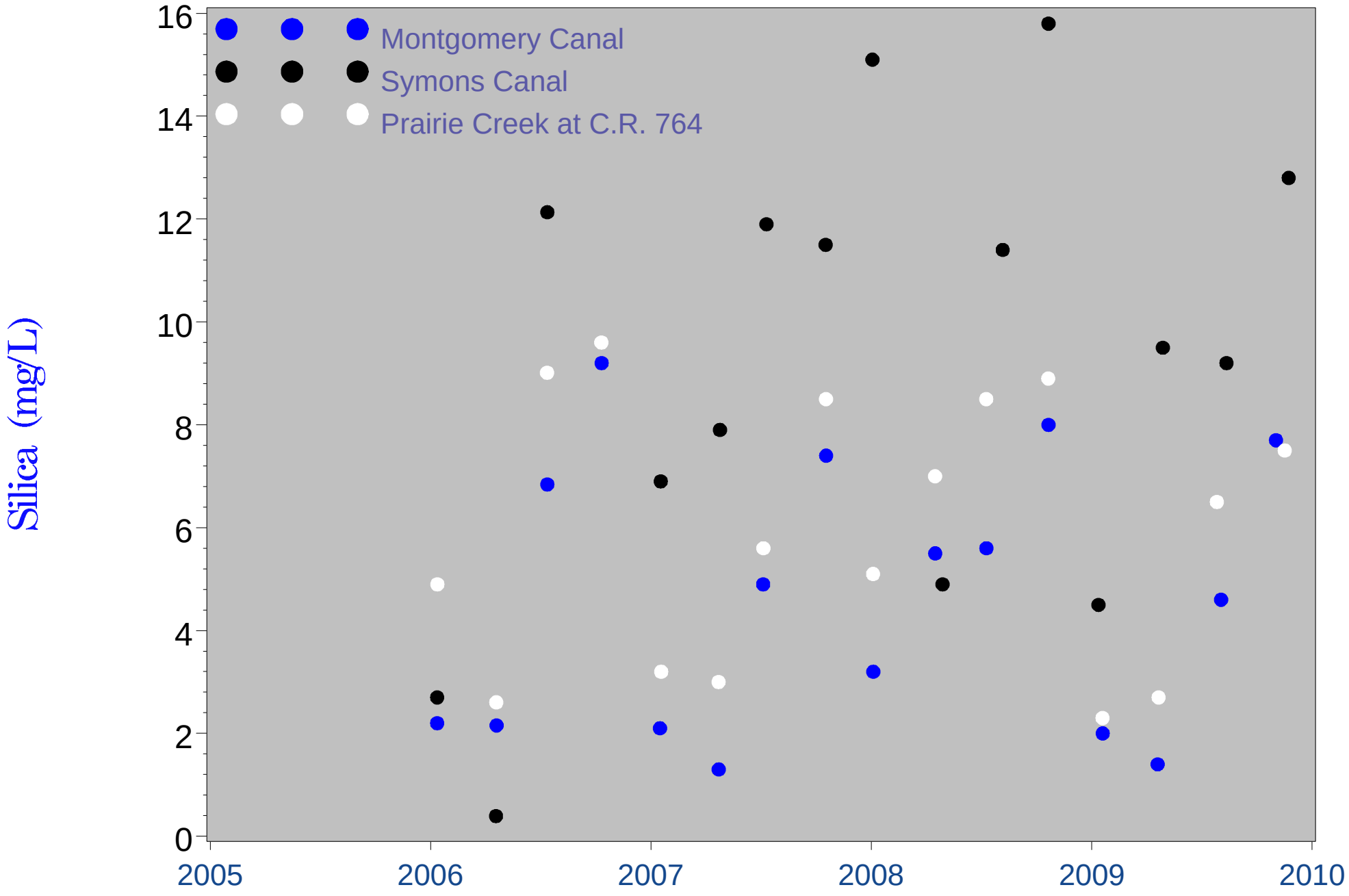


Figure 3.153b Silica concentrations at District's Prairie Creek sites 2005-2009

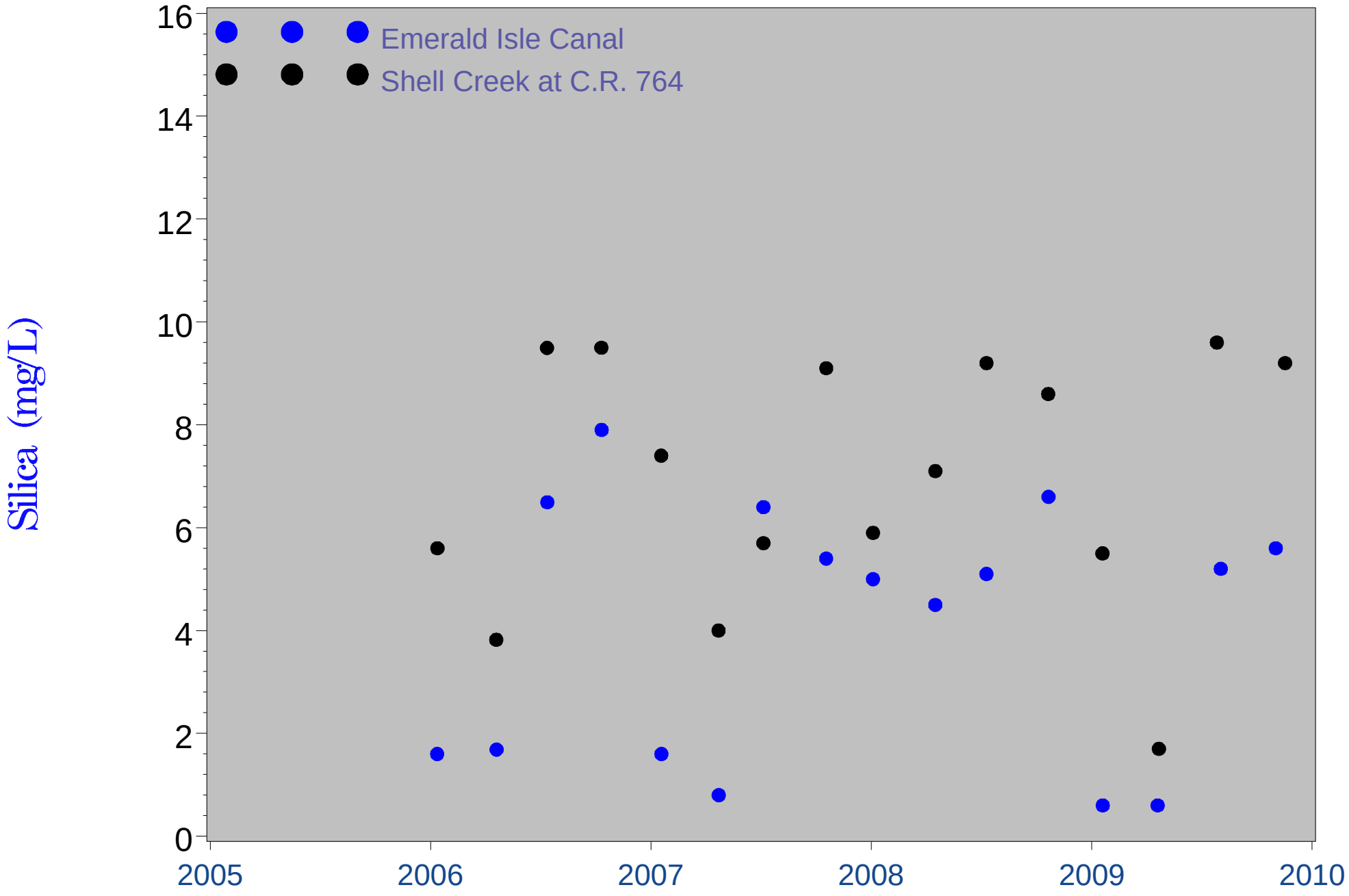


Figure 3.153c Silica concentrations at District's Shell Creek sites 2005-2009

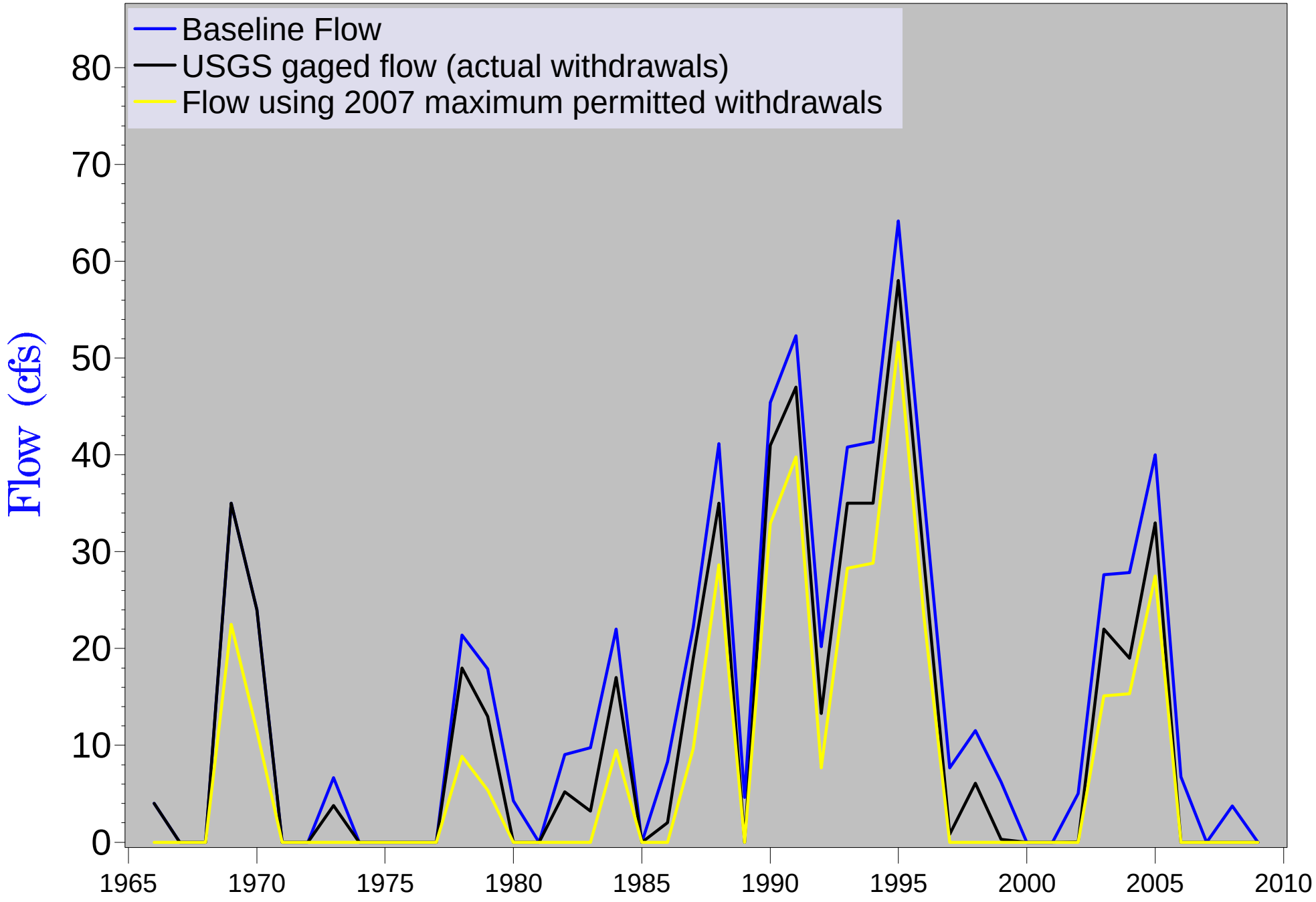


Figure 4.1 Differences in annual minimum Shell Creek flow with and without withdrawals (1966-2009)

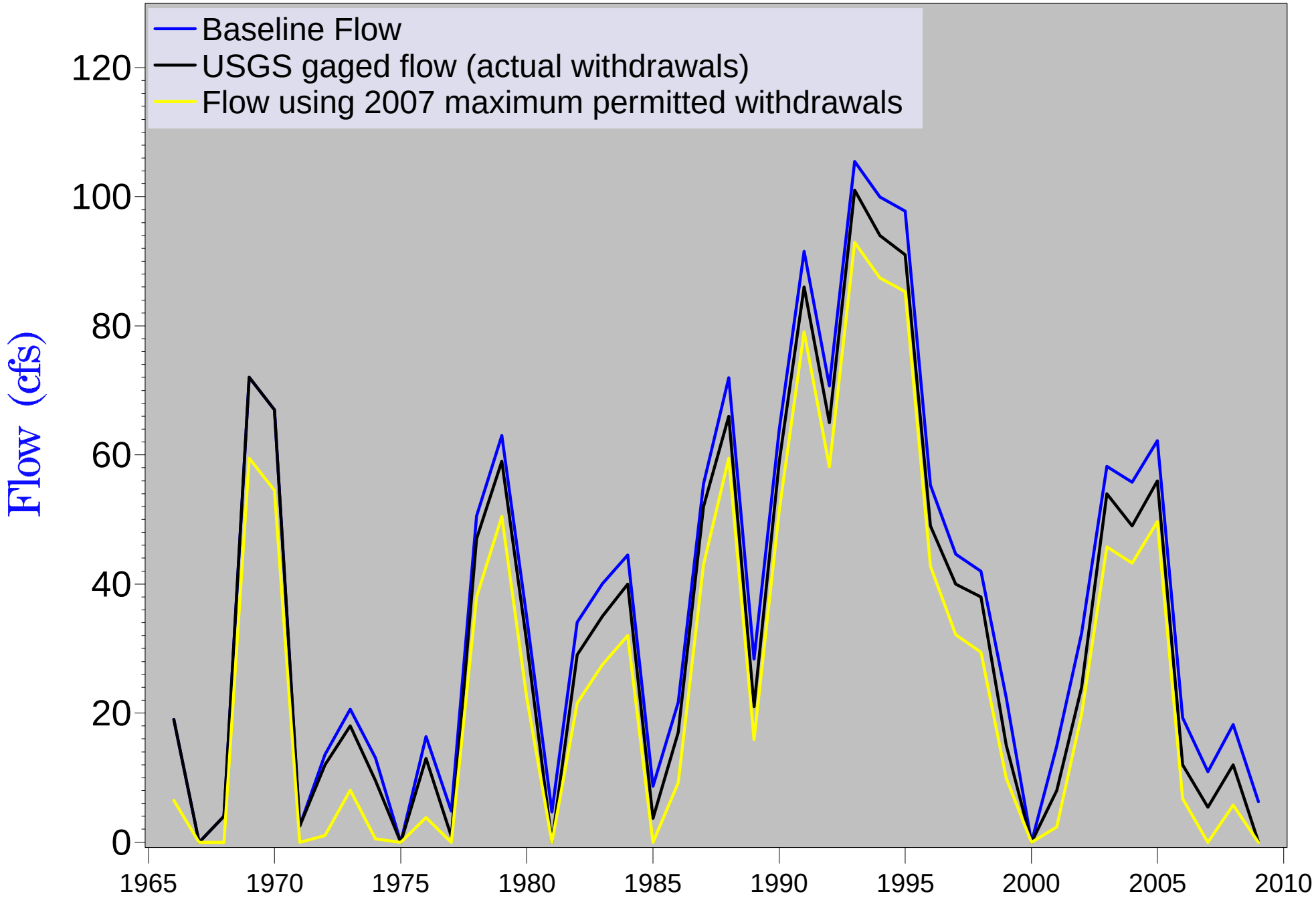


Figure 4.2 Differences in annual P10 Shell Creek flow with and without withdrawals (1966-2009)

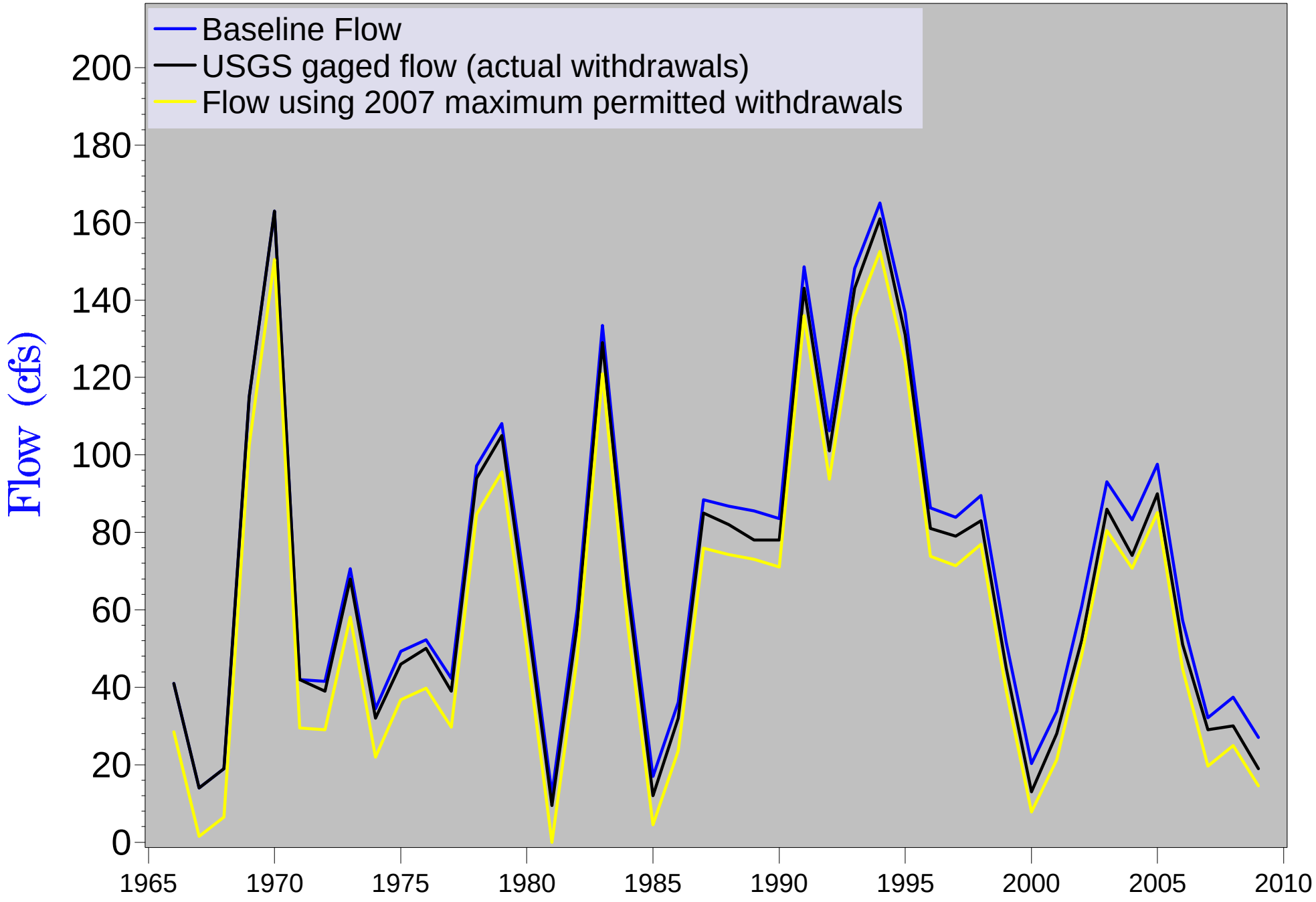


Figure 4.3 Differences in annual P25 Shell Creek flow with and without withdrawals (1966-2009)

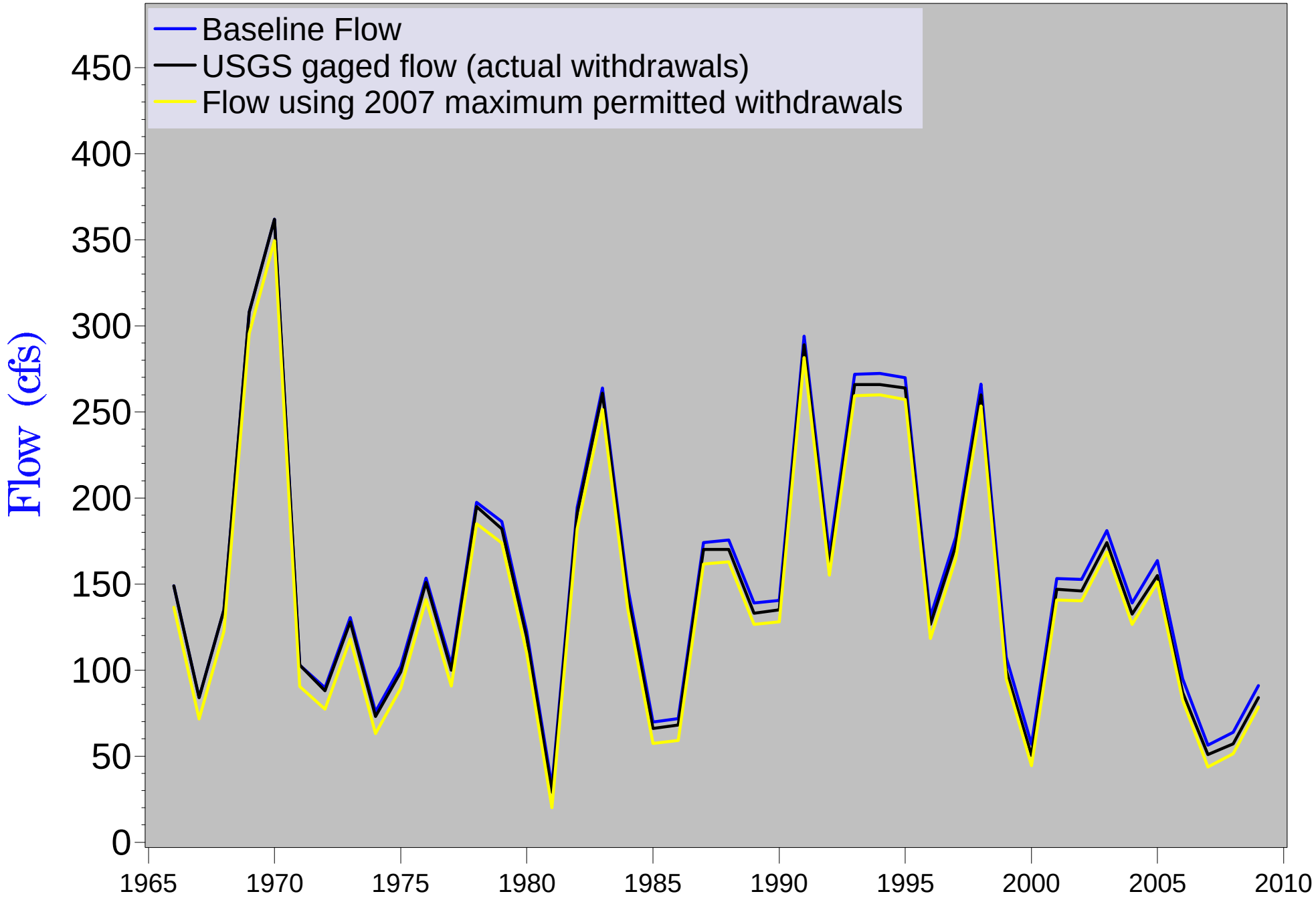


Figure 4.4 Differences in annual P50 (median) Shell Creek flow with and without withdrawals (1966-2009)

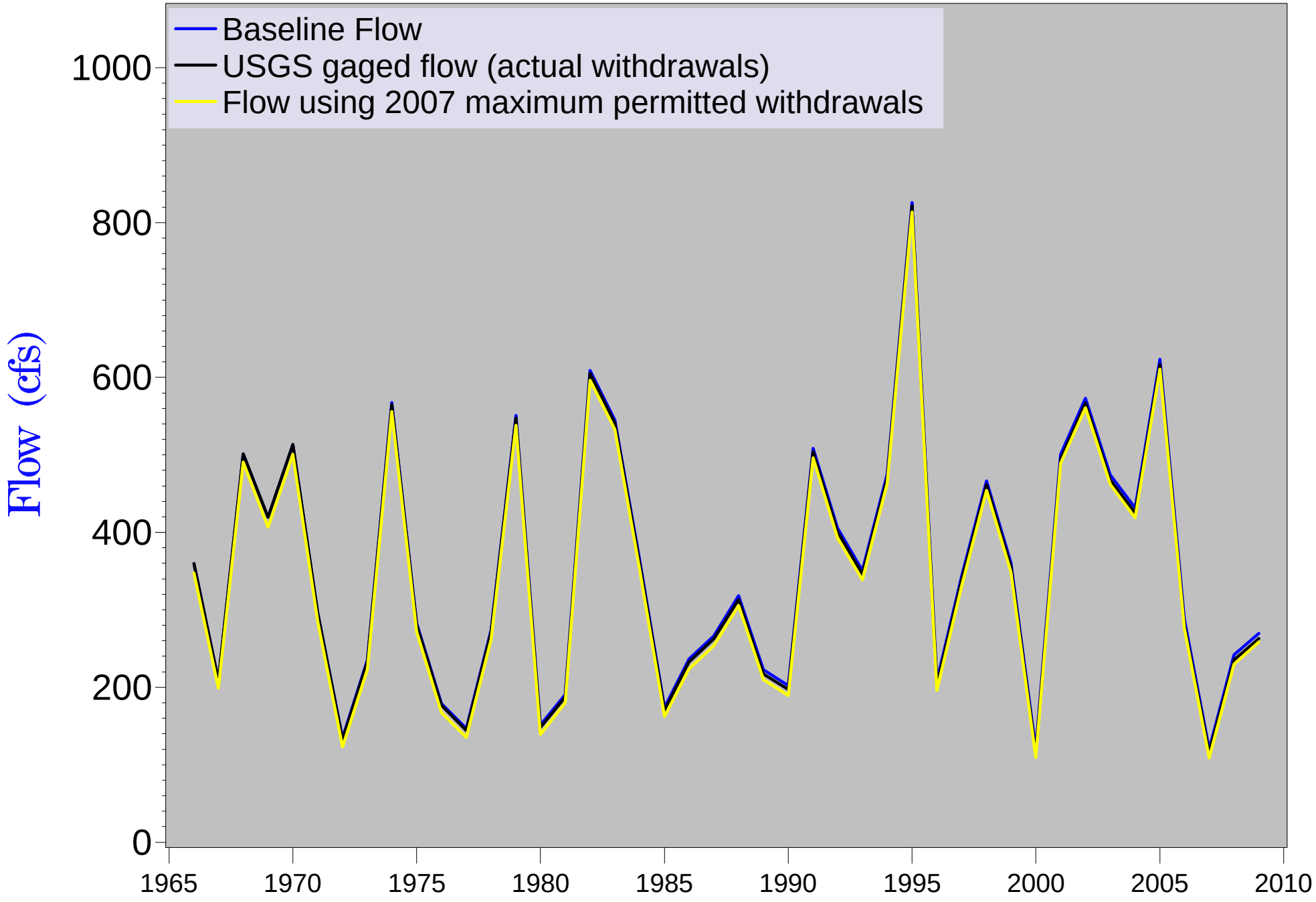


Figure 4.5 Differences in annual mean Shell Creek flow with and without withdrawals (1966-2009)

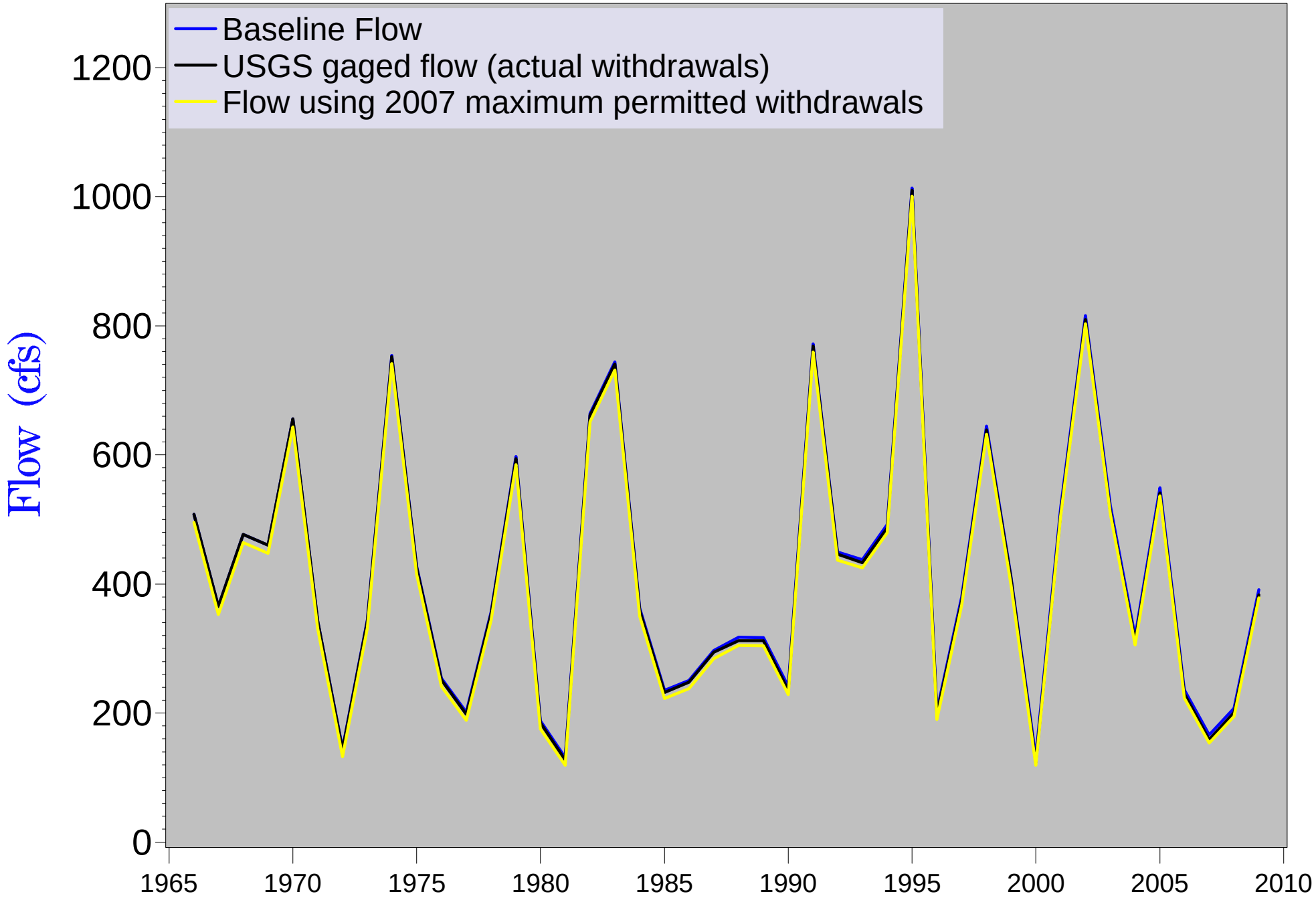


Figure 4.6 Differences in annual P75 Shell Creek flow with and without withdrawals (1966-2009)

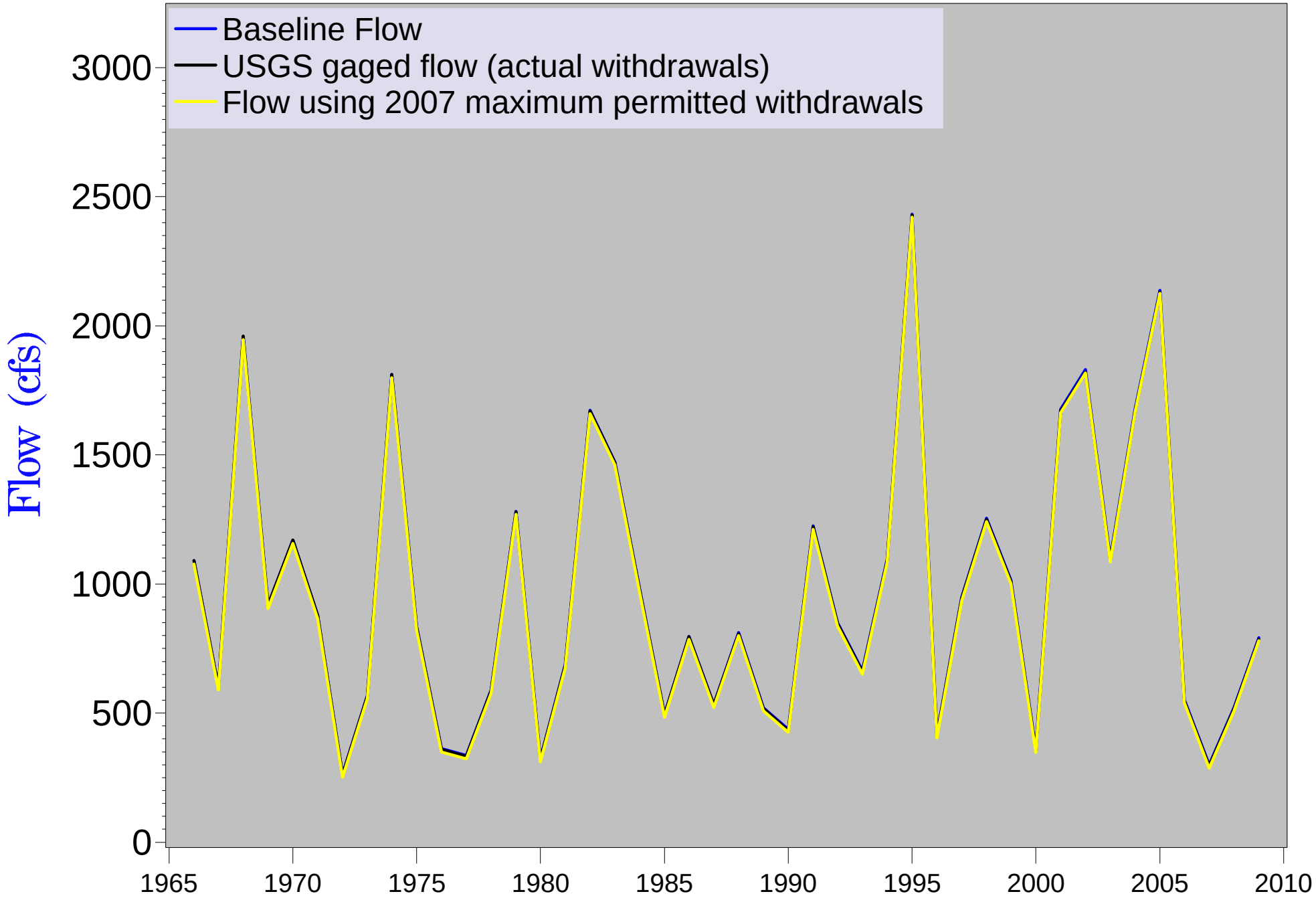


Figure 4.7 Differences in annual p90 Shell Creek flow with and without withdrawals (1966-2009)

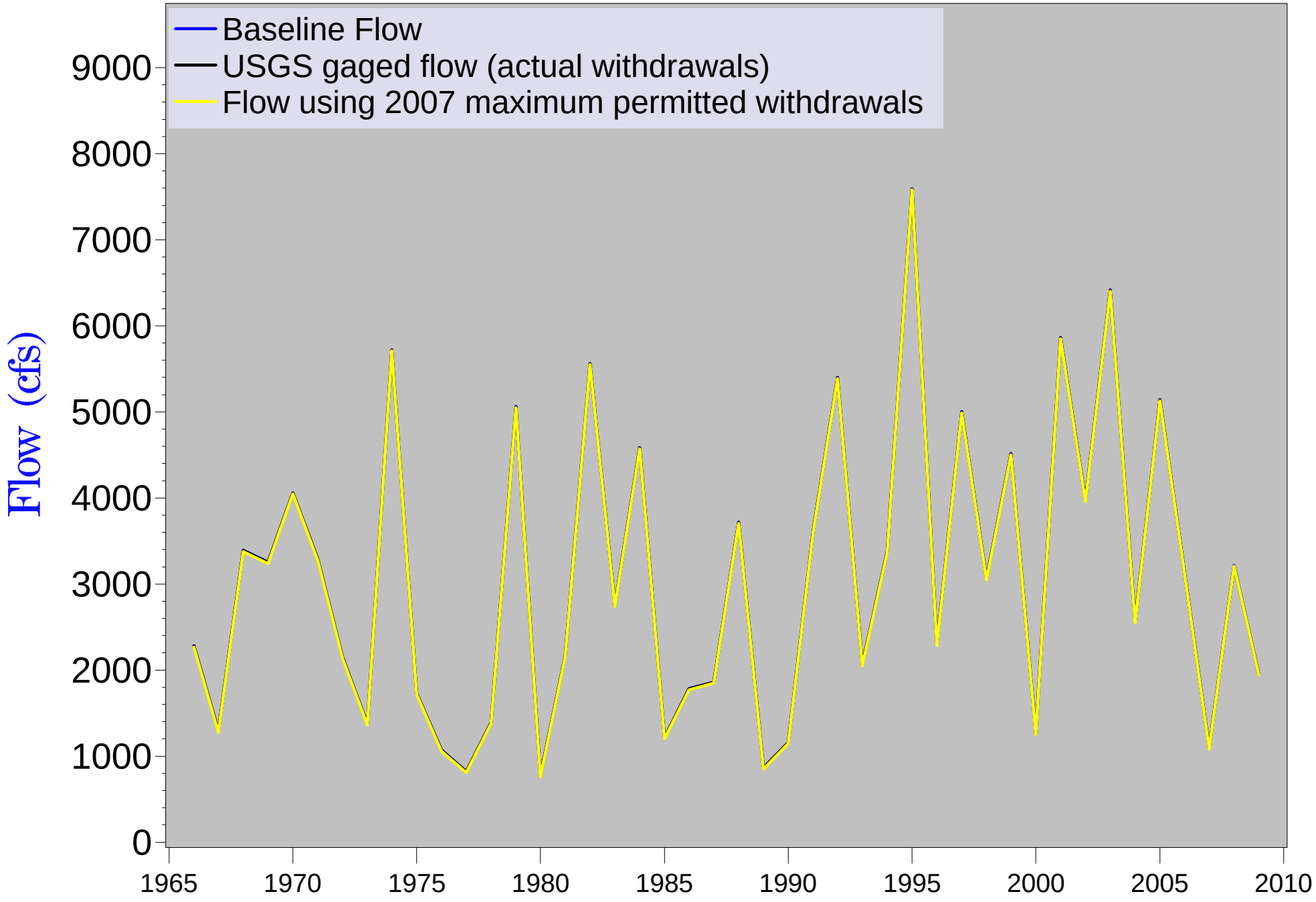


Figure 4.8 Differences in annual maximum Shell Creek flow with and without withdrawals (1966-2009)

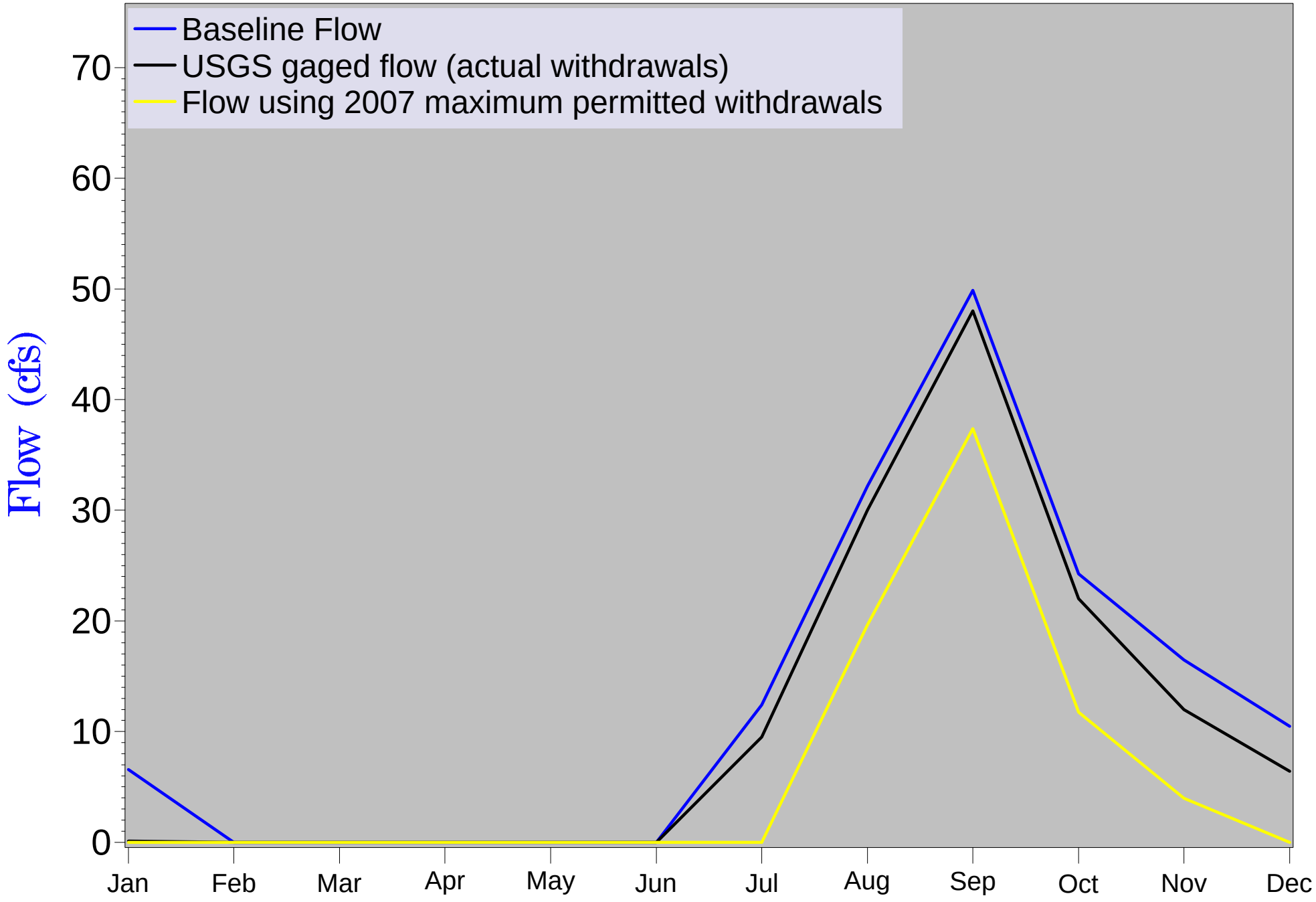


Figure 4.9 Differences in monthly minimum Shell Creek flow with and without withdrawals (1966-2009)

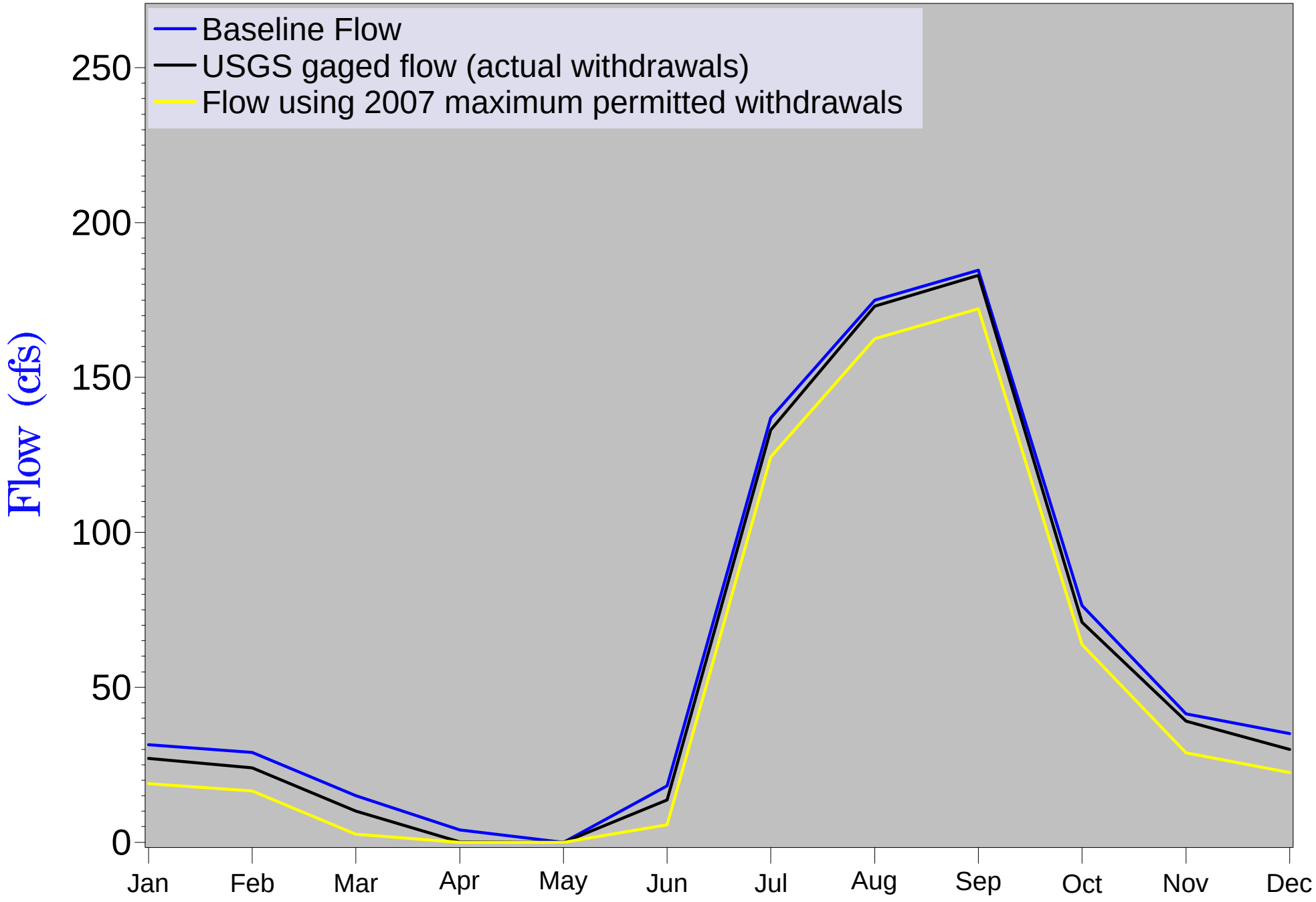


Figure 4.10 Differences in monthly P10 Shell Creek flow with and without withdrawals (1966-2009)

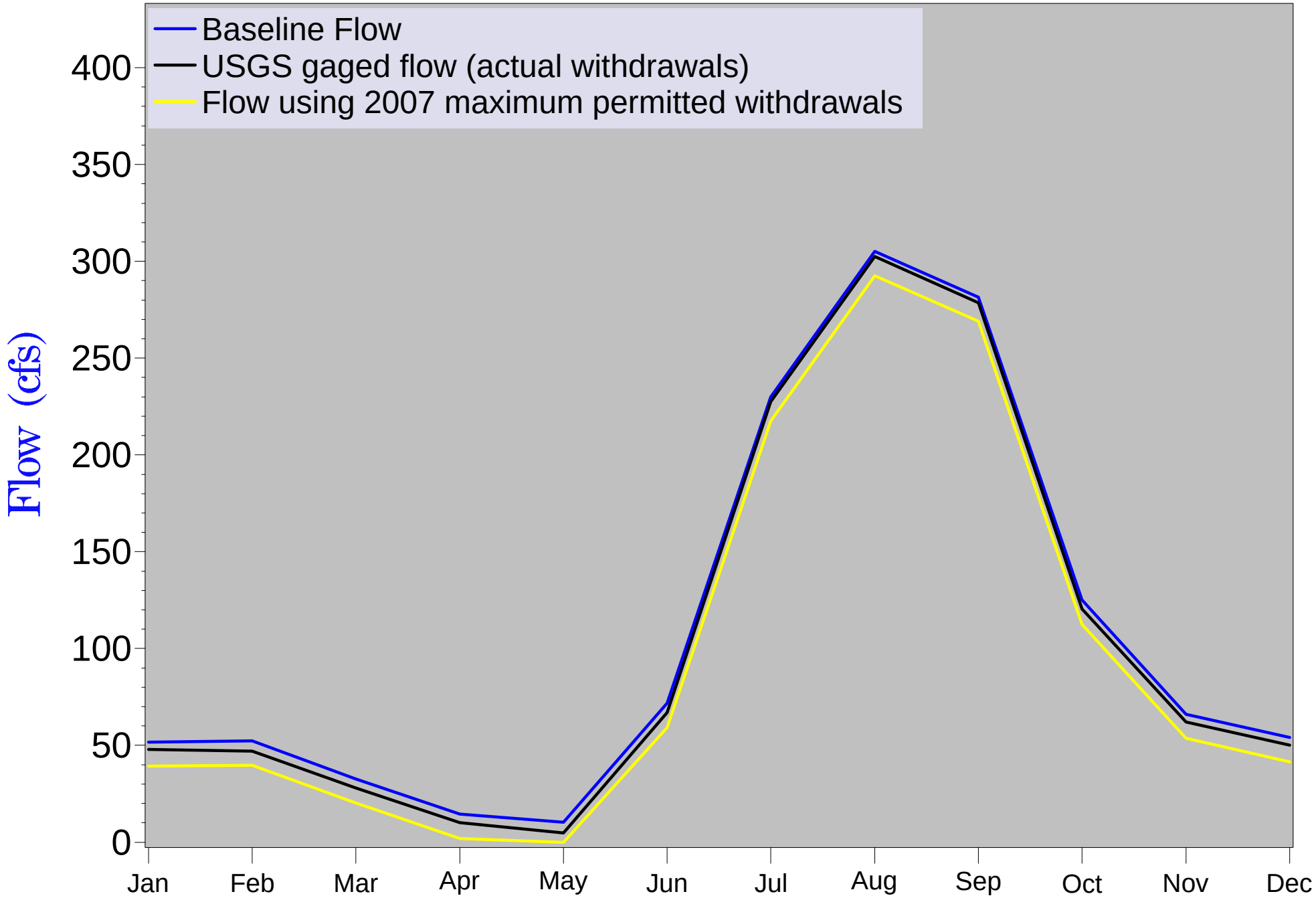


Figure 4.11 Differences in monthly P25 Shell Creek flow with and without withdrawals (1966-2009)

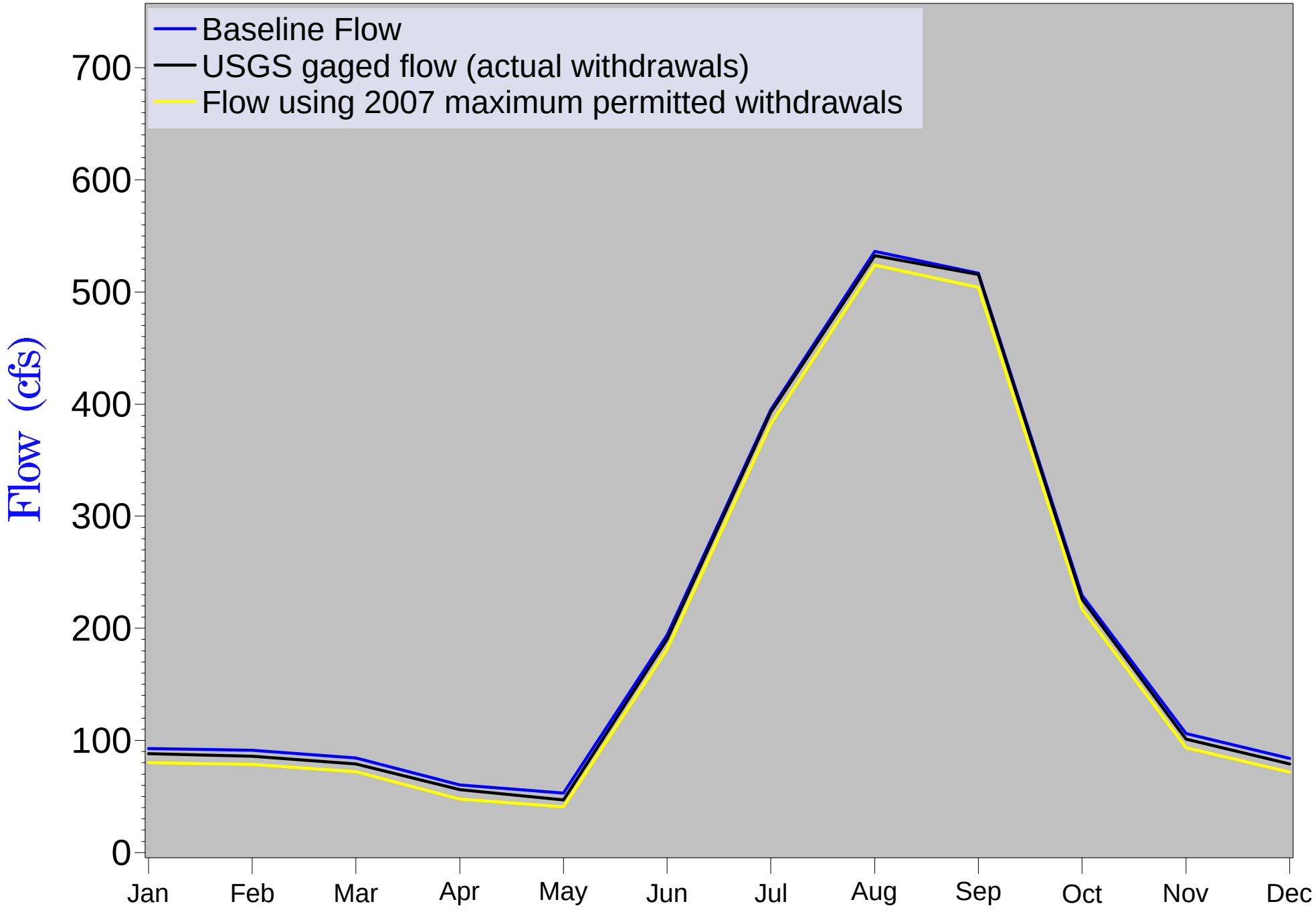


Figure 4.12 Differences in monthly P50 (median) Shell Creek flow with and without withdrawals (1966-2009)

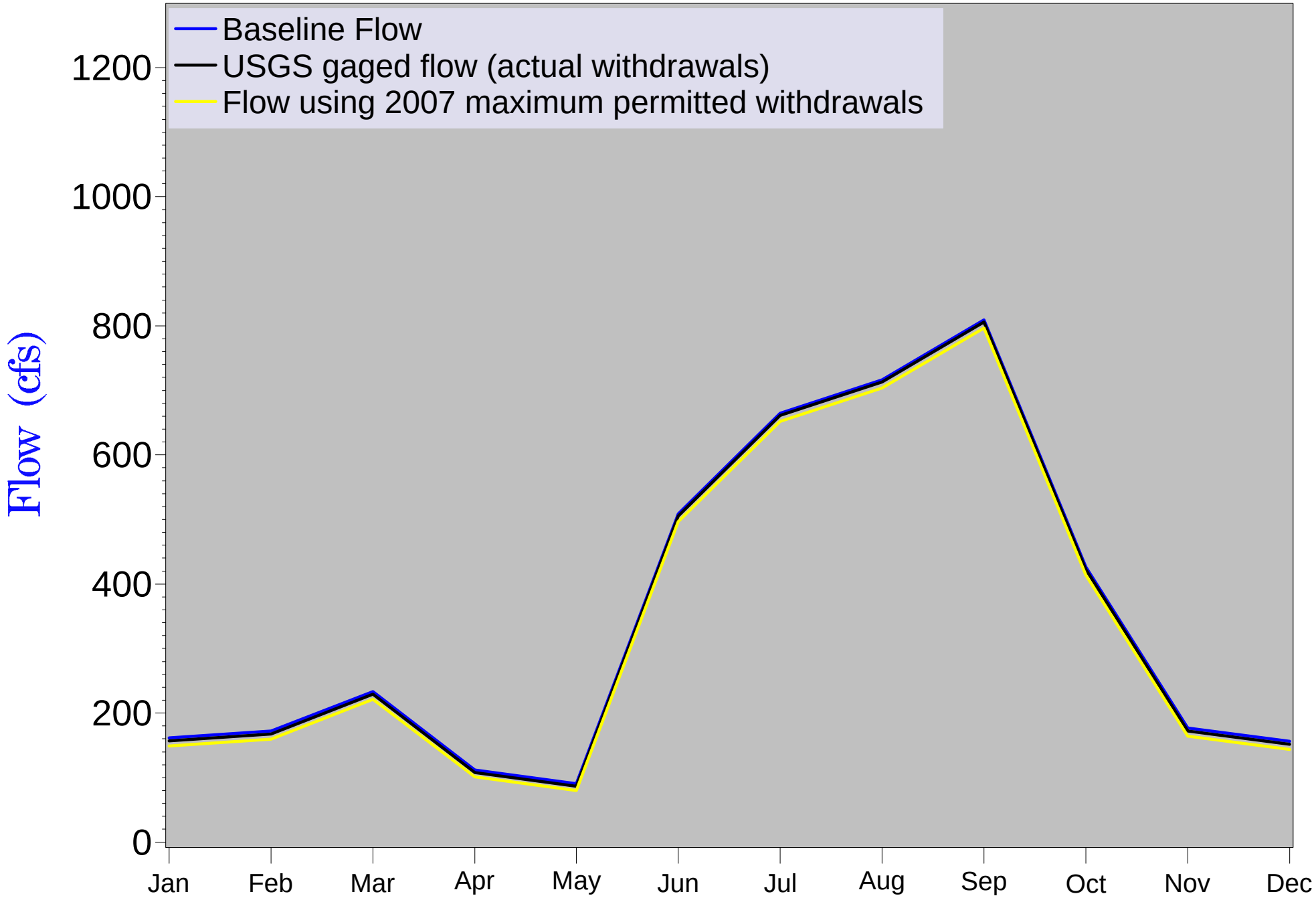


Figure 4.13 Differences in monthly mean Shell Creek flow with and without withdrawals (1966-2009)

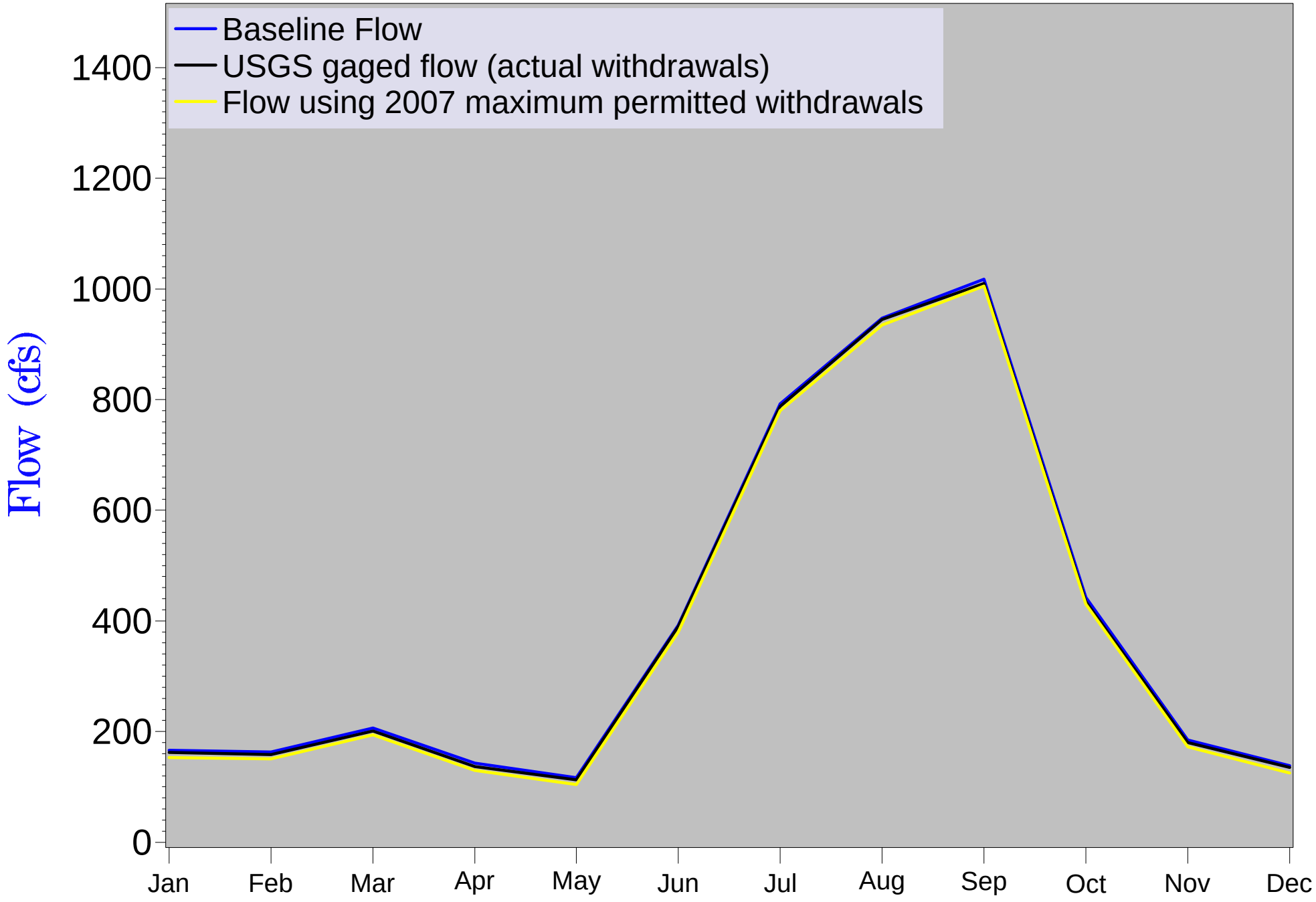


Figure 4.14 Differences in monthly P75 Shell Creek flow with and without withdrawals (1966-2009)

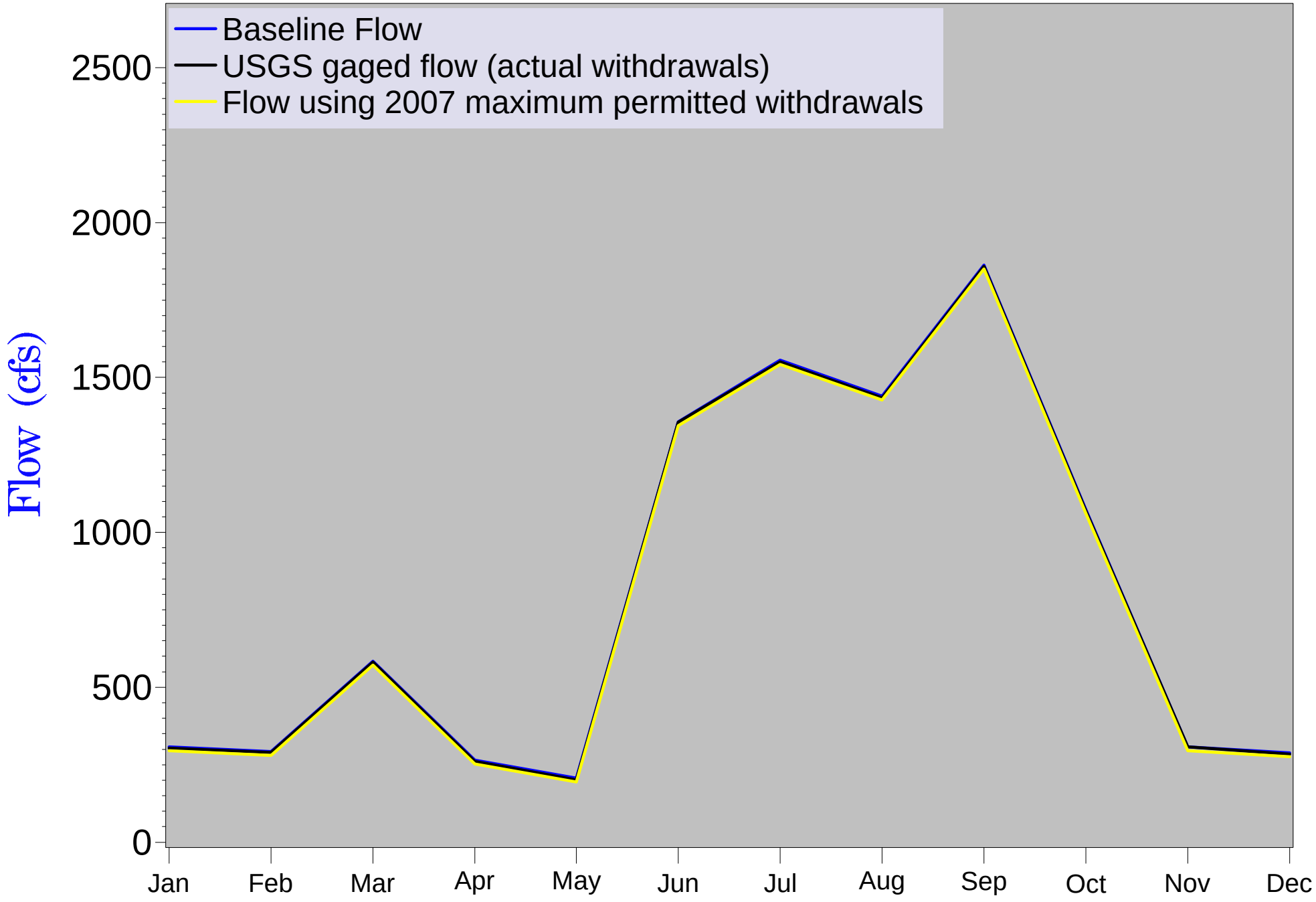


Figure 4.15 Differences in monthly P90 Shell Creek flow with and without withdrawals (1966-2009)

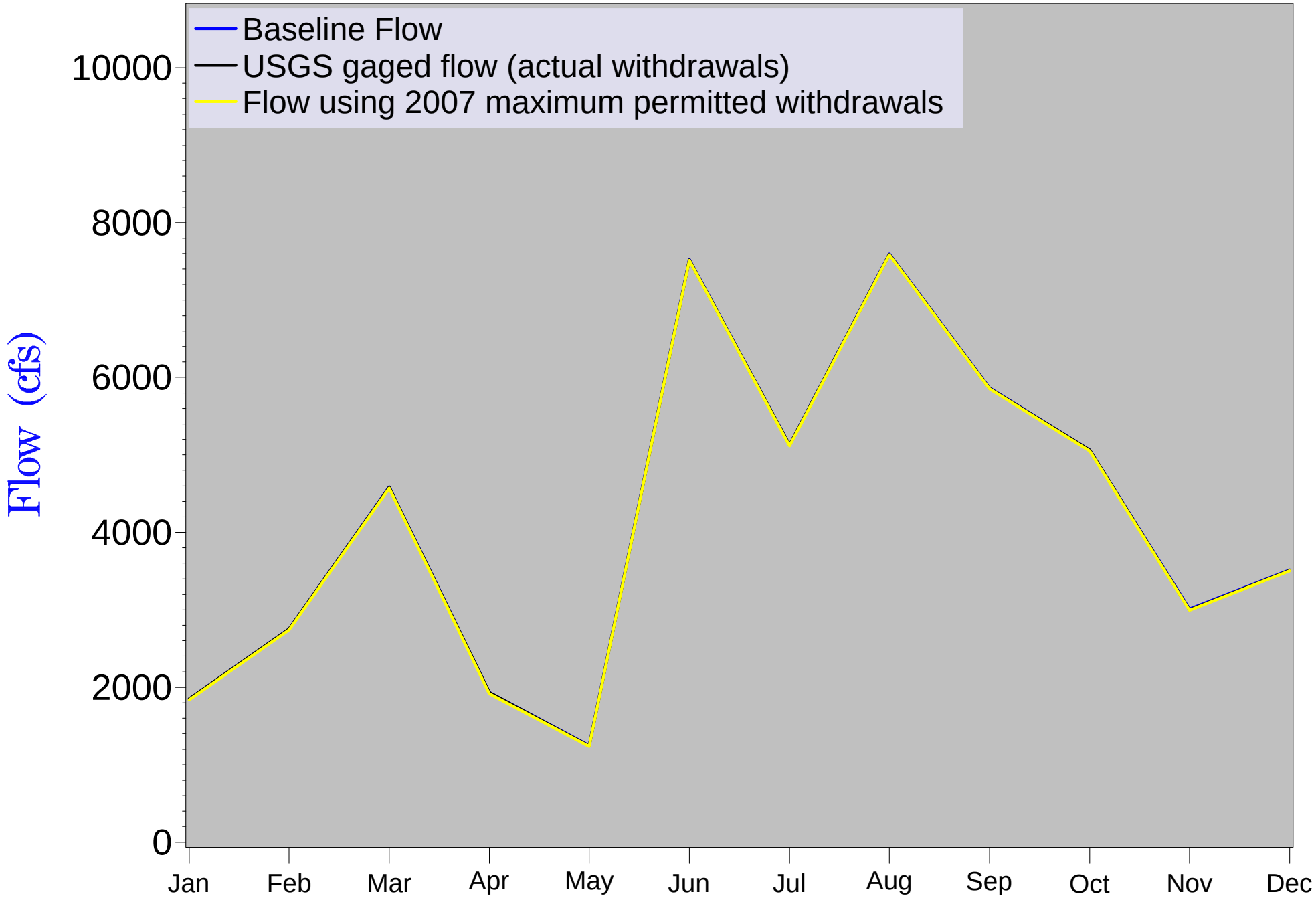


Figure 4.16 Differences in monthly maximum Shell Creek flow with and without withdrawals (1966-2009)

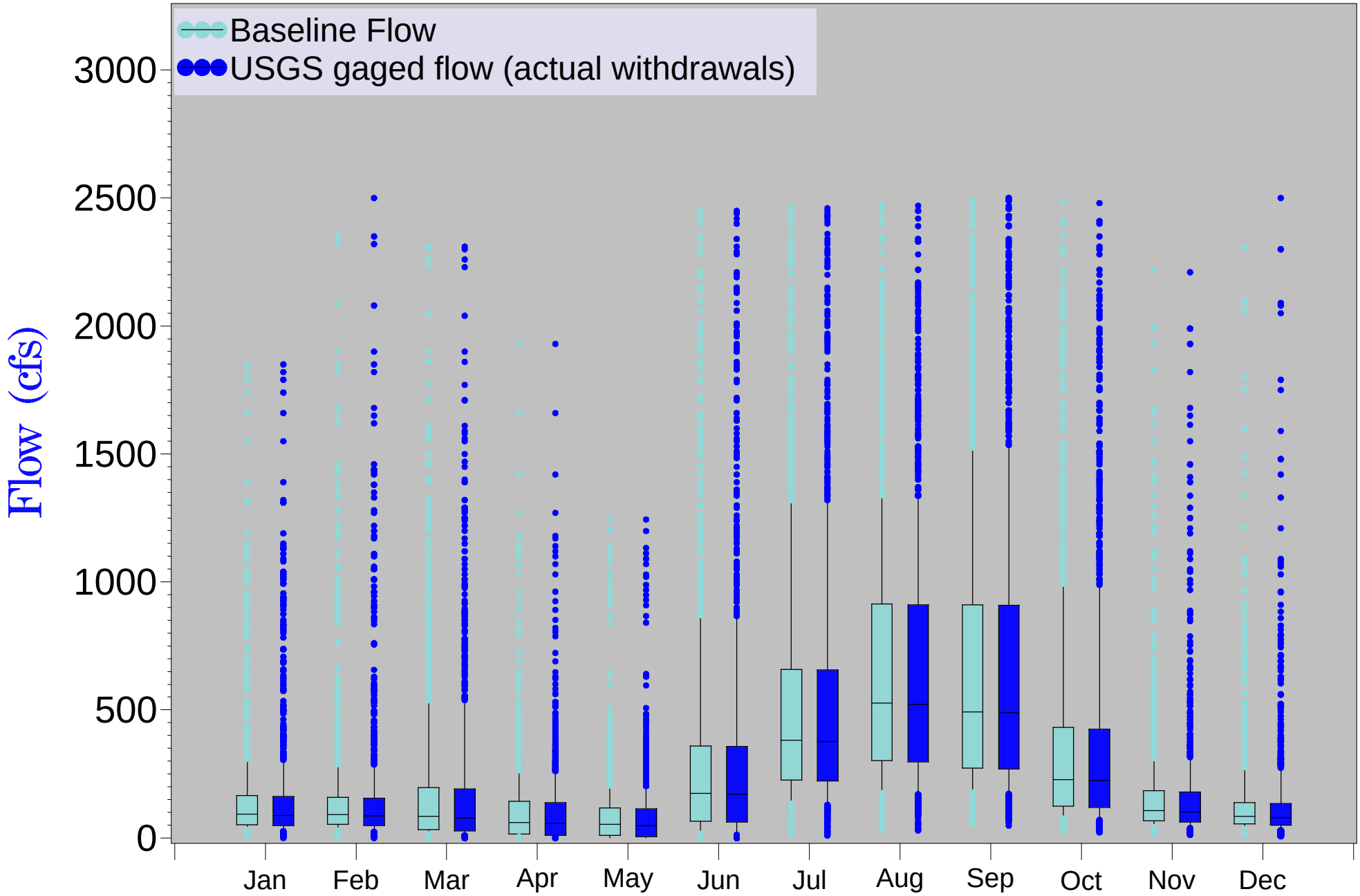


Figure 4.17a Seasonal differences in monthly Shell Creek flow without and with historic withdrawals (1966-2009)

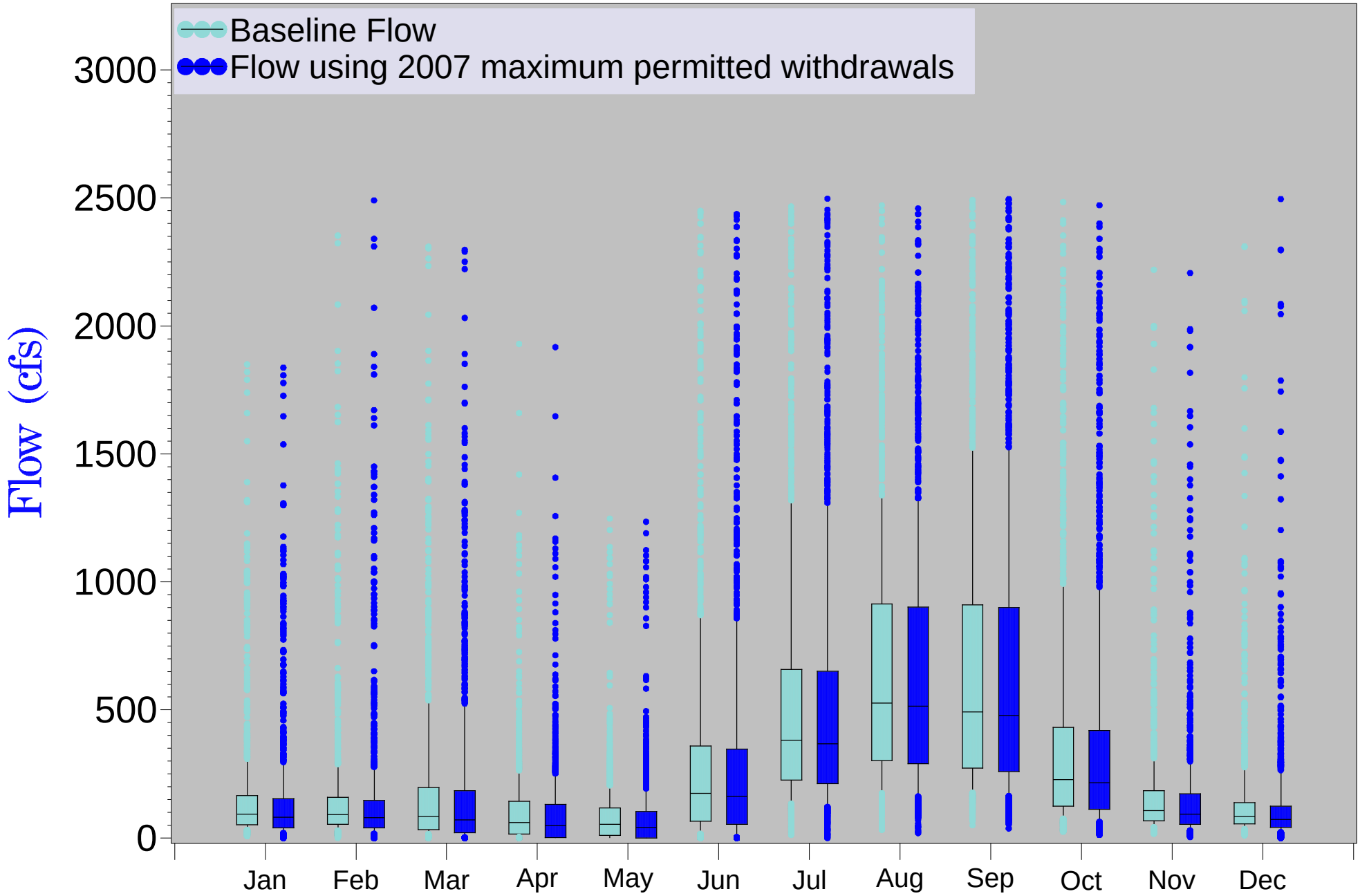


Figure 4.17b Seasonal differences in monthly Shell Creek flow without and using current maximum daily permitted withdrawals (1966-2009)

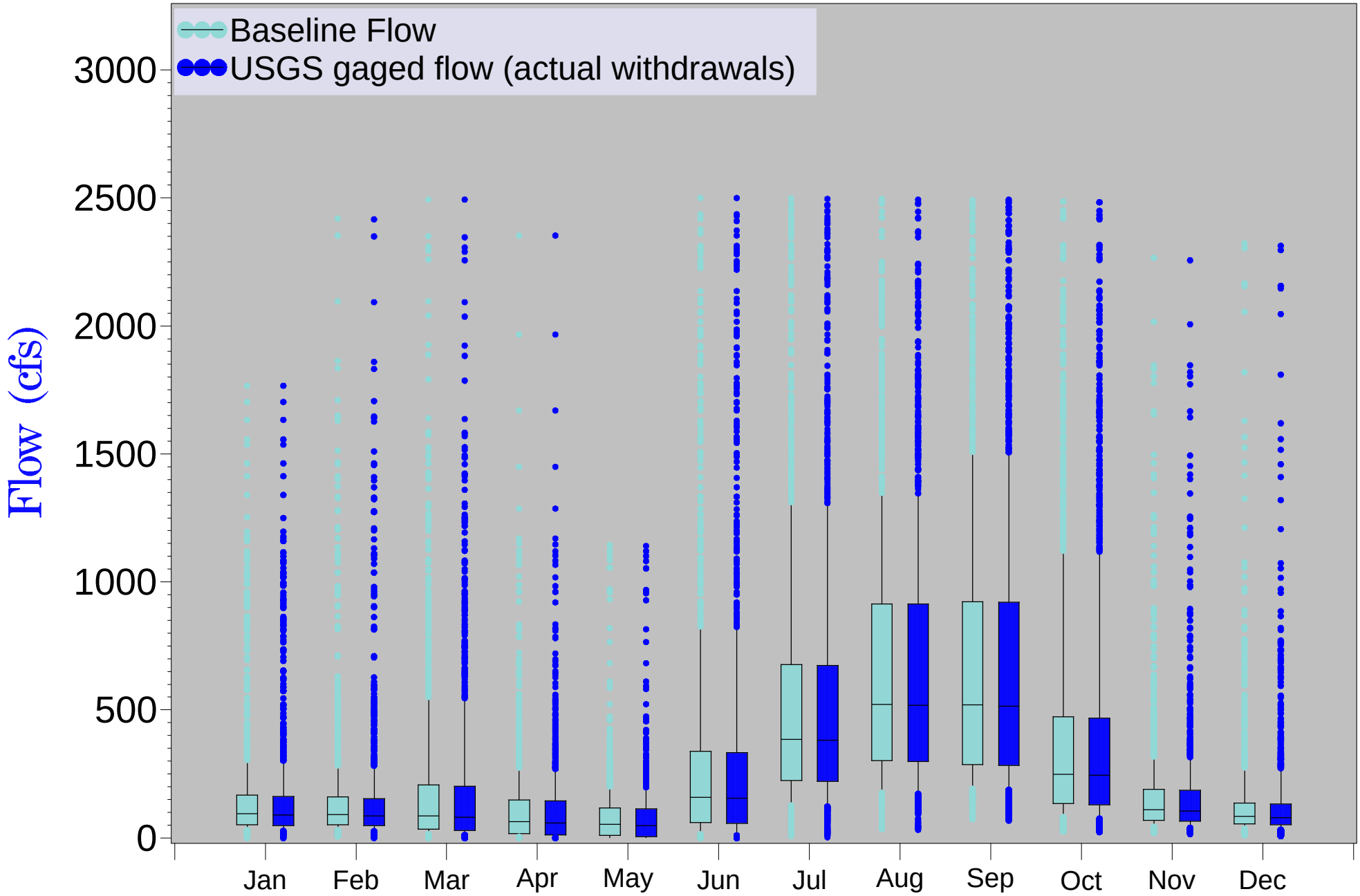


Figure 4.18a Seasonal differences in 3-day lag monthly Shell Creek flow without and with historic withdrawals (1966-2009)

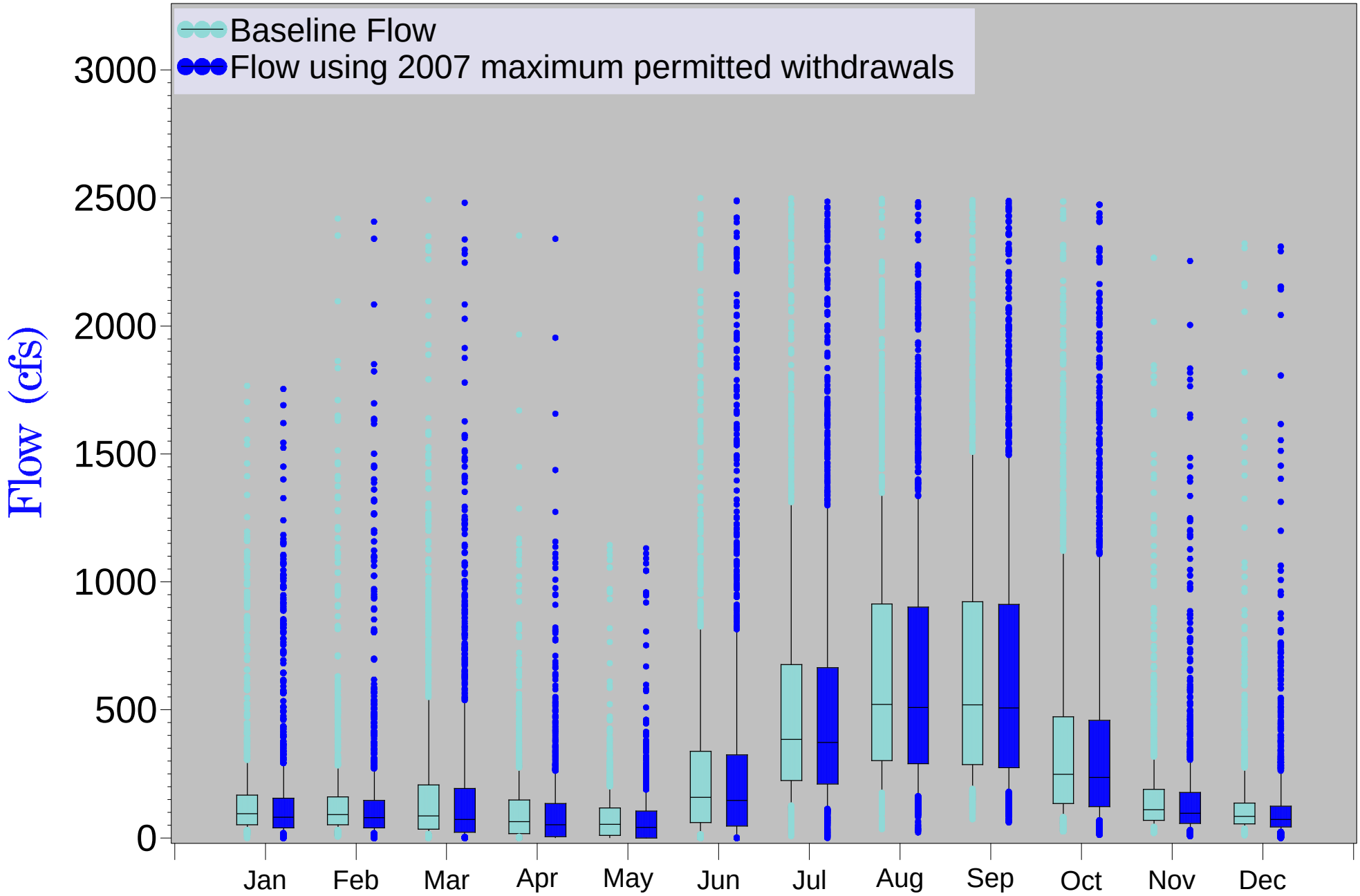


Figure 4.18b Seasonal differences in 3-day lag monthly Shell Creek flow without and using current maximum daily permitted withdrawals (1966-2009)

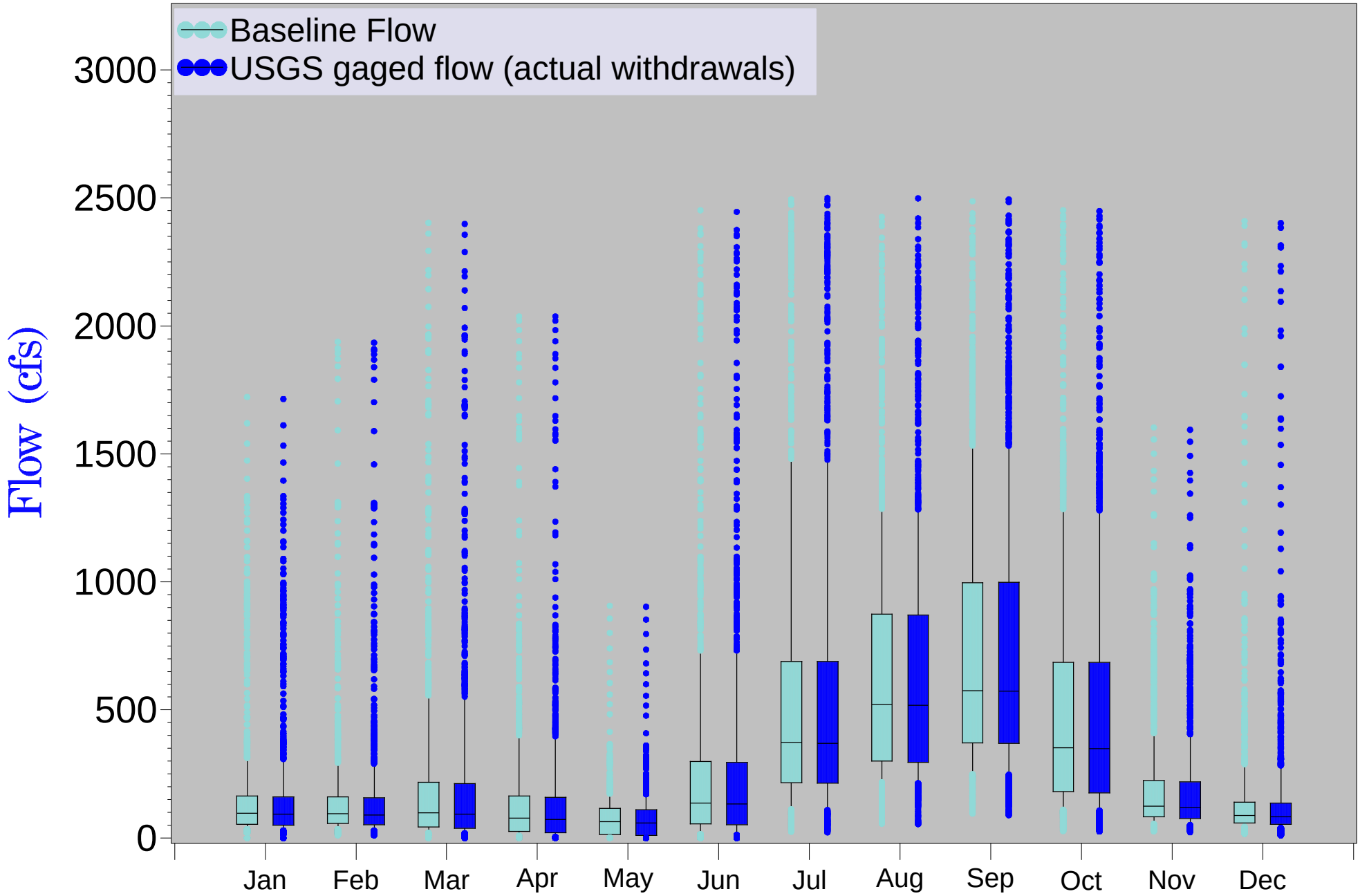


Figure 4.19a Seasonal differences in 15-day lag monthly Shell Creek flow without and with historic withdrawals (1966-2009)

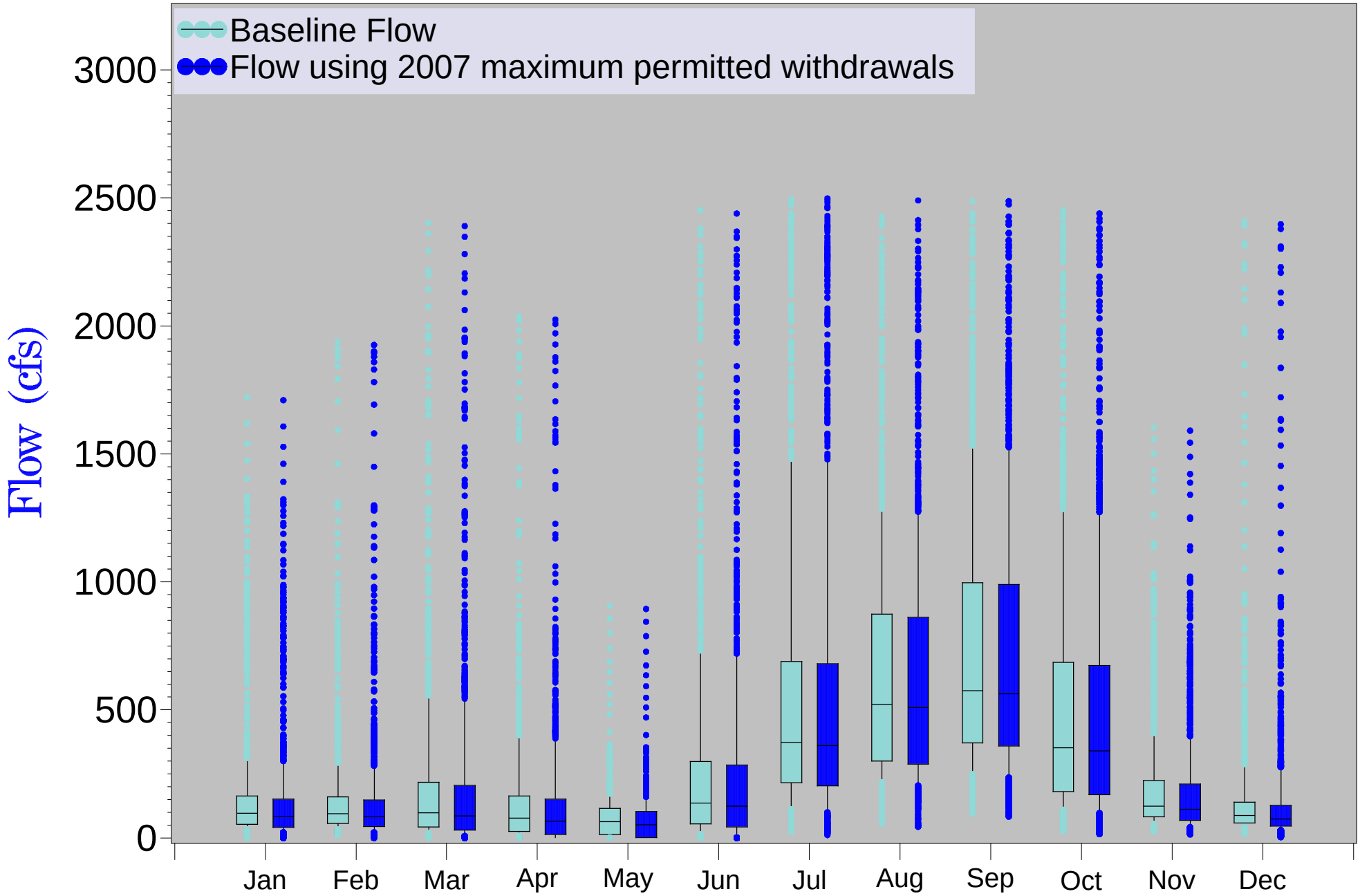


Figure 4.19b Seasonal differences in 15-day lag monthly Shell Creek flow without and using current maximum daily permitted withdrawals (1966-2009)

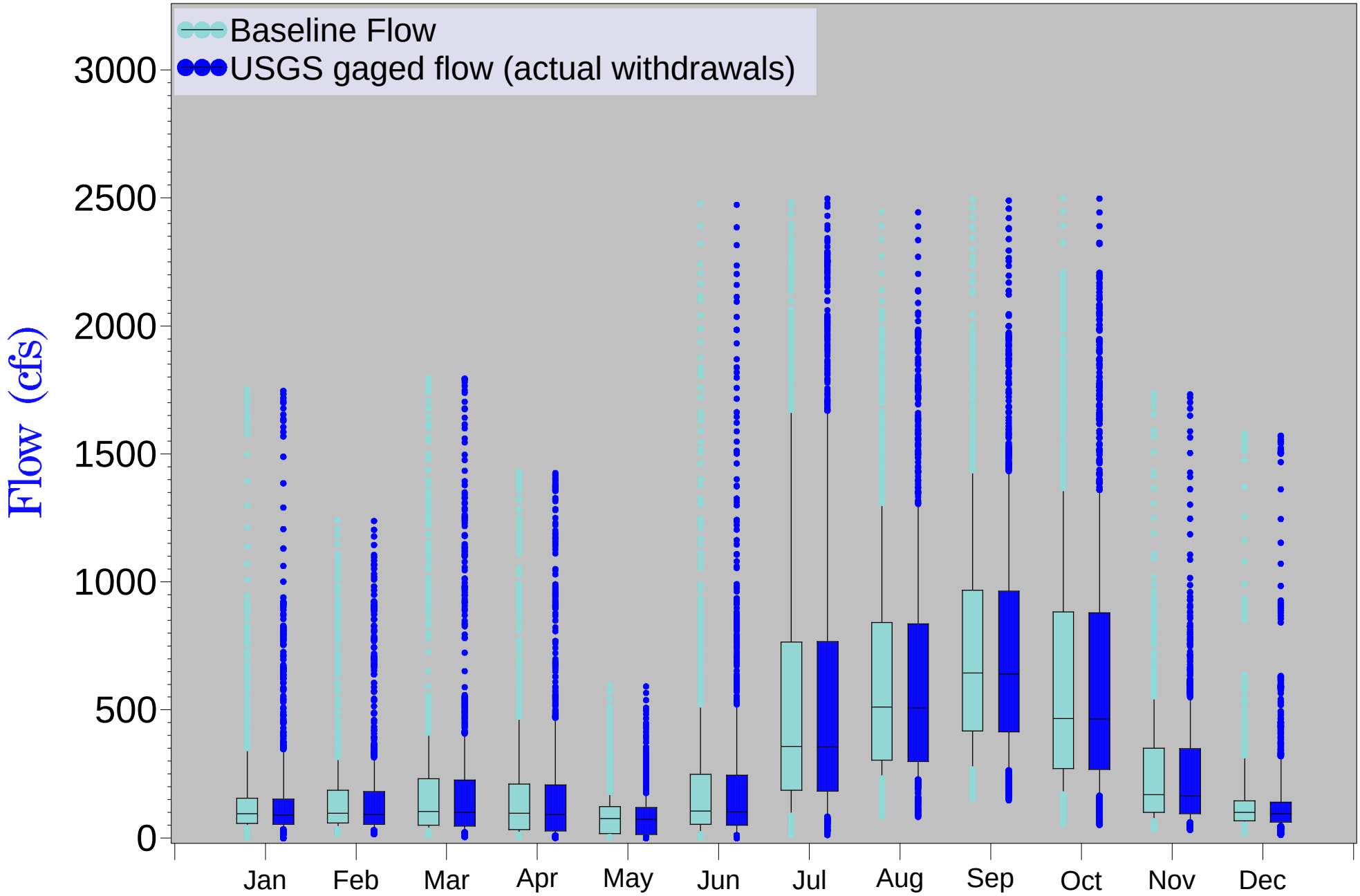


Figure 4.20a Seasonal differences in 30-day lag monthly Shell Creek flow without and with historic withdrawals (1966-2009)

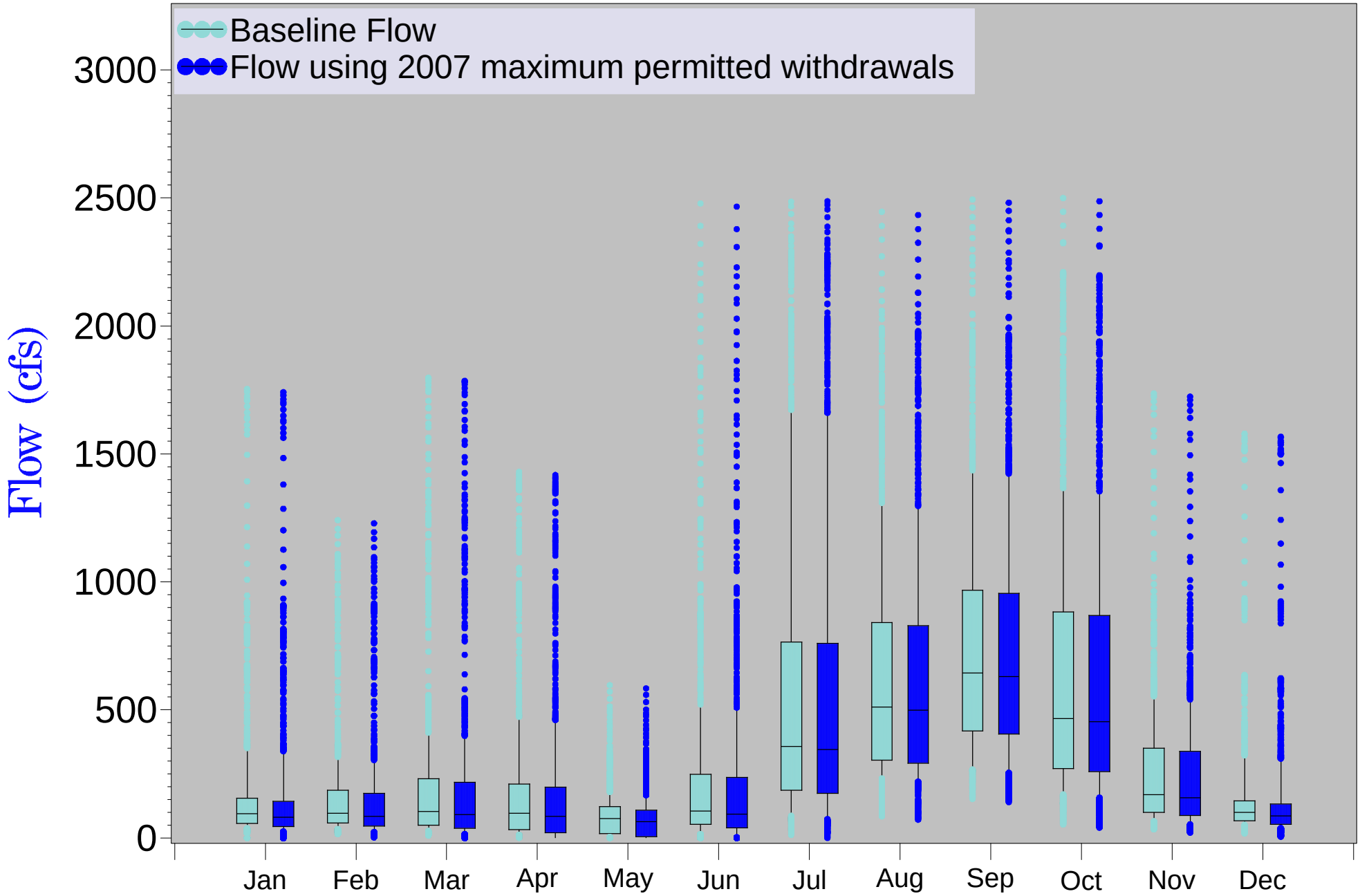


Figure 4.20b Seasonal differences in 30-day lag monthly Shell Creek flow without and using current maximum daily permitted withdrawals (1966-2009)

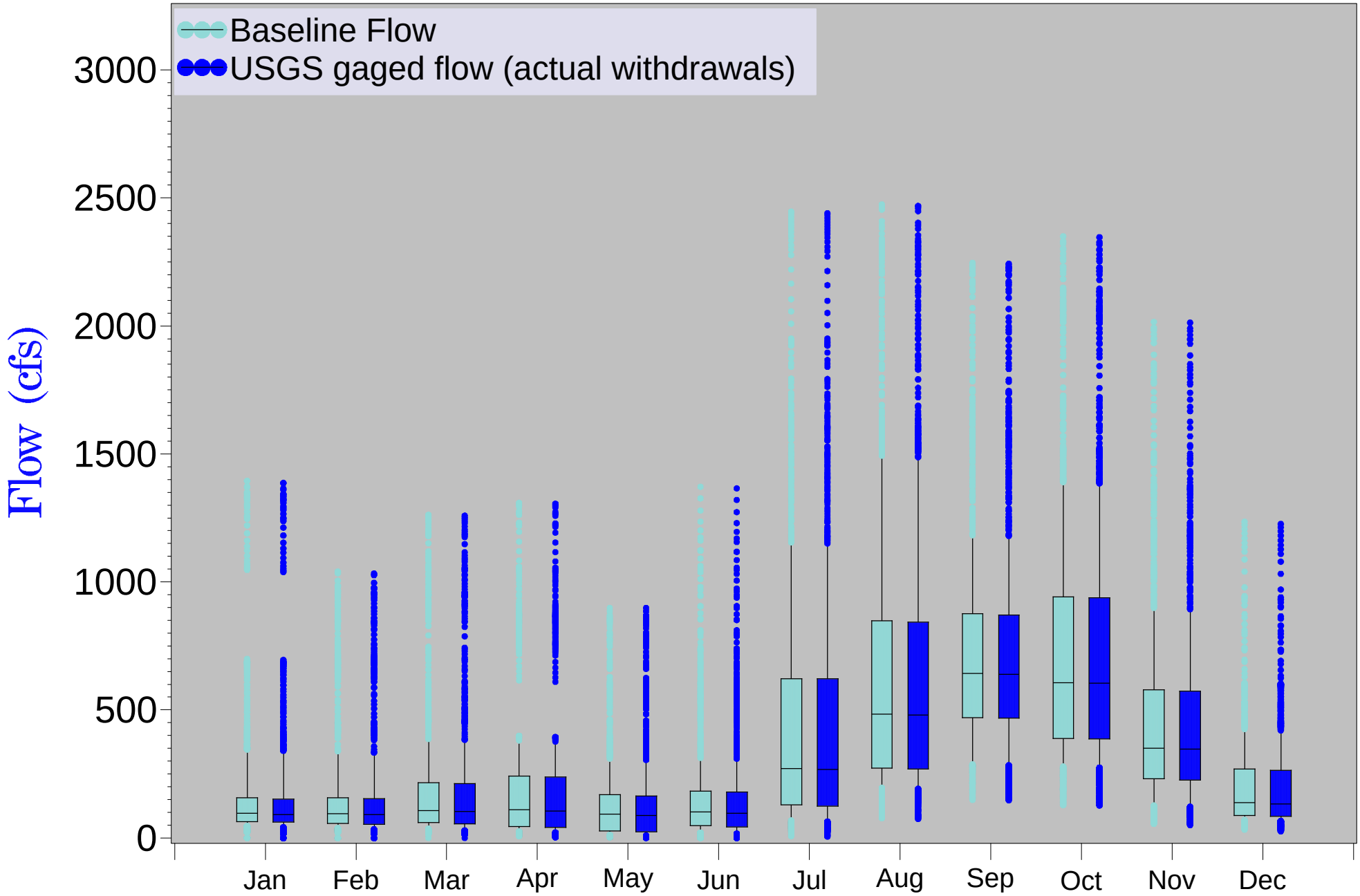


Figure 4.21a Seasonal differences in 60-day lag monthly Shell Creek flow without and with historic withdrawals (1966-2009)

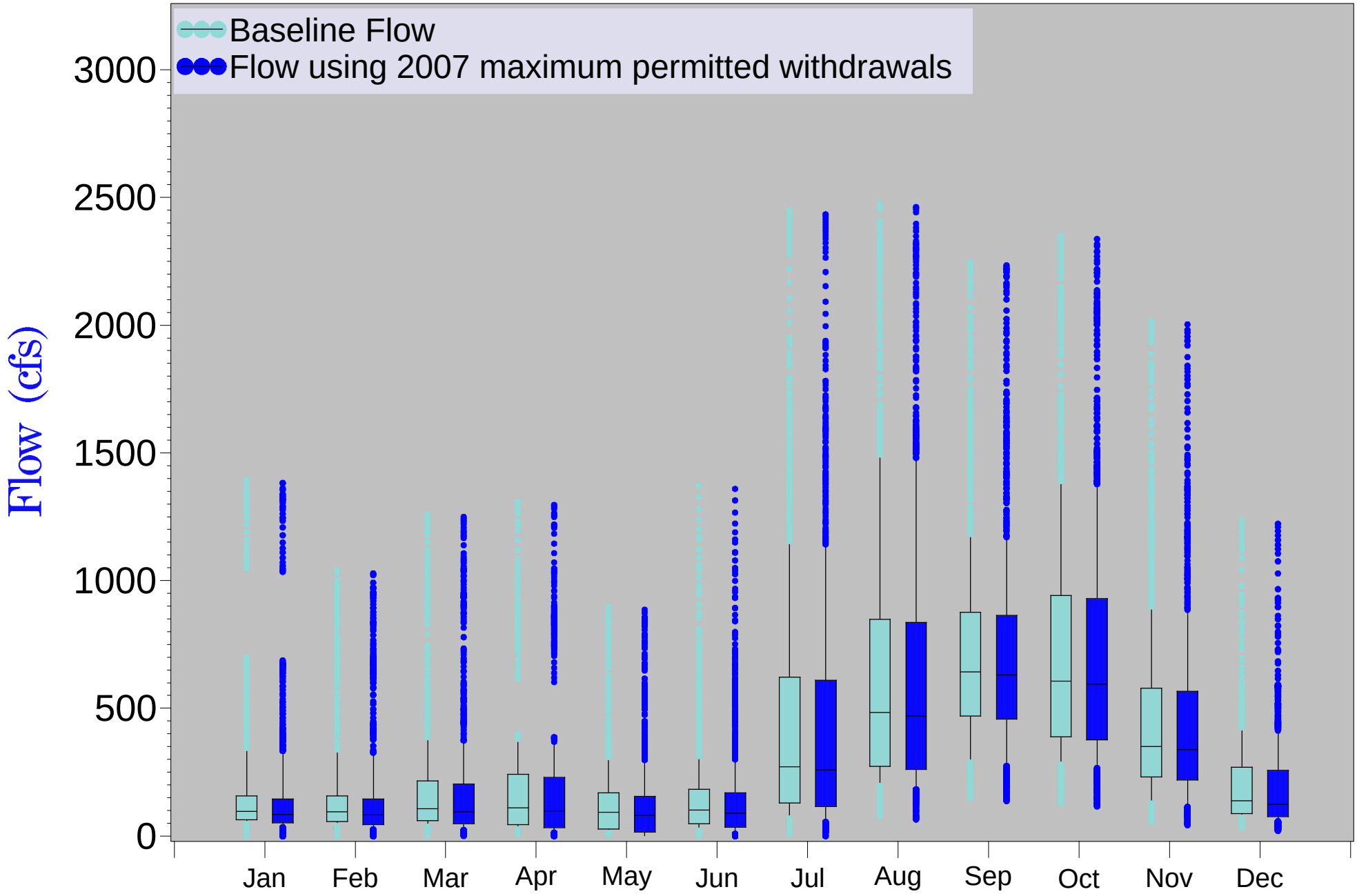


Figure 4.21b Seasonal differences in 60-day lag monthly Shell Creek flow without and using current maximum daily permitted withdrawals (1966-2009)

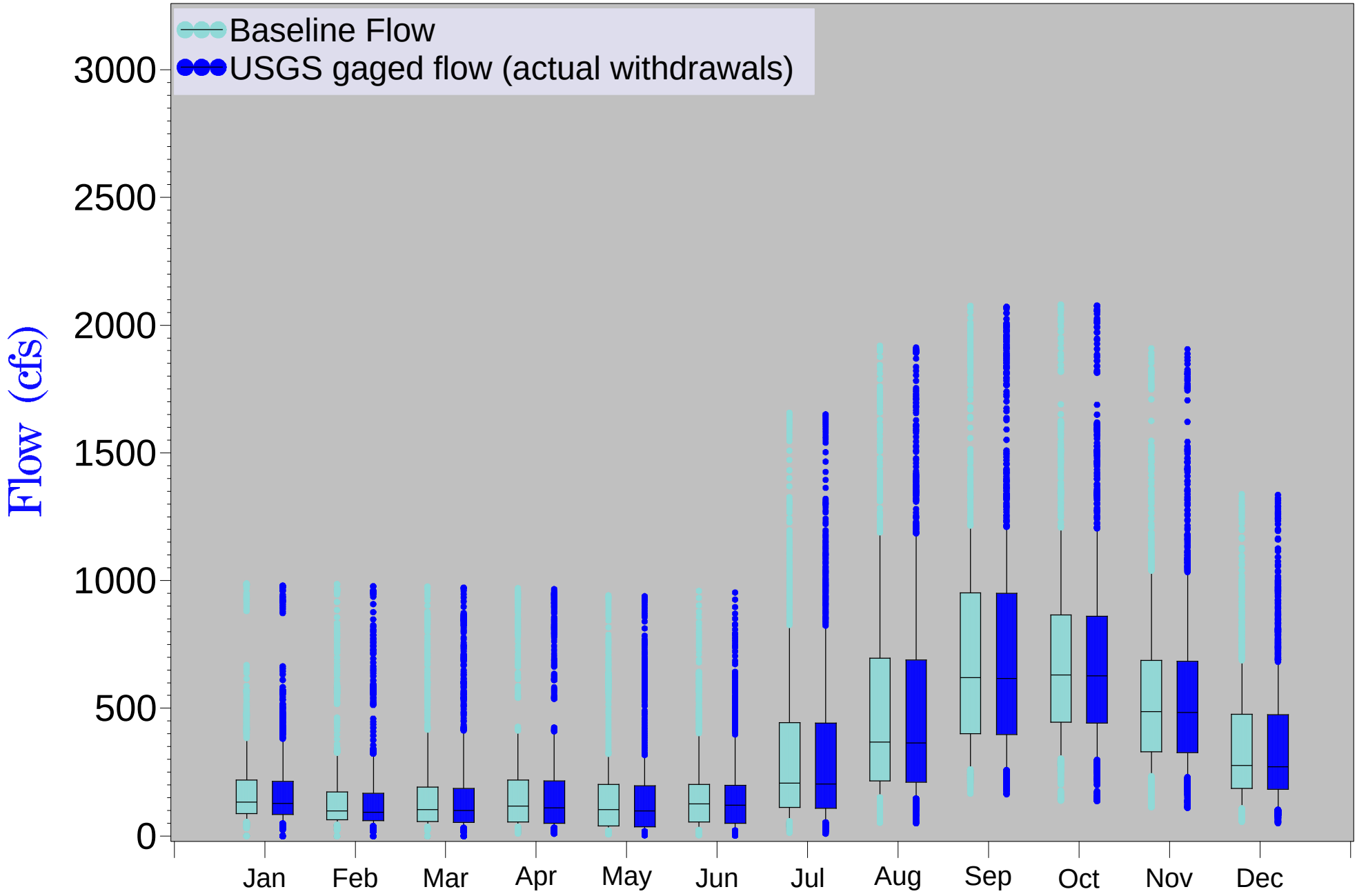


Figure 4.22a Seasonal differences in 90-day lag monthly Shell Creek flow without and with historic withdrawals (1966-2009)

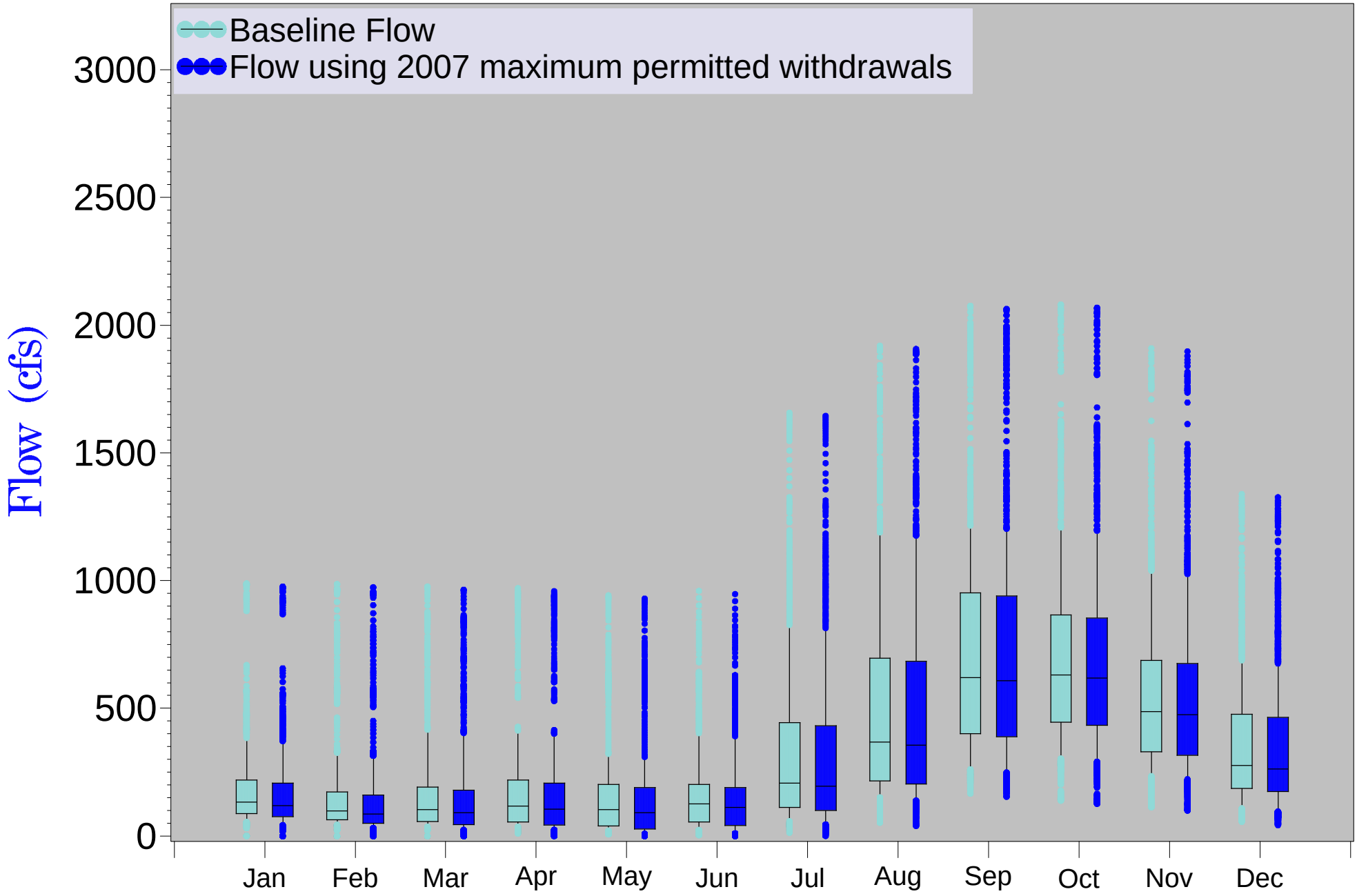


Figure 4.22b Seasonal differences in 90-day lag monthly Shell Creek flow without and using current maximum daily permitted withdrawals (1966-2009)

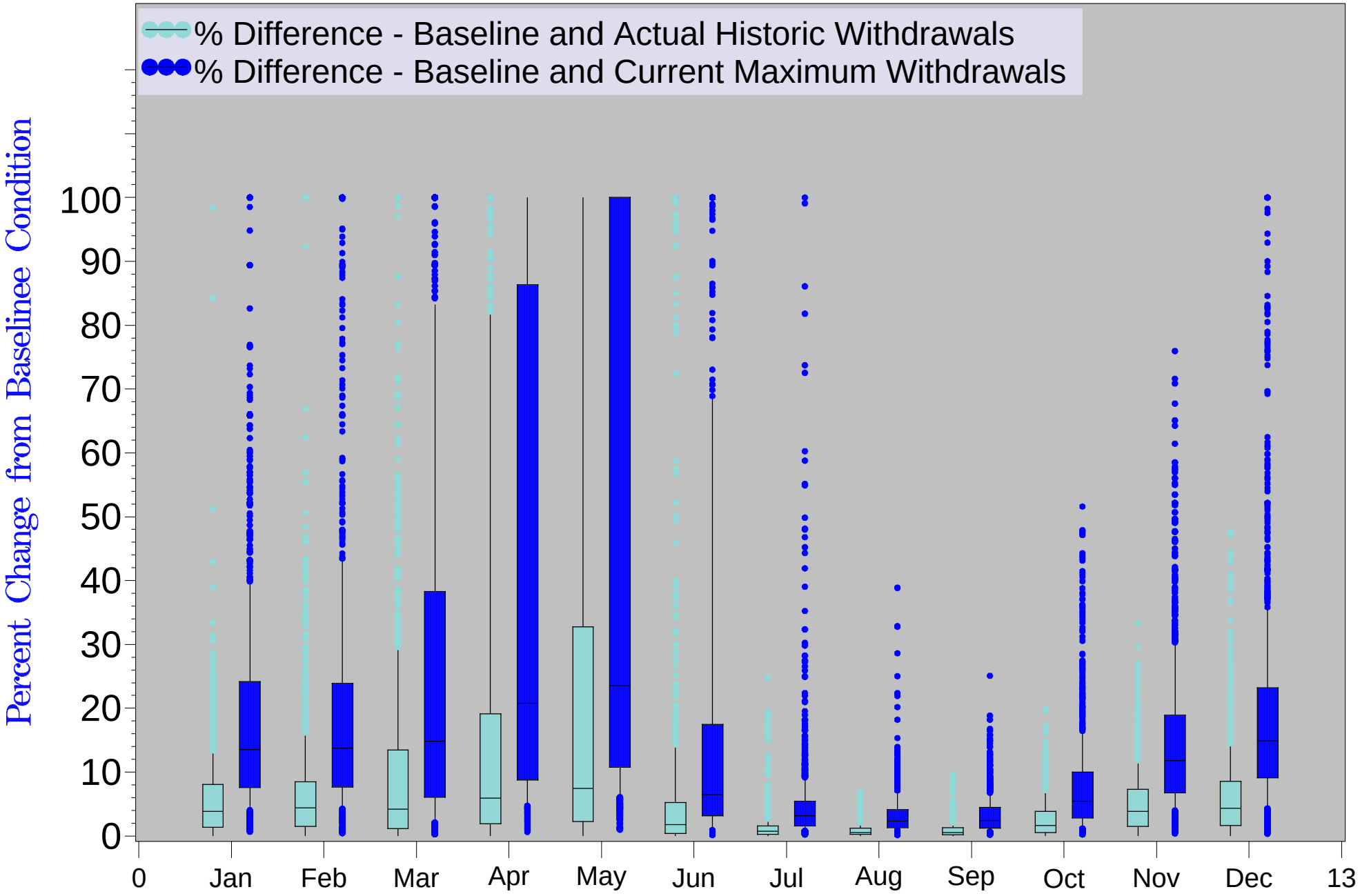


Figure 4.23 Seasonal percent change in monthly Shell Creek flow due to actual historic and current maximum City withdrawals based on 1966-2009 flow record

Flow Duration Curve for Shell Creek Flow (1966-2009)

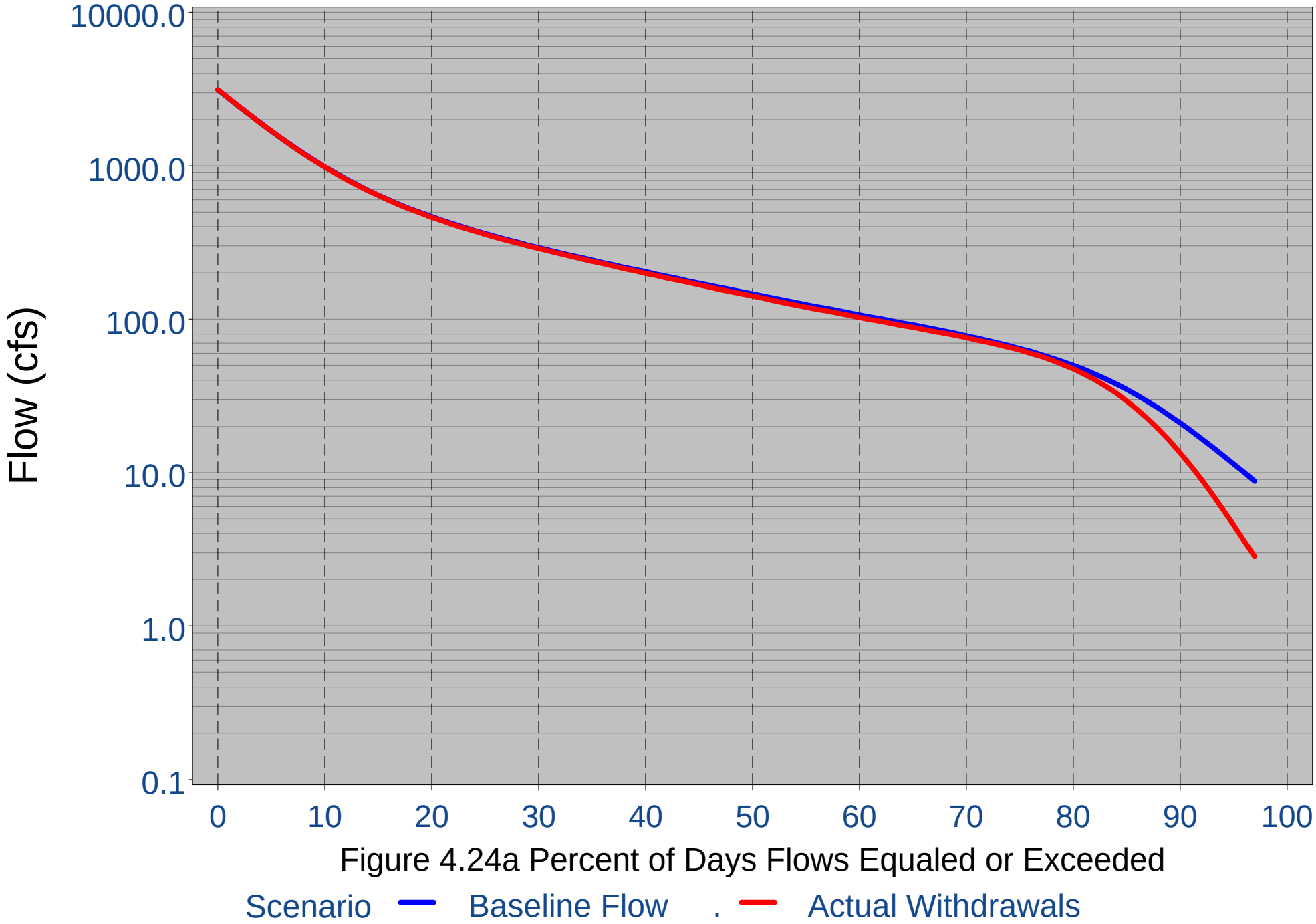


Figure 4.24a Percent of Days Flows Equaled or Exceeded

Flow Duration Curve for Shell Creek Flow (1966-2009)

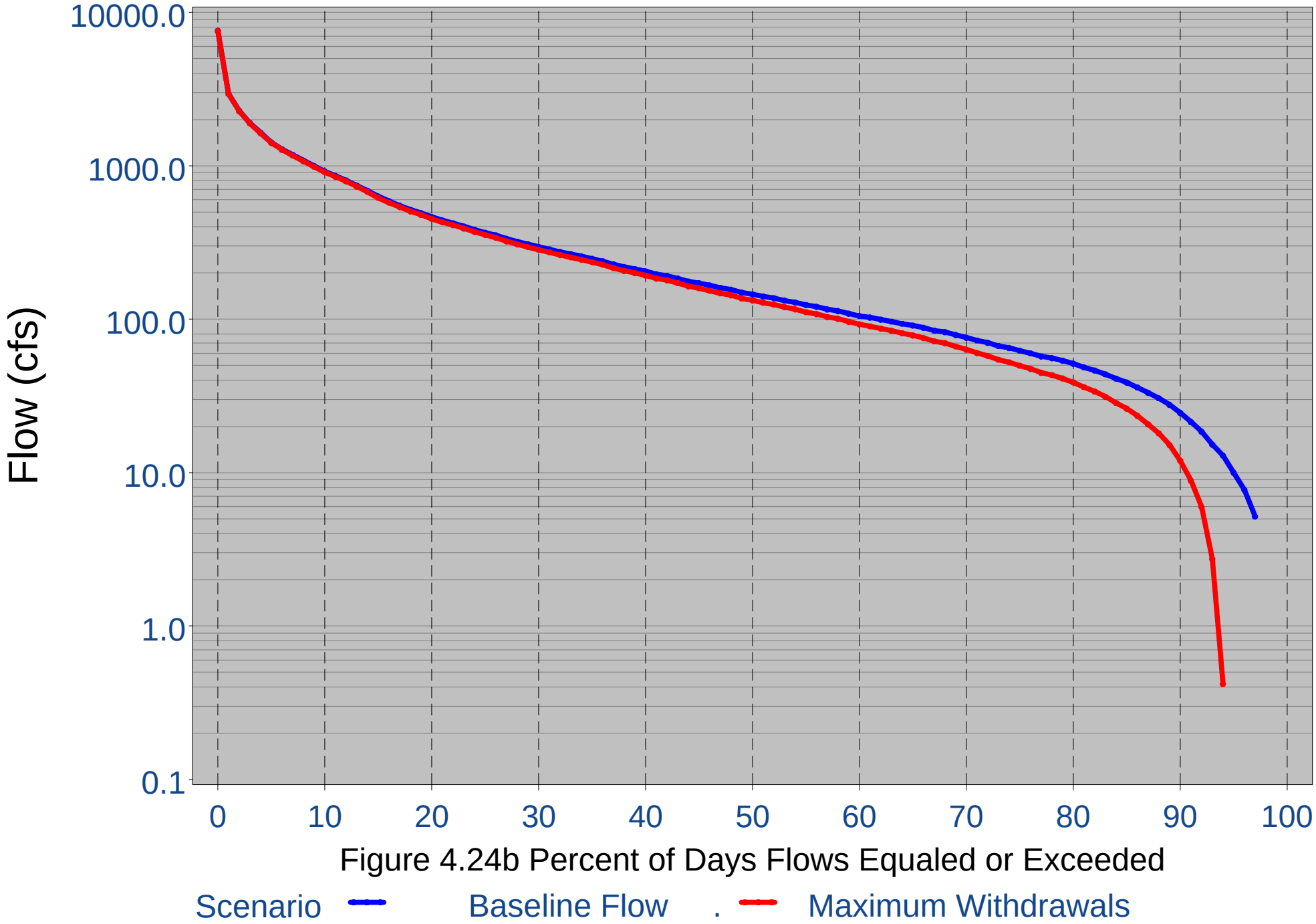


Figure 4.24b Percent of Days Flows Equaled or Exceeded

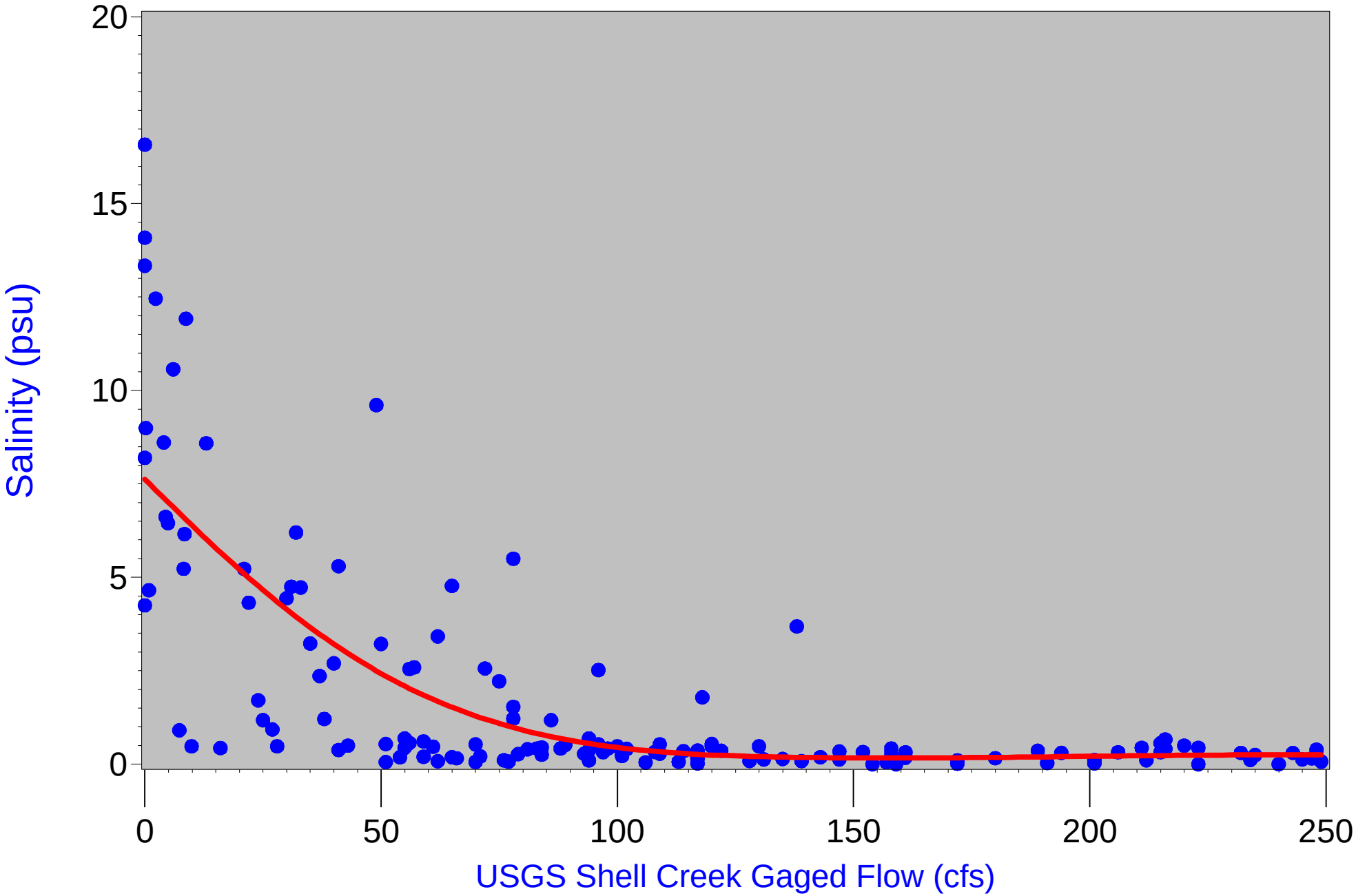


Figure 4.25a Surface salinity at Station #11 (River Kilometer 9.90) versus Shell Creek flow 1991-2009

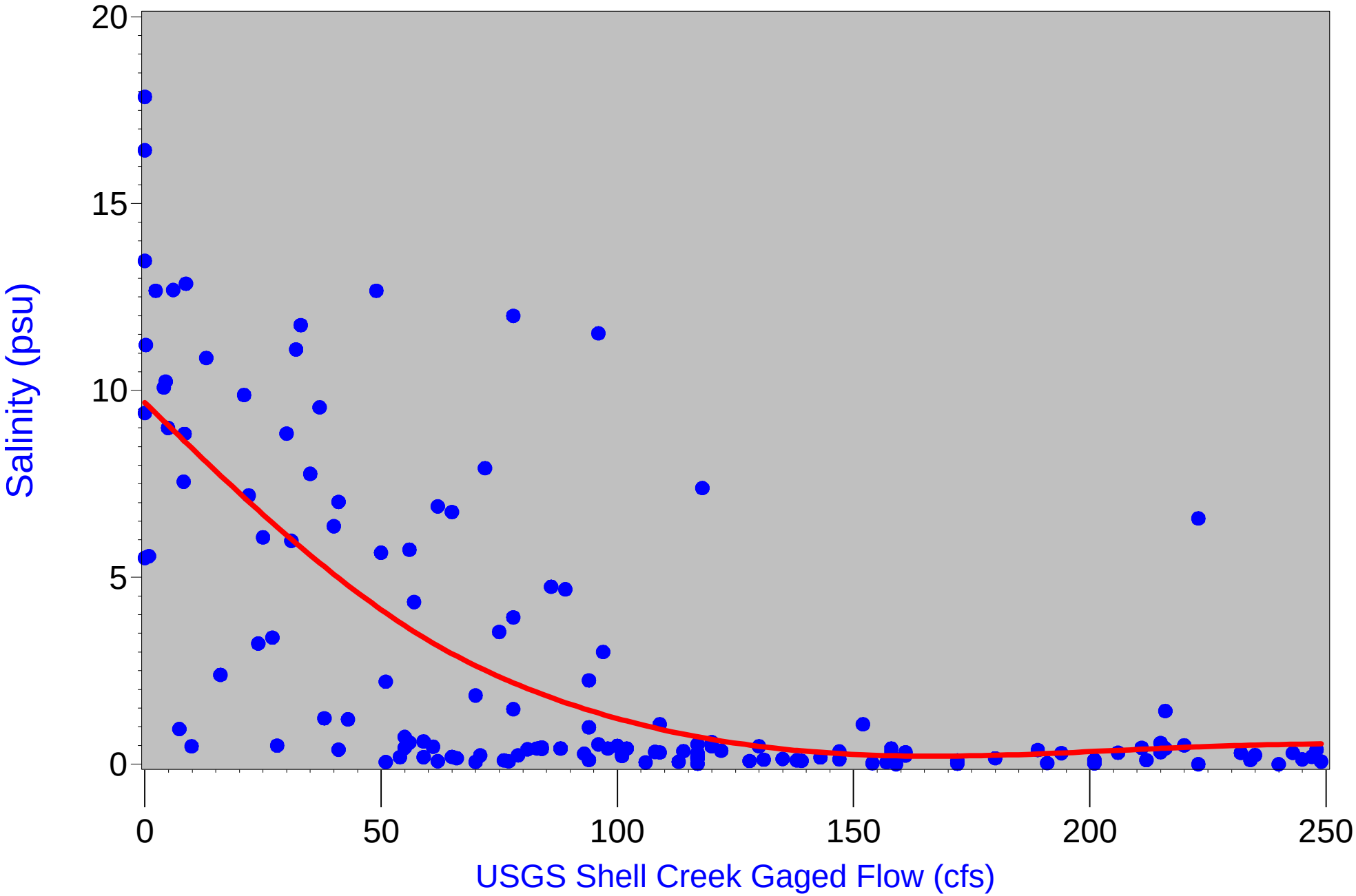


Figure 4.25b Bottom salinity at Station #11 (River Kilometer 9.90) versus Shell Creek flow 1991-2009

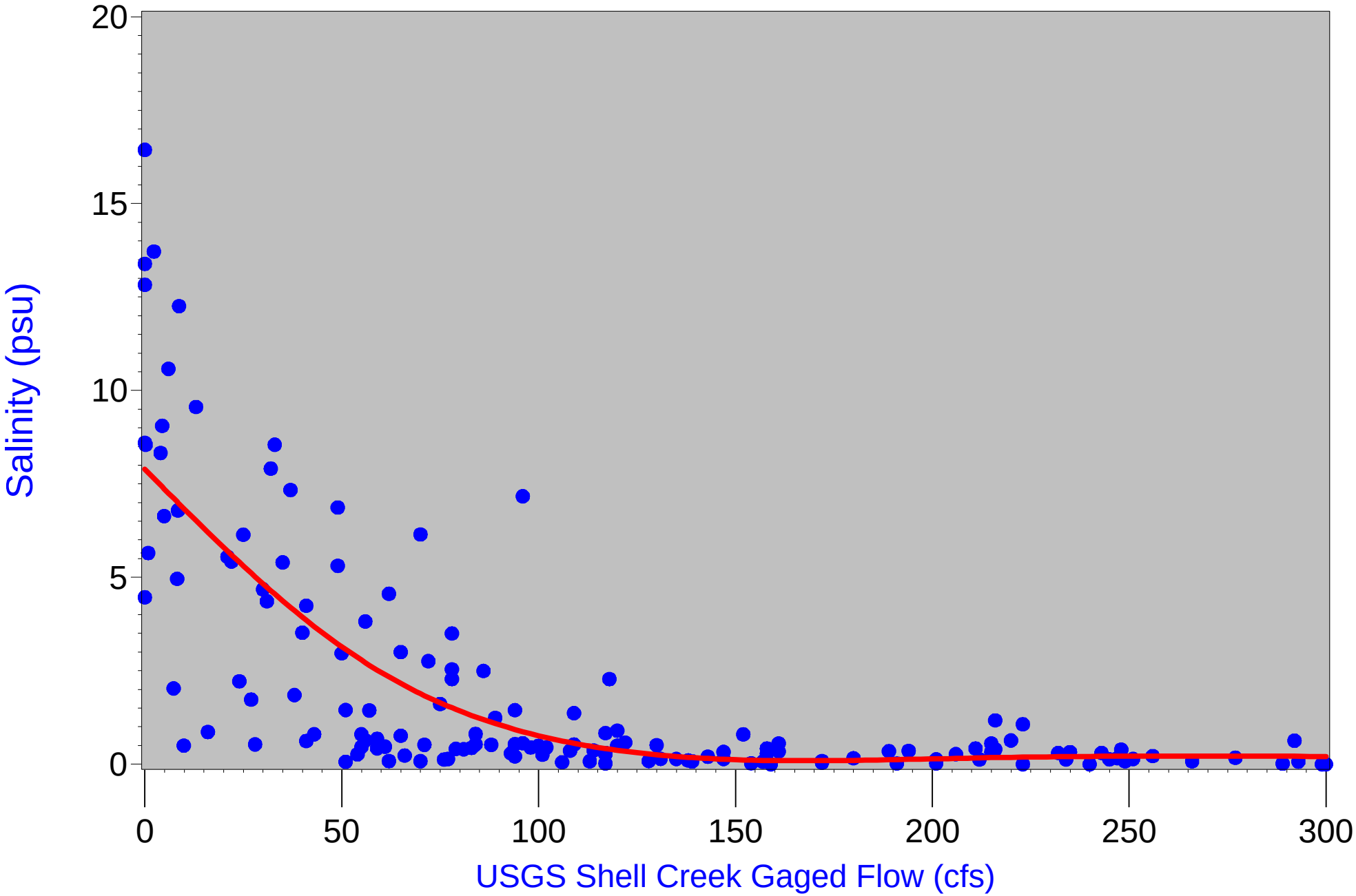


Figure 4.26a Surface salinity at Station #4 (River Kilometer 8.74) versus Shell Creek flow 1991-2009

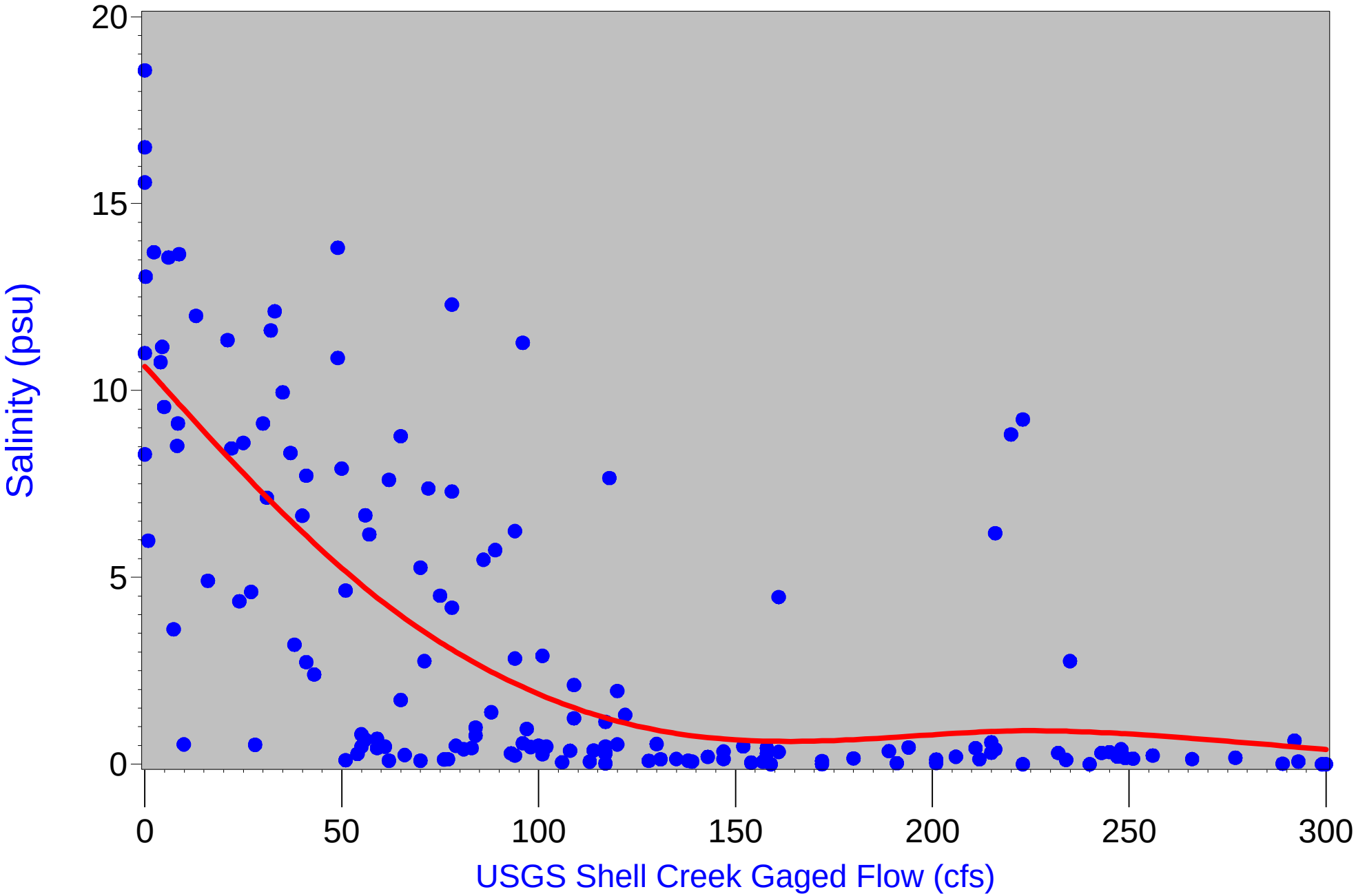


Figure 4.26b Bottom salinity at Station #4 (River Kilometer 8.74) versus Shell Creek flow 1991-2009

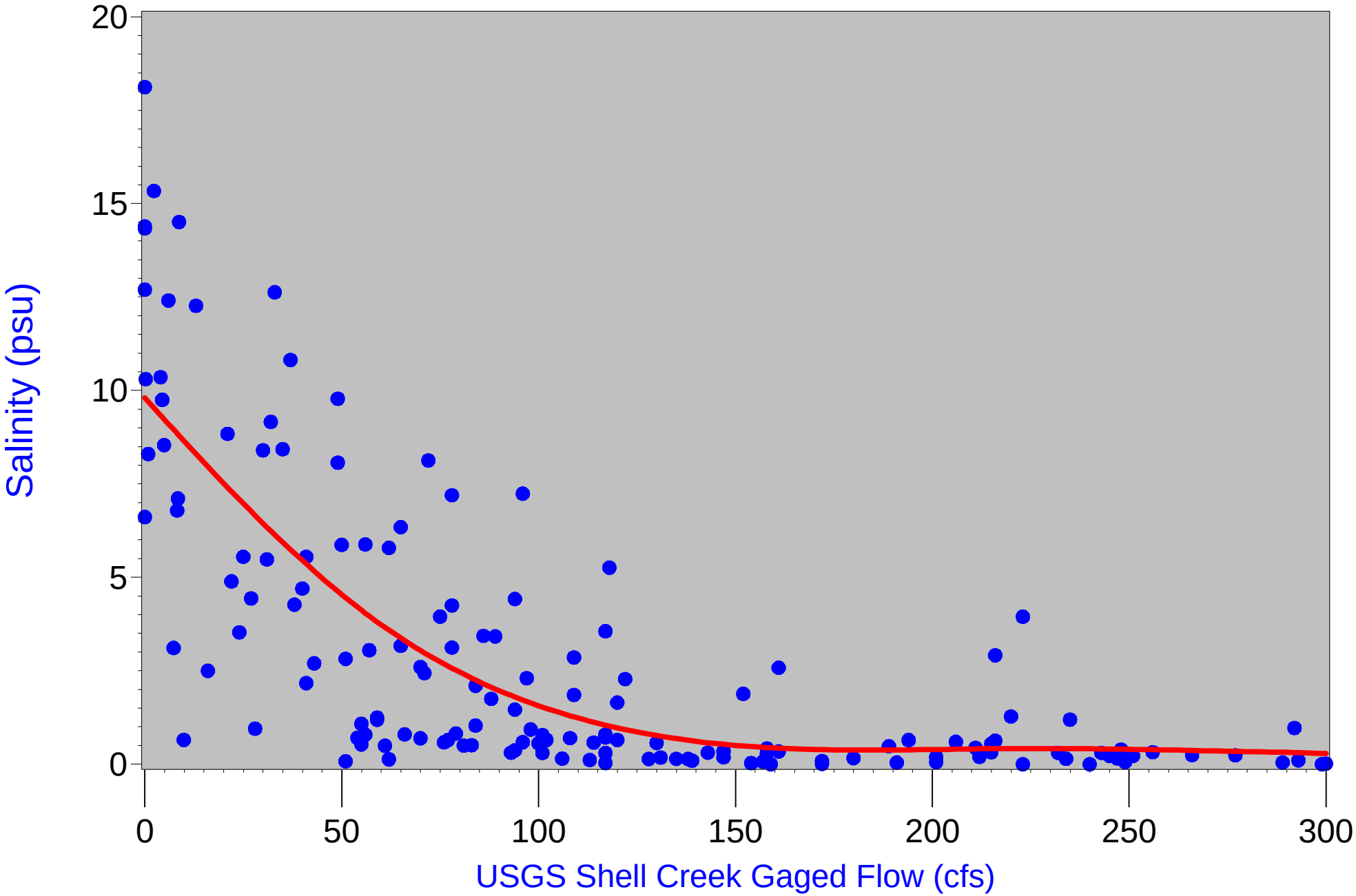


Figure 4.27a Surface salinity at Station #5 (River Kilometer 6.72) versus Shell Creek flow 1991-2009

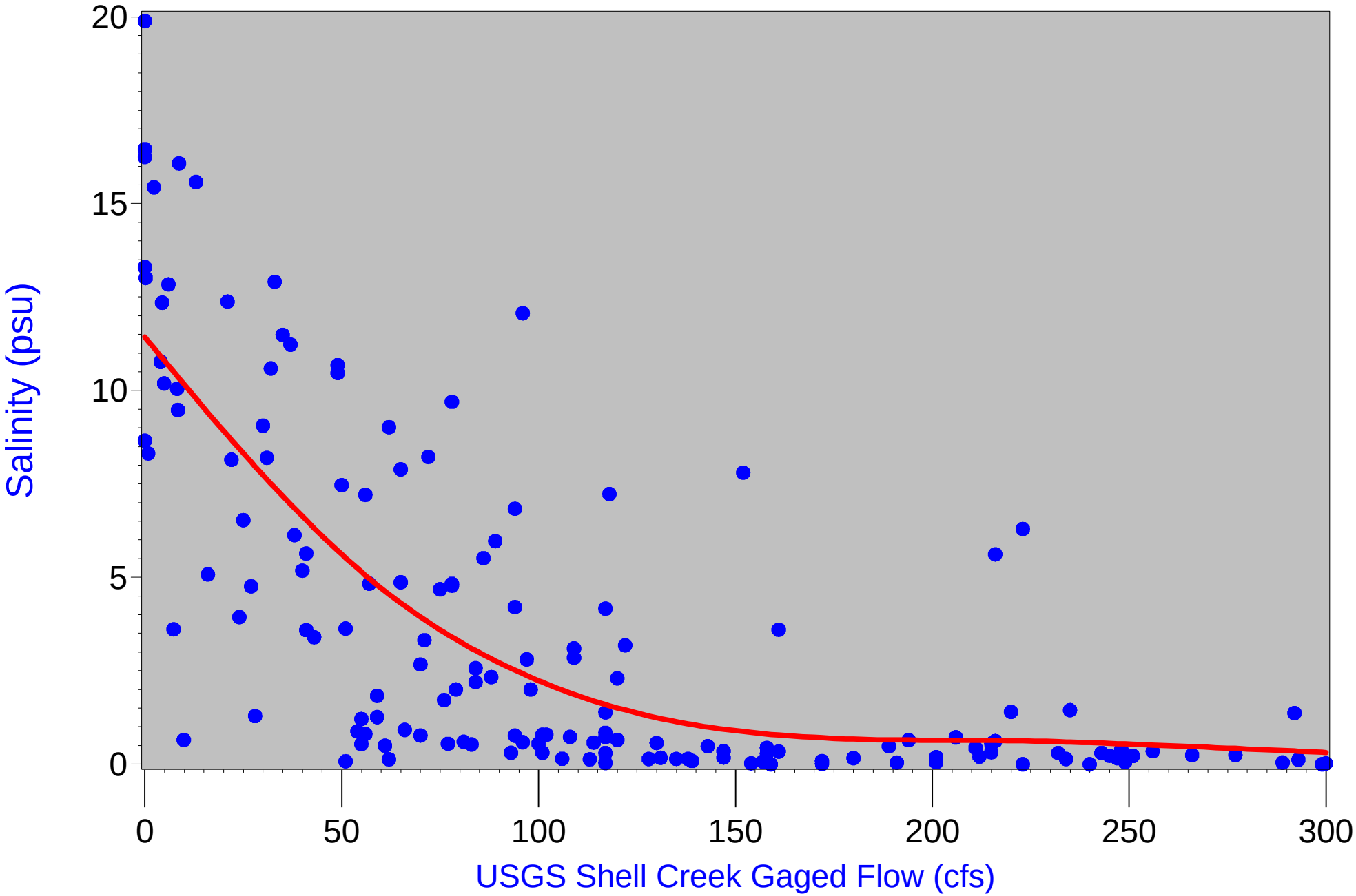


Figure 4.27b Bottom salinity at Station #5 (River Kilometer 6.72) versus Shell Creek flow 1991-2009

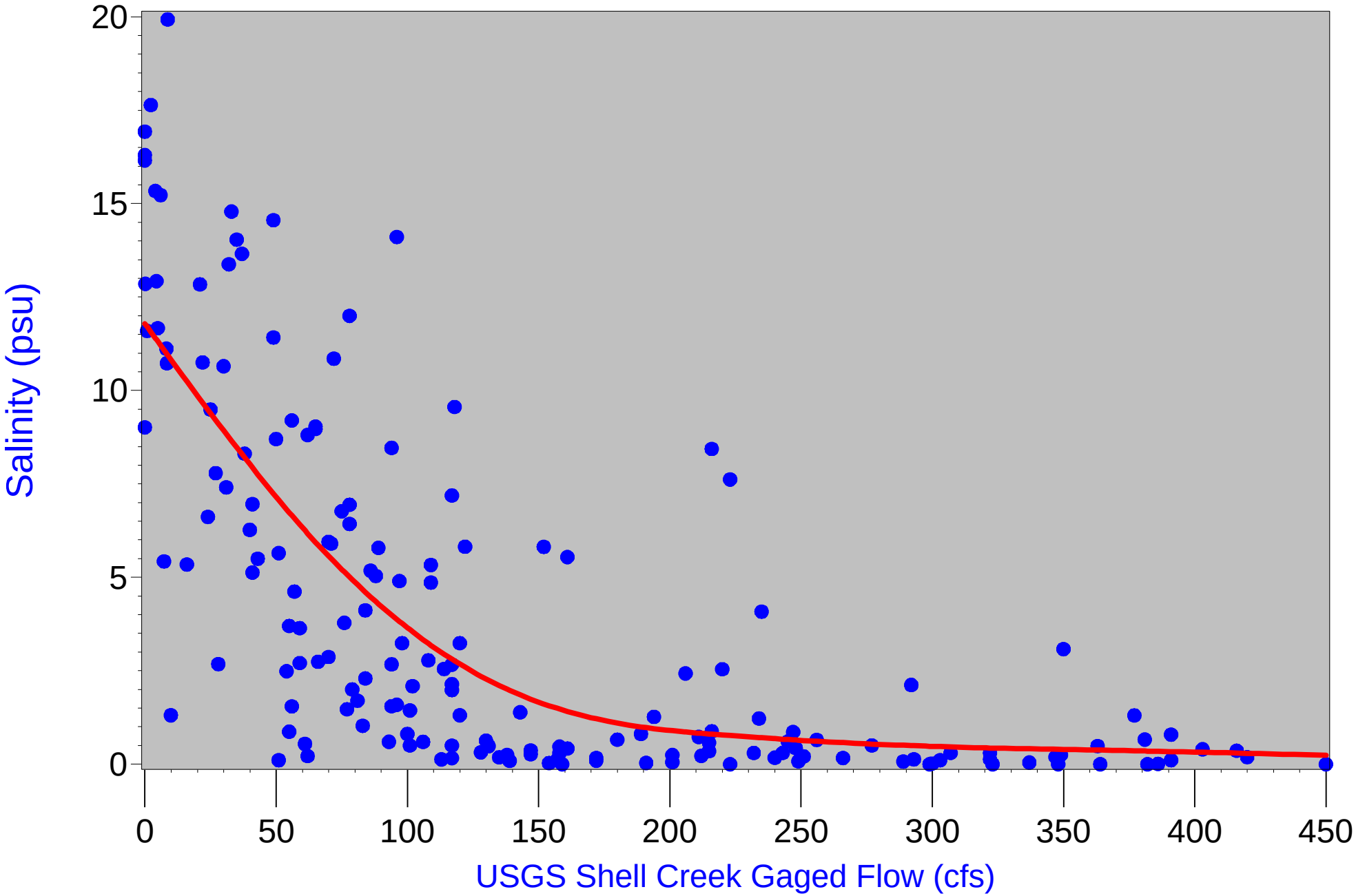


Figure 4.28a Surface salinity at Station #6 (River Kilometer 4.61) versus Shell Creek flow 1991-2009

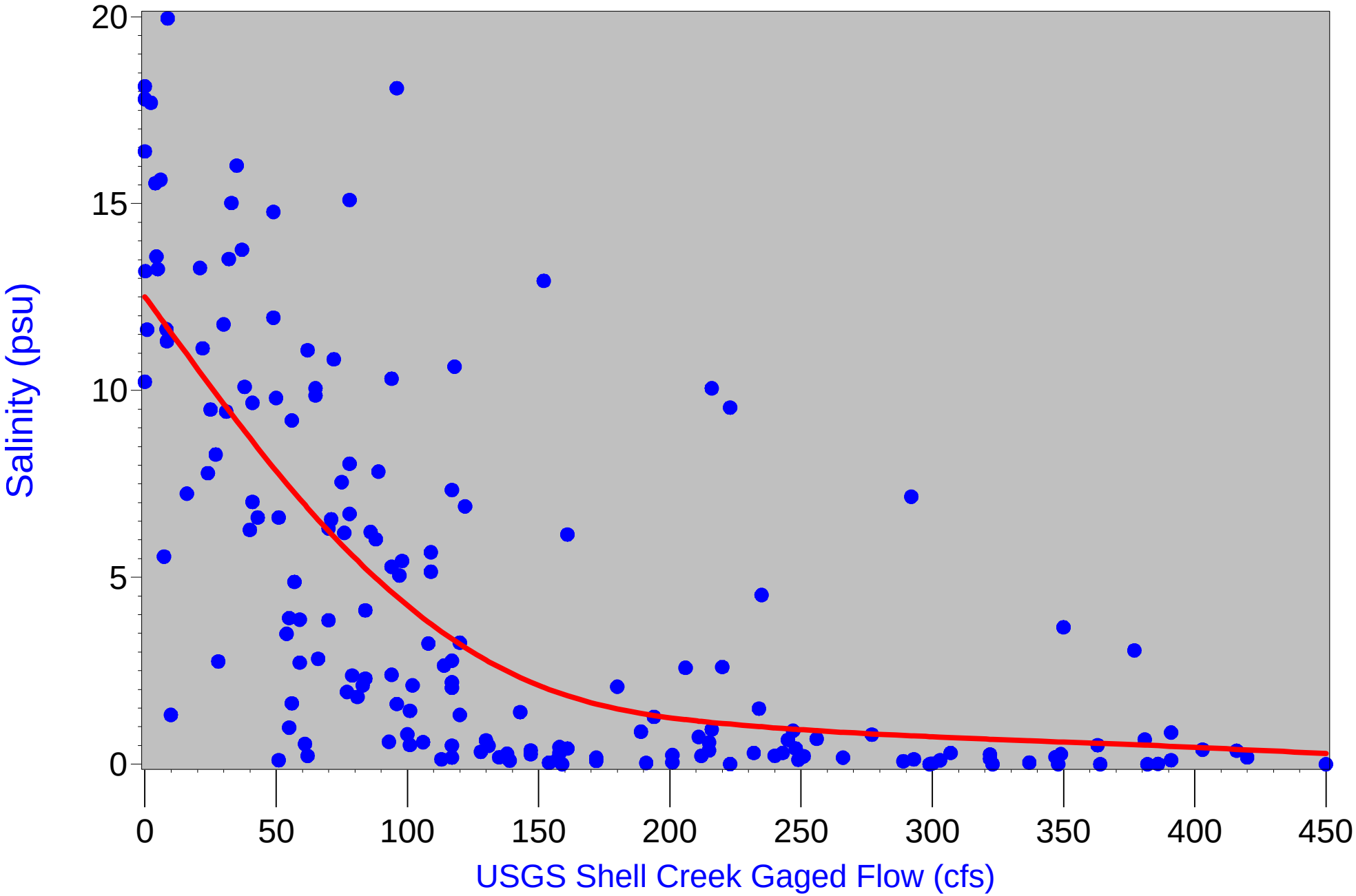


Figure 4.28b Bottom salinity at Station #6 (River Kilometer 4.61) versus Shell Creek flow 1991-2009

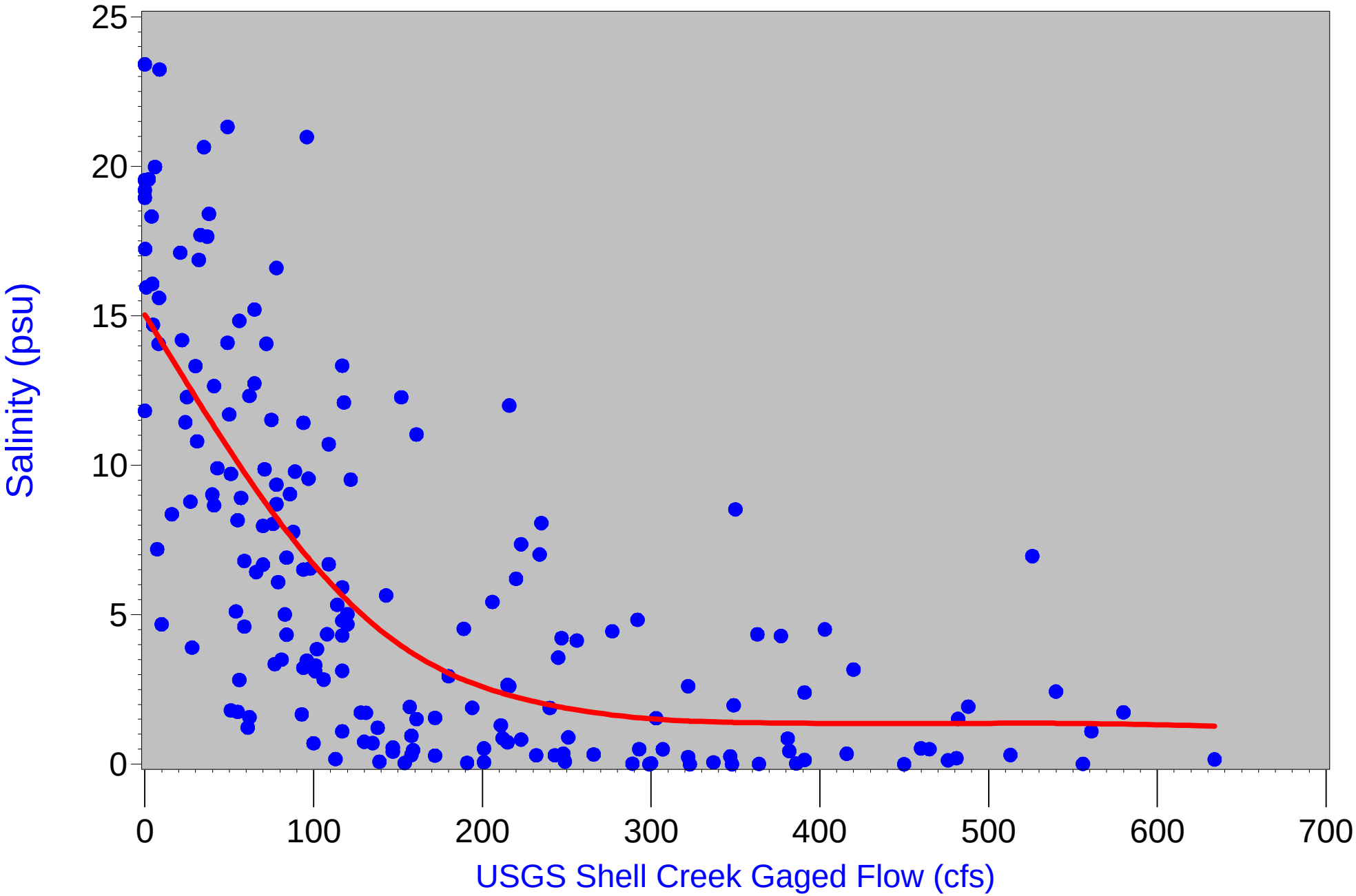


Figure 4.29a Surface salinity at Station #7 (River Kilometer 2.35) versus Shell Creek flow 1991-2009

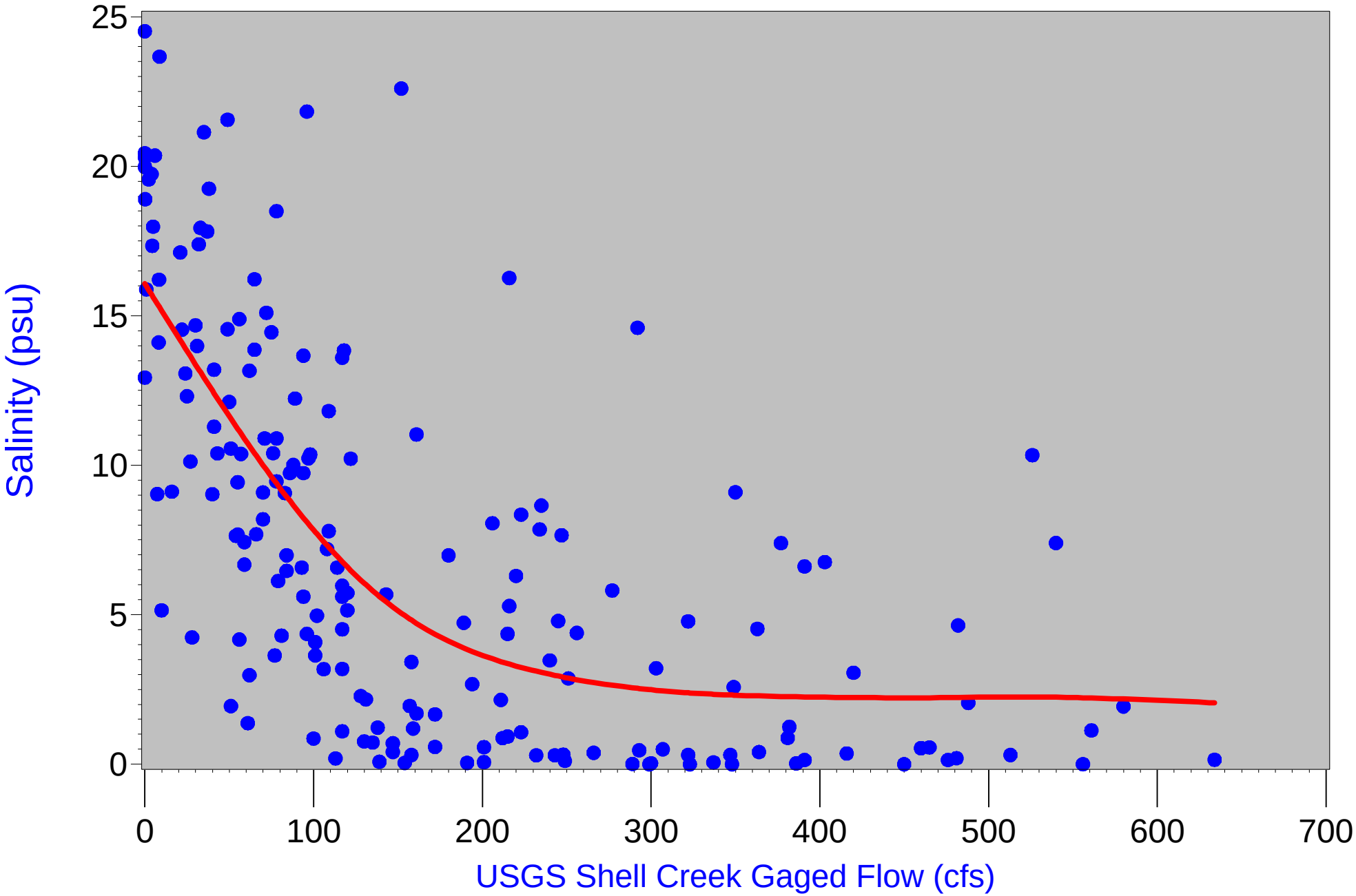


Figure 4.29b Bottom salinity at Station #7 (River Kilometer 2.35) versus Shell Creek flow 1991-2009

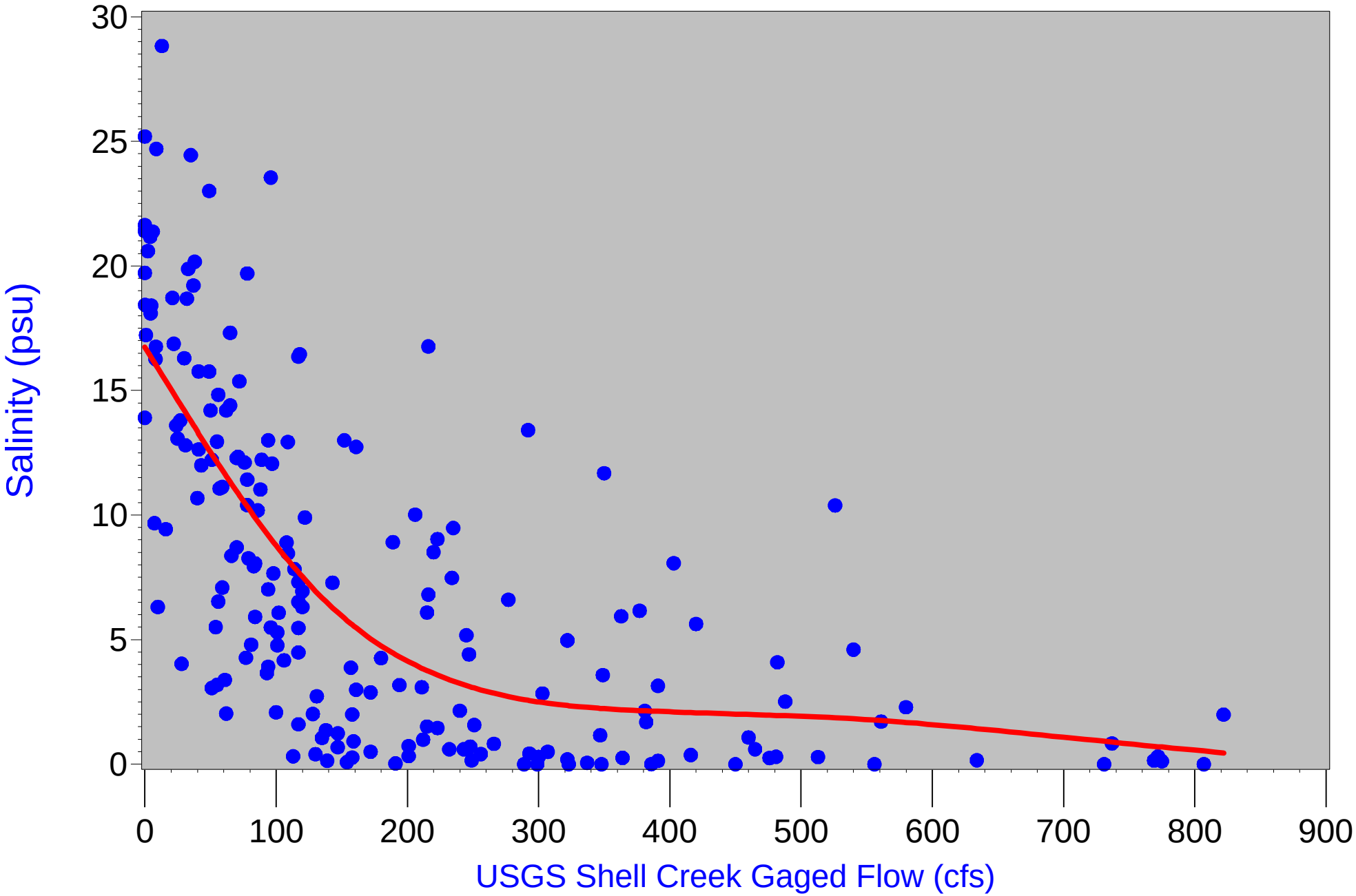


Figure 4.30a Surface salinity at Station #16 (River Kilometer 1.26) versus Shell Creek flow 1991-2009

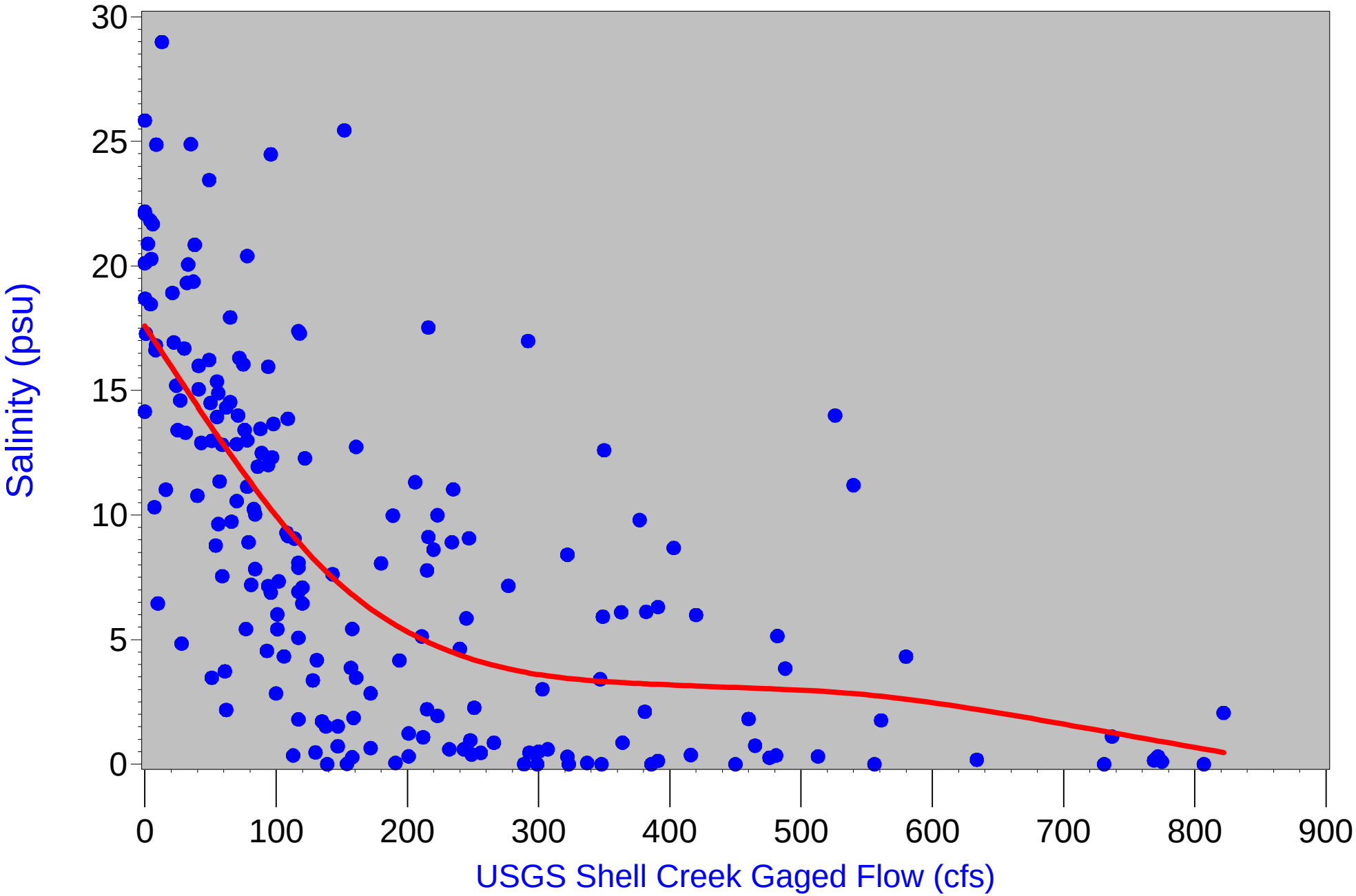


Figure 4.30b Bottom salinity at Station #16 (River Kilometer 1.26) versus Shell Creek flow 1991-2009

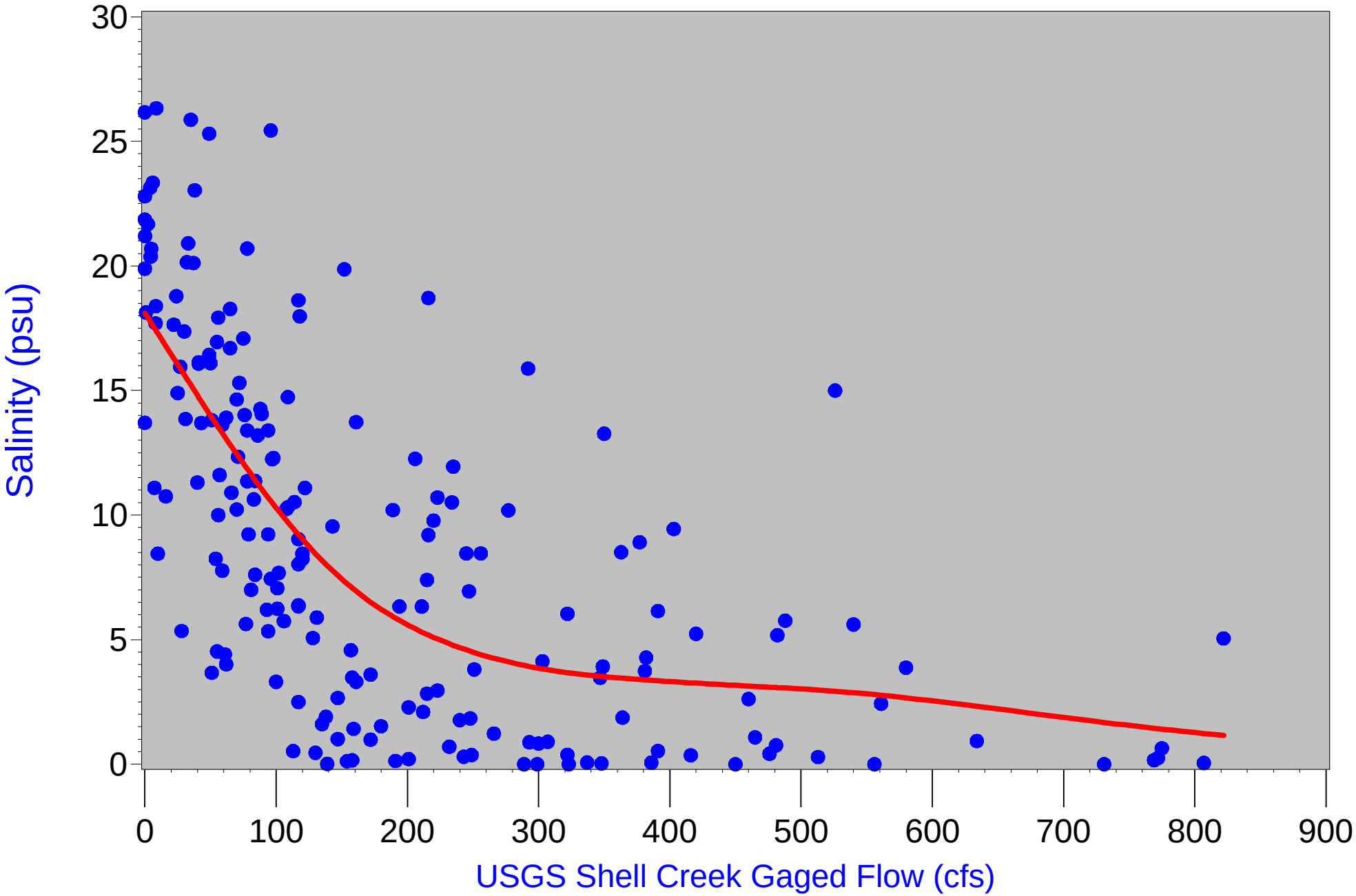


Figure 4.31a Surface salinity at Station #17 (River Kilometer 0.43) versus Shell Creek flow 1991-2009

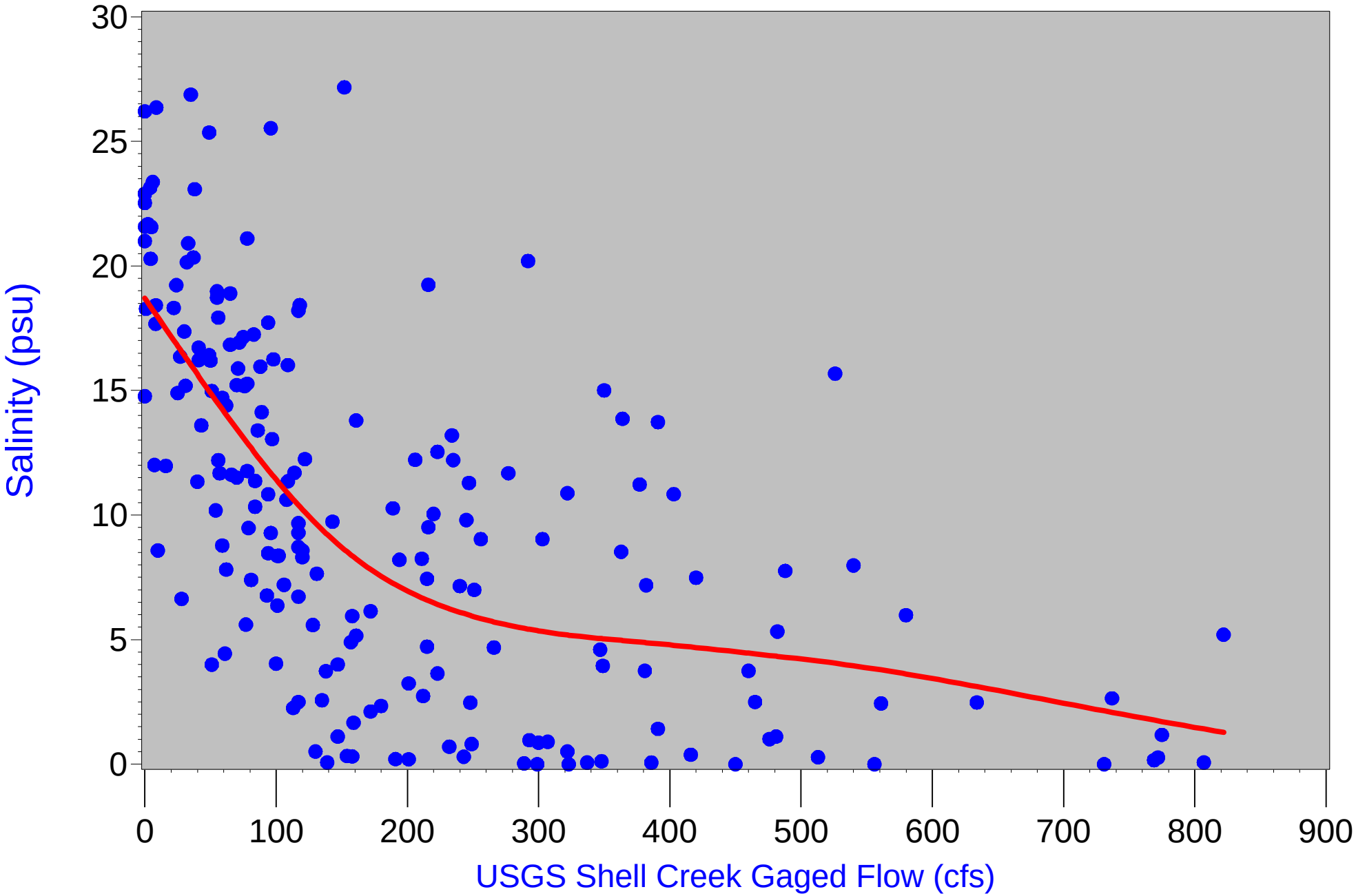


Figure 4.31b Bottom salinity at Station #17 (River Kilometer 0.43) versus Shell Creek flow 1991-2009

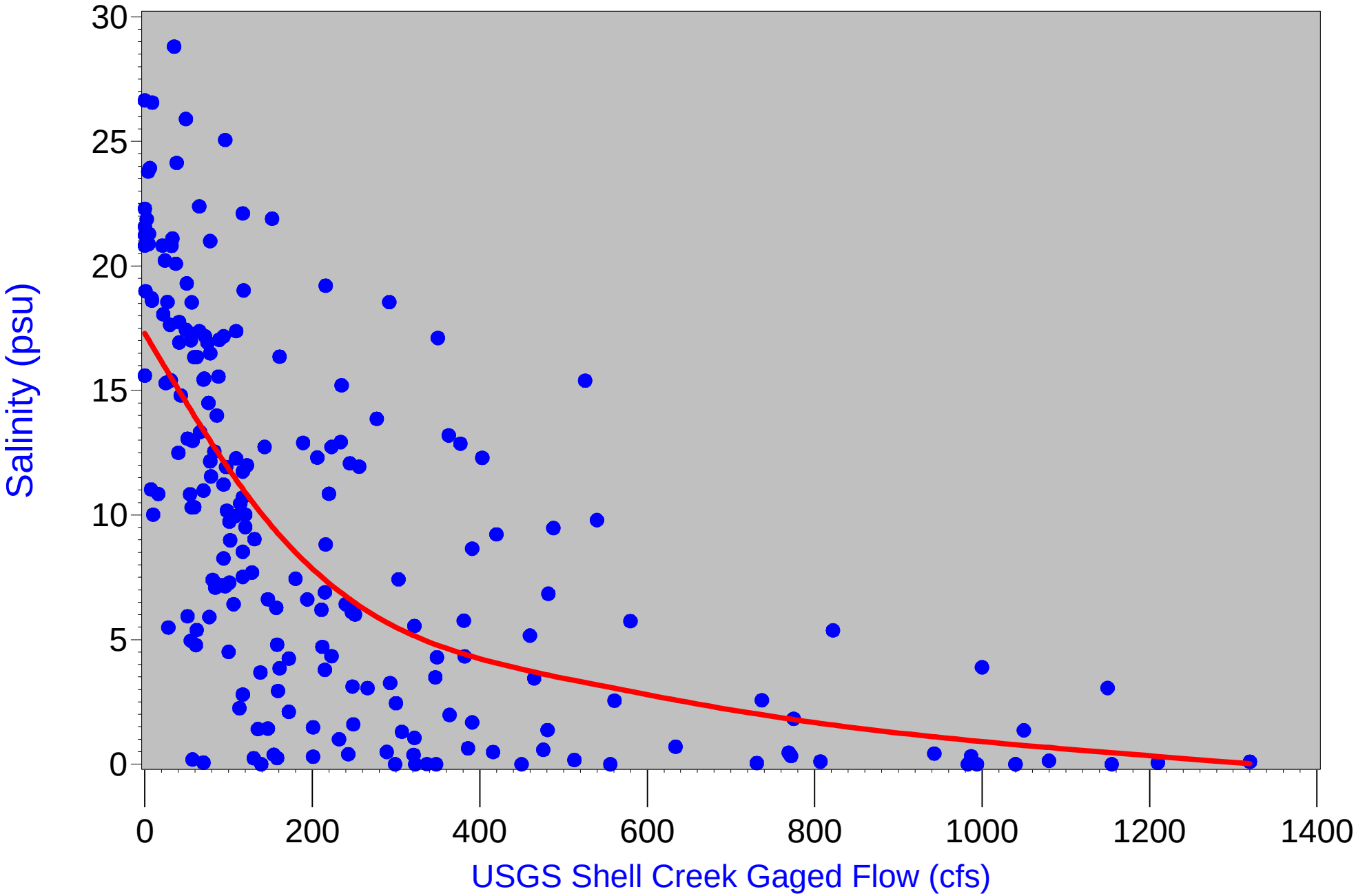


Figure 4.32a Surface salinity at Station #9 (River Kilometer -0.37) versus Shell Creek flow 1991-2009

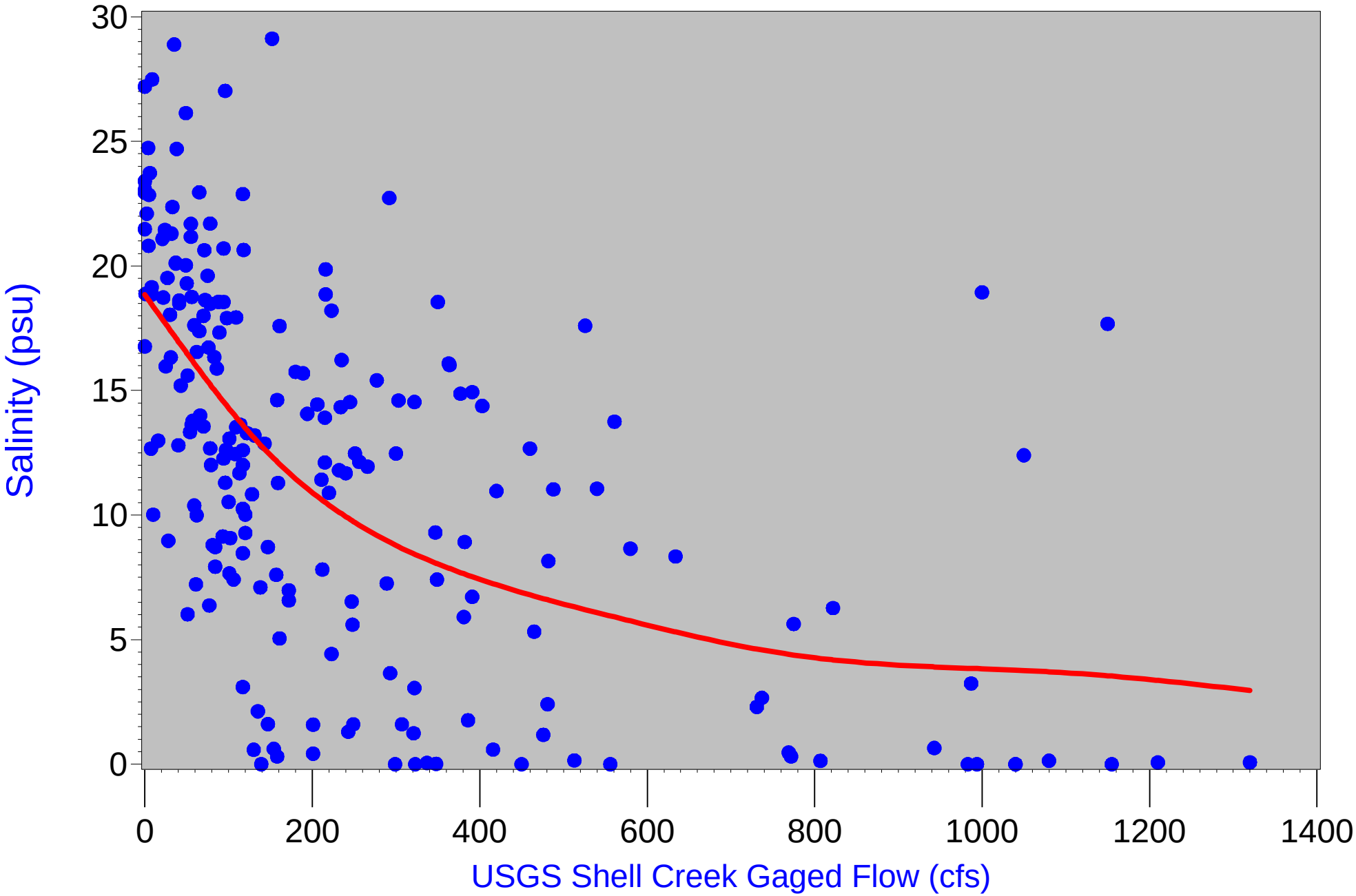


Figure 4.32b Bottom salinity at Station #9 (River Kilometer -0.37) versus Shell Creek flow 1991-2009

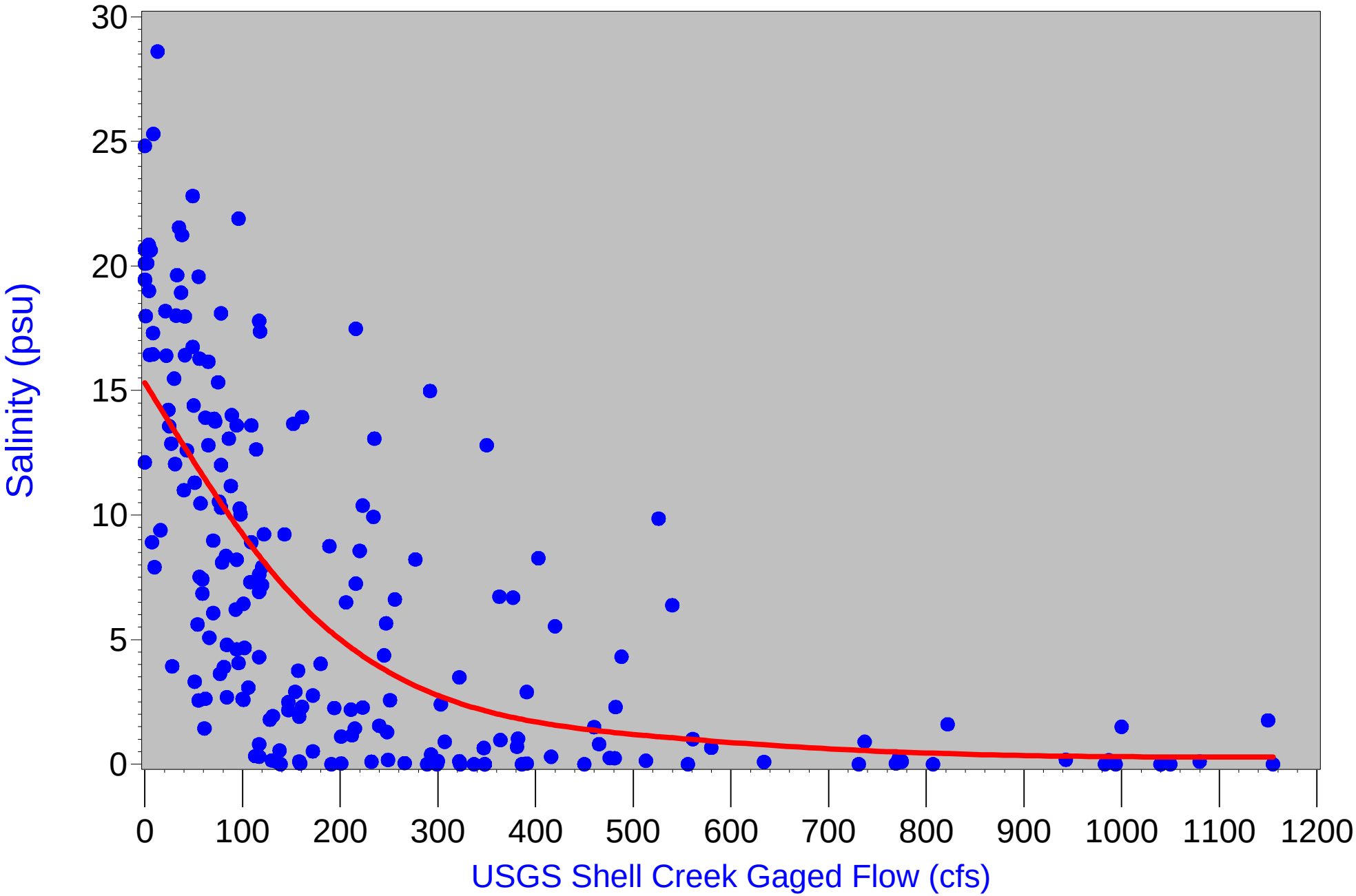


Figure 4.33a Surface salinity at Station #8 in lower Peace River versus Shell Creek flow 1991-2009

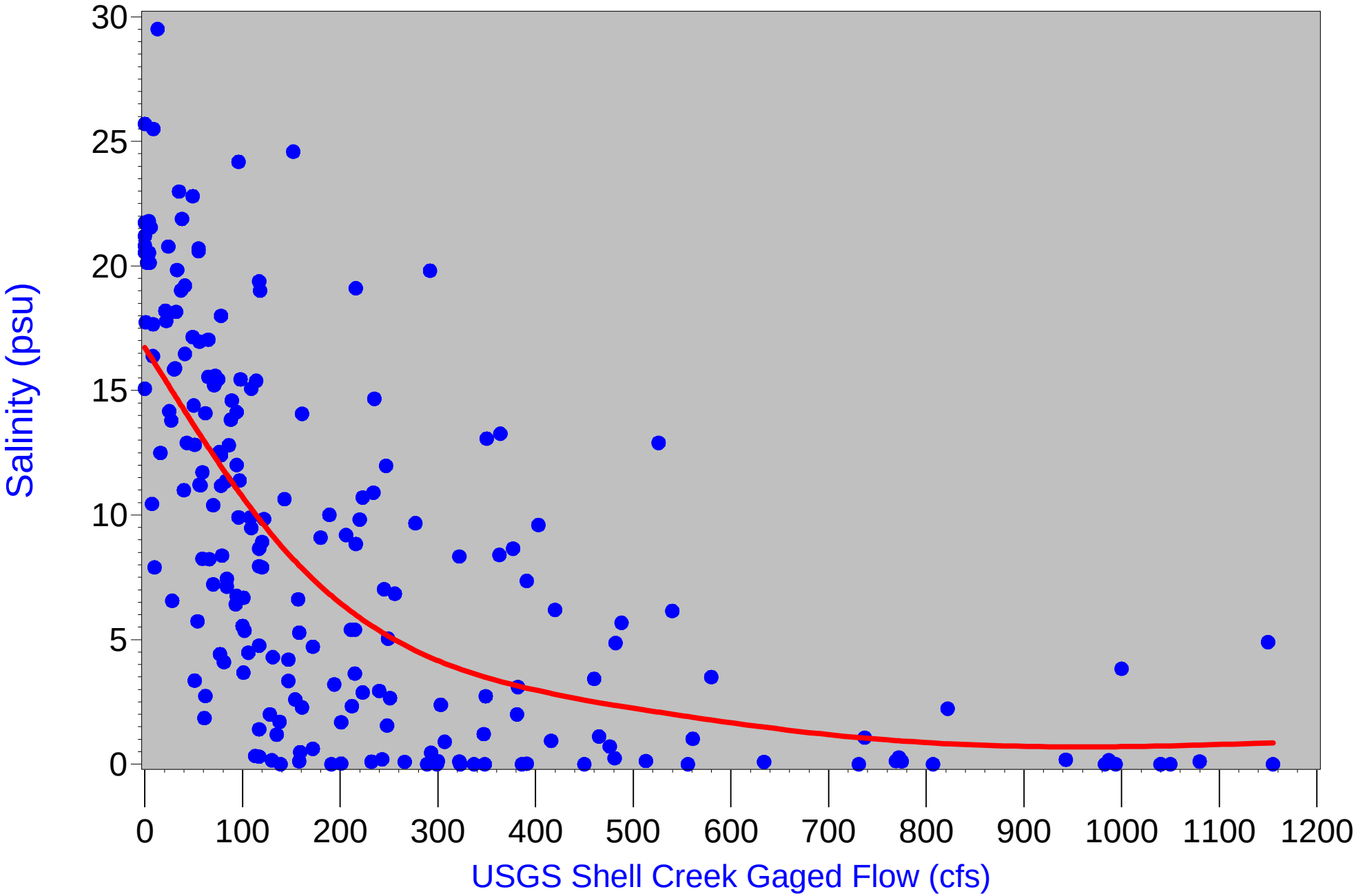


Figure 4.33b Bottom salinity at Station #8 in lower Peace River versus Shell Creek flow 1991-2009

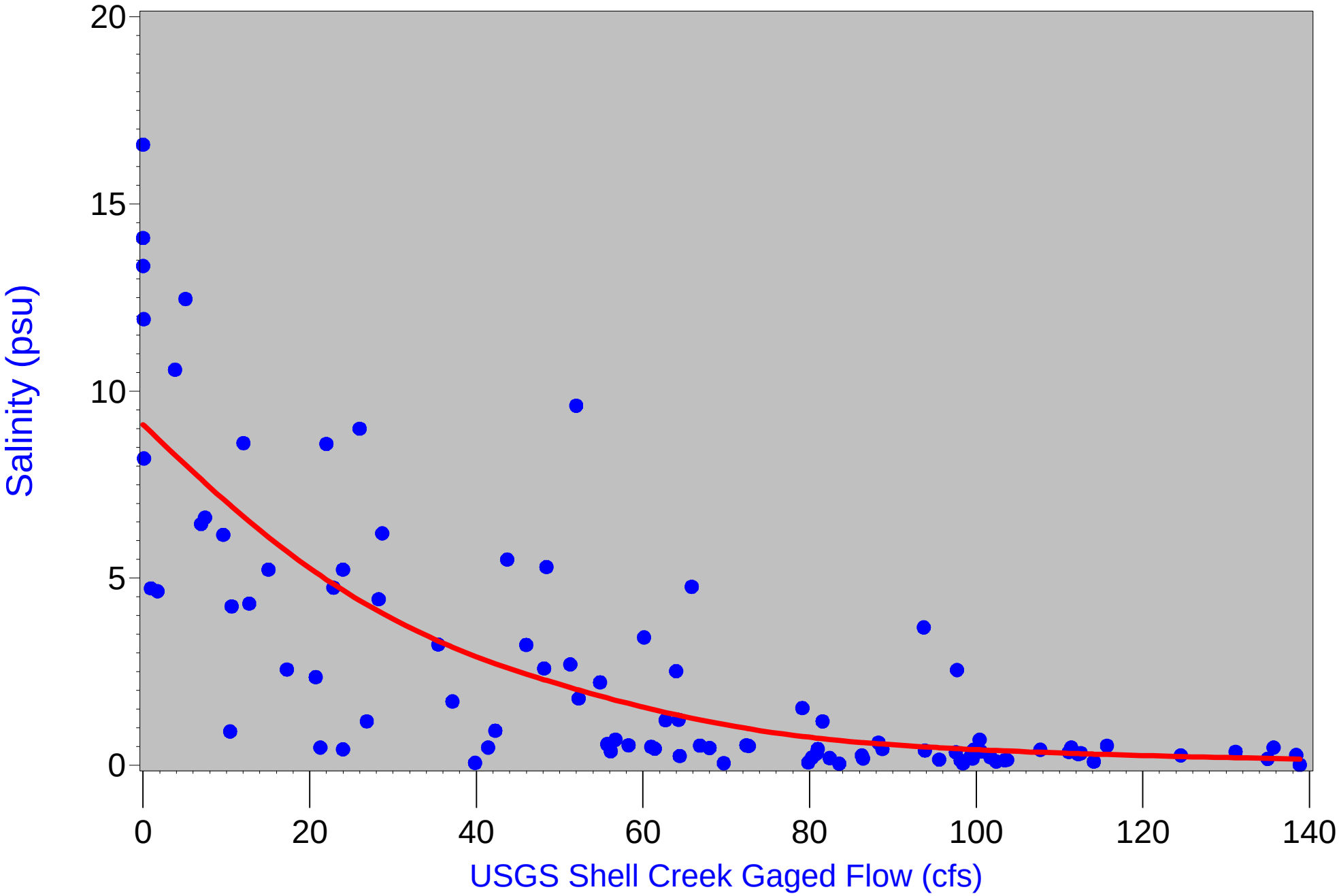


Figure 4.34a Surface salinity at Station #11 (River Kilometer 9.90) versus 7-day average Shell Creek flow 1991-2009

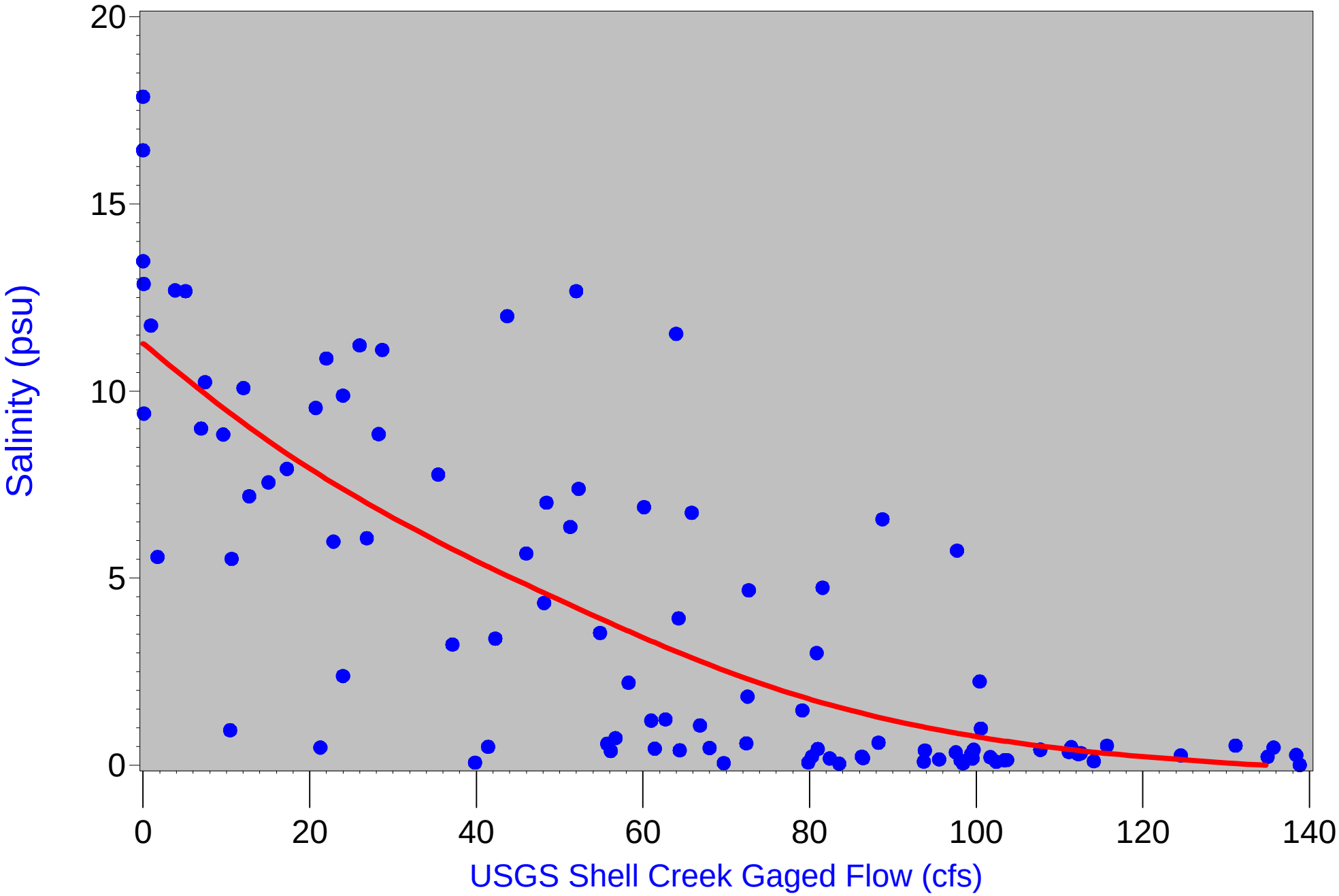


Figure 4.34b Bottom salinity at Station #11 (River Kilometer 9.90) versus 7-day average Shell Creek flow 1991-2009

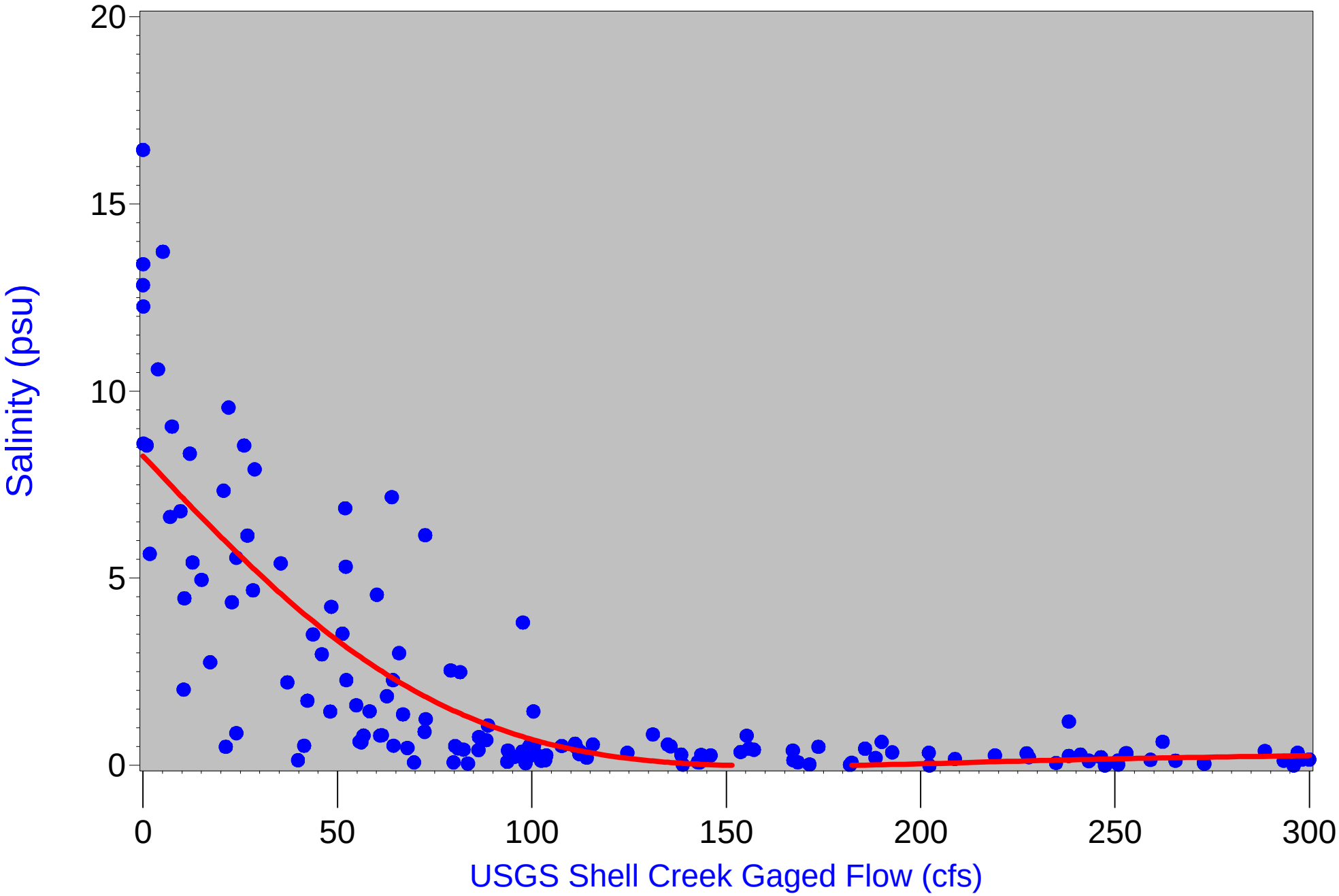


Figure 4.35a Surface salinity at Station #4 (River Kilometer 8.74) versus 7-day average Shell Creek flow 1991-2009

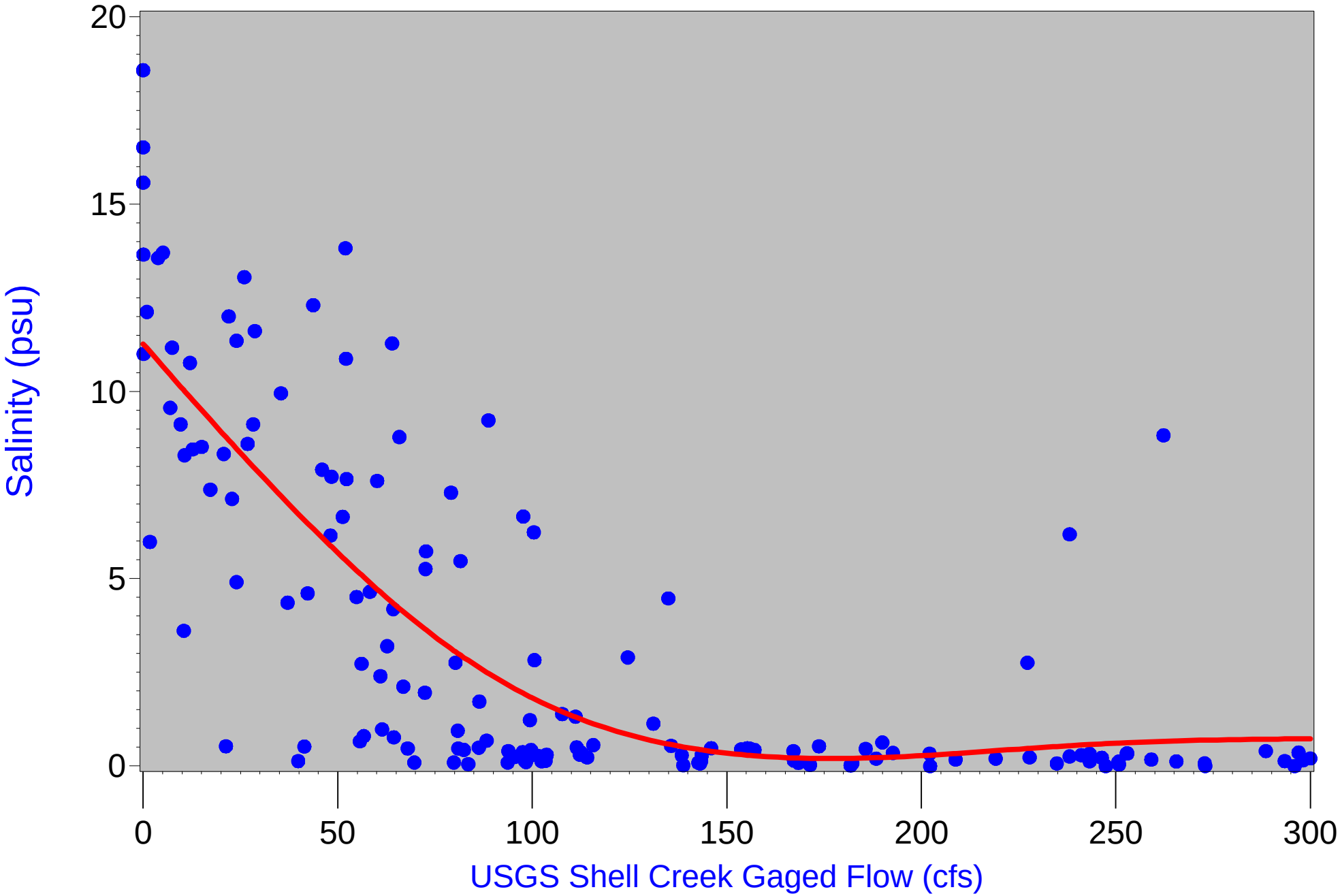


Figure 4.35b Bottom salinity at Station #4 (River Kilometer 8.74) versus 7-day average Shell Creek flow 1991-2009

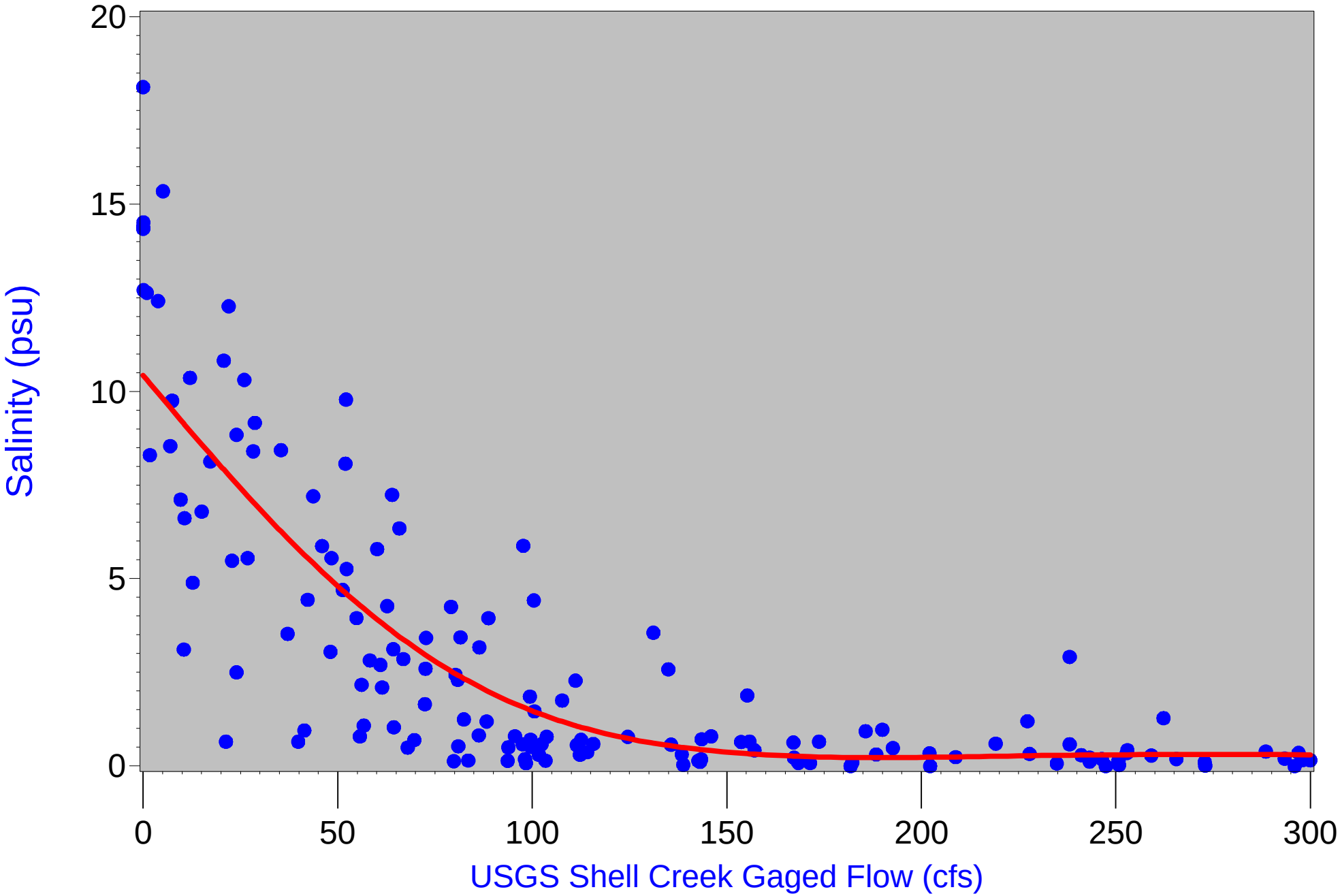


Figure 4.36a Surface salinity at Station #5 (River Kilometer 6.72) versus 7-day average Shell Creek flow 1991-2009

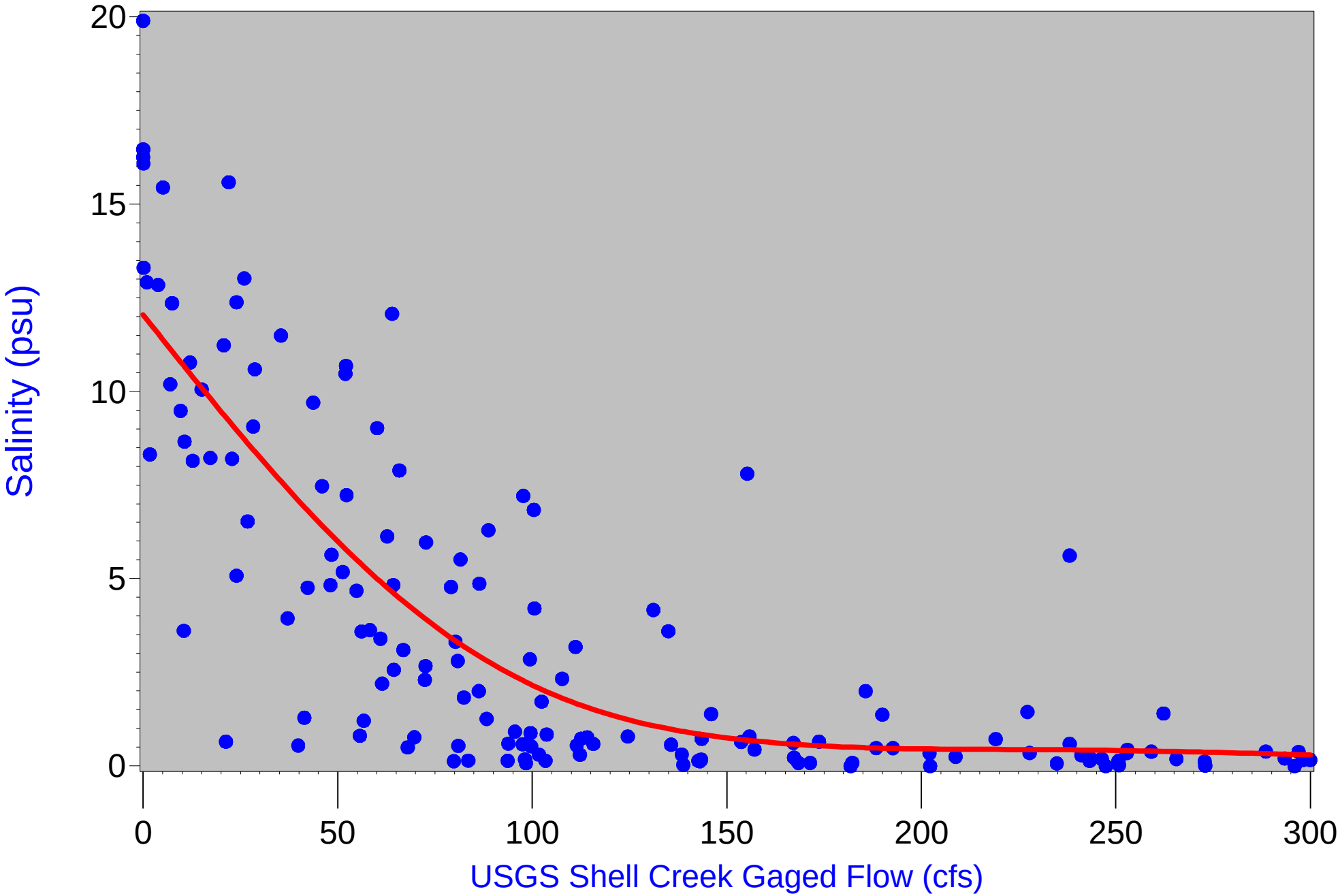


Figure 4.36b Bottom salinity at Station #5 (River Kilometer 6.72) versus 7-day average Shell Creek flow 1991-2009

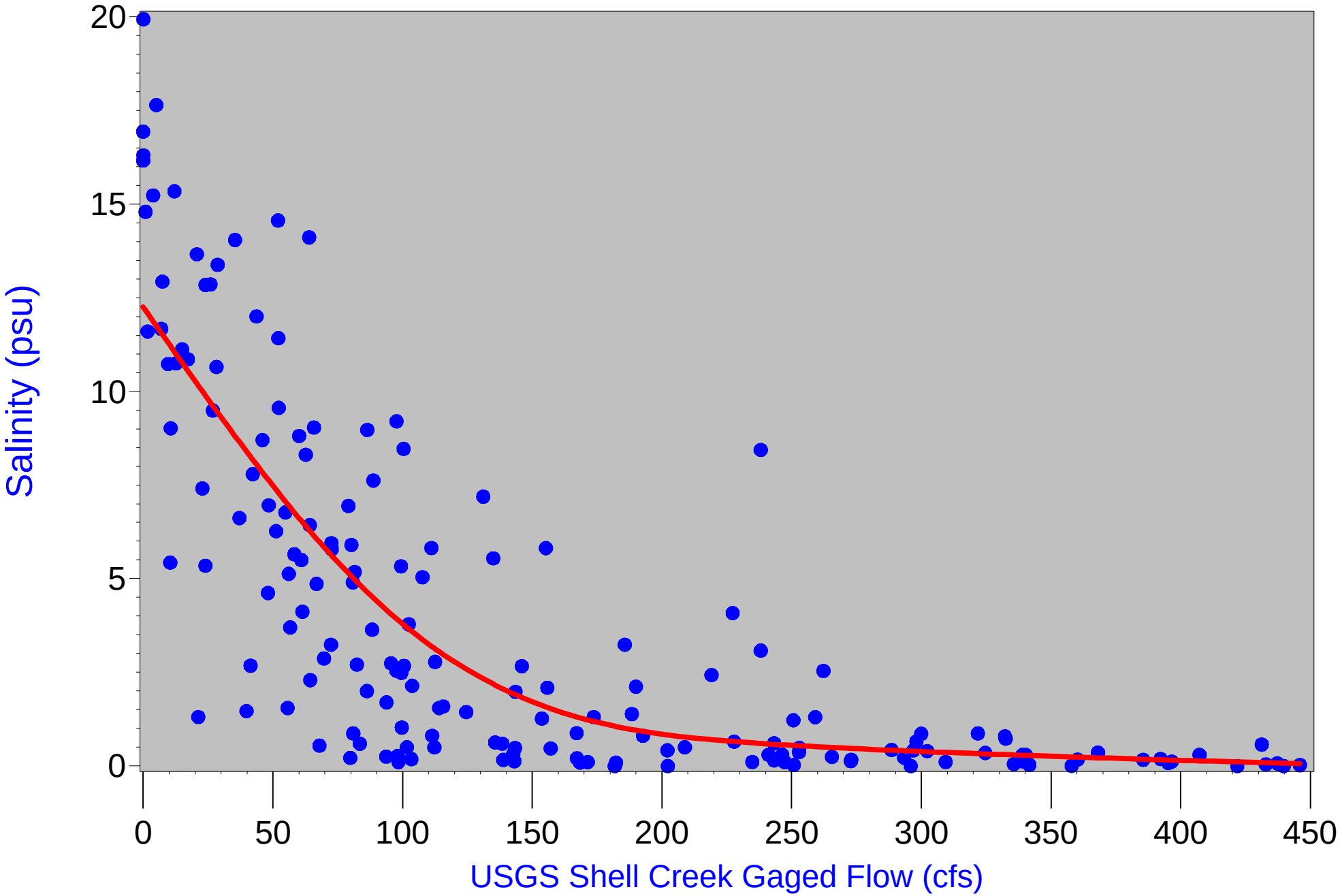


Figure 4.37a Surface salinity at Station #6 (River Kilometer 4.61) versus 7-day average Shell Creek flow 1991-2009

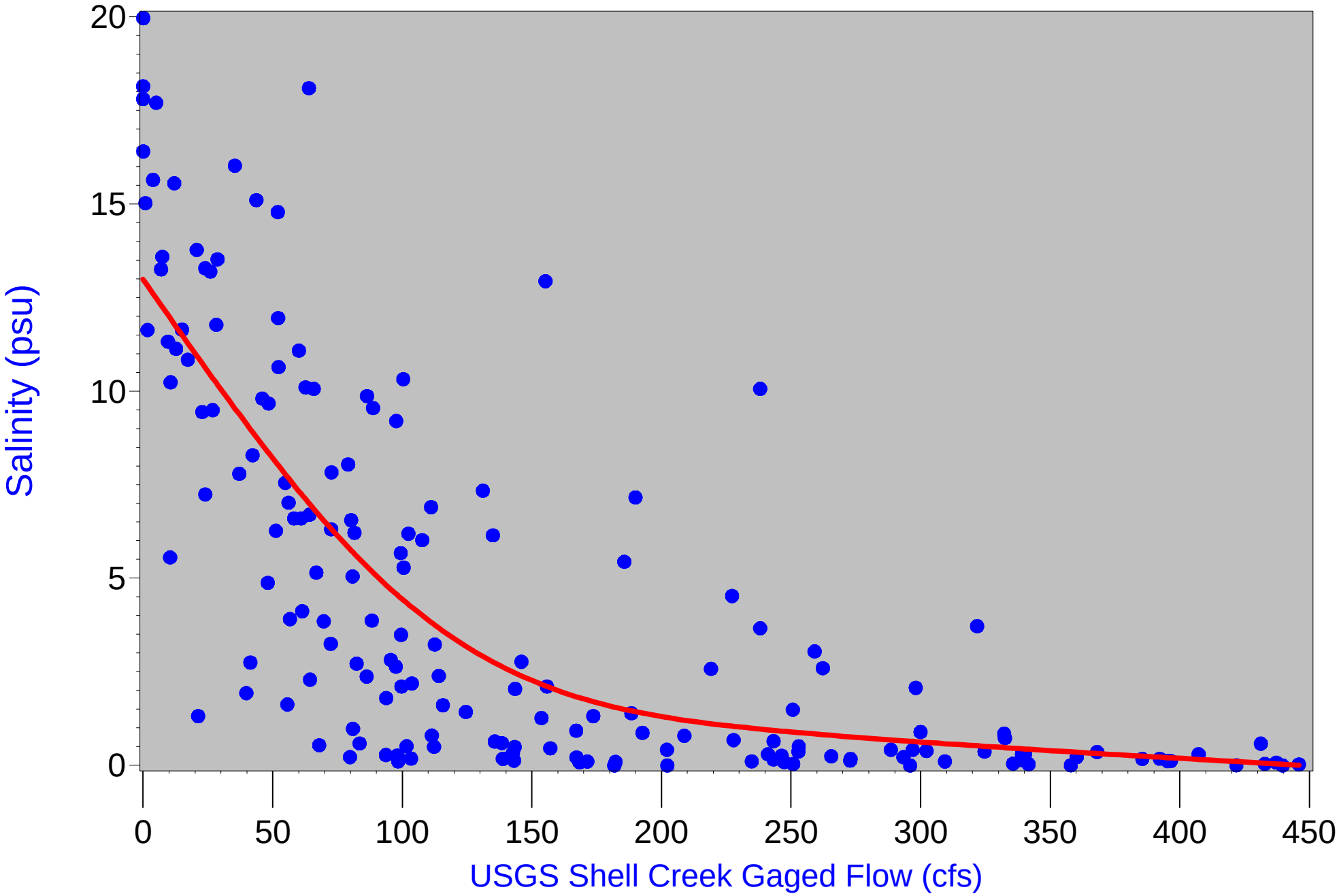


Figure 4.37b Bottom salinity at Station #6 (River Kilometer 4.61) versus 7-day average Shell Creek flow 1991-2009

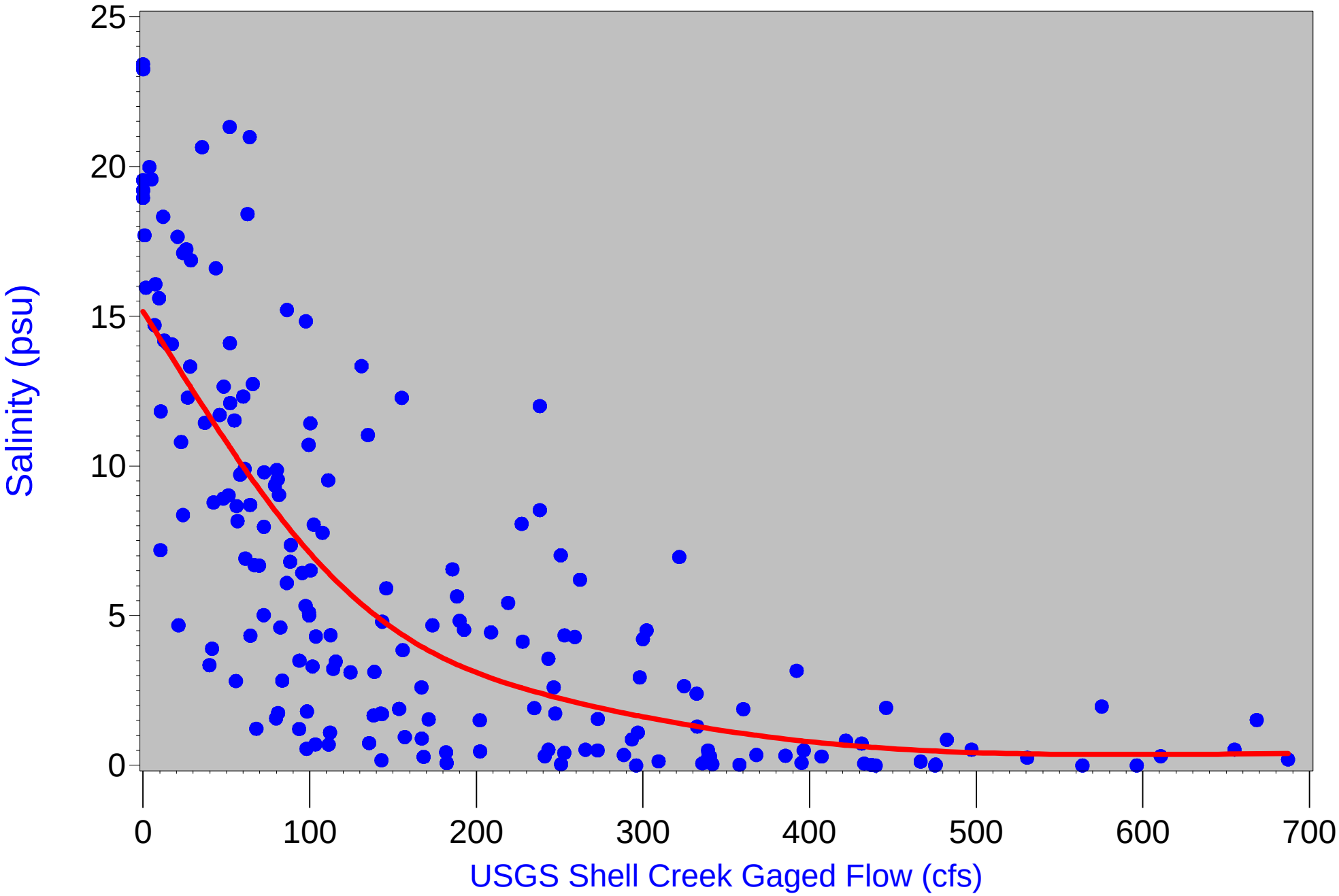


Figure 4.38a Surface salinity at Station #7 (River Kilometer 2.35) versus 7-day average Shell Creek flow 1991-2009

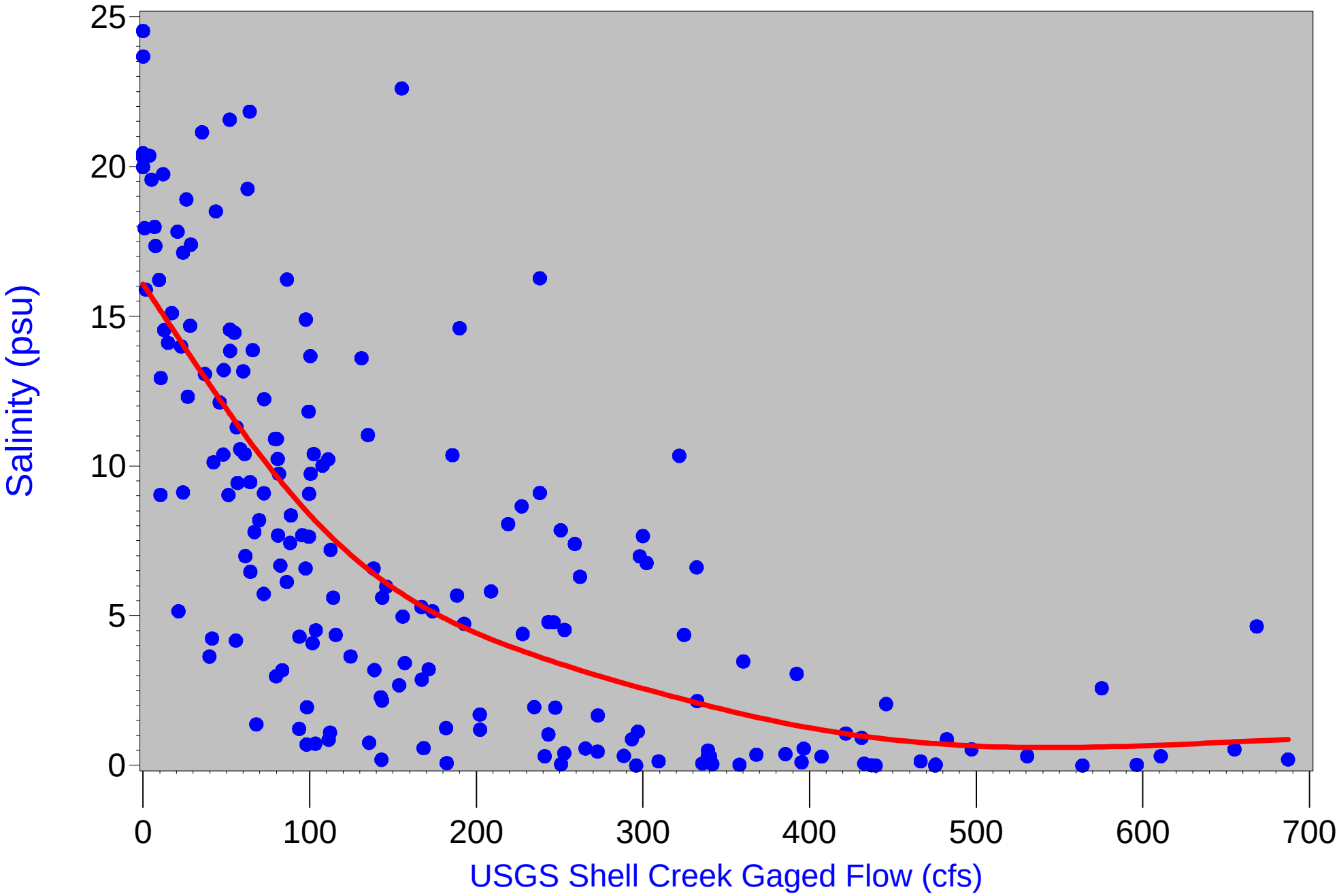


Figure 4.38b Bottom salinity at Station #7 (River Kilometer 2.35) versus 7-day average Shell Creek flow 1991-2009

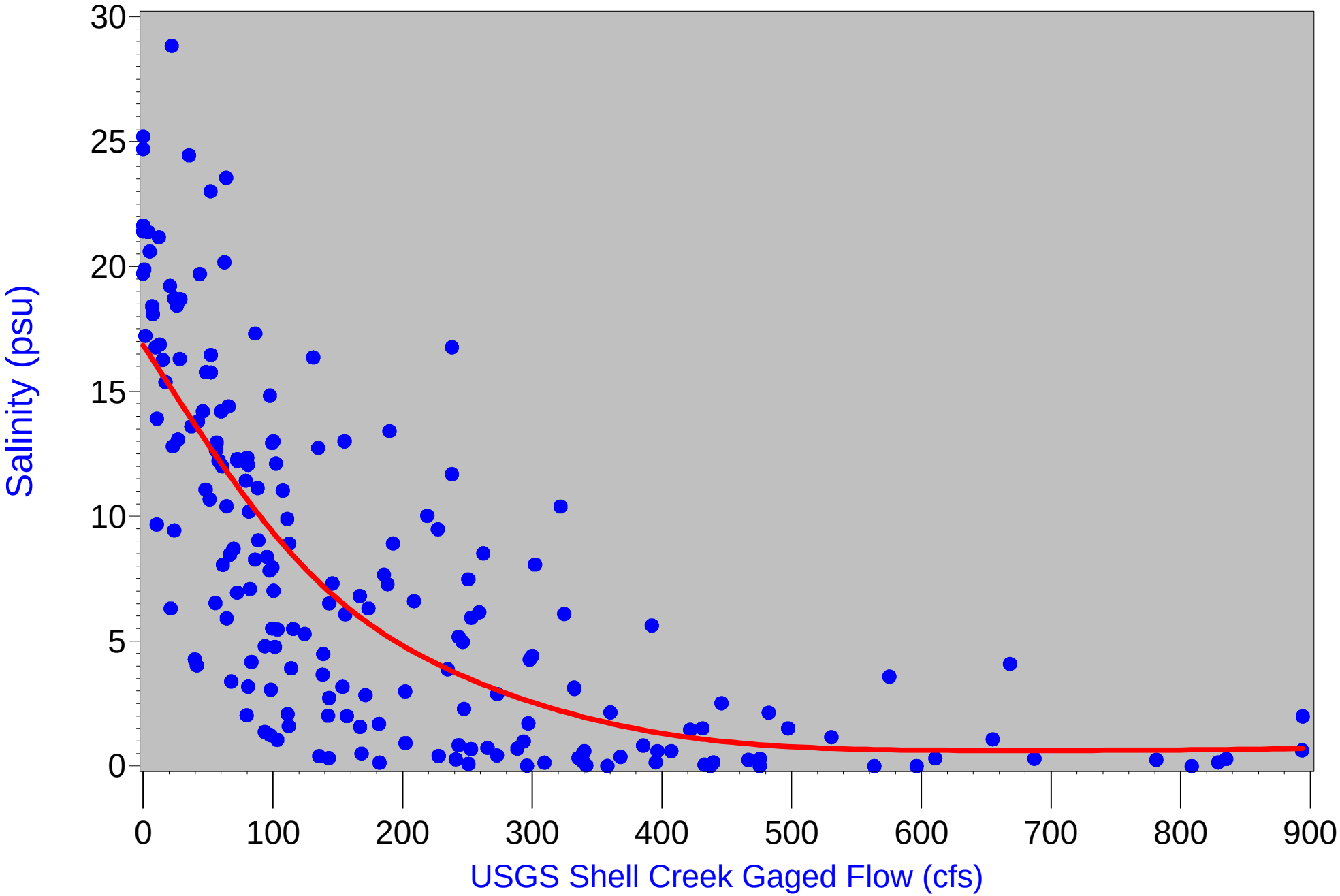


Figure 4.39a Surface salinity at Station #16 (River Kilometer 1.26) versus 7-day average Shell Creek flow 1991-2009

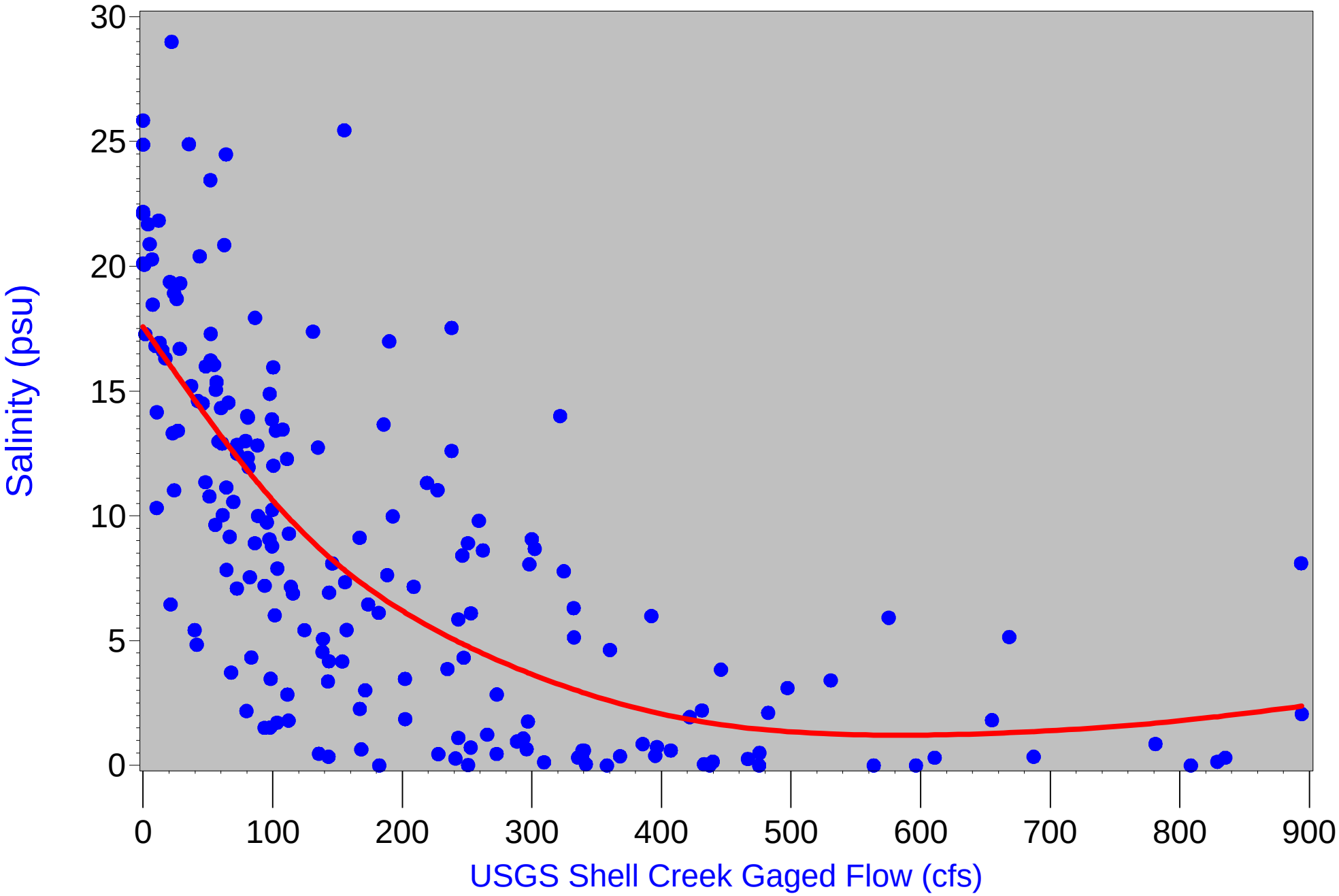


Figure 4.39b Bottom salinity at Station #16 (River Kilometer 1.26) versus 7-day average Shell Creek flow 1991-2009

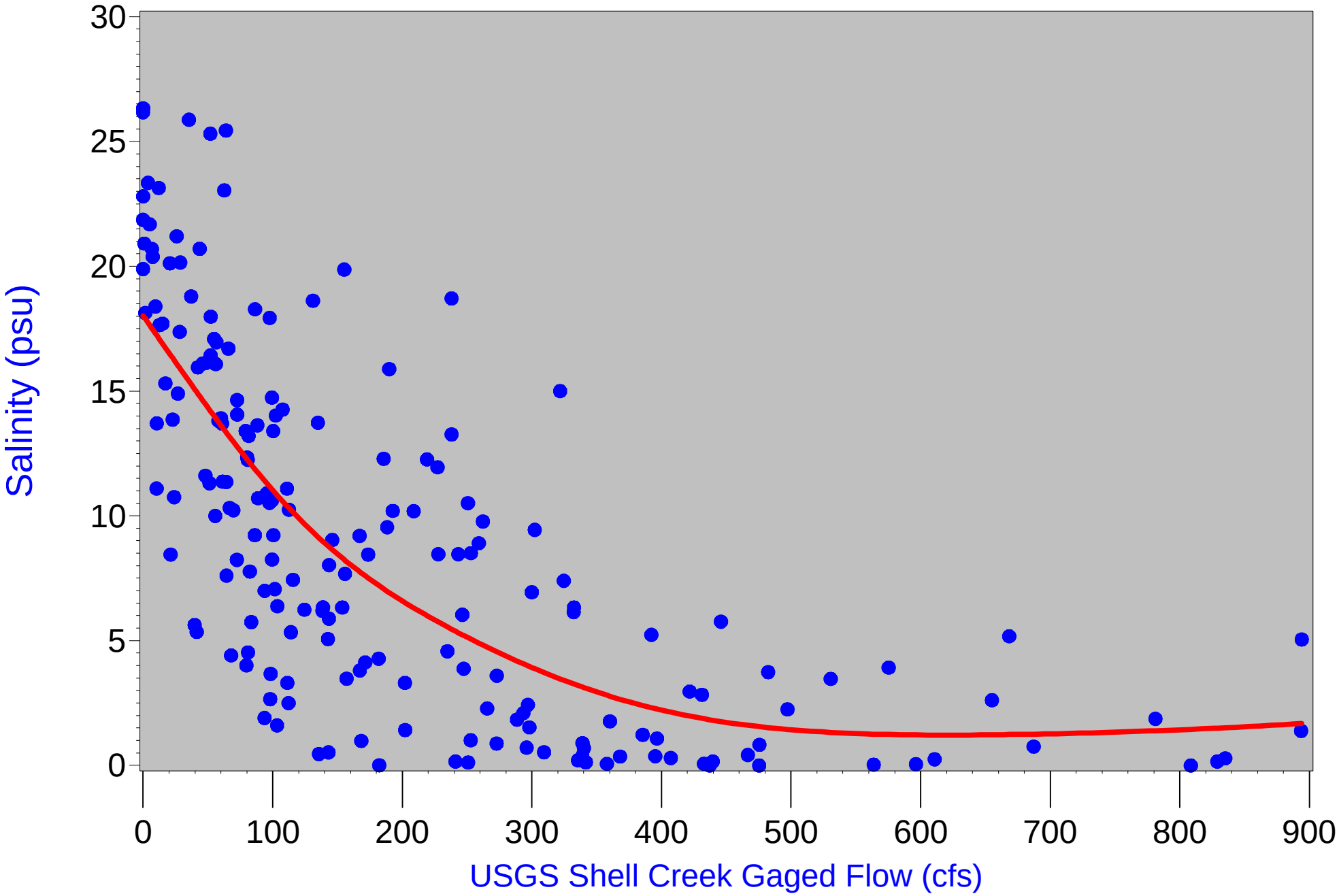


Figure 4.40a Surface salinity at Station #17 (River Kilometer 0.43) versus 7-day average Shell Creek flow 1991-2009

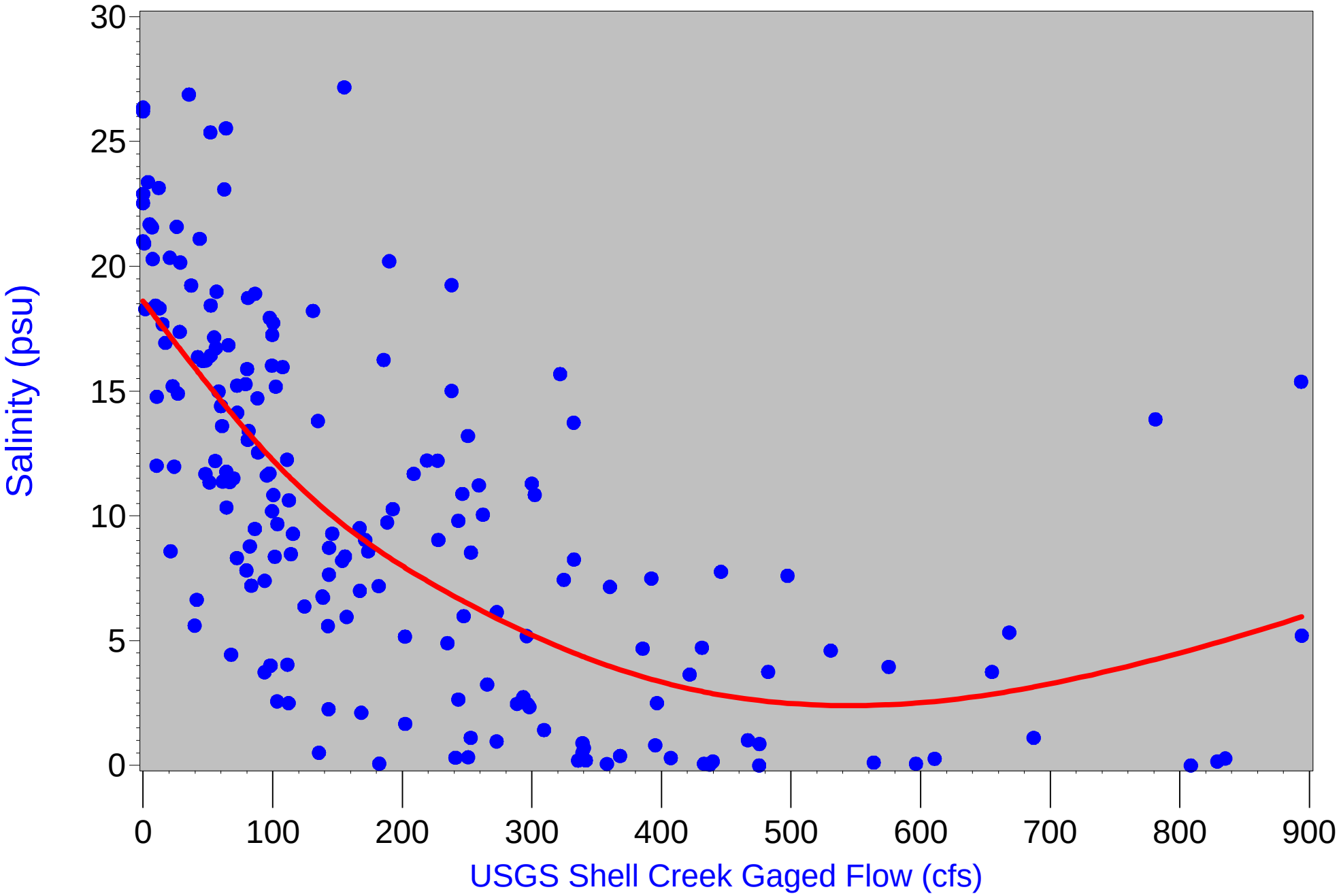


Figure 4.40b Bottom salinity at Station #17 (River Kilometer 0.43) versus 7-day average Shell Creek flow 1991-2009

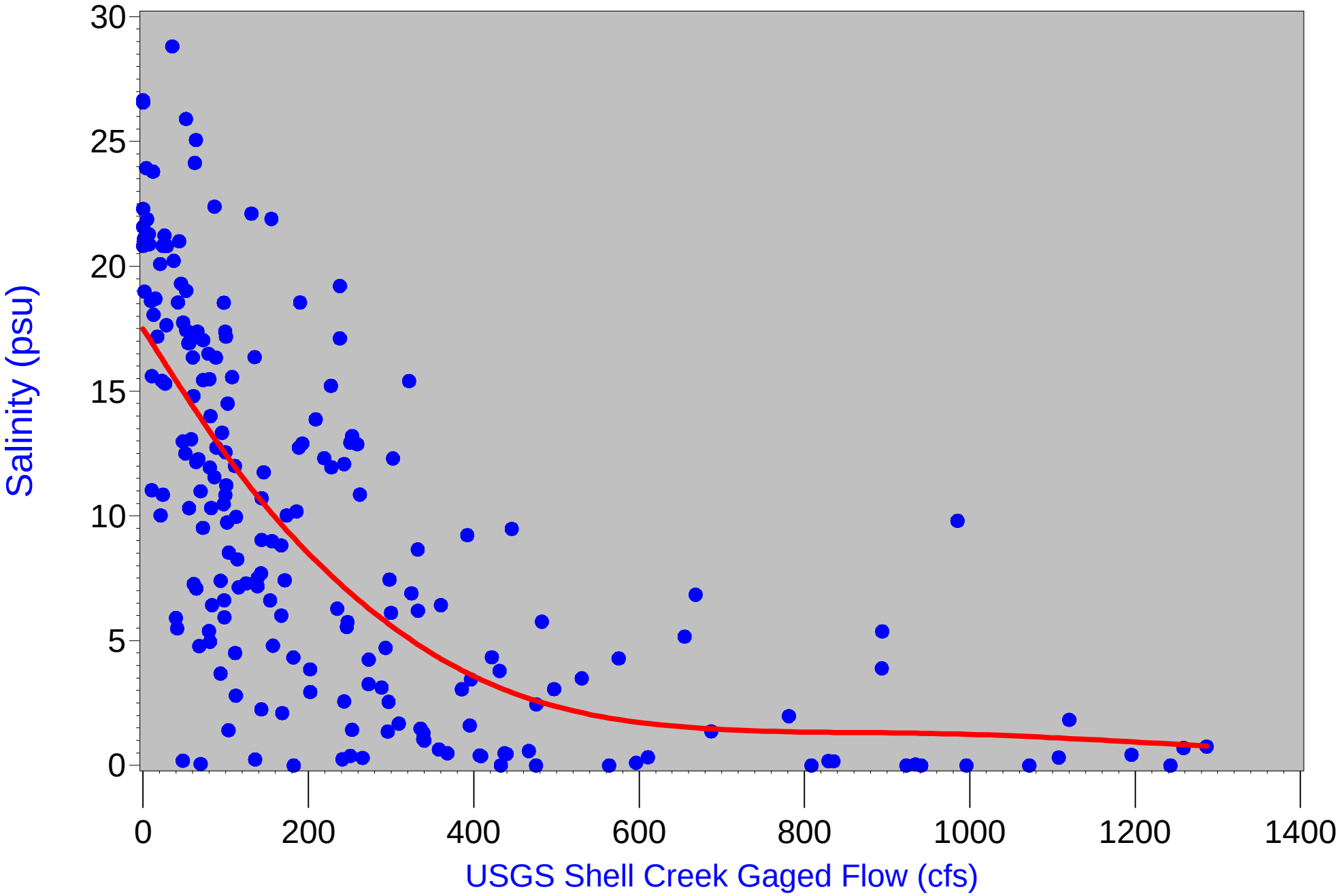


Figure 4.41a Surface salinity at Station #9 (River Kilometer -0.37) versus 7-day average Shell Creek flow 1991-2009

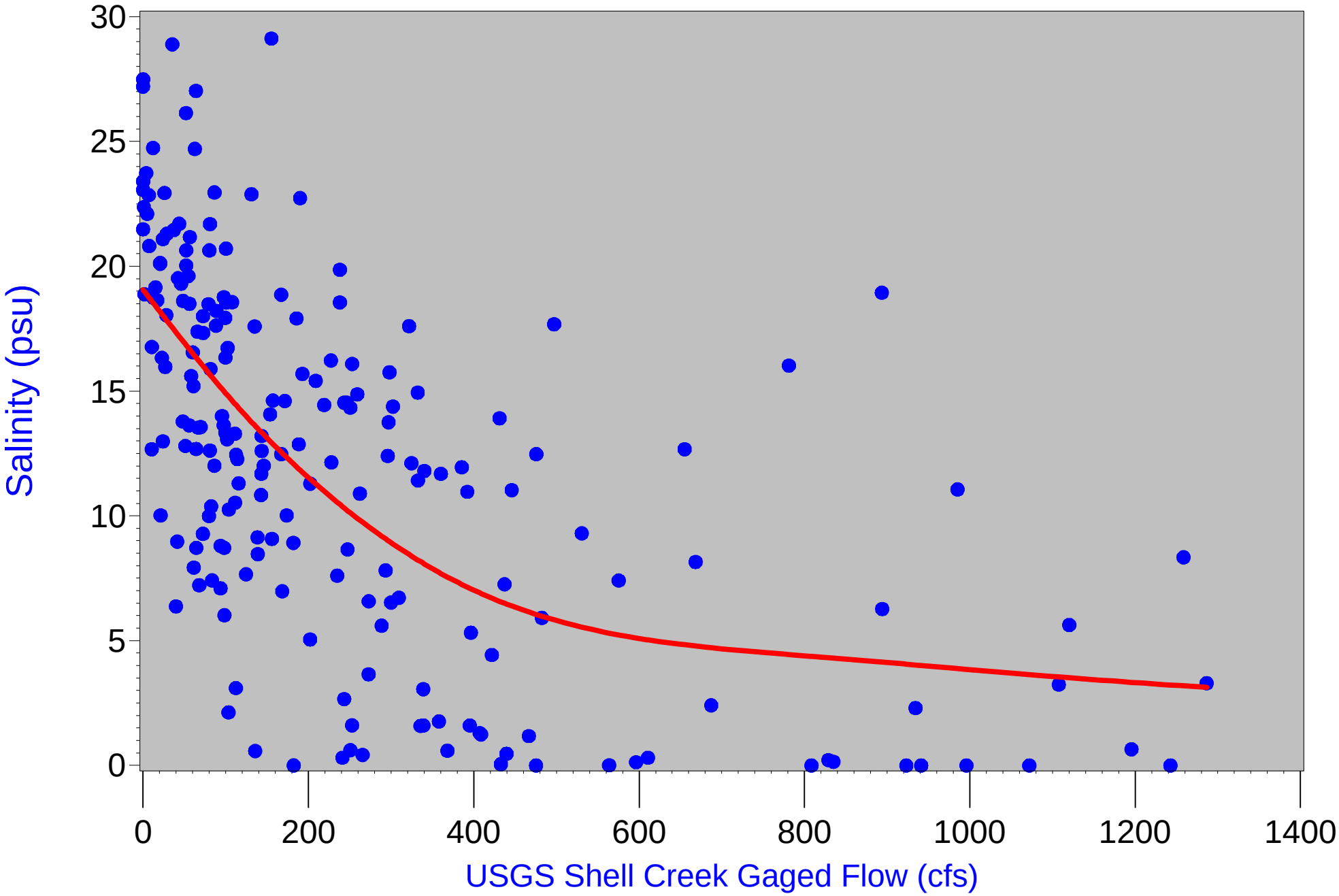


Figure 4.41b Bottom salinity at Station #9 (River Kilometer -0.37) versus 7-day average Shell Creek flow 1991-2009

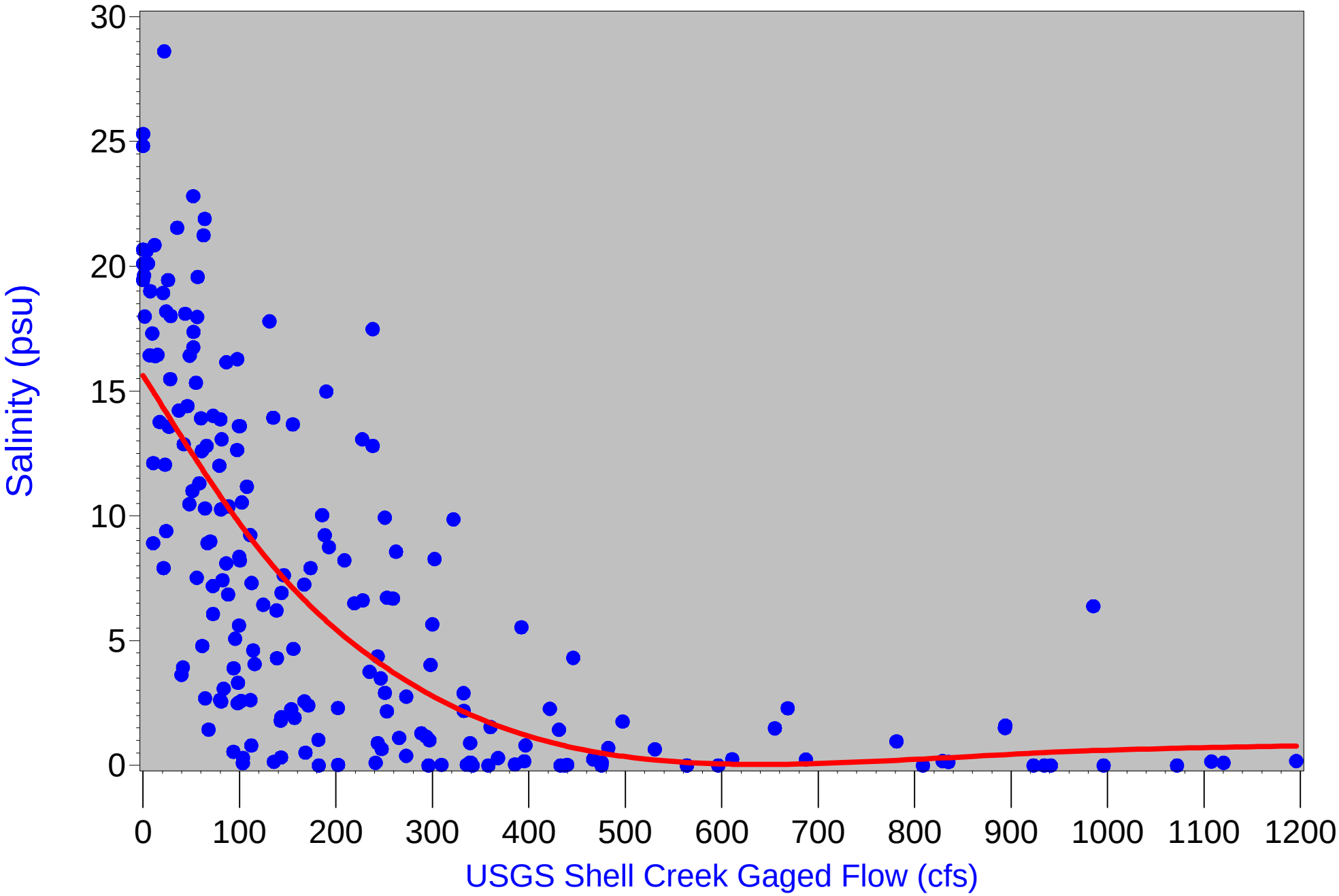


Figure 4.42a Surface salinity at Station #8 in lower Peace River versus 7-day average Shell Creek flow 1991-2009

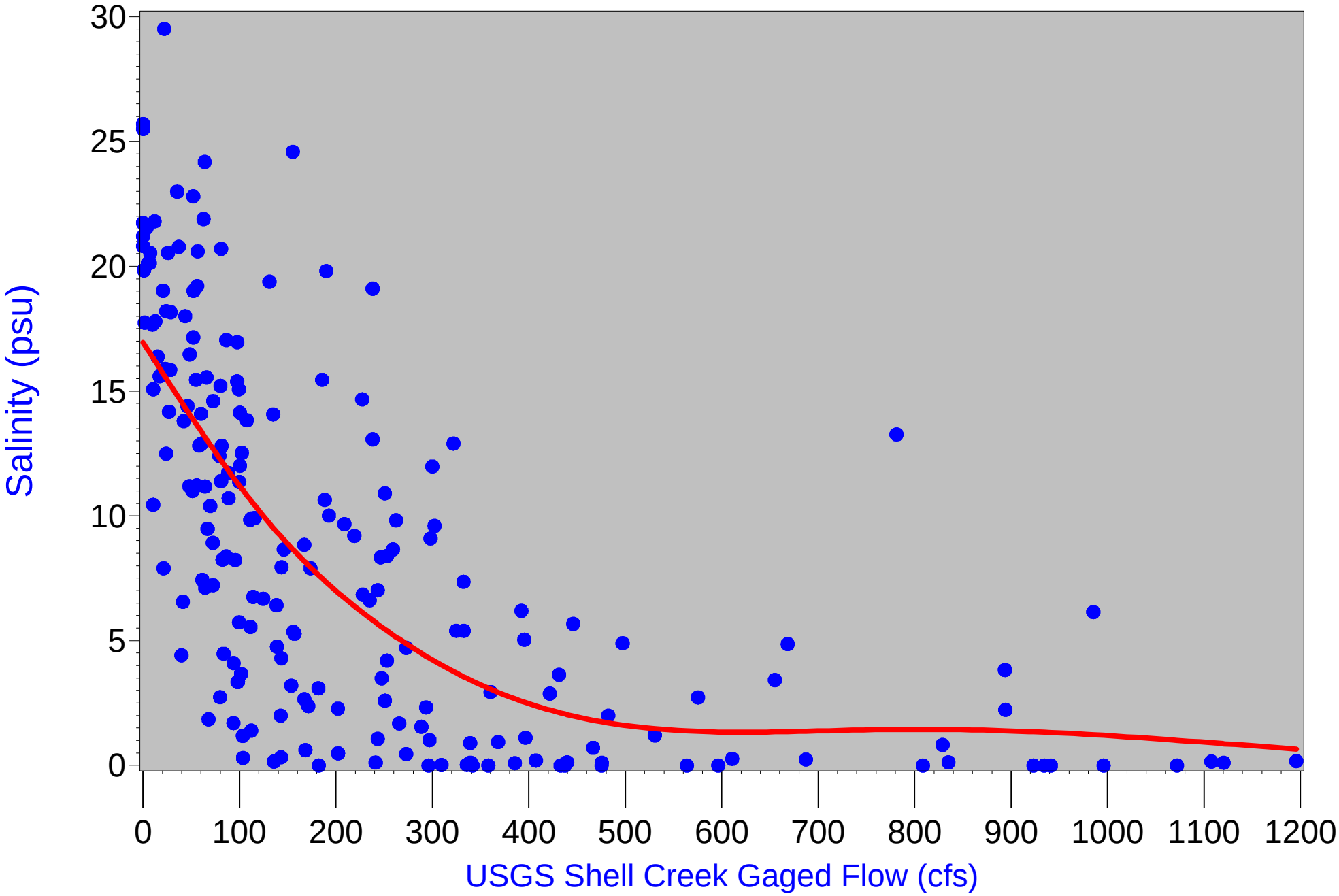


Figure 4.42b Bottom salinity at Station #8 in lower Peace River versus 7-day average Shell Creek flow 1991-2009

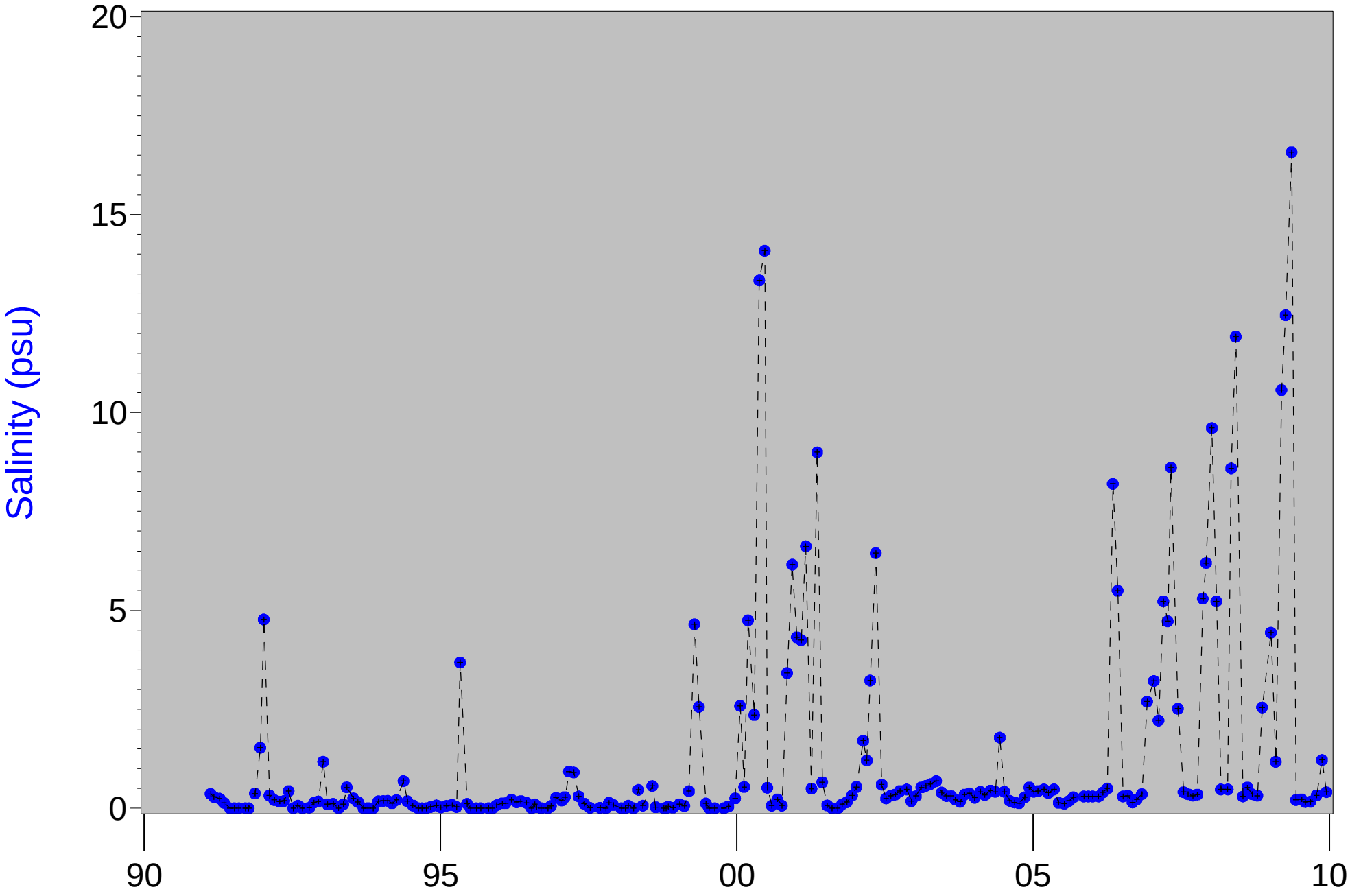


Figure 4.A1a Surface salinity at Station #11 (River Kilometer 9.90) 1991-2009

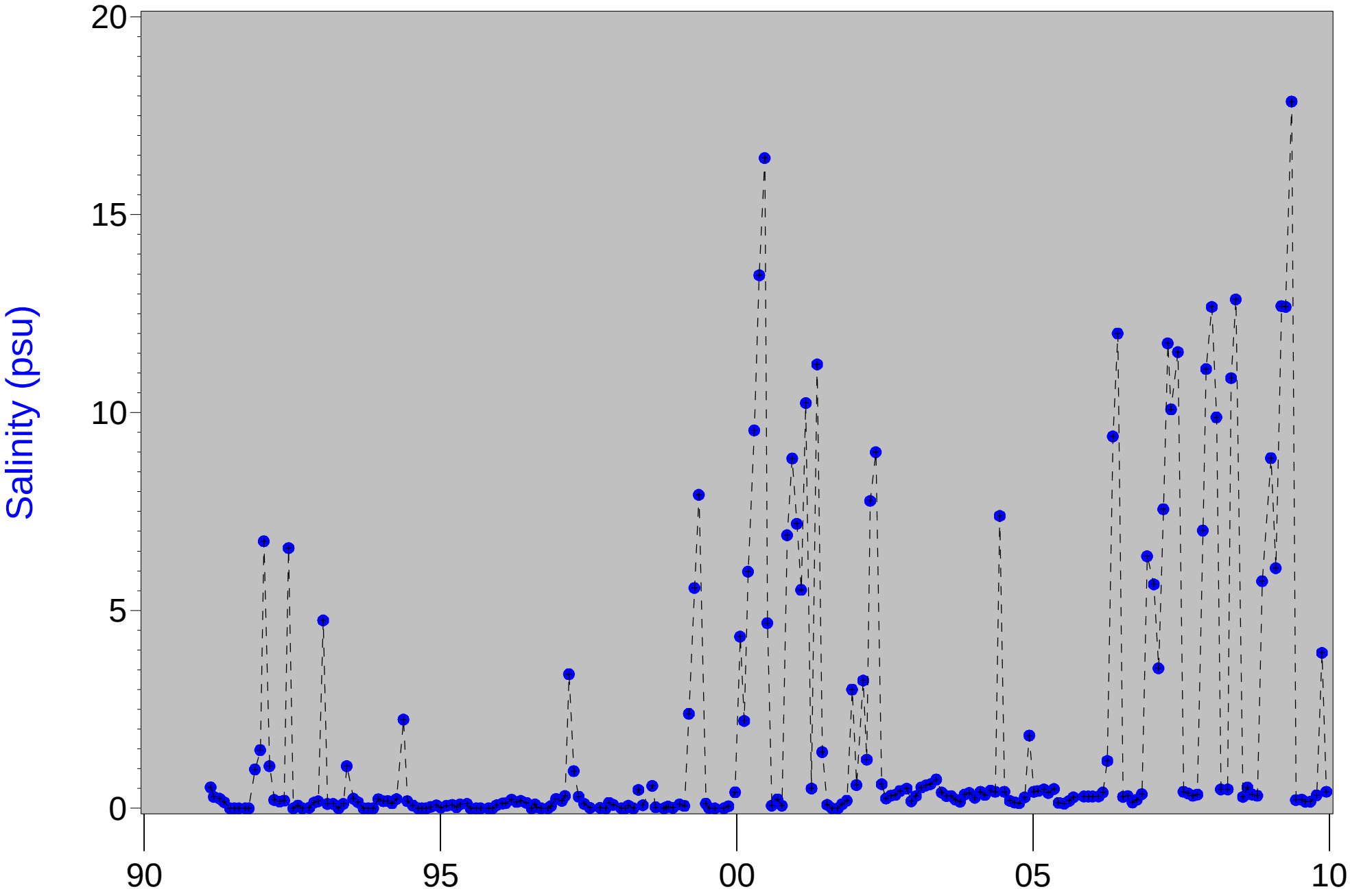


Figure 4.A1b Bottom salinity at Station #11 (River Kilometer 9.90) 1991-2009

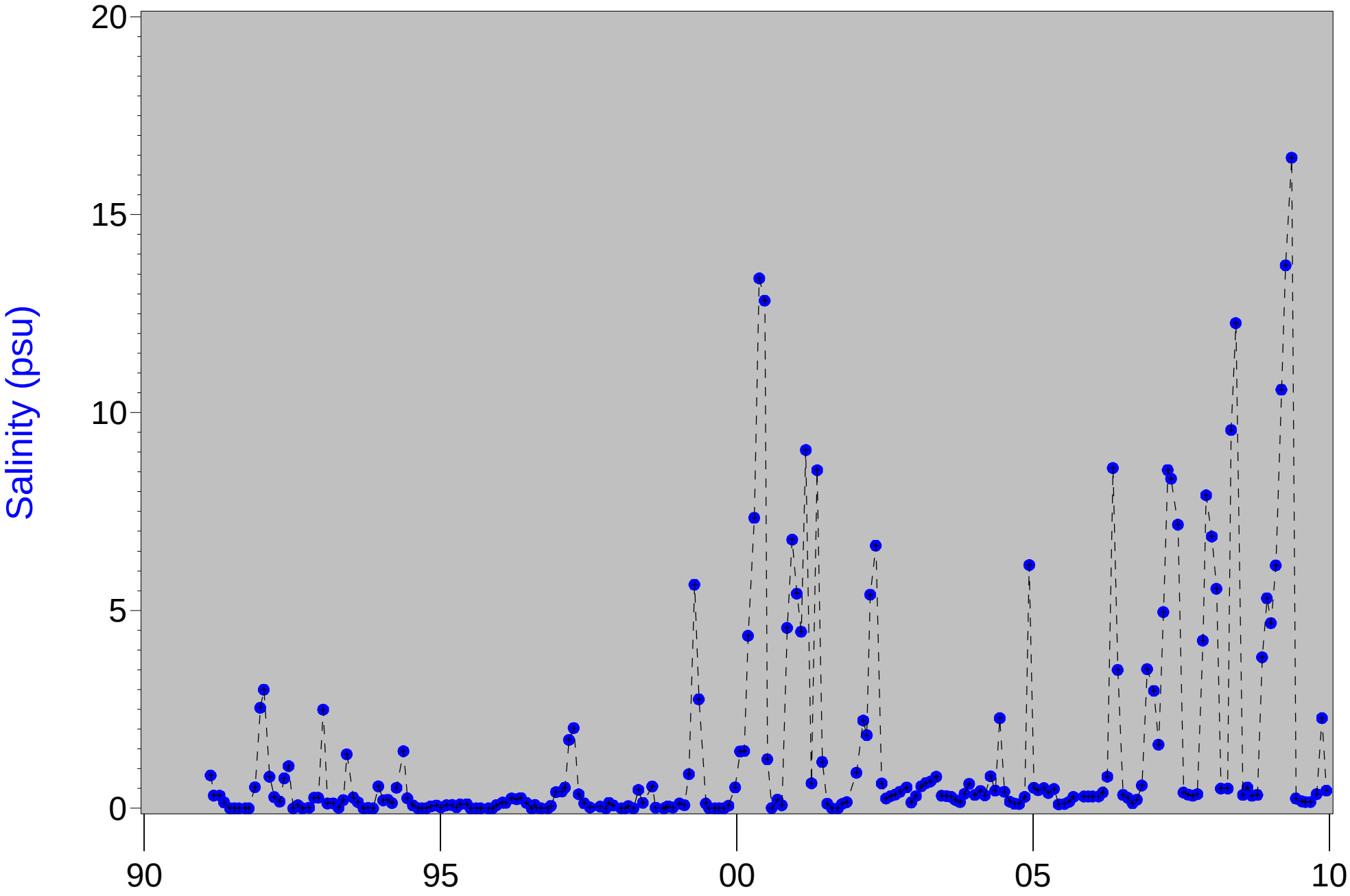


Figure 4.A2a Surface salinity at Station #4 (River Kilometer 8.74) 1991-2009

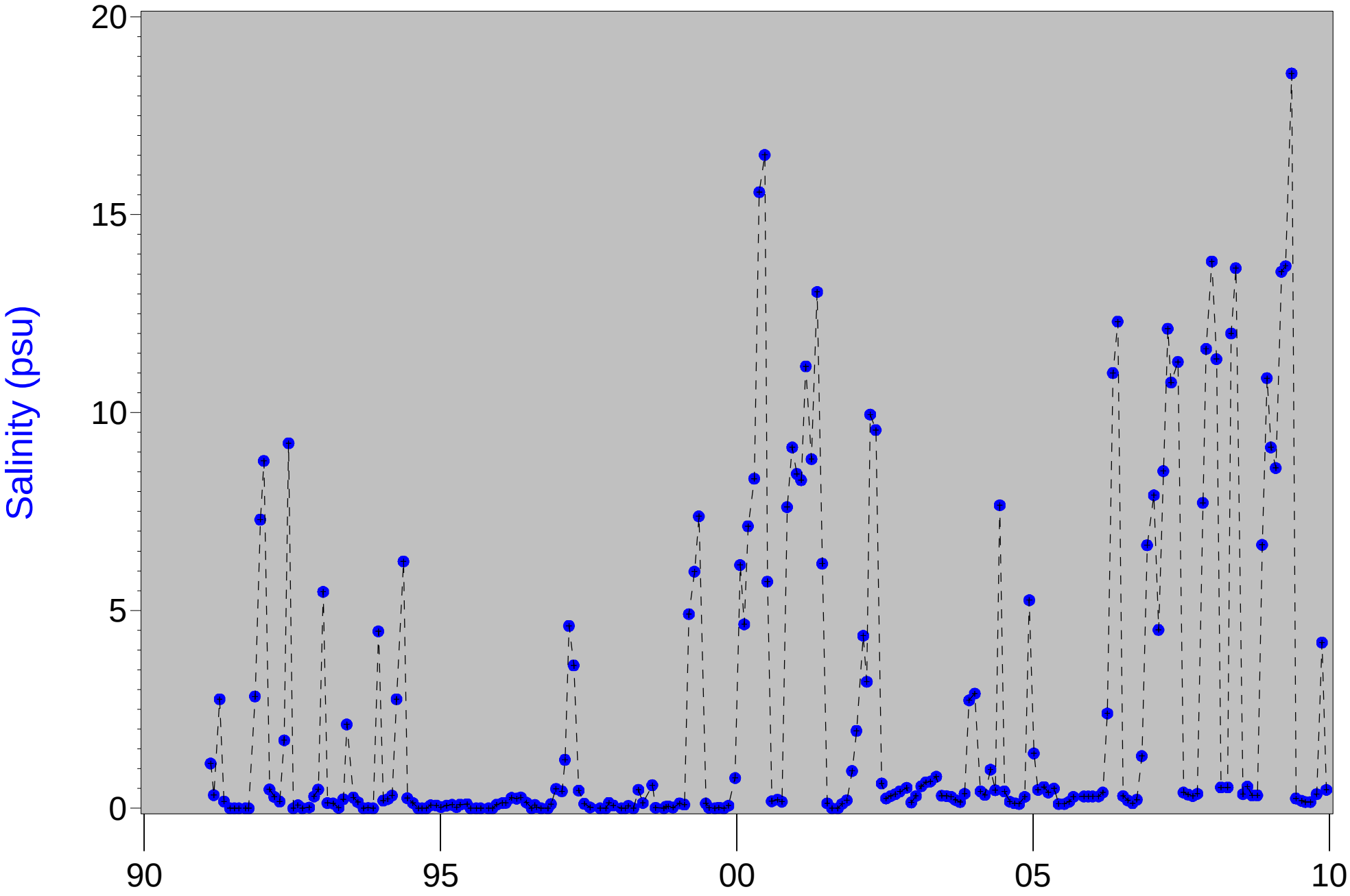


Figure 4.A2b Bottom salinity at Station #4 (River Kilometer 8.74) 1991-2009

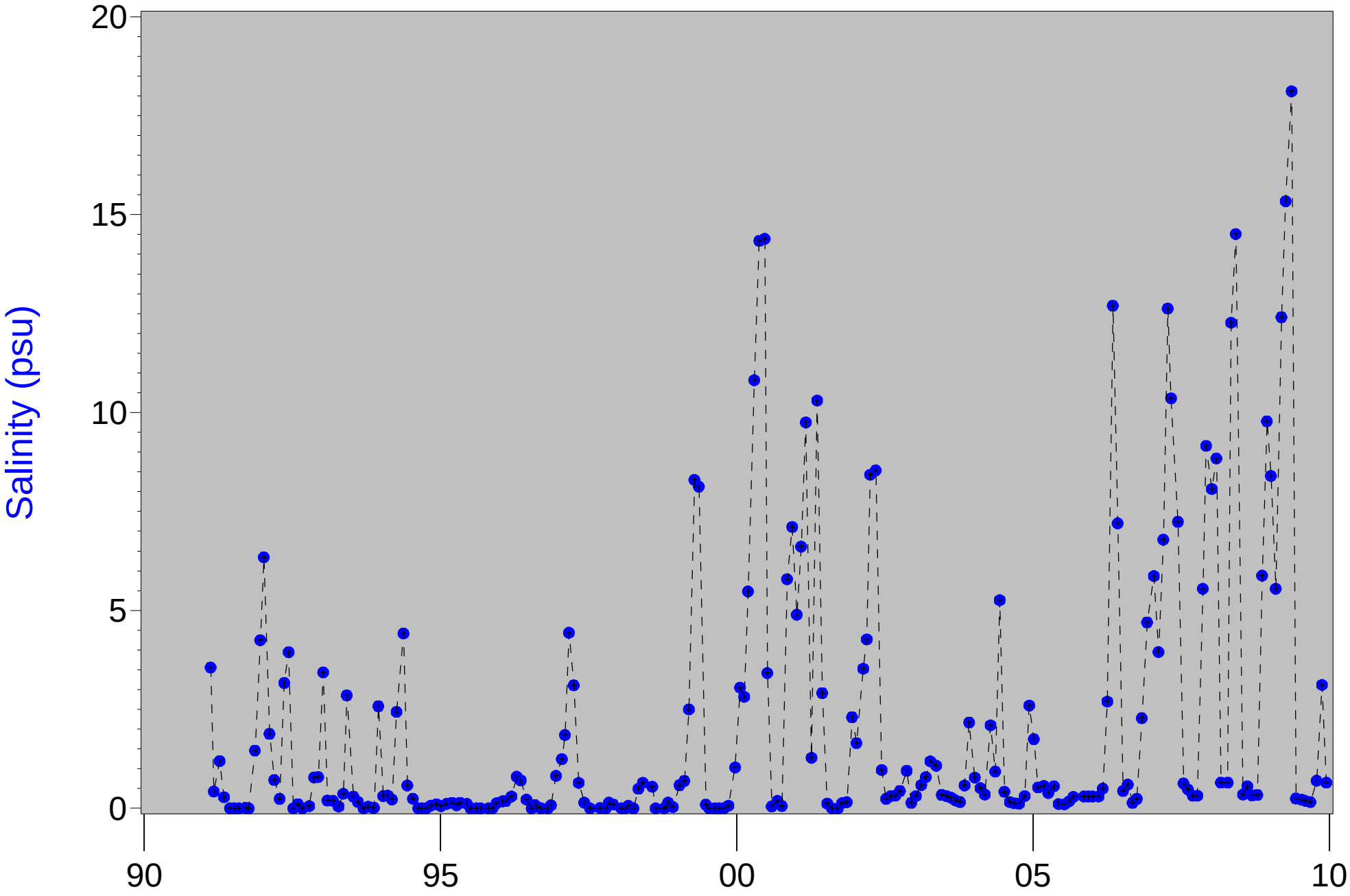


Figure 4.A3a Surface salinity at Station #5 (River Kilometer 6.72) 1991-2009

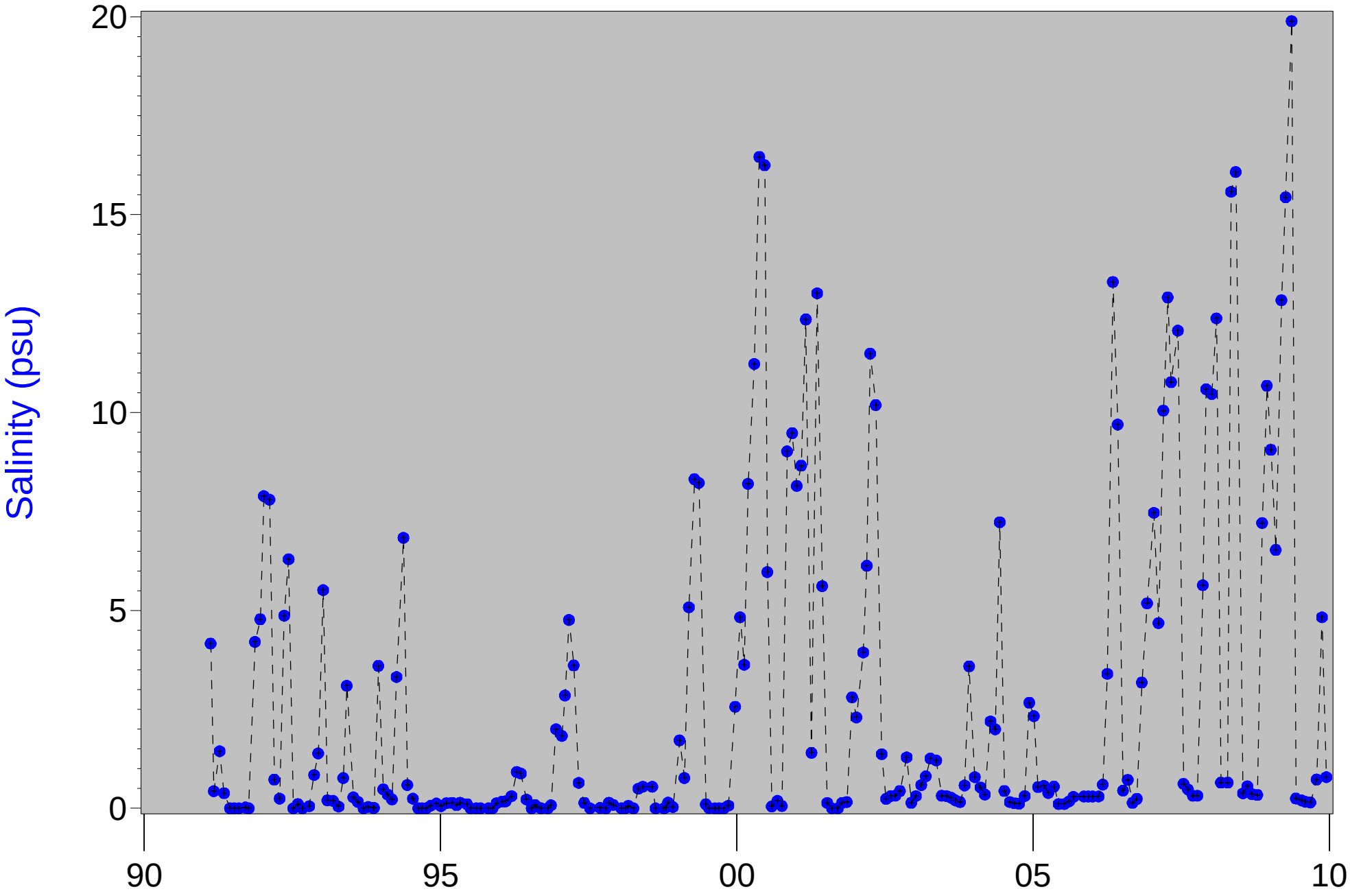


Figure 4.A3b Bottom salinity at Station #5 (River Kilometer 6.72) 1991-2009

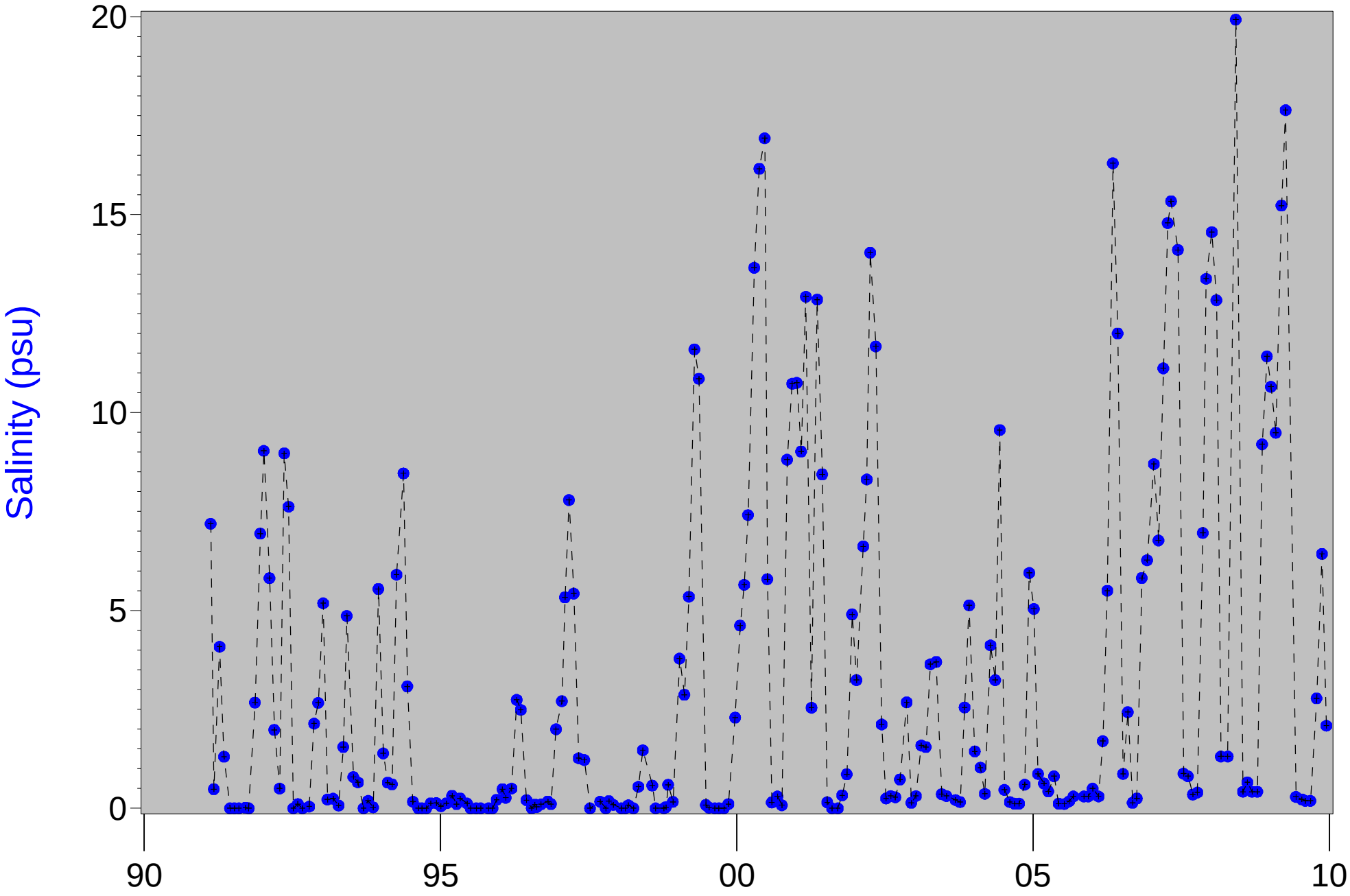


Figure 4.A4a Surface salinity at Station #6 (River Kilometer 4.61) 1991-2009

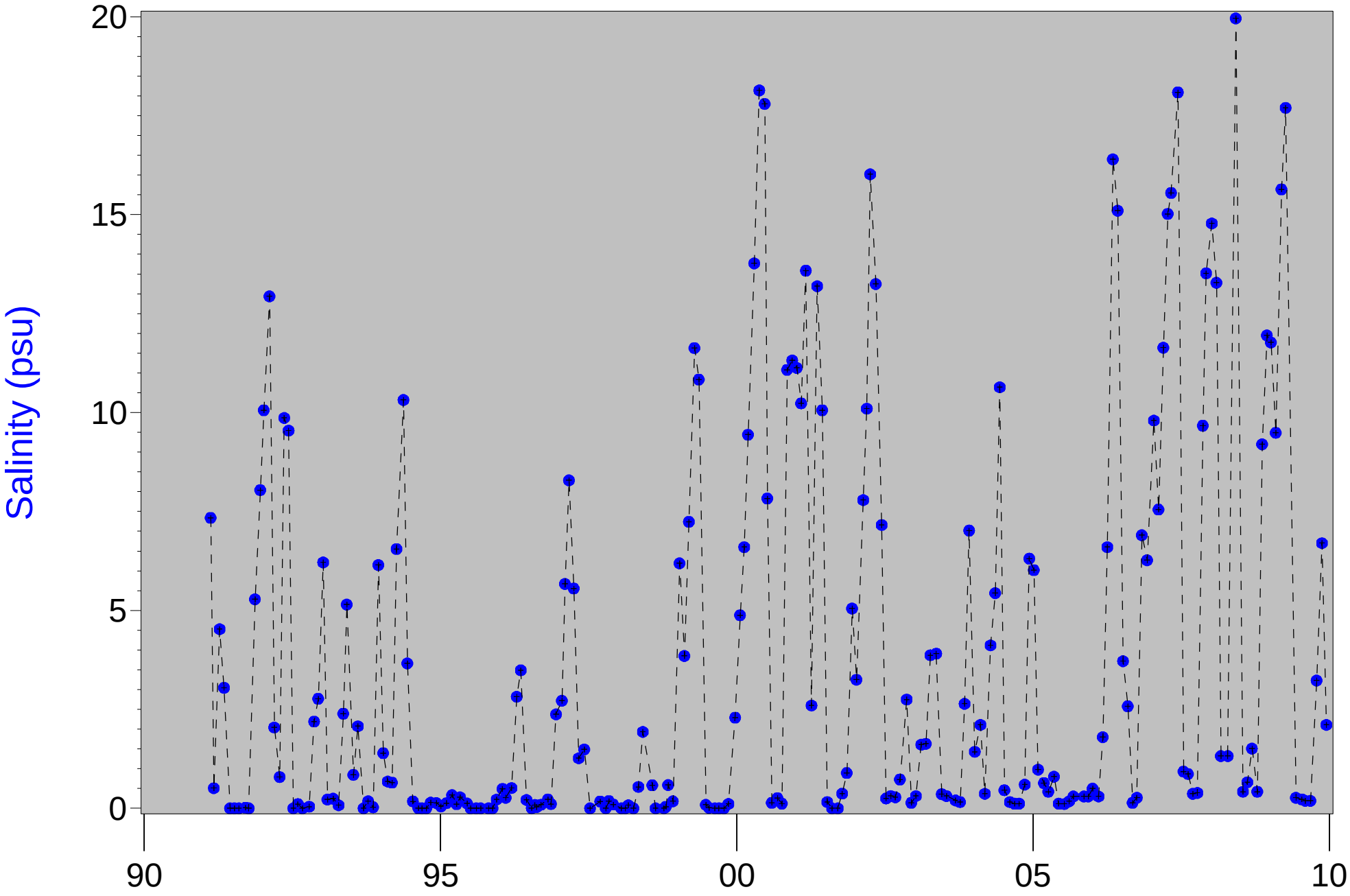


Figure 4.A4b Bottom salinity at Station #6 (River Kilometer 4.61) 1991-2009

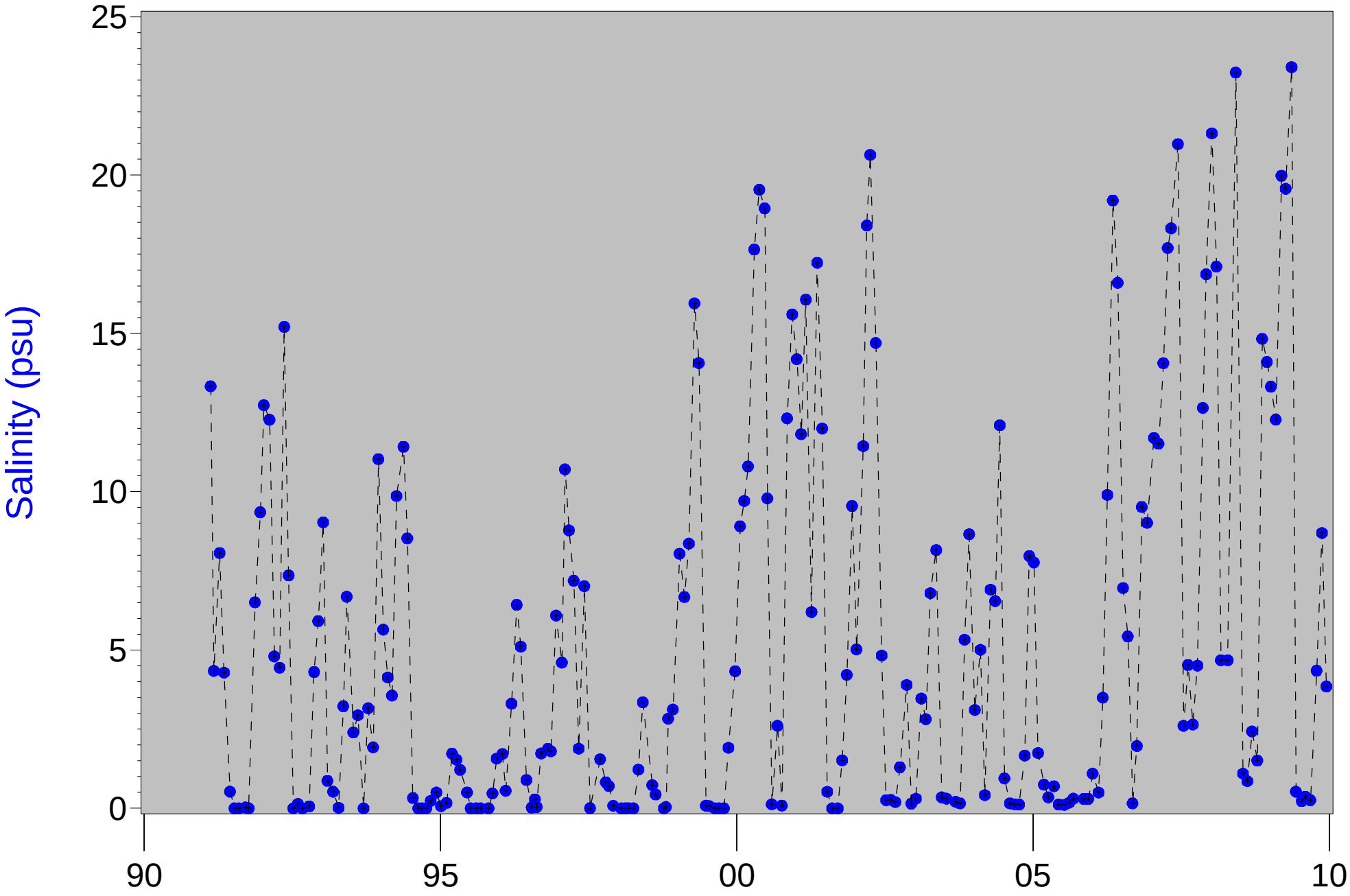


Figure 4.A5a Surface salinity at Station #7 (River Kilometer 2.35) 1991-2009

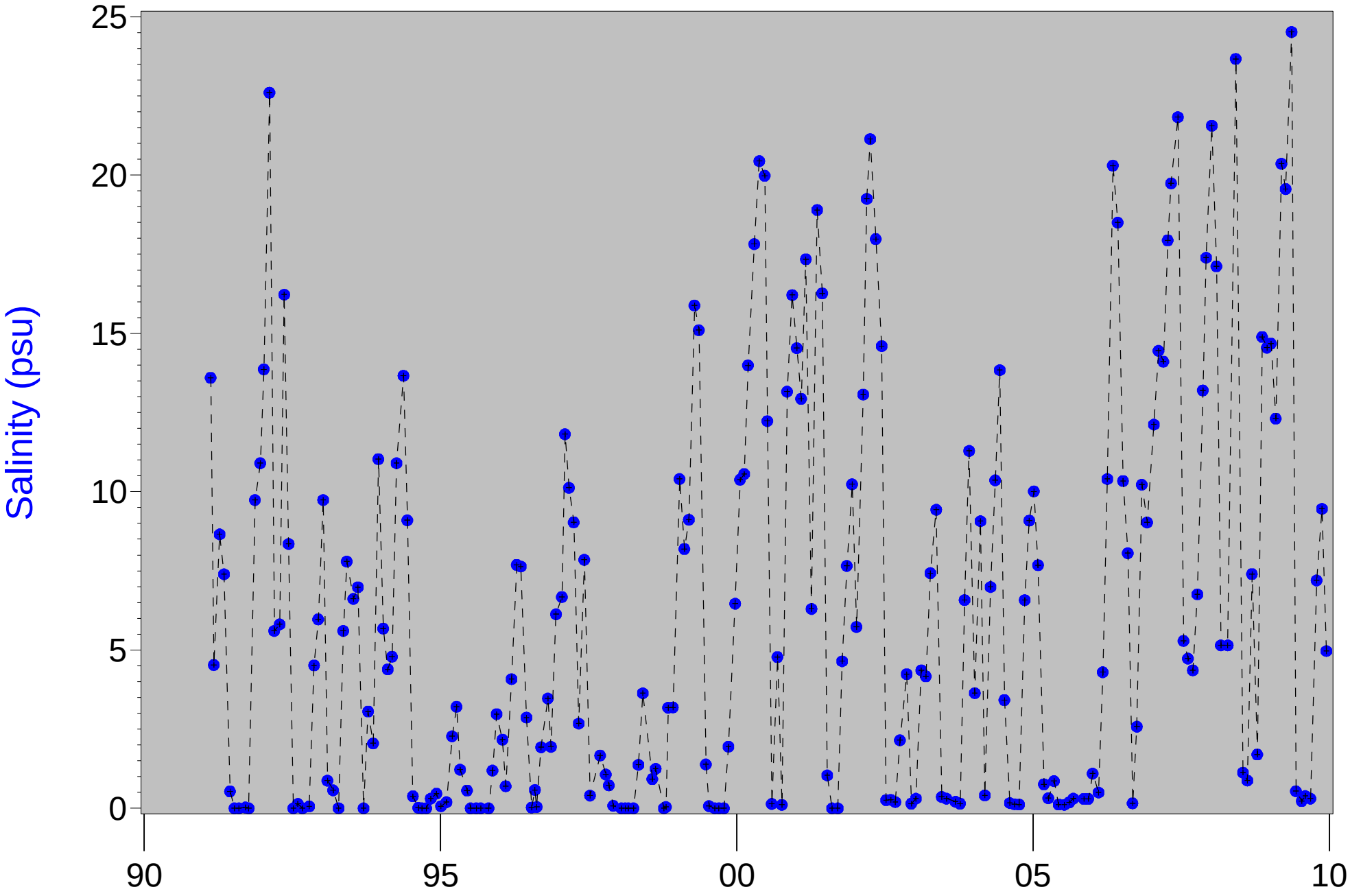


Figure 4.A5b Bottom salinity at Station #7 (River Kilometer 2.35) 1991-2009

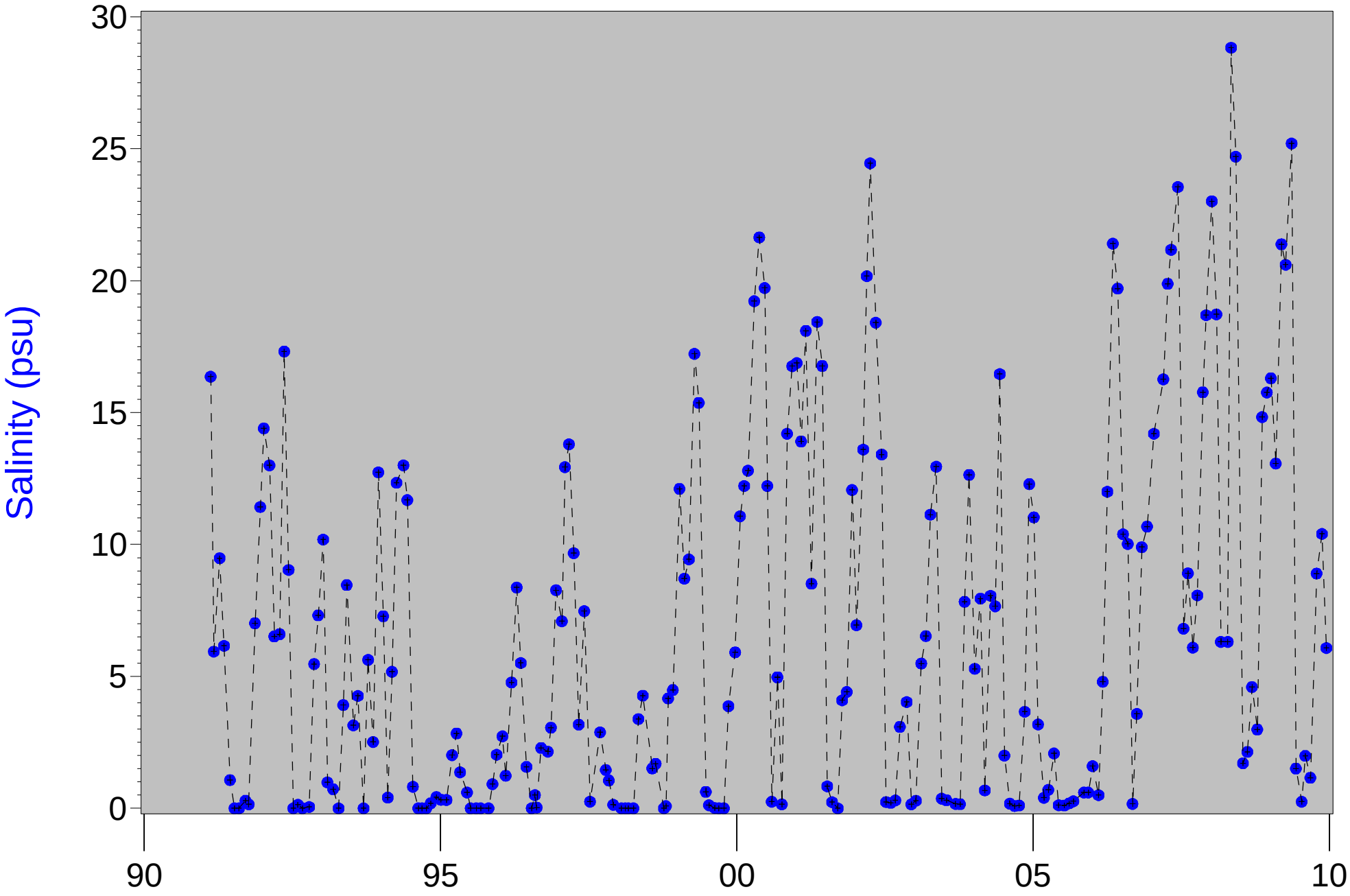


Figure 4.A6a Surface salinity at Station #16 (River Kilometer 1.26) 1991-2009

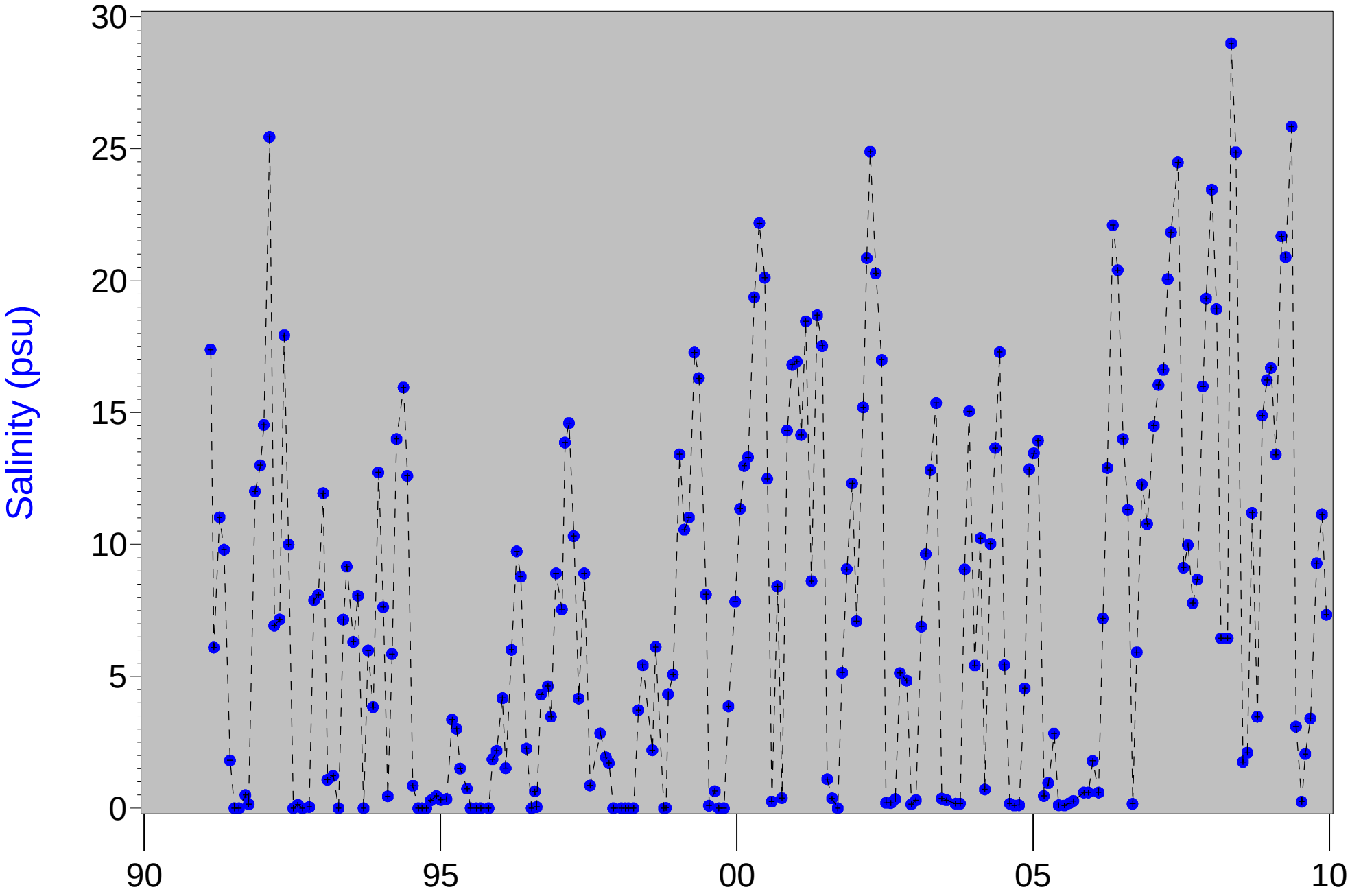


Figure 4.A6b Bottom salinity at Station #16 (River Kilometer 1.26) 1991-2009

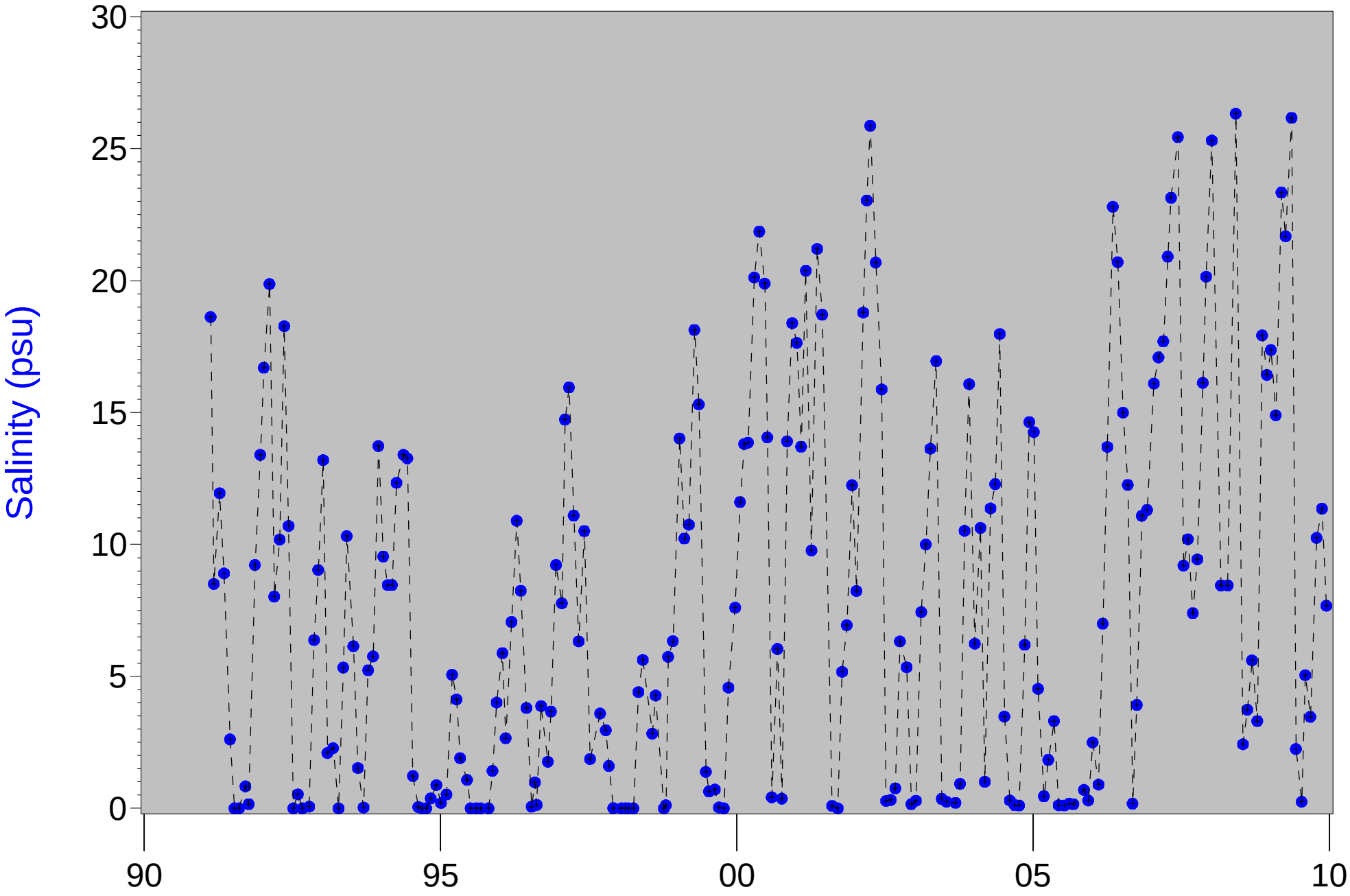


Figure 4.A7a Surface salinity at Station #17 (River Kilometer 0.43) 1991-2009

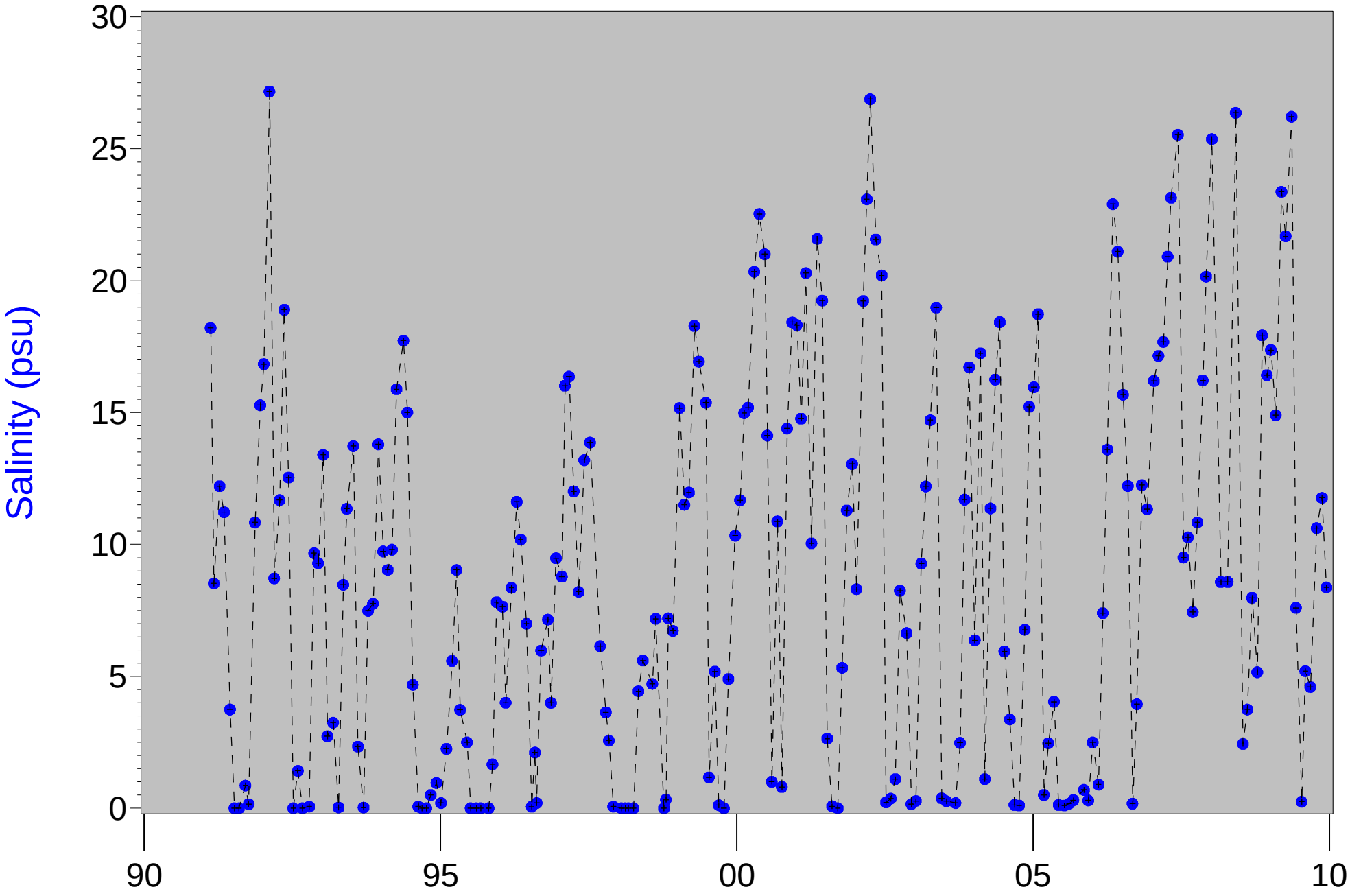


Figure 4.A7b Bottom salinity at Station #17 (River Kilometer 0.43) 1991-2009

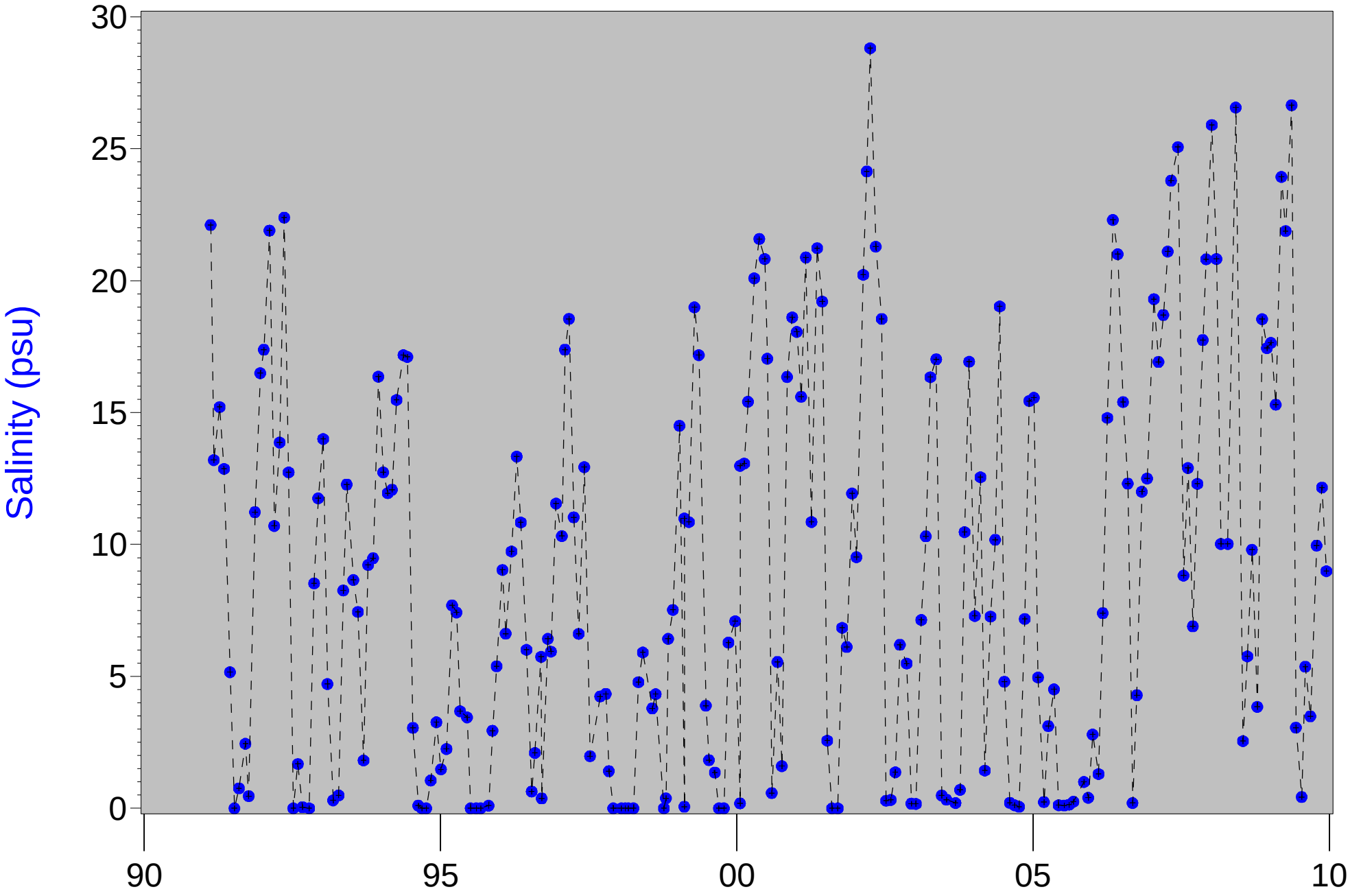


Figure 4.A8a Surface salinity at Station #9 (River Kilometer -0.37) 1991-2009

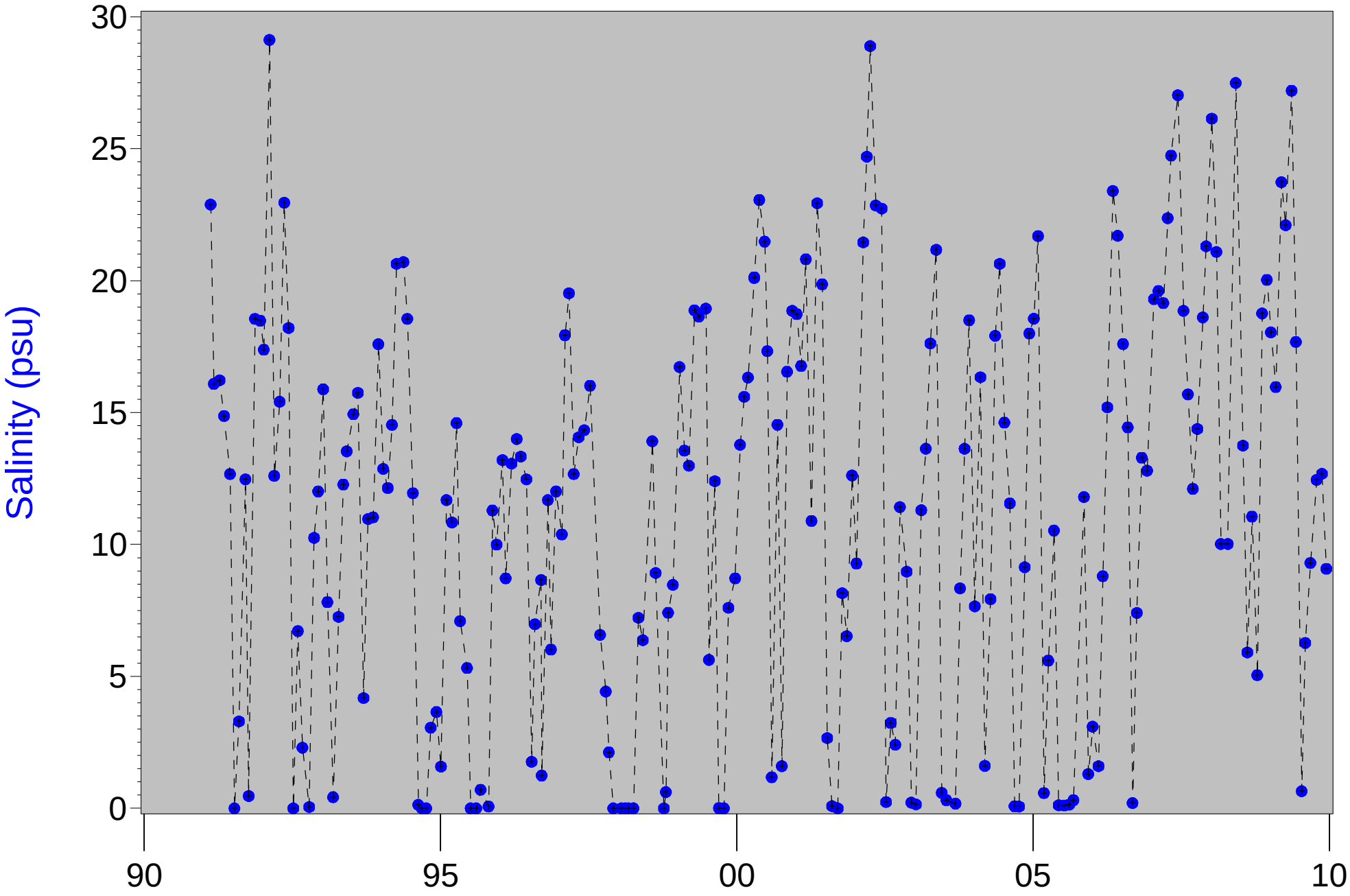


Figure 4.A8b Bottom salinity at Station #9 (River Kilometer -0.37) 1991-2009

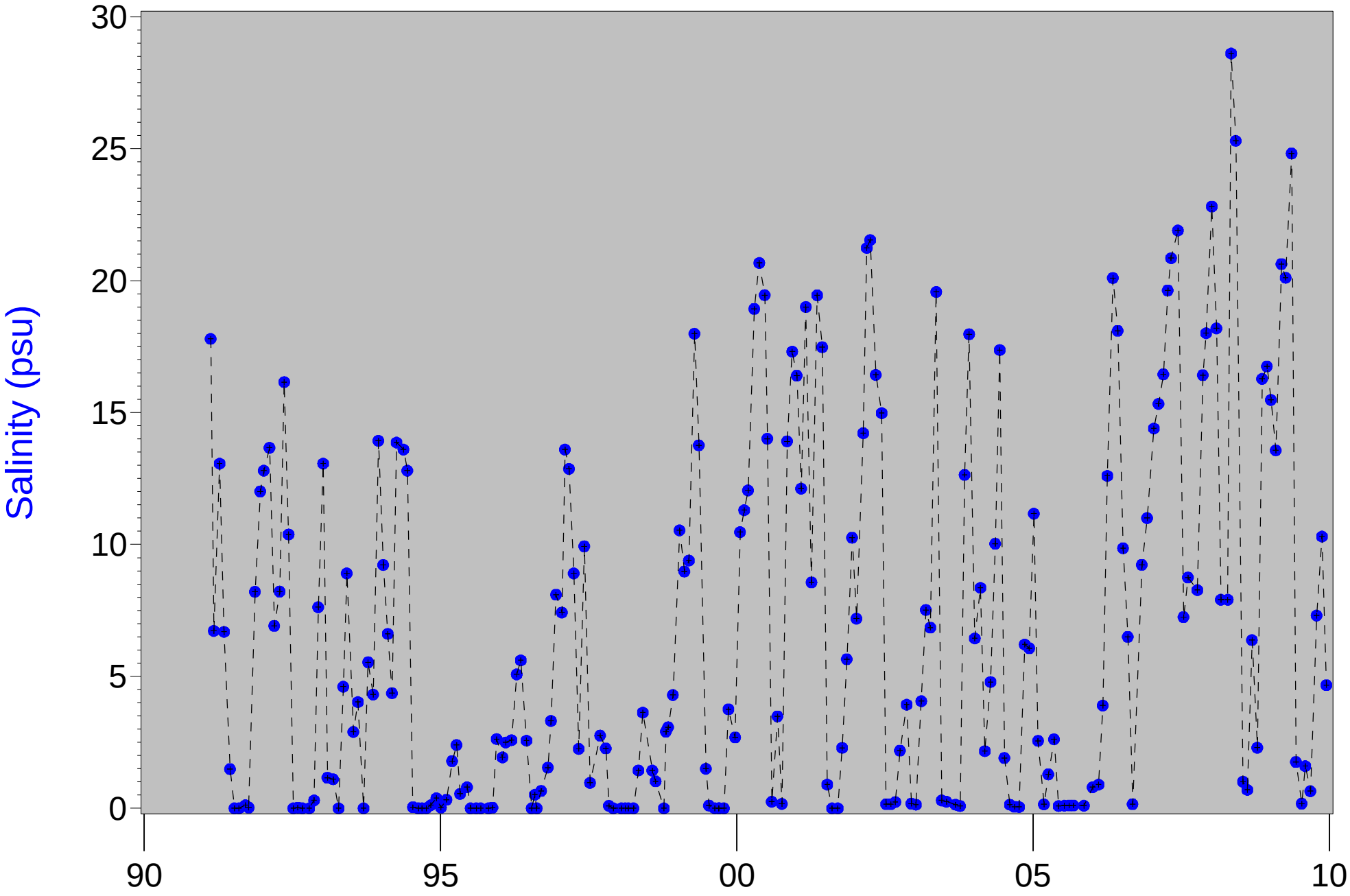


Figure 4.A9a Surface salinity at Station #8 in lower Peace River 1991-2009

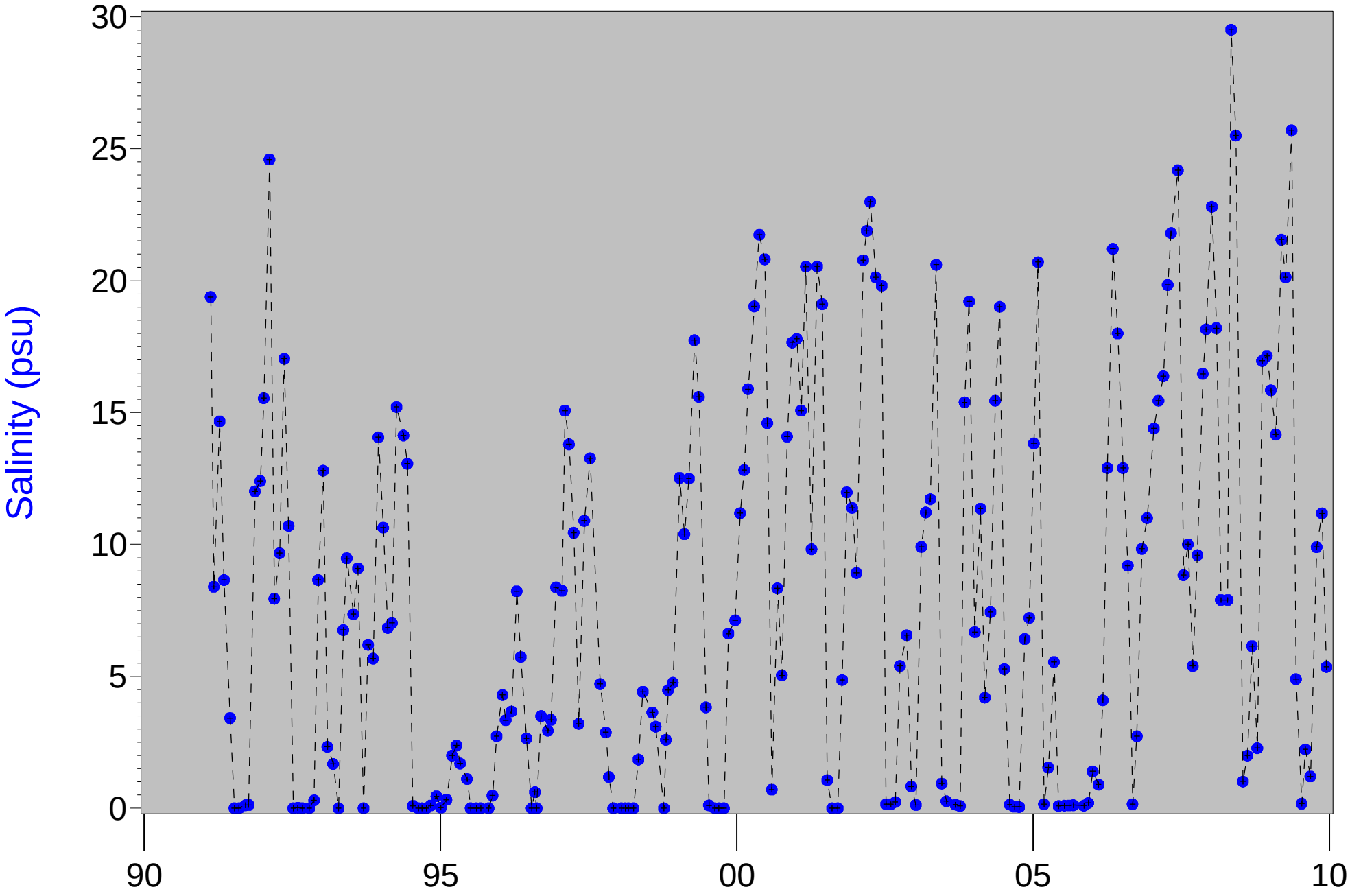


Figure 4.A9b Bottom salinity at Station #8 in lower Peace River 1991-2009

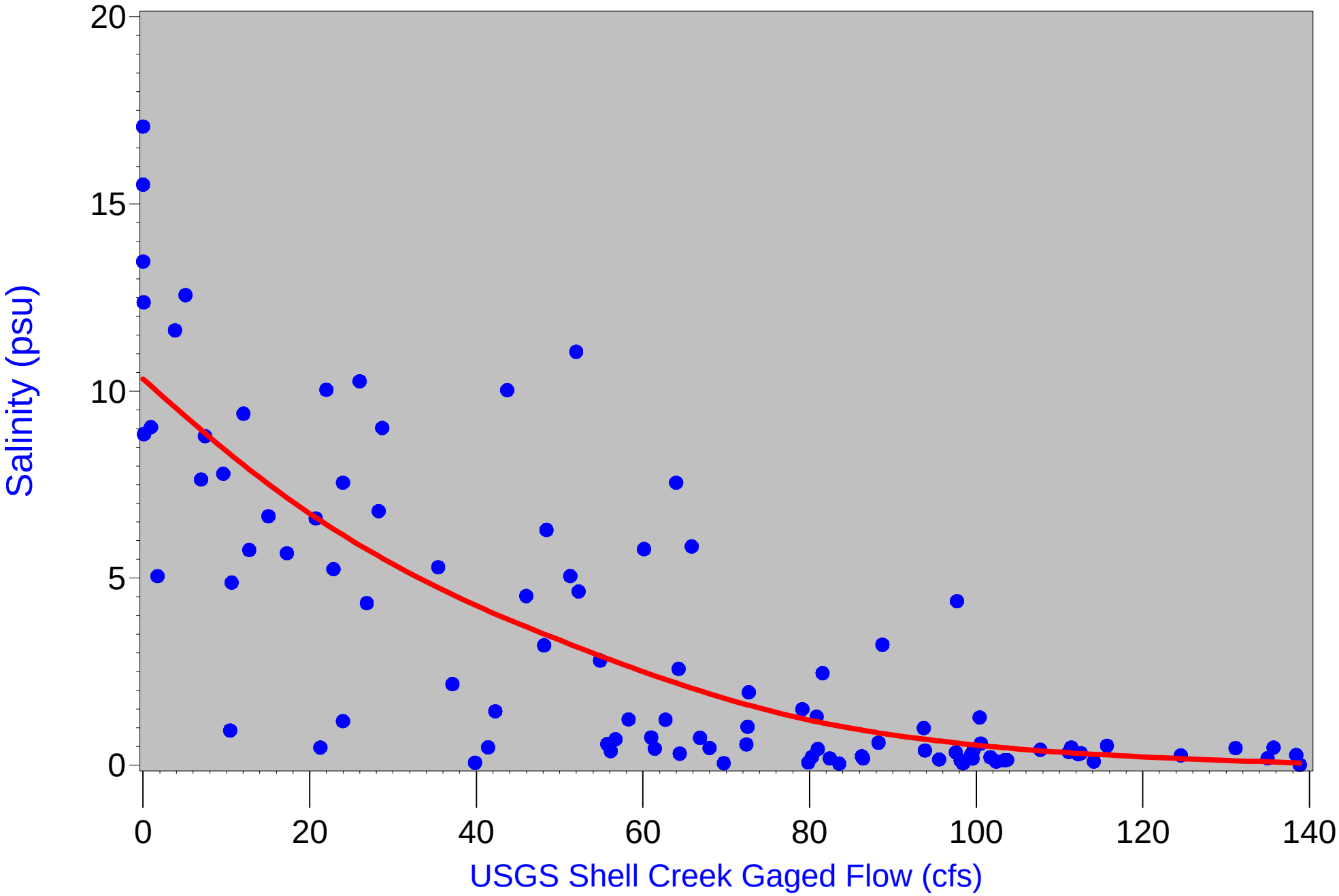


Figure 4.43a Mean salinity at Station #11 (River Kilometer 9.90) versus 7-day average Shell Creek flow 1991-2009

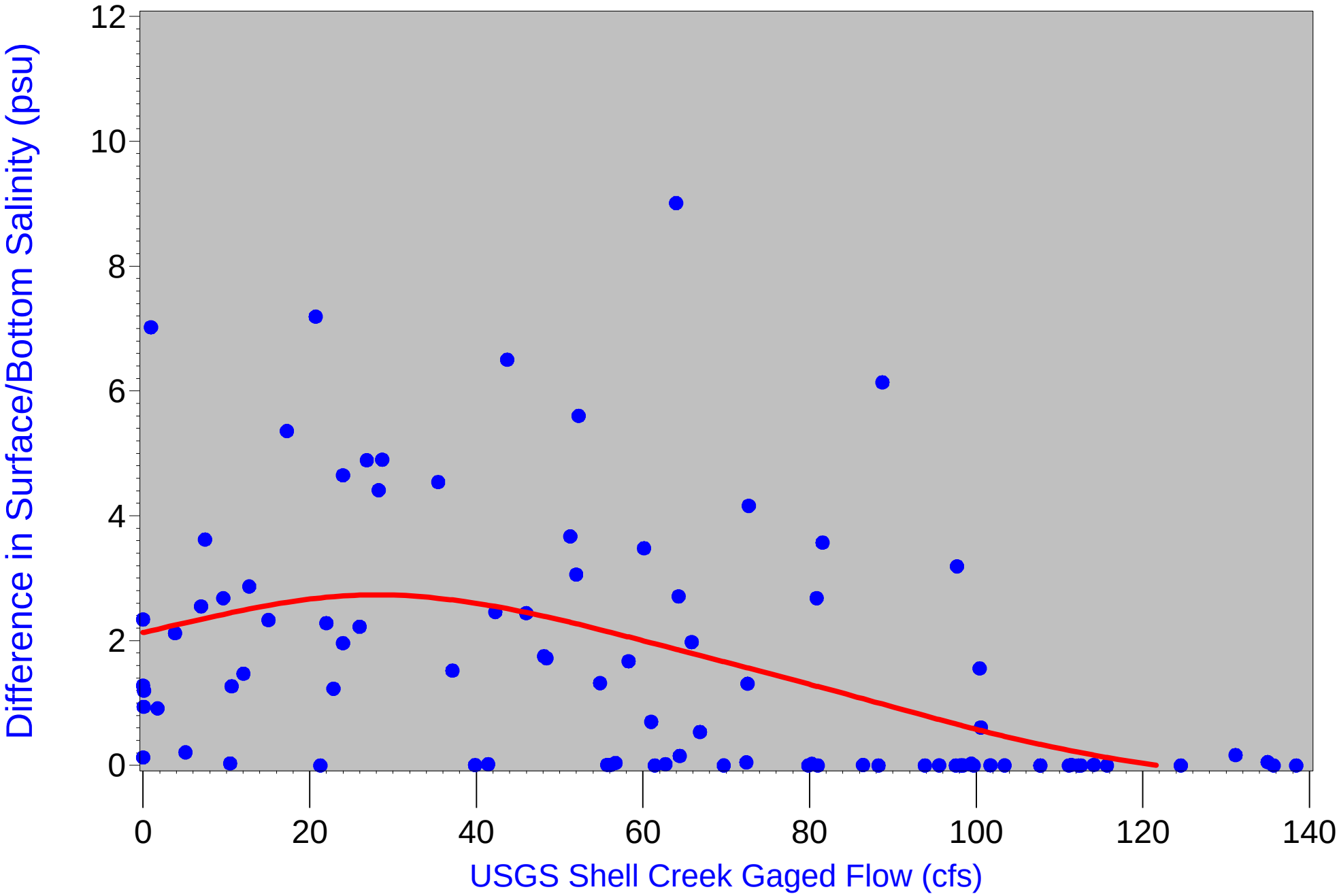


Figure 4.43b Salinity stratification at Station #11 (River Kilometer 9.90) versus 7-day average Shell Creek flow 1991-2009

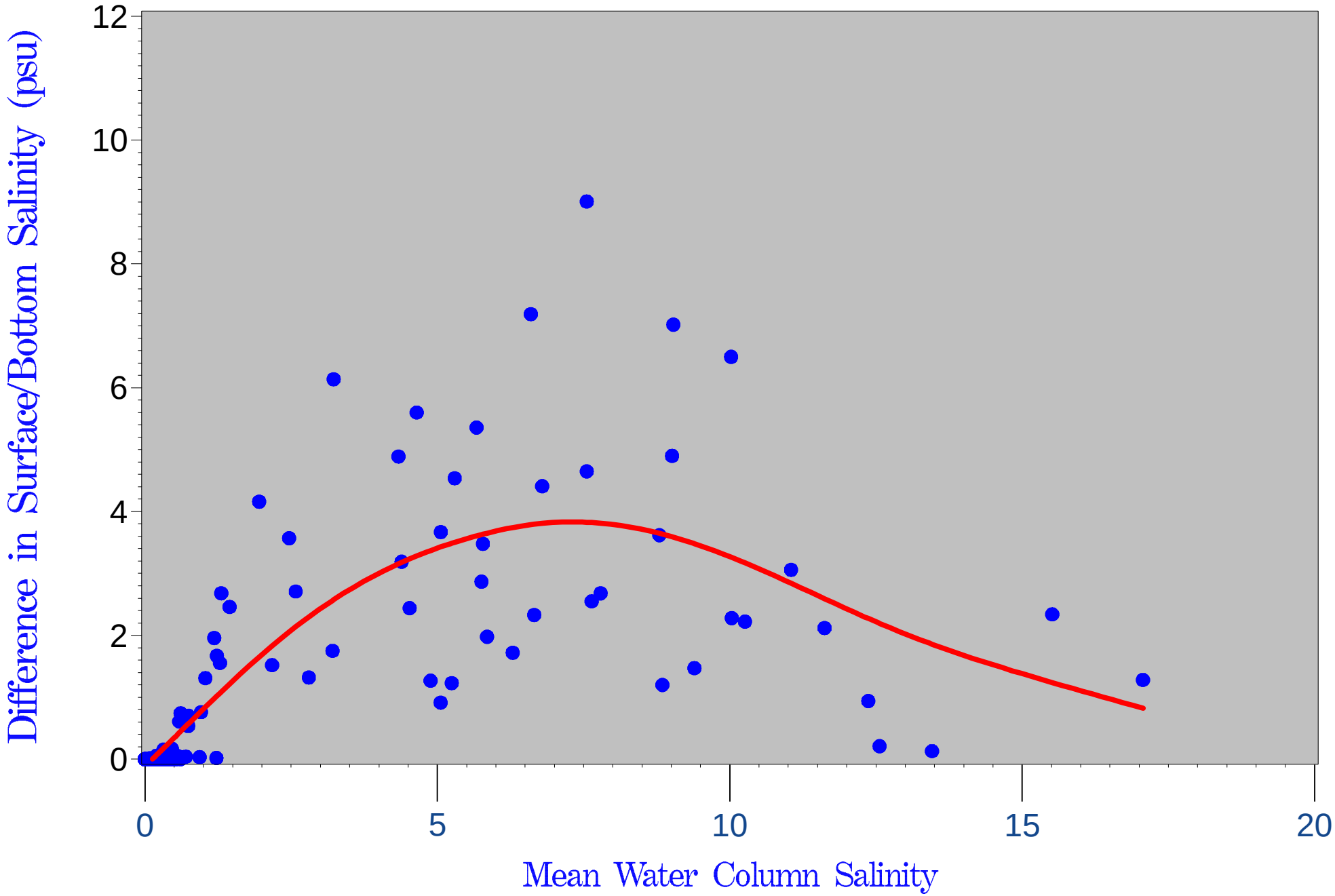


Figure 4.43c Salinity stratification at Station #11 (River Kilometer 9.90) versus mean water column salinity

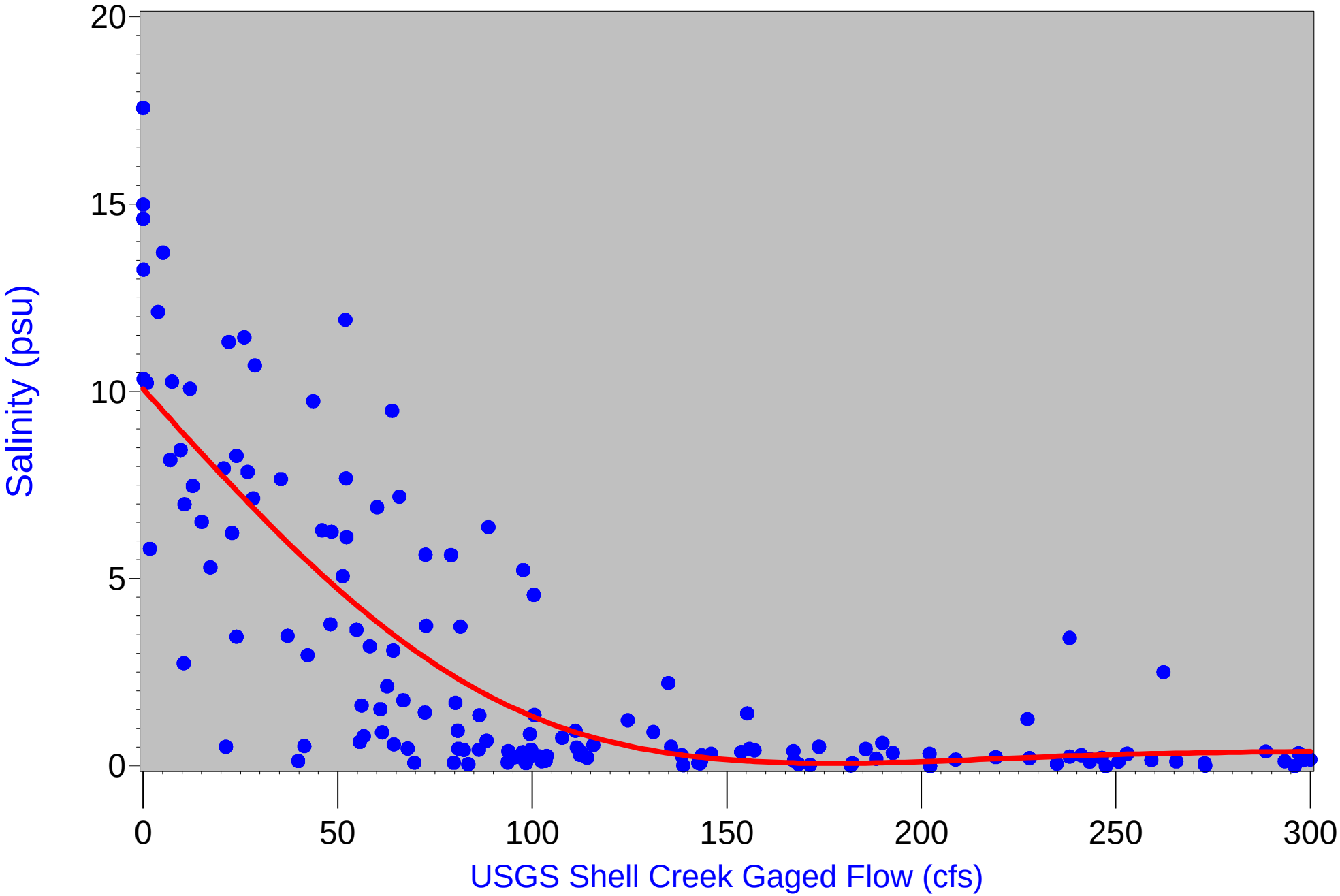


Figure 4.44a Mean salinity at Station #4 (River Kilometer 8.74) versus 7-day average Shell Creek flow 1991-2009

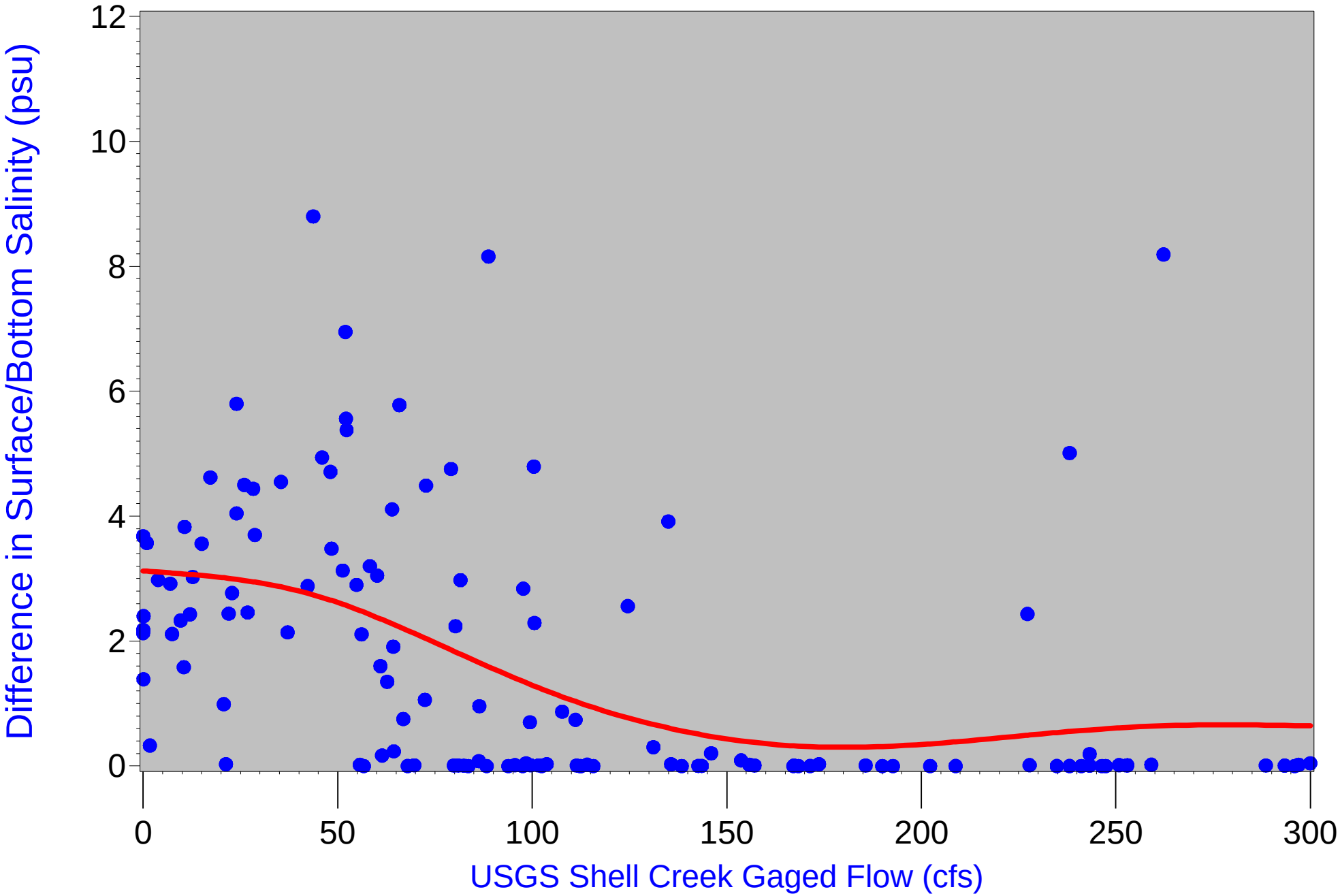


Figure 4.44b Salinity stratification at Station #4 (River Kilometer 8.74) versus 7-day average Shell Creek flow 1991-2009

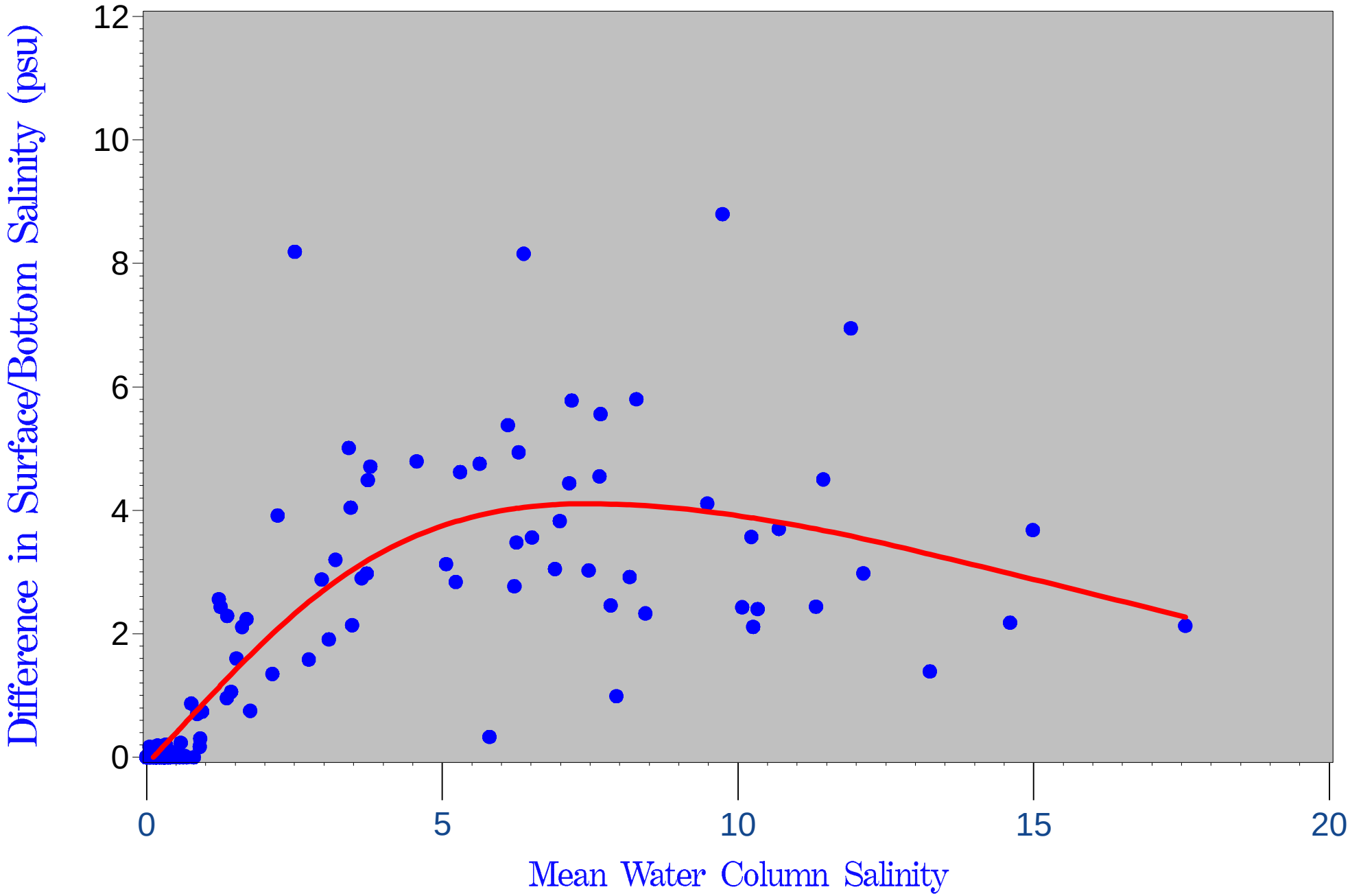


Figure 4.44c Salinity stratification at Station #4 (River Kilometer 8.74) versus mean water column salinity

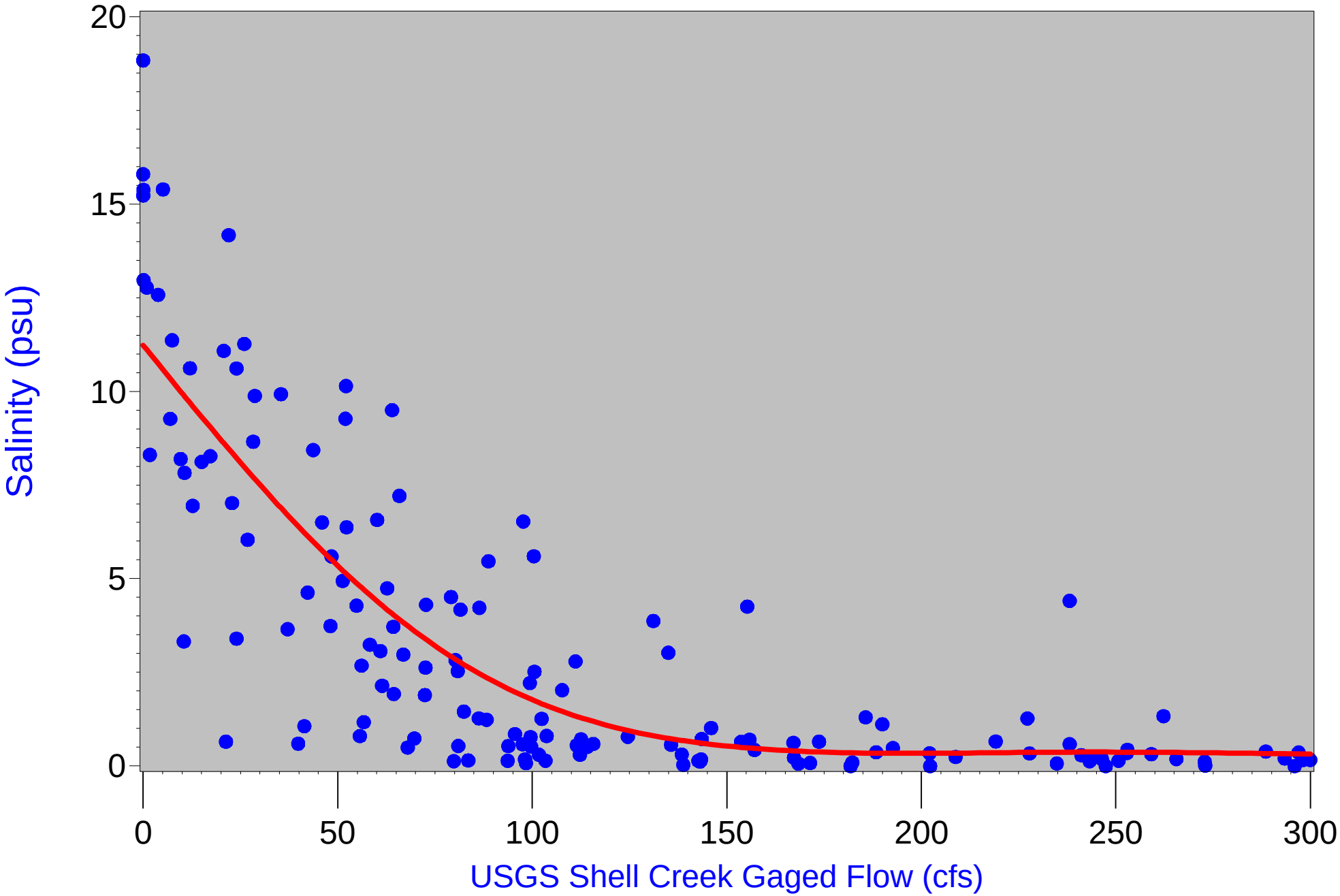


Figure 4.45a Mean salinity at Station #5 (River Kilometer 6.72) versus 7-day average Shell Creek flow 1991-2009

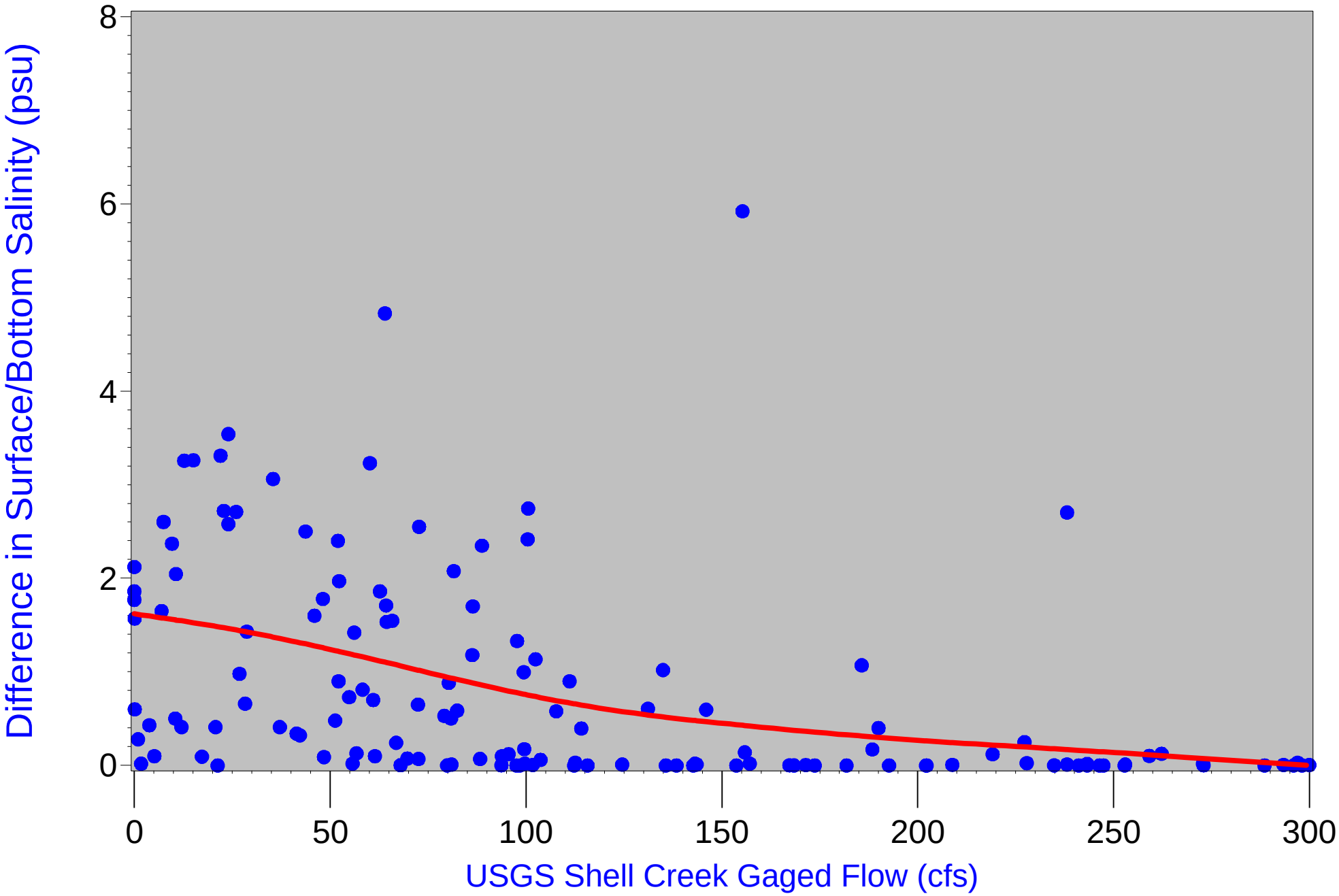


Figure 4.45b Salinity stratification at Station #5 (River Kilometer 6.72) versus 7-day average Shell Creek flow 1991-2009

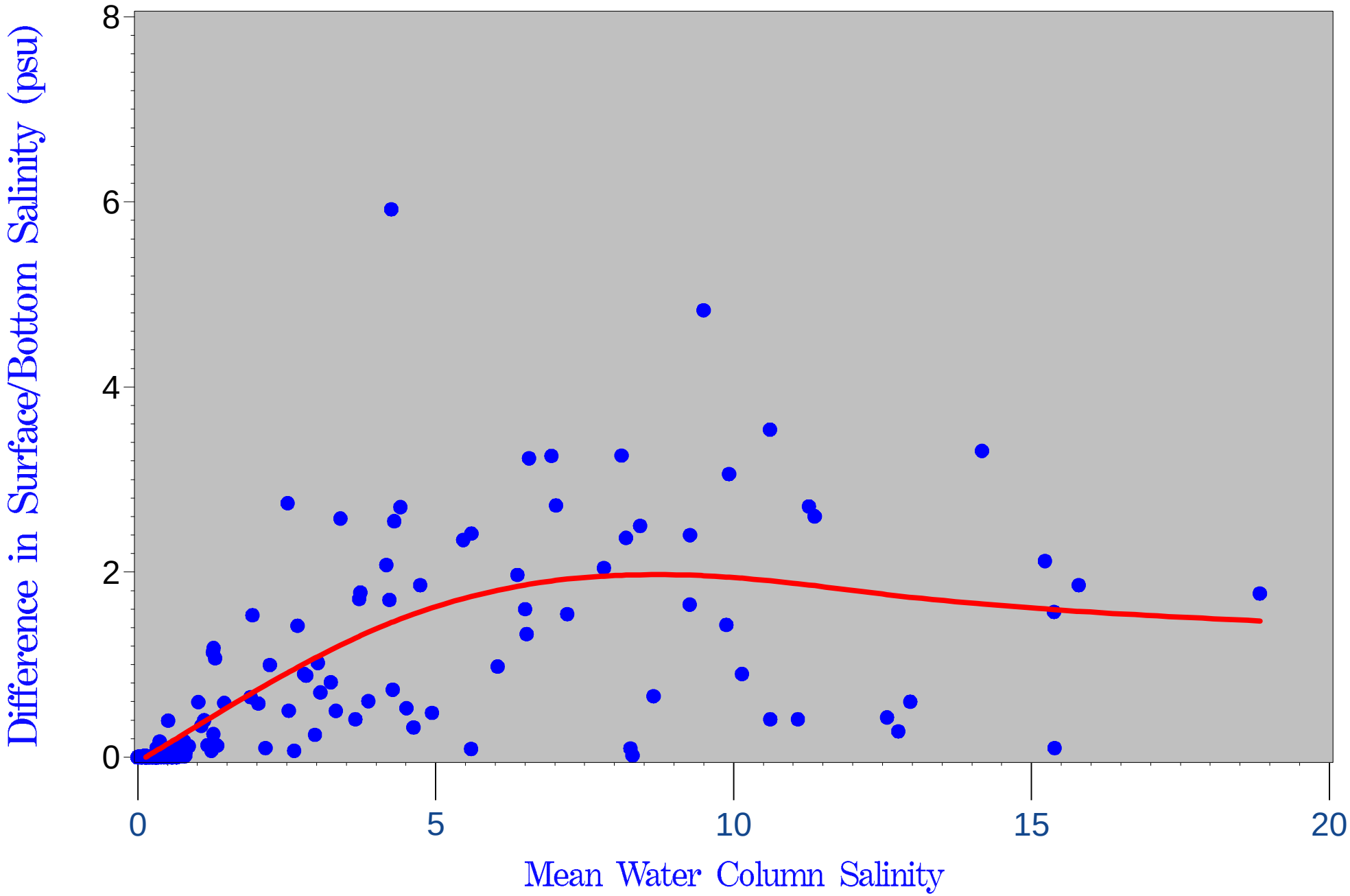


Figure 4.45c Salinity stratification at Station #5 (River Kilometer 6.72) versus mean water column salinity

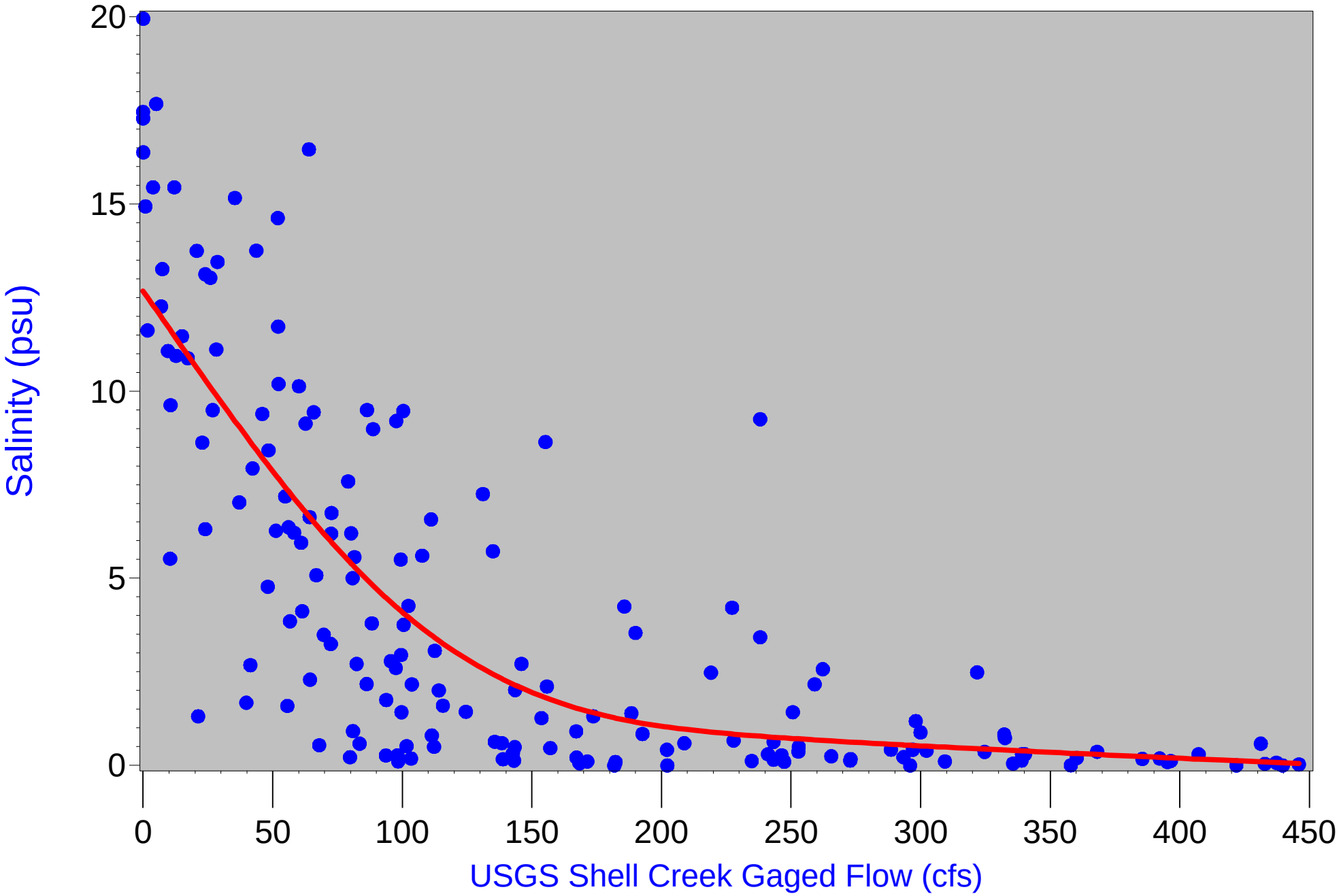


Figure 4.46a Mean salinity at Station #6 (River Kilometer 4.61) versus 7-day average Shell Creek flow 1991-2009

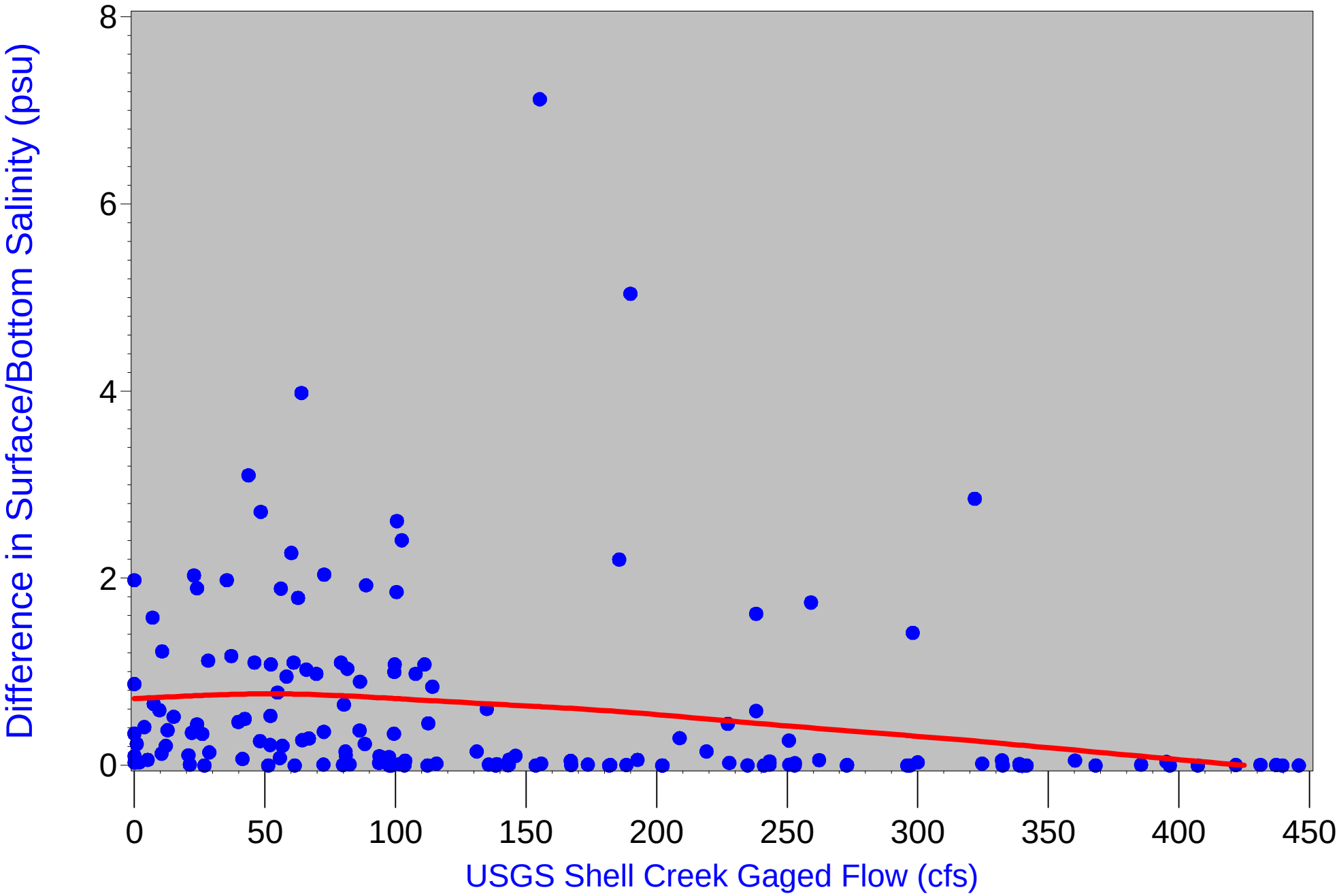


Figure 4.46b Salinity stratification at Station #6 (River Kilometer 4.61) versus 7-day average Shell Creek flow 1991-2009

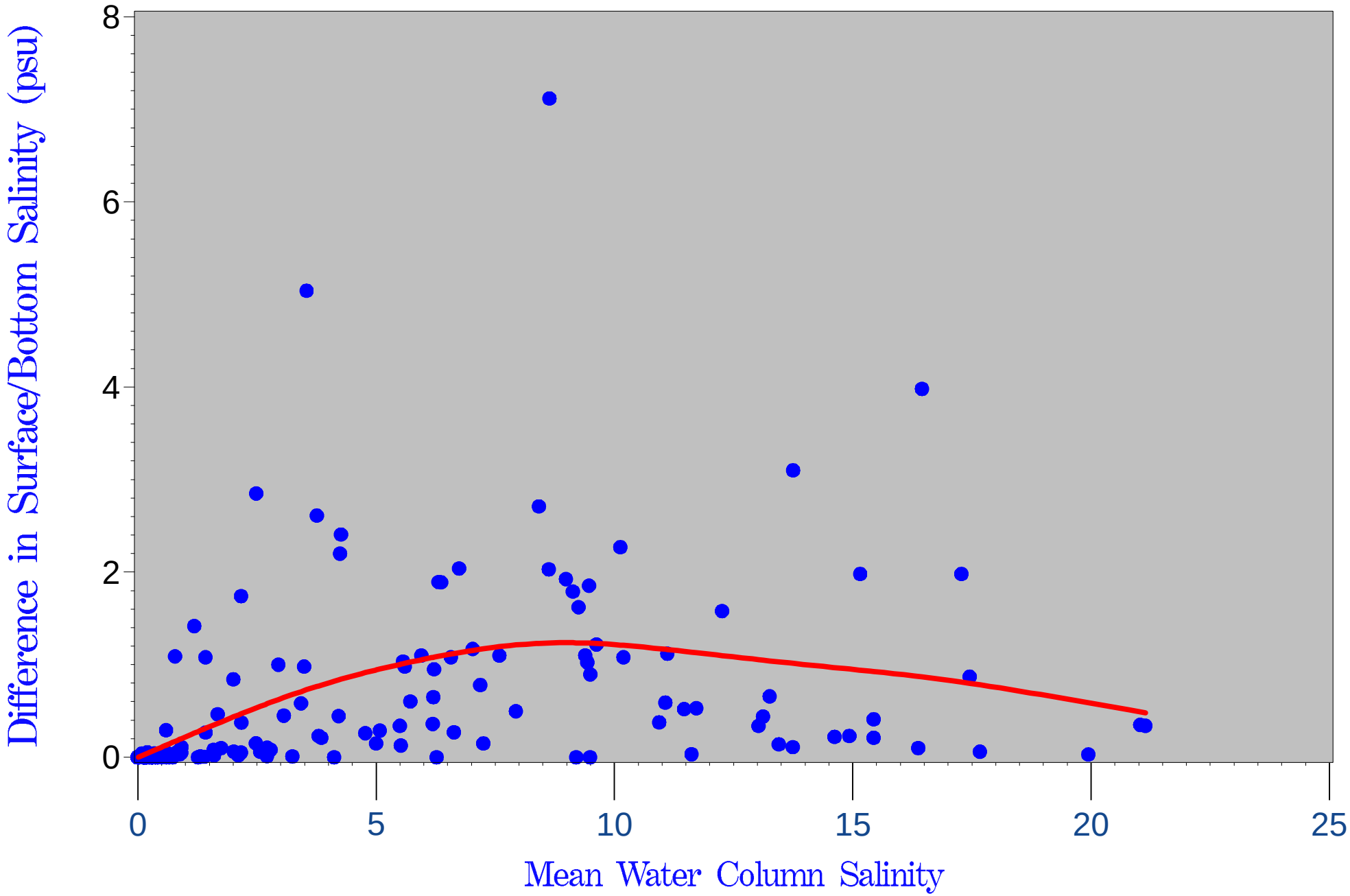


Figure 4.46c Salinity stratification at Station #6 (River Kilometer 4.61) versus mean water column salinity

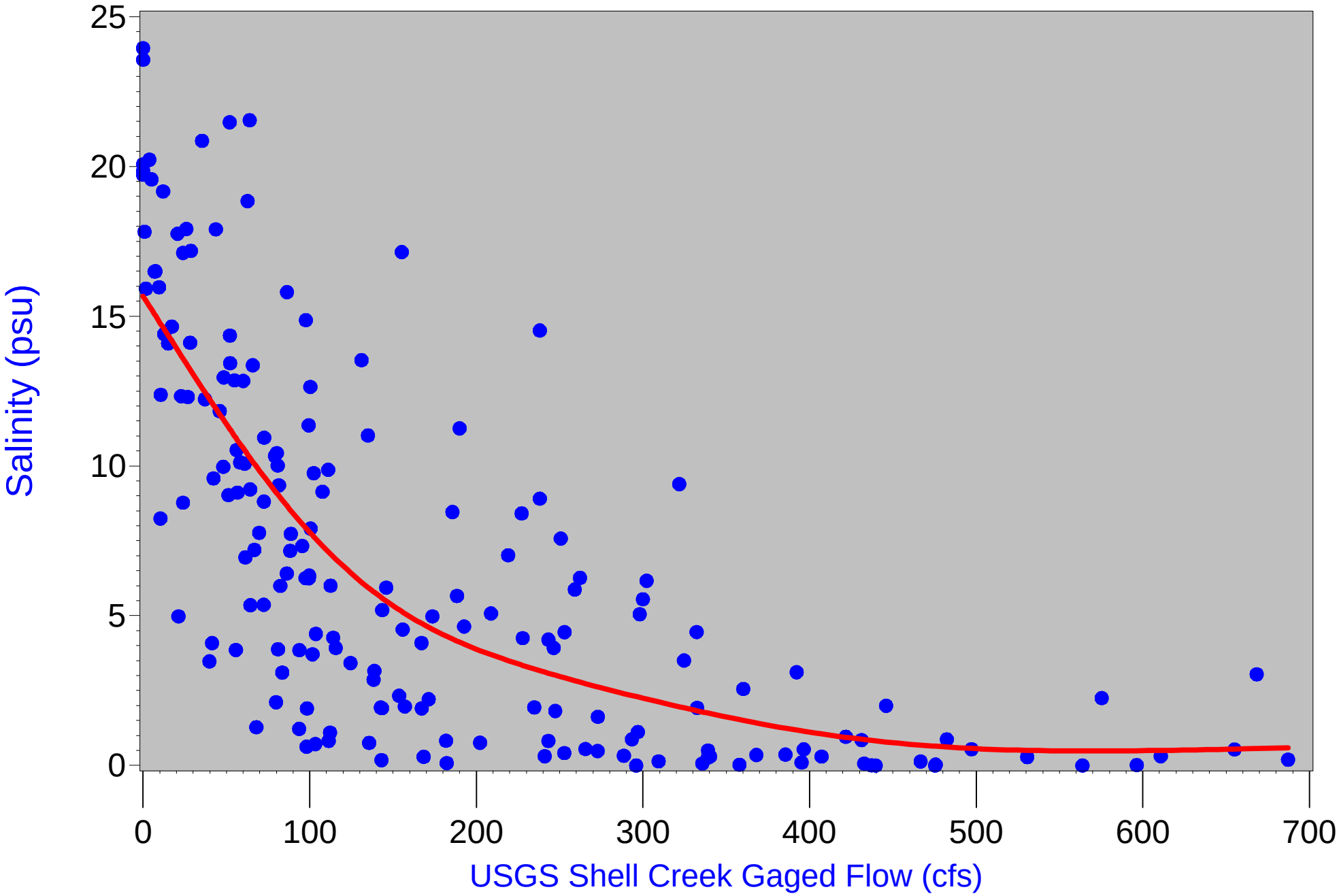


Figure 4.47a Mean salinity at Station #7 (River Kilometer 2.35) versus 7-day average Shell Creek flow 1991-2009

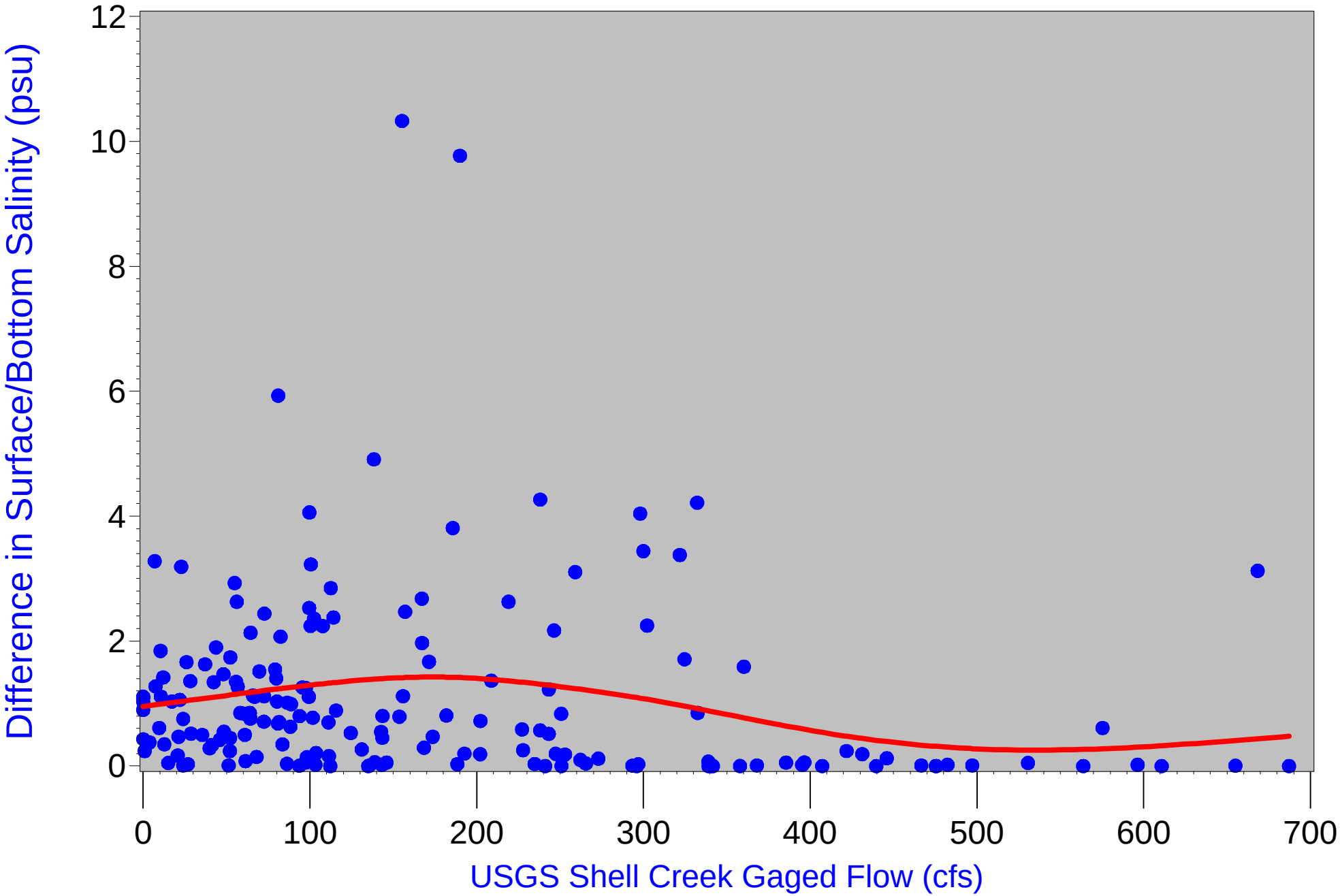


Figure 4.47b Salinity stratification at Station #7 (River Kilometer 2.35) versus 7-day average Shell Creek flow 1991-2009

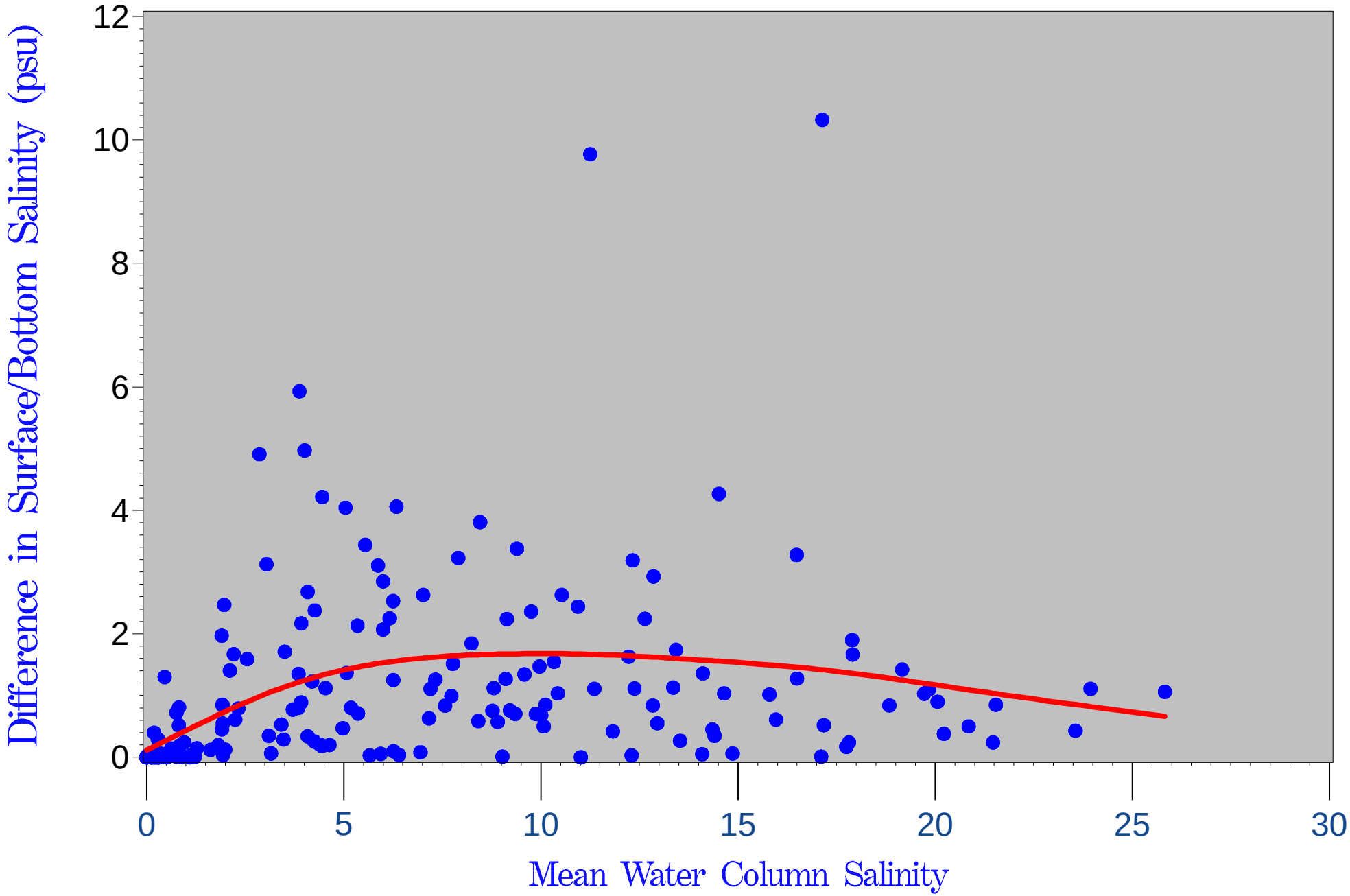


Figure 4.47c Salinity stratification at Station #7 (River Kilometer 2.35) versus mean water column salinity

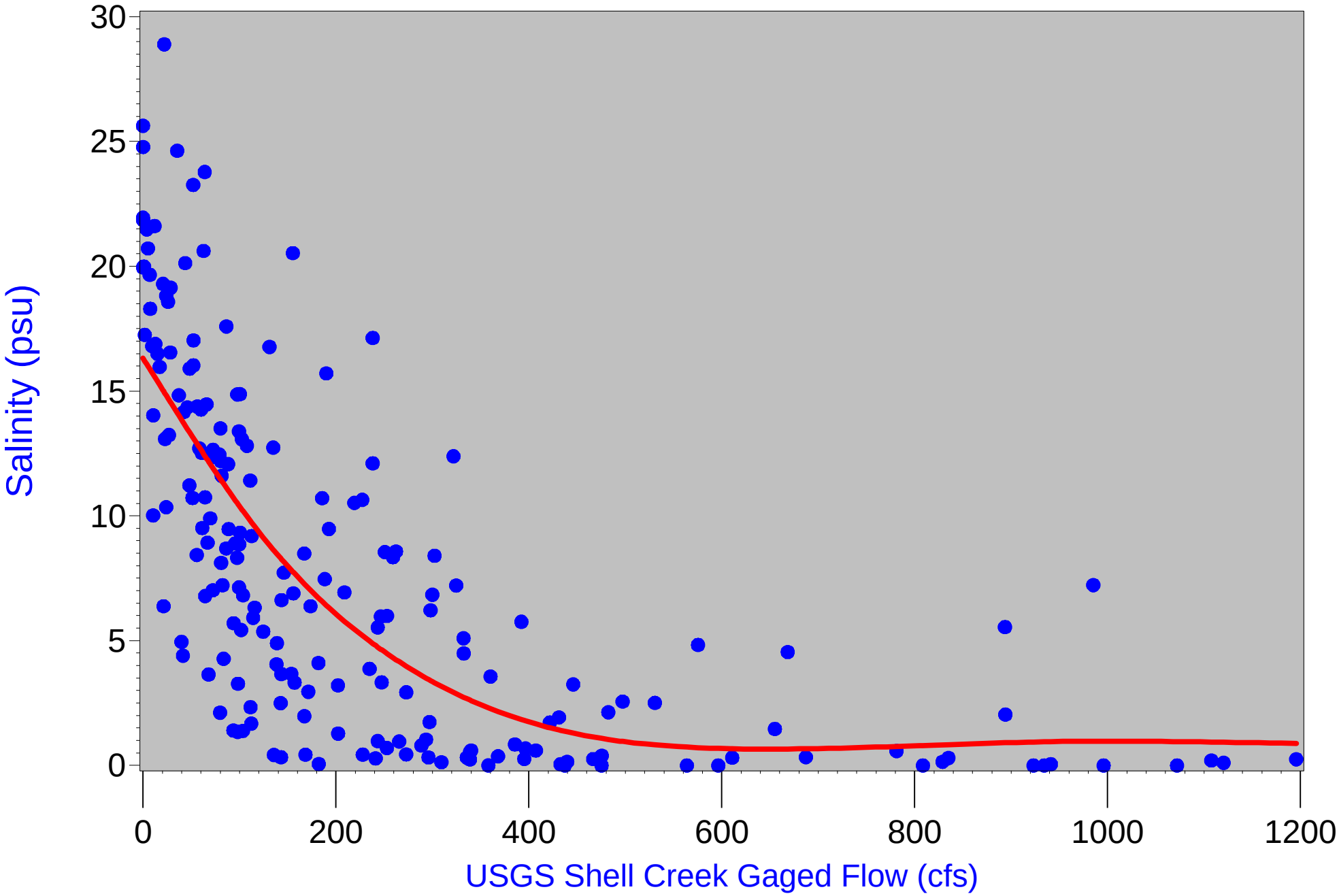


Figure 4.48a Mean salinity at Station #16 (River Kilometer 1.26) versus 7-day average Shell Creek flow 1991-2009

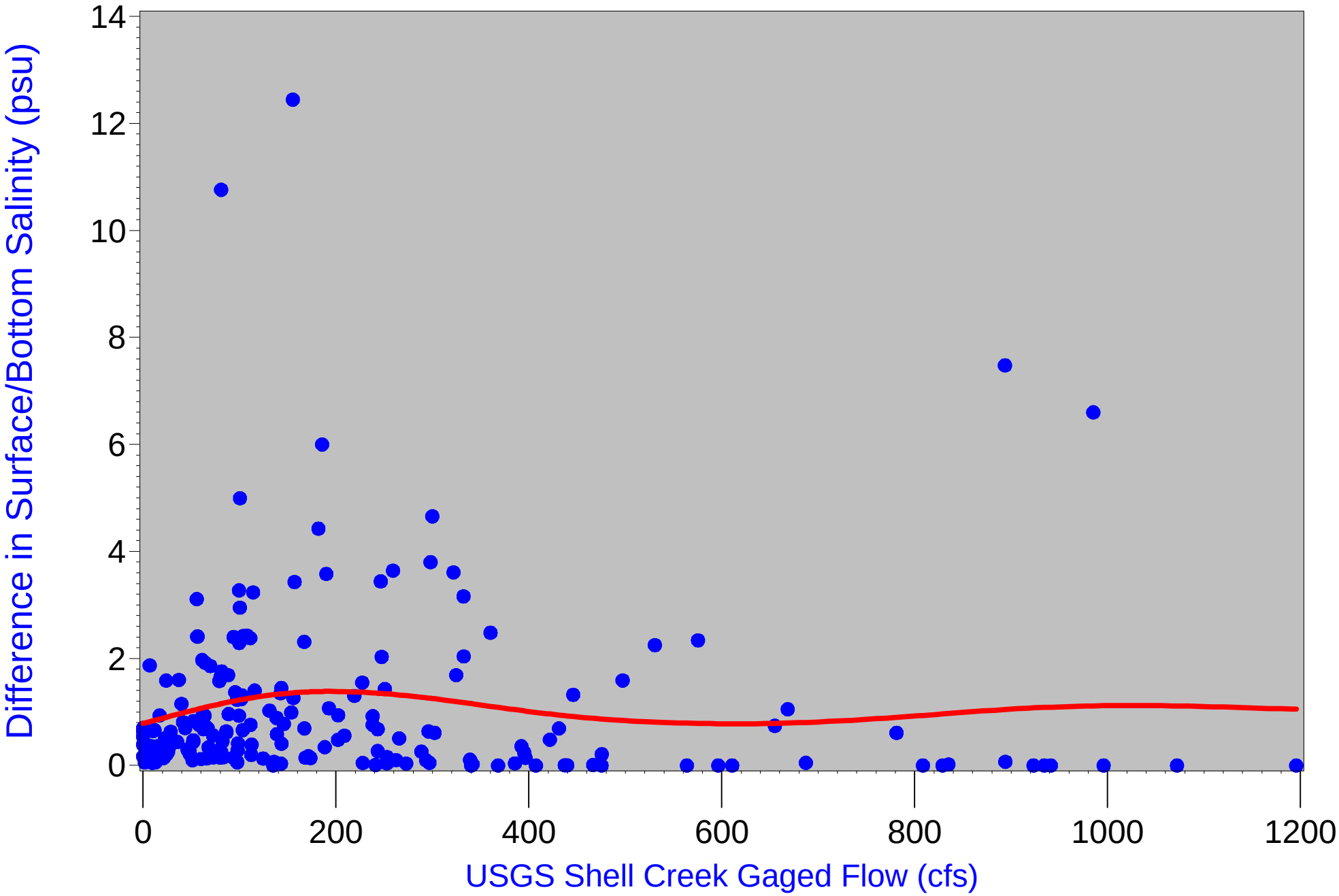


Figure 4.48b Salinity stratification at Station #16 (River Kilometer 1.26) versus 7-day average Shell Creek flow 1991-2009

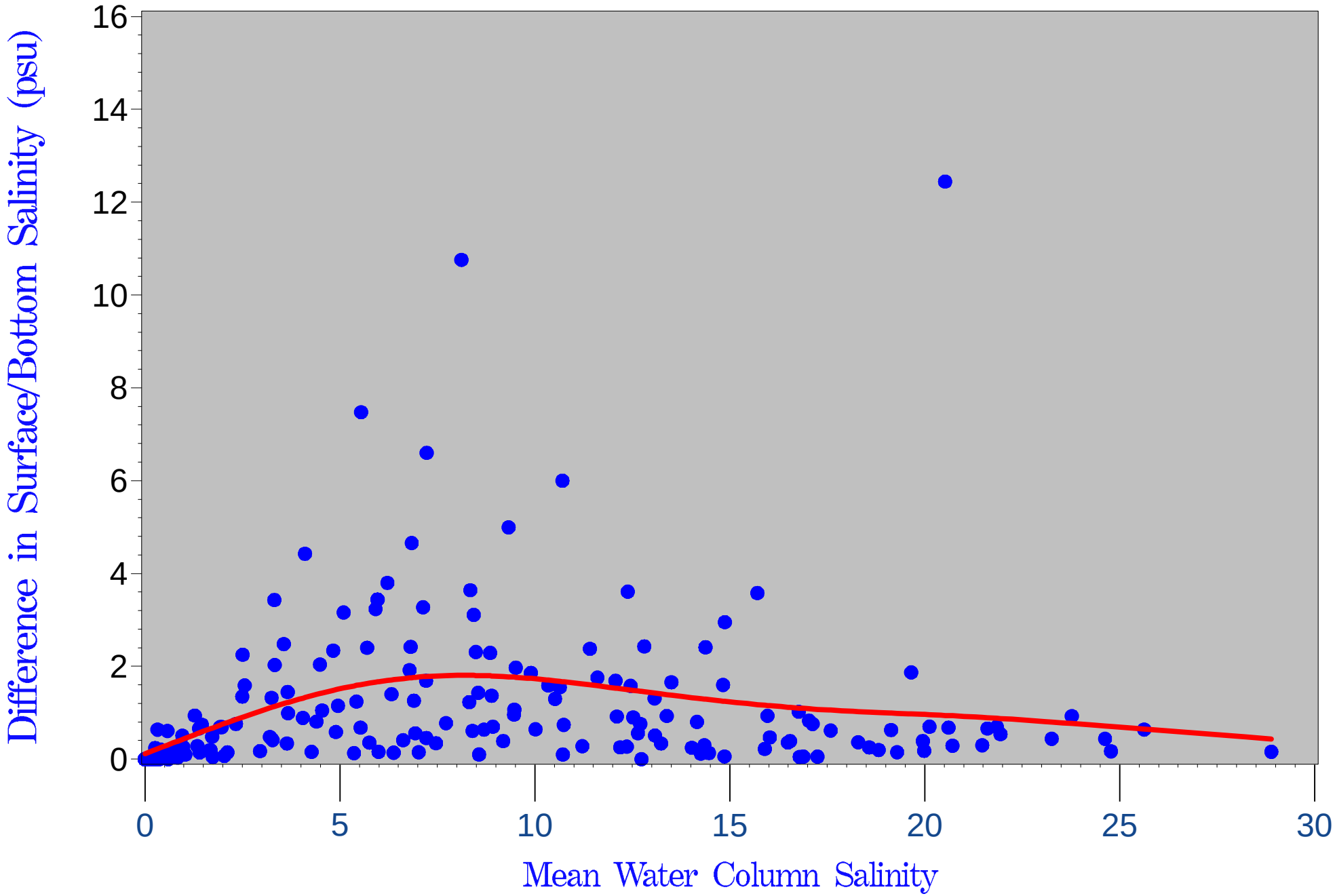


Figure 4.48c Salinity stratification at Station #16 (River Kilometer 1.26) versus mean water column salinity

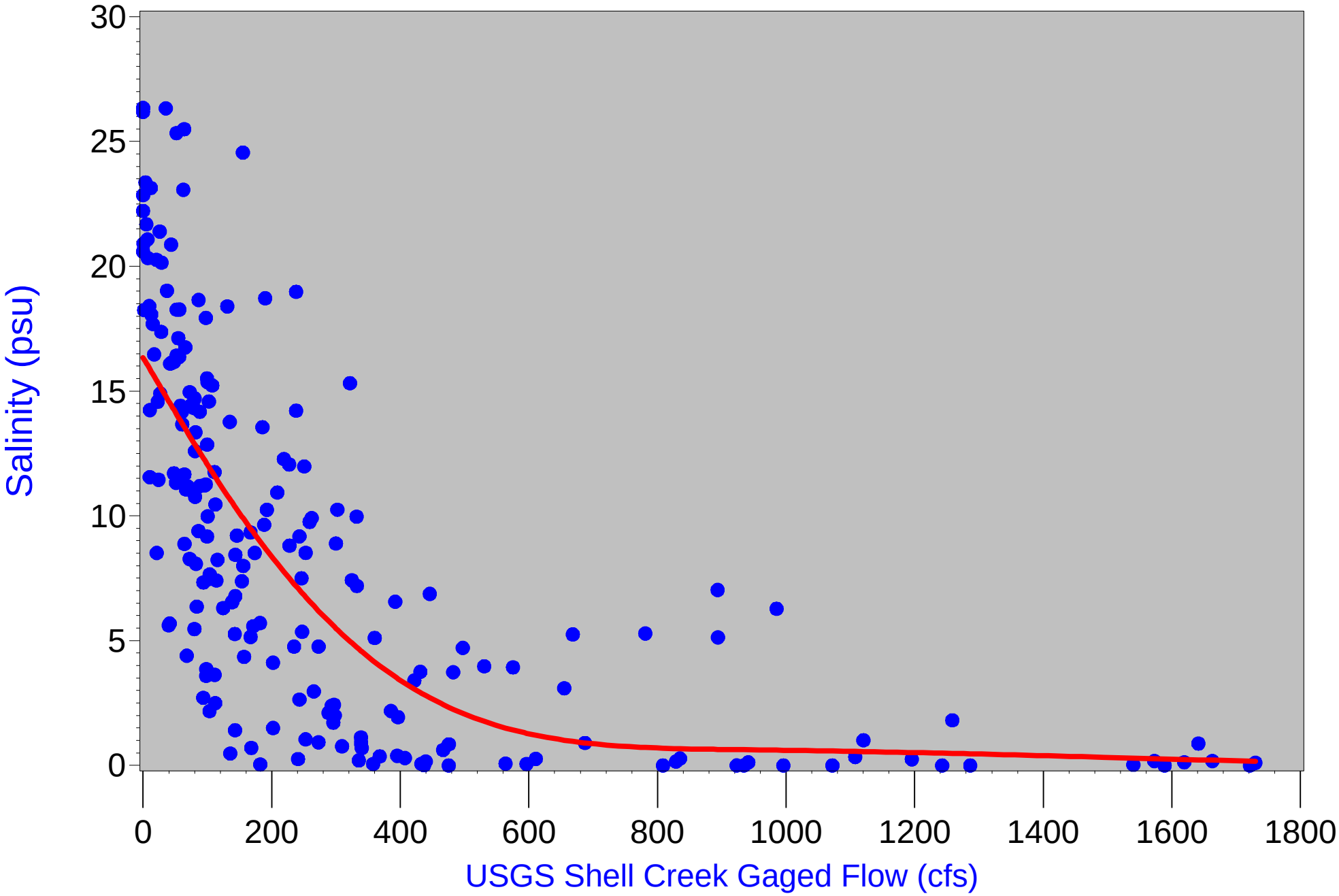


Figure 4.49a Mean salinity at Station #17 (River Kilometer 0.43) versus 7-day average Shell Creek flow 1991-2009

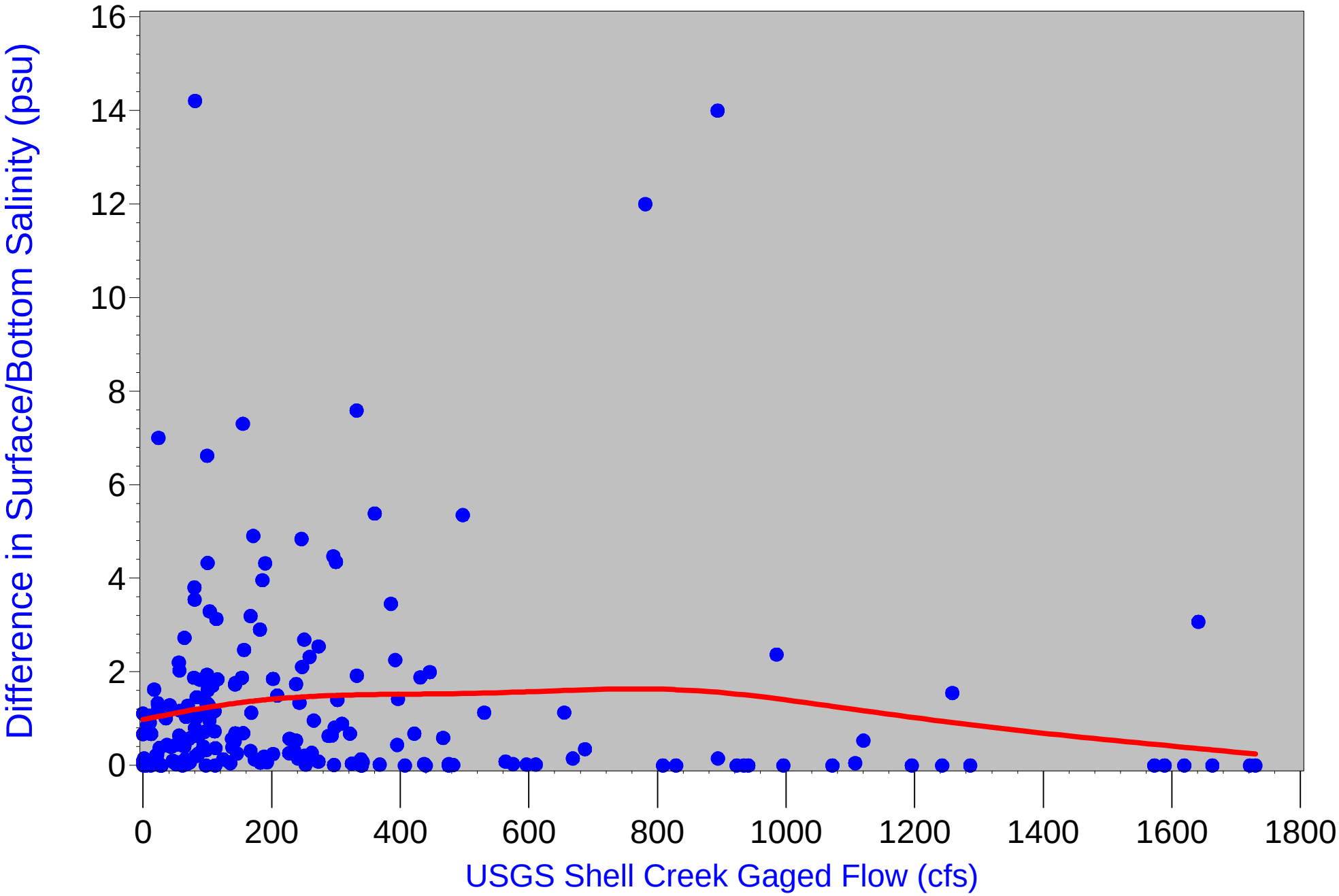


Figure 4.49b Salinity stratification at Station #17 (River Kilometer 0.43) versus 7-day average Shell Creek flow 1991-2009

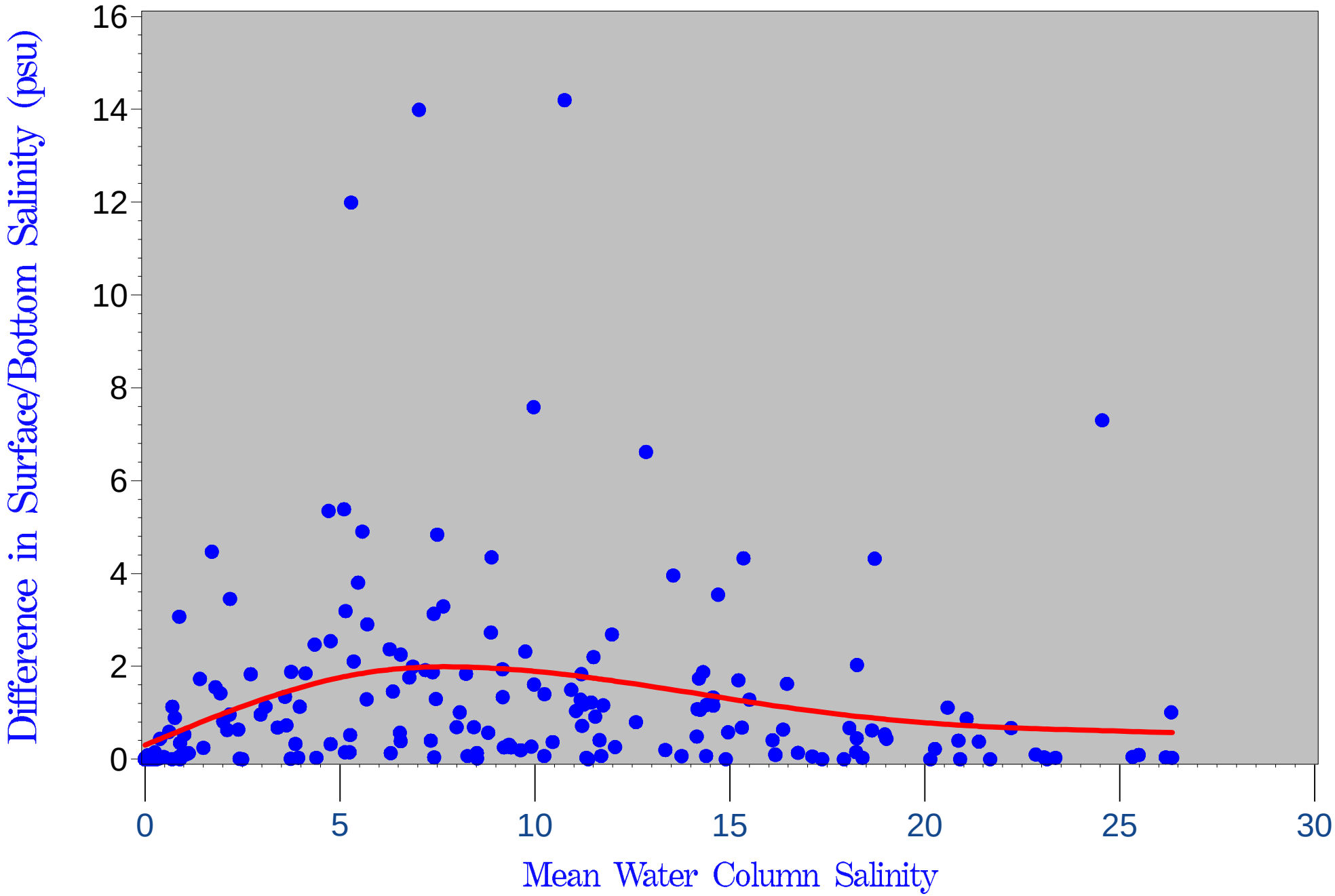


Figure 4.49c Salinity stratification at Station #17 (River Kilometer 0.43) versus mean water column salinity

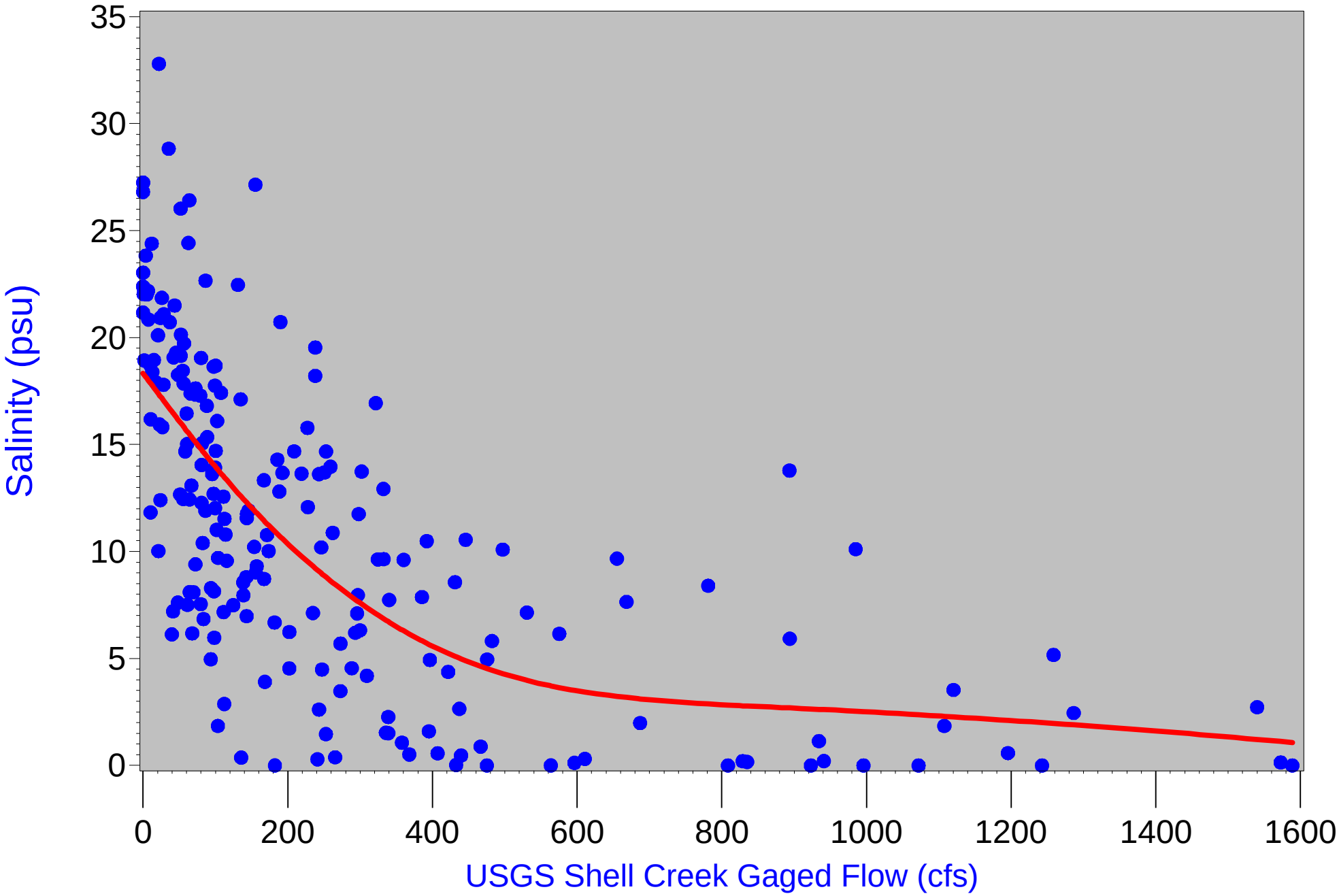


Figure 4.50a Mean salinity at Station #9 (River Kilometer -0.37) versus 7-day average Shell Creek flow 1991-2009

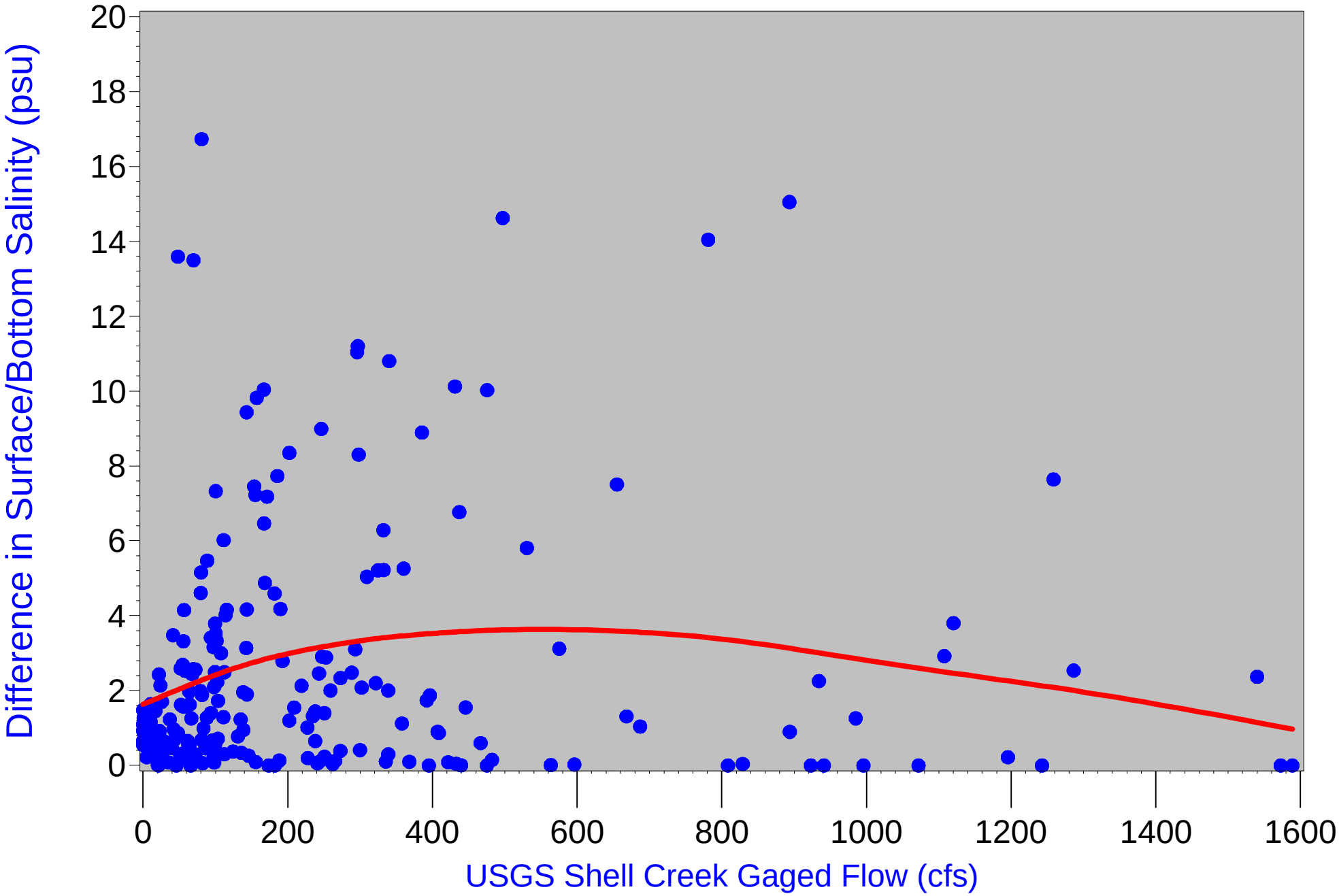


Figure 4.50b Salinity stratification at Station #9 (River Kilometer -0.37) versus 7-day average Shell Creek flow 1991-2009

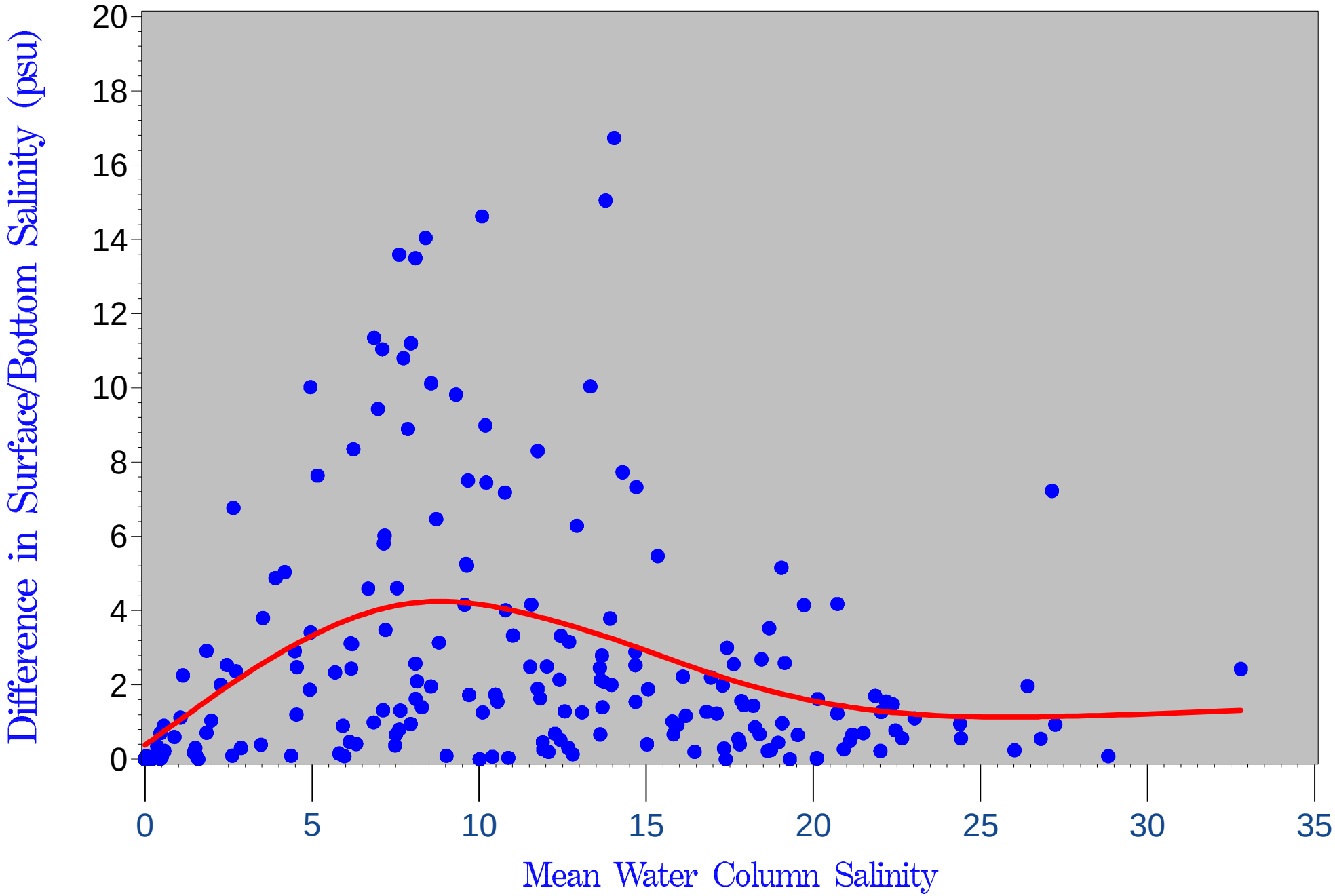


Figure 4.50c Salinity stratification at Station #9 (River Kilometer -0.37) versus mean water column salinity

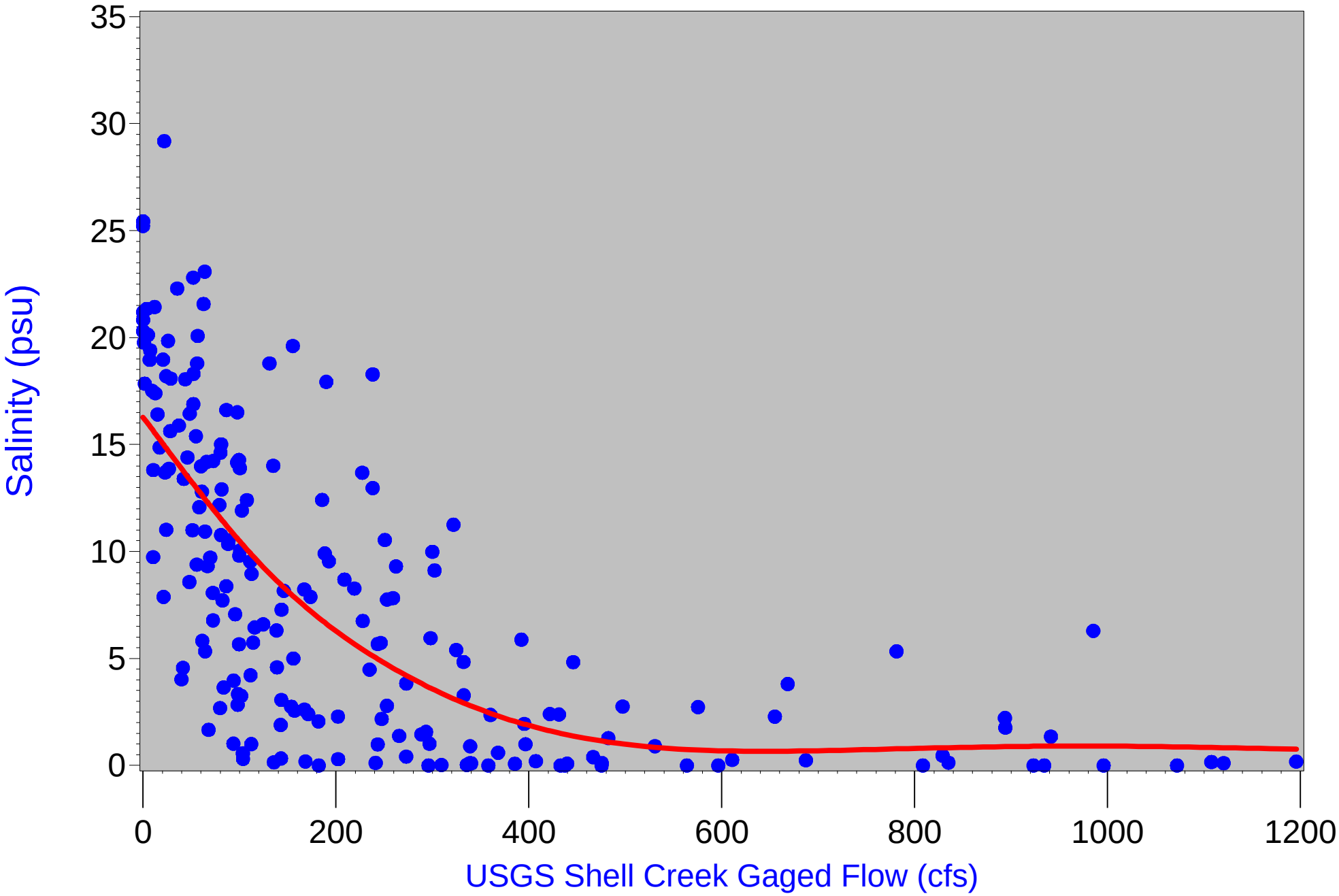


Figure 4.51a Mean salinity at Station #8 in lower Peace River versus 7-day average Shell Creek flow 1991-2009

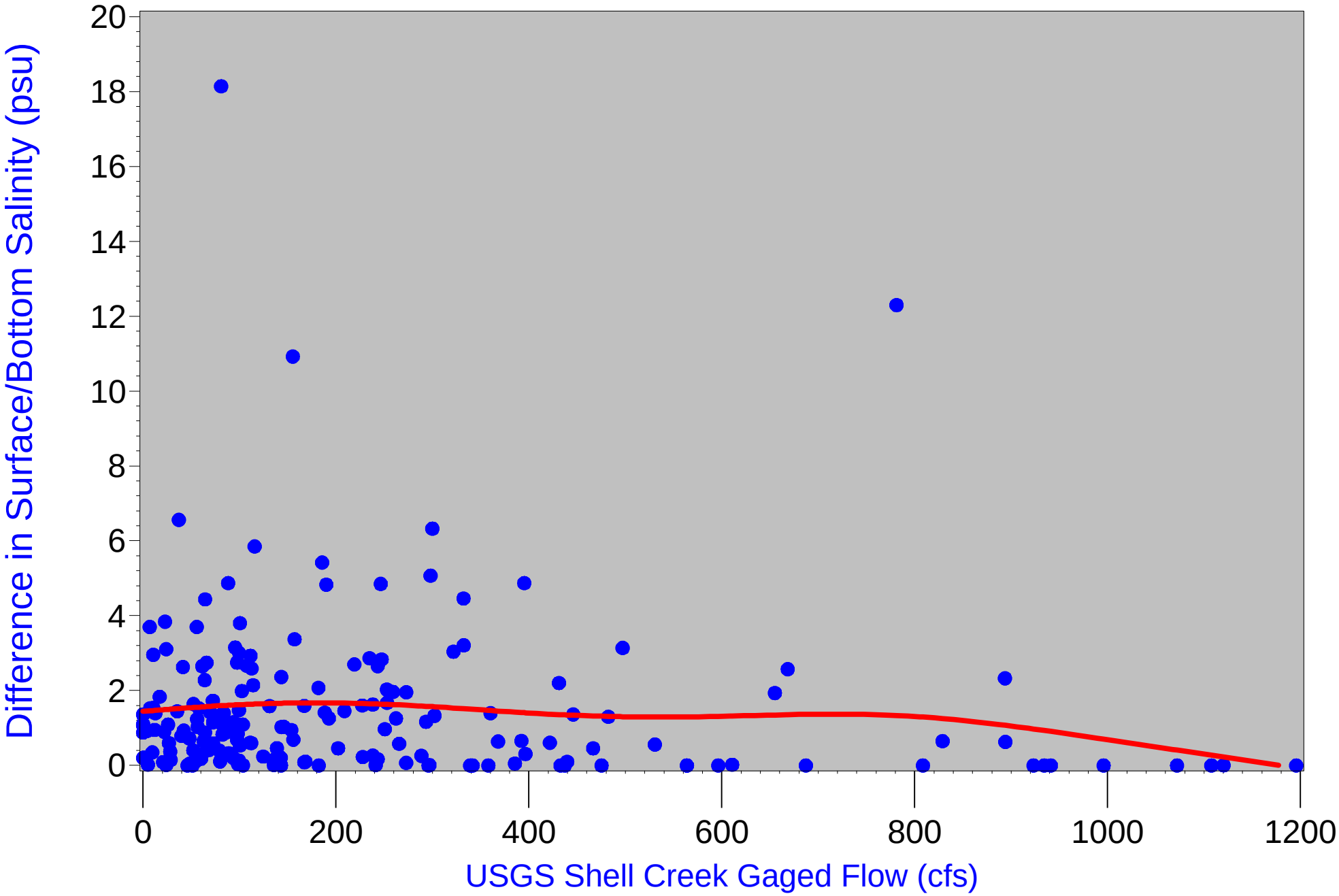


Figure 4.51b Salinity stratification at Station #8 in lower Peace River versus 7-day average Shell Creek flow 1991-2009

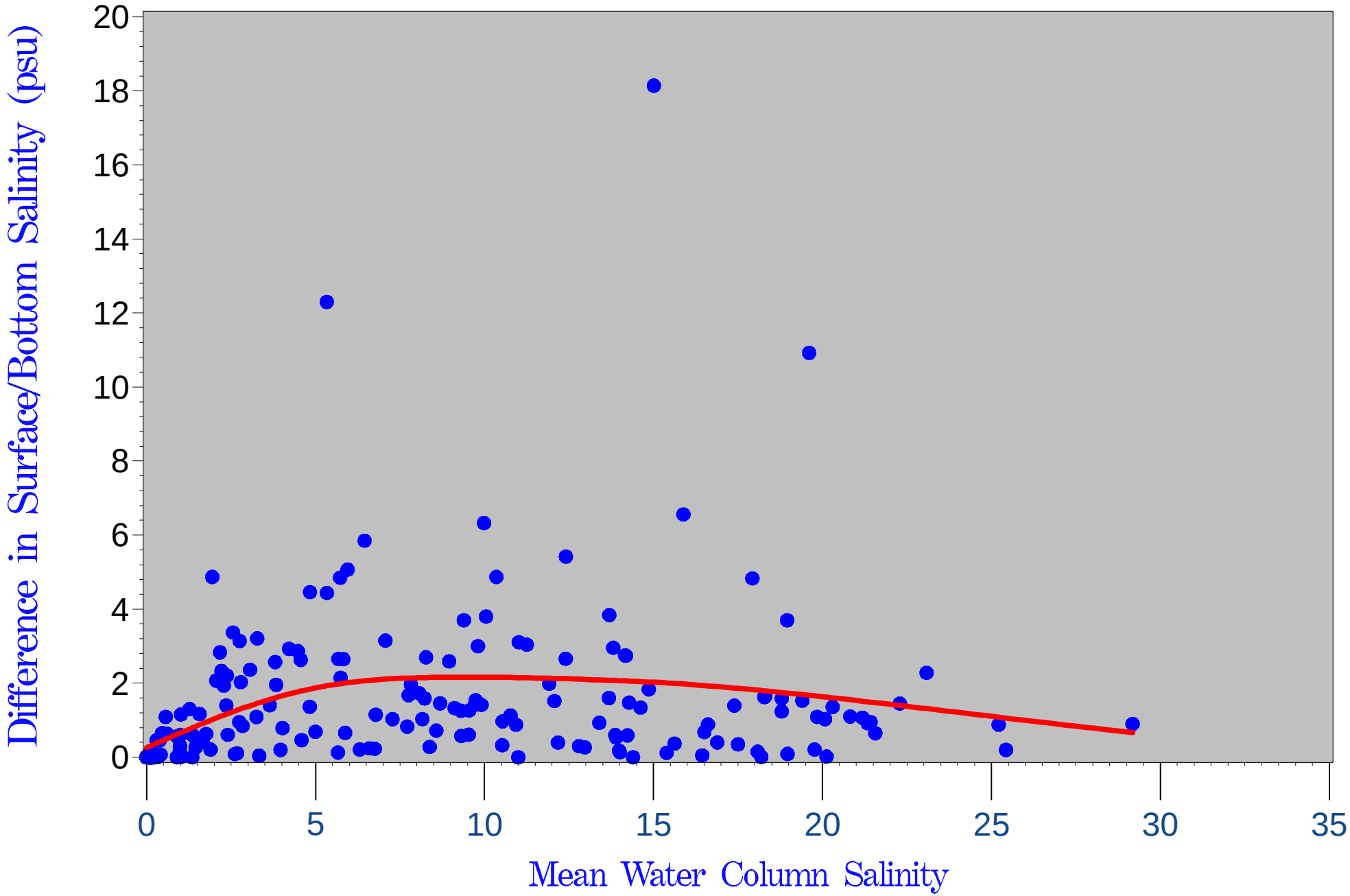


Figure 4.51c Salinity stratification at Station #8 versus mean water column salinity

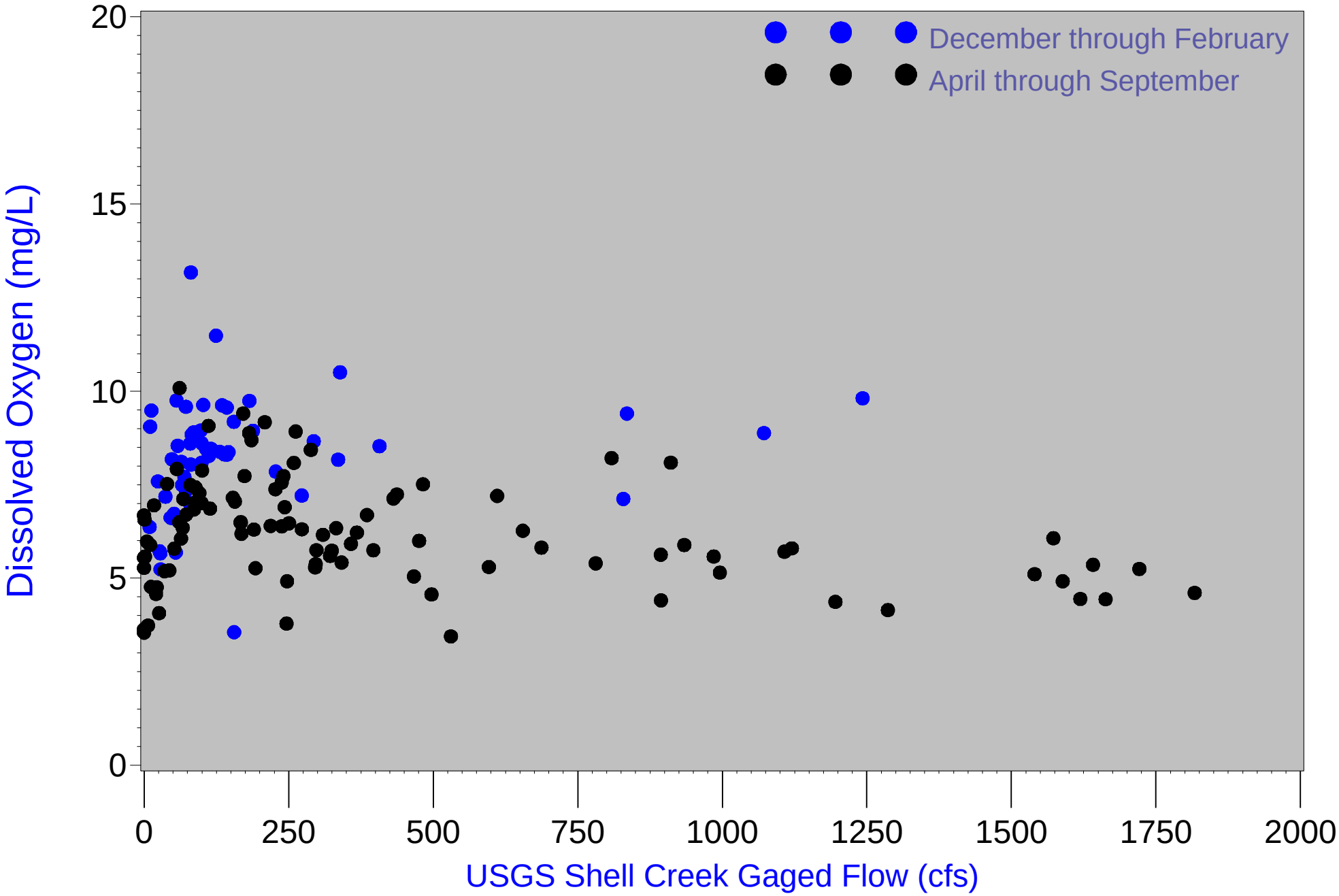


Figure 4.52a Surface D.O. at Station #11 (River Kilometer 9.90) versus 7-day average Shell Creek flow 1991-2009

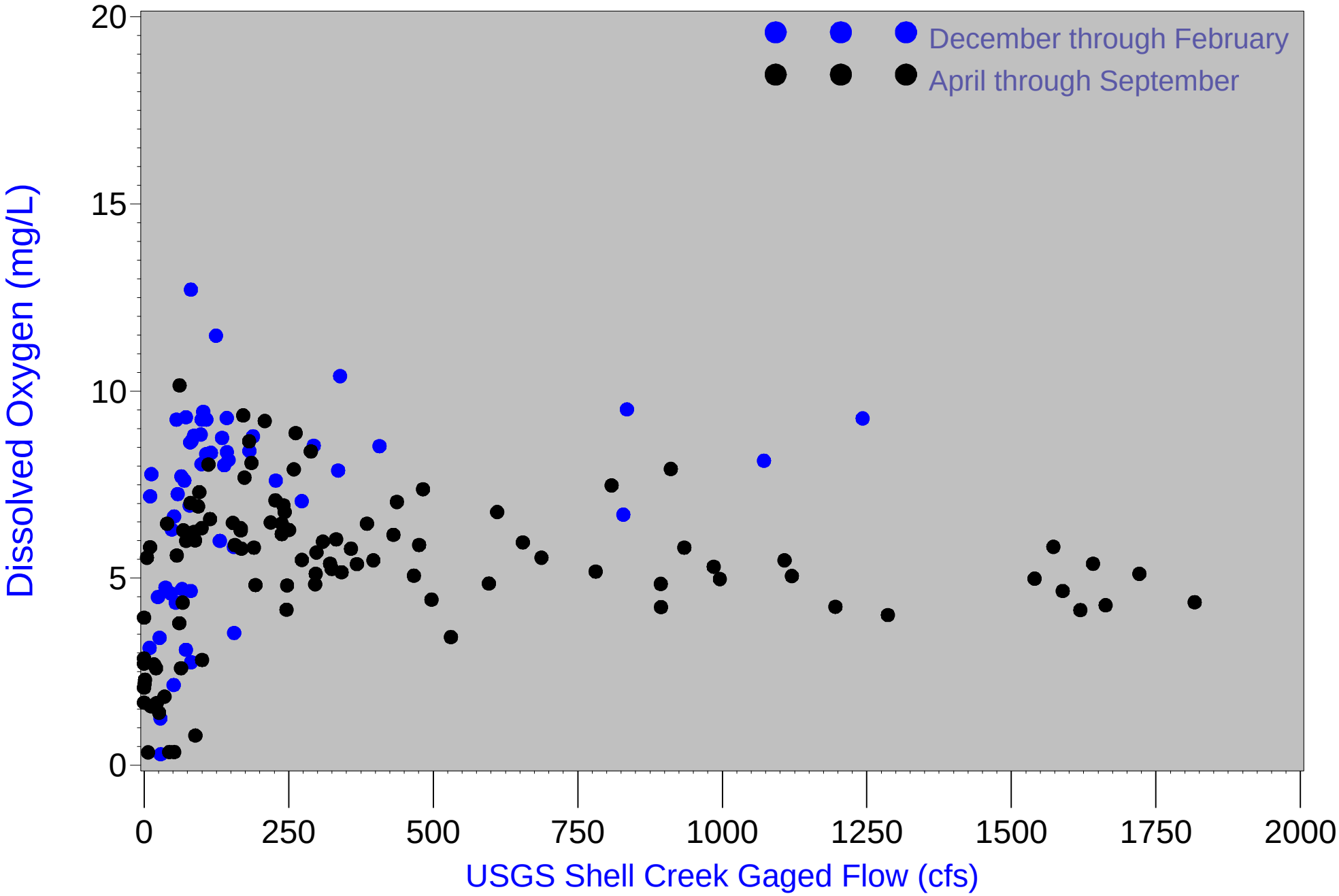


Figure 4.52b Bottom D.O. at Station #11 (River Kilometer 9.90) versus 7-day average Shell Creek flow 1991-2009

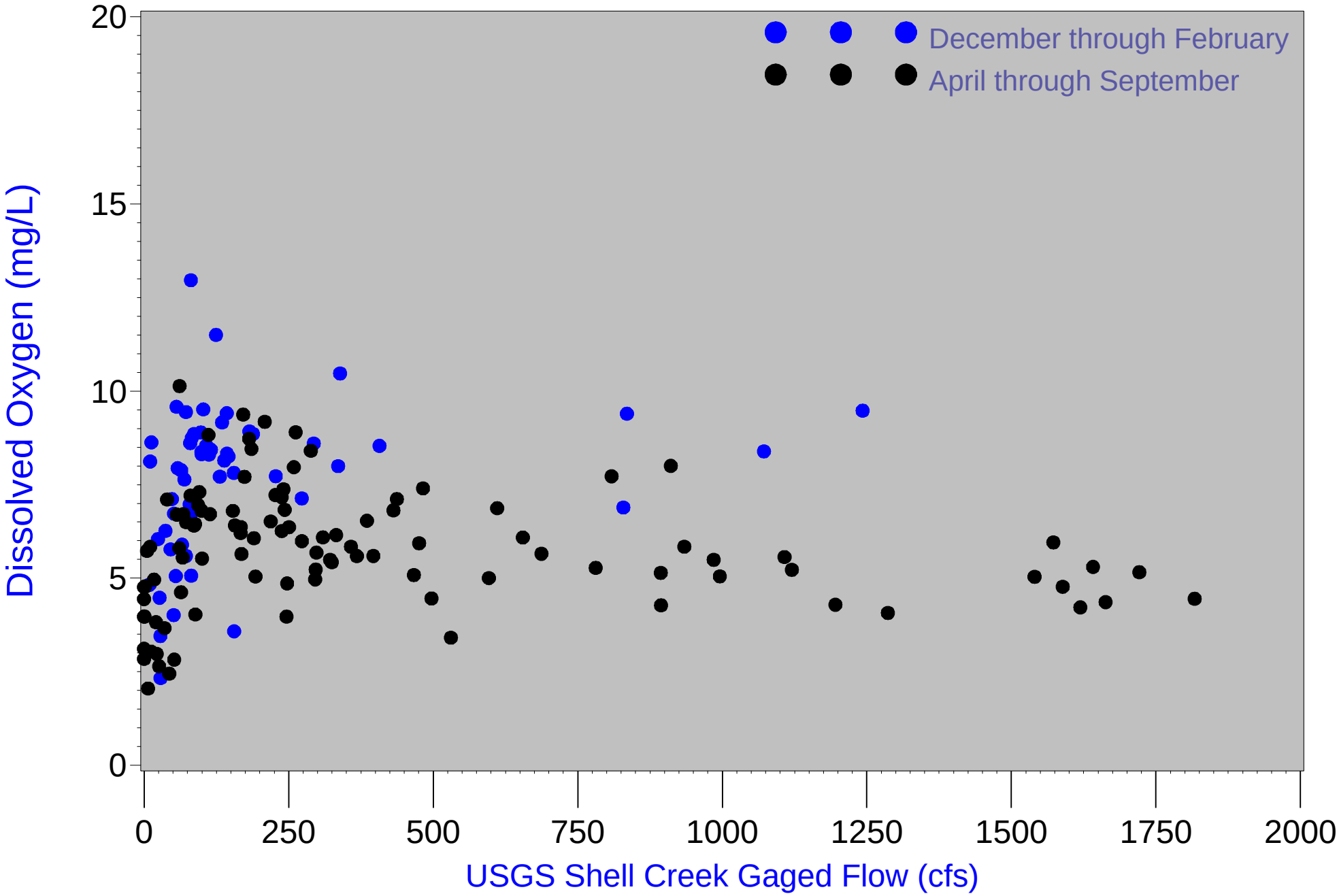


Figure 4.52c Mean D.O. at Station #11 (River Kilometer 9.90) versus 7-day average Shell Creek flow 1991-2009

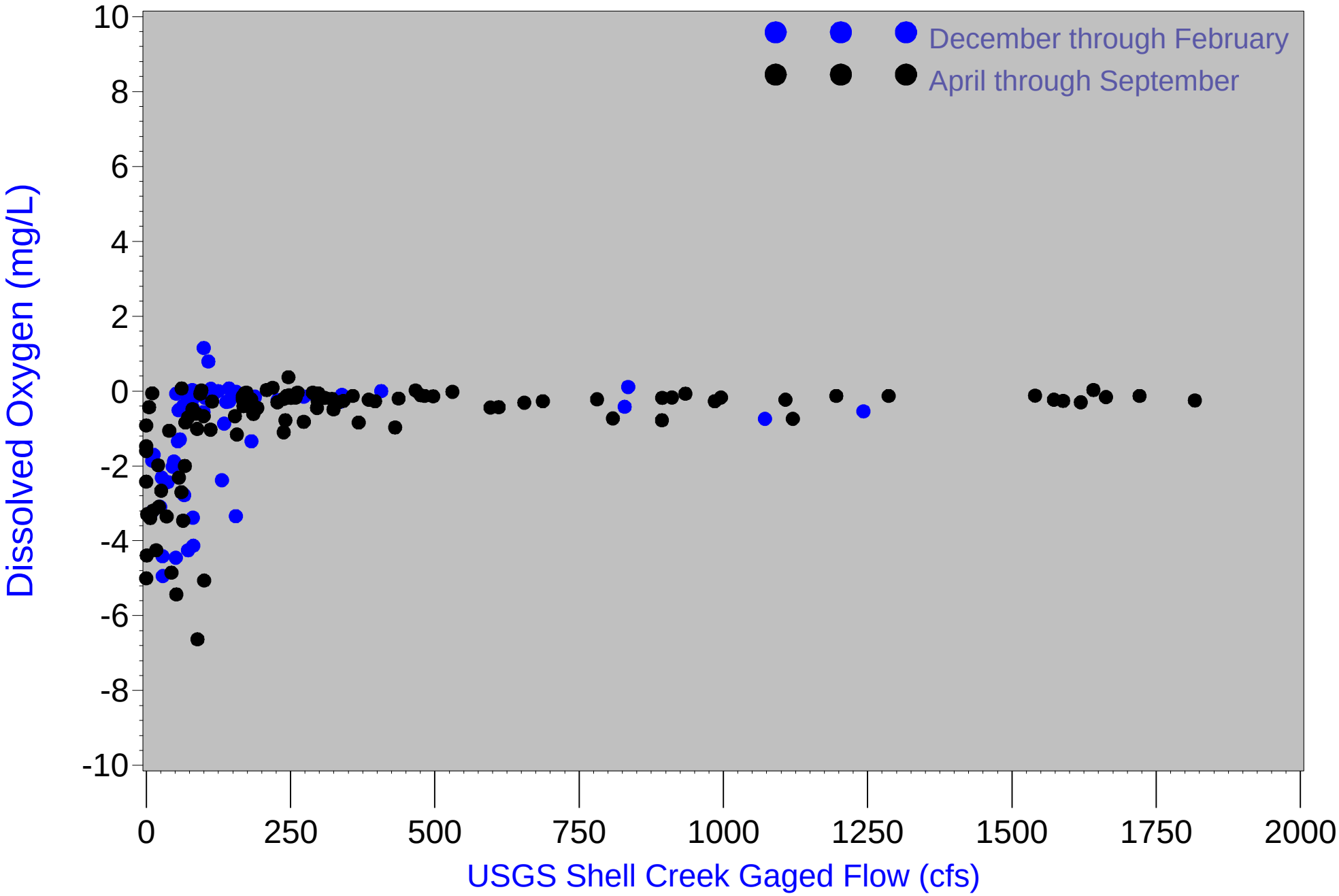


Figure 4.52d D.O. stratification at Station #11 (River Kilometer 9.90) versus 7-day average Shell Creek flow 1991-2009

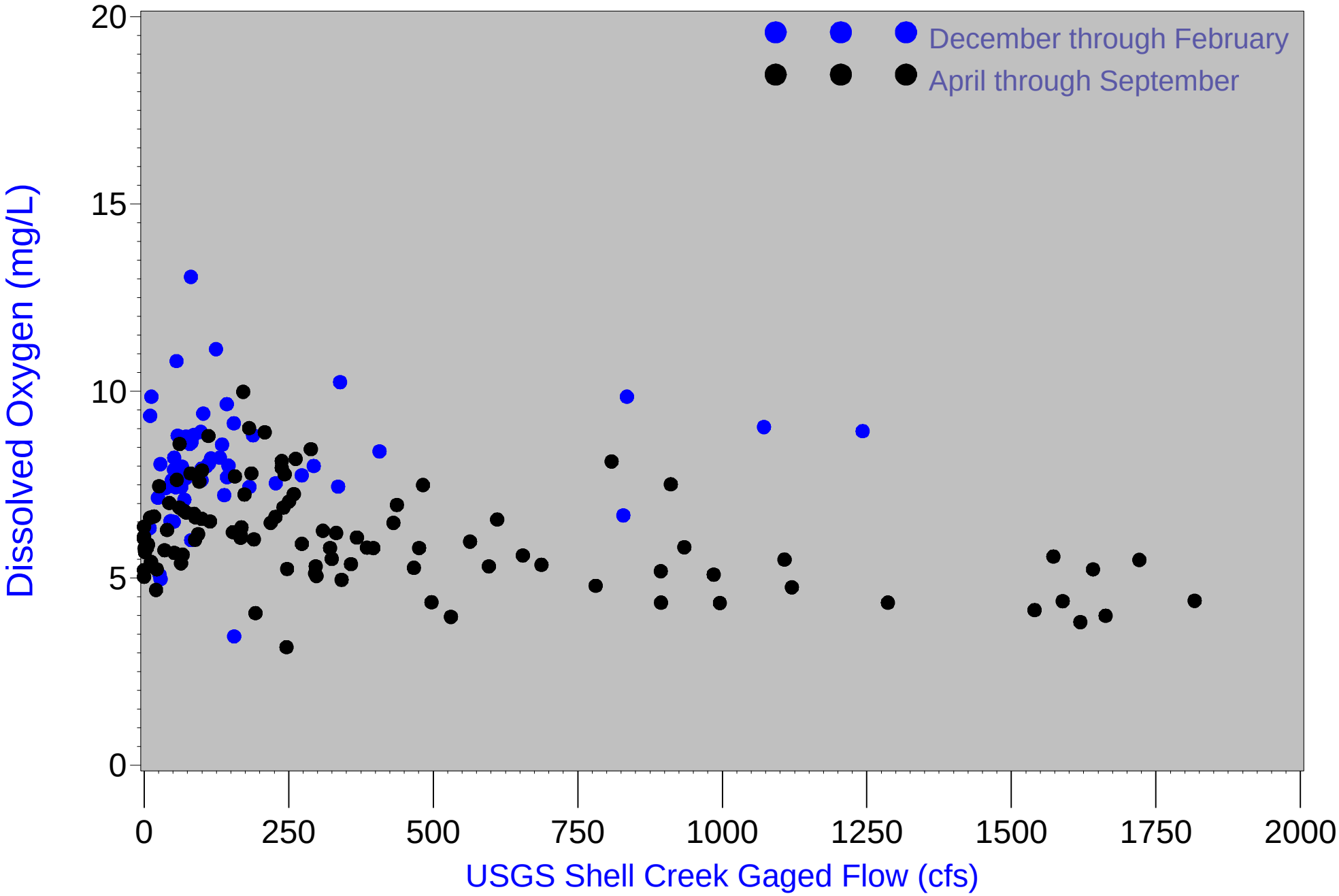


Figure 4.53a Surface D.O. at Station #4 (River Kilometer 8.74) versus 7-day average Shell Creek flow 1991-2009

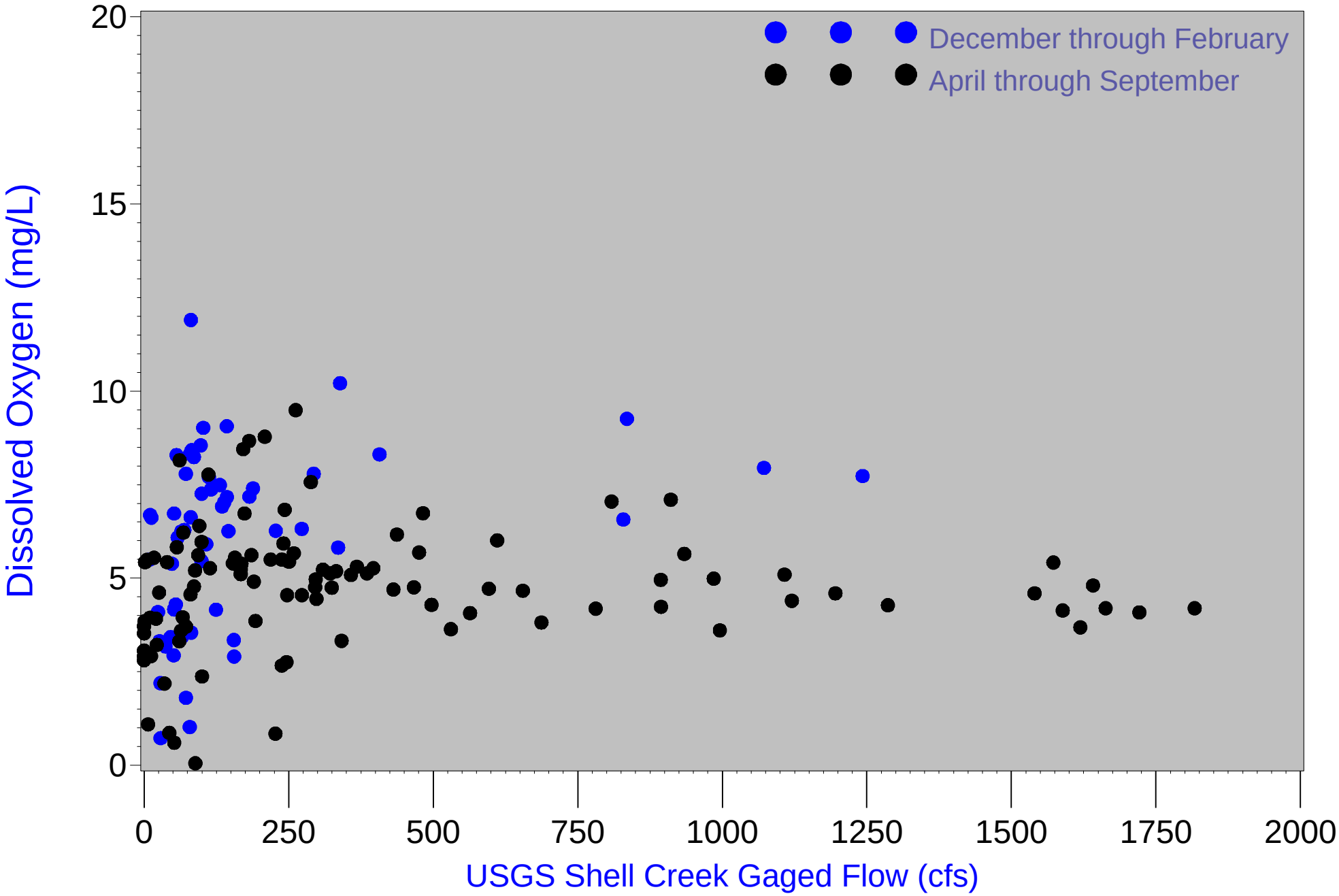


Figure 4.53b Bottom D.O. at Station #4 (River Kilometer 8.74) versus 7-day average Shell Creek flow 1991-2009

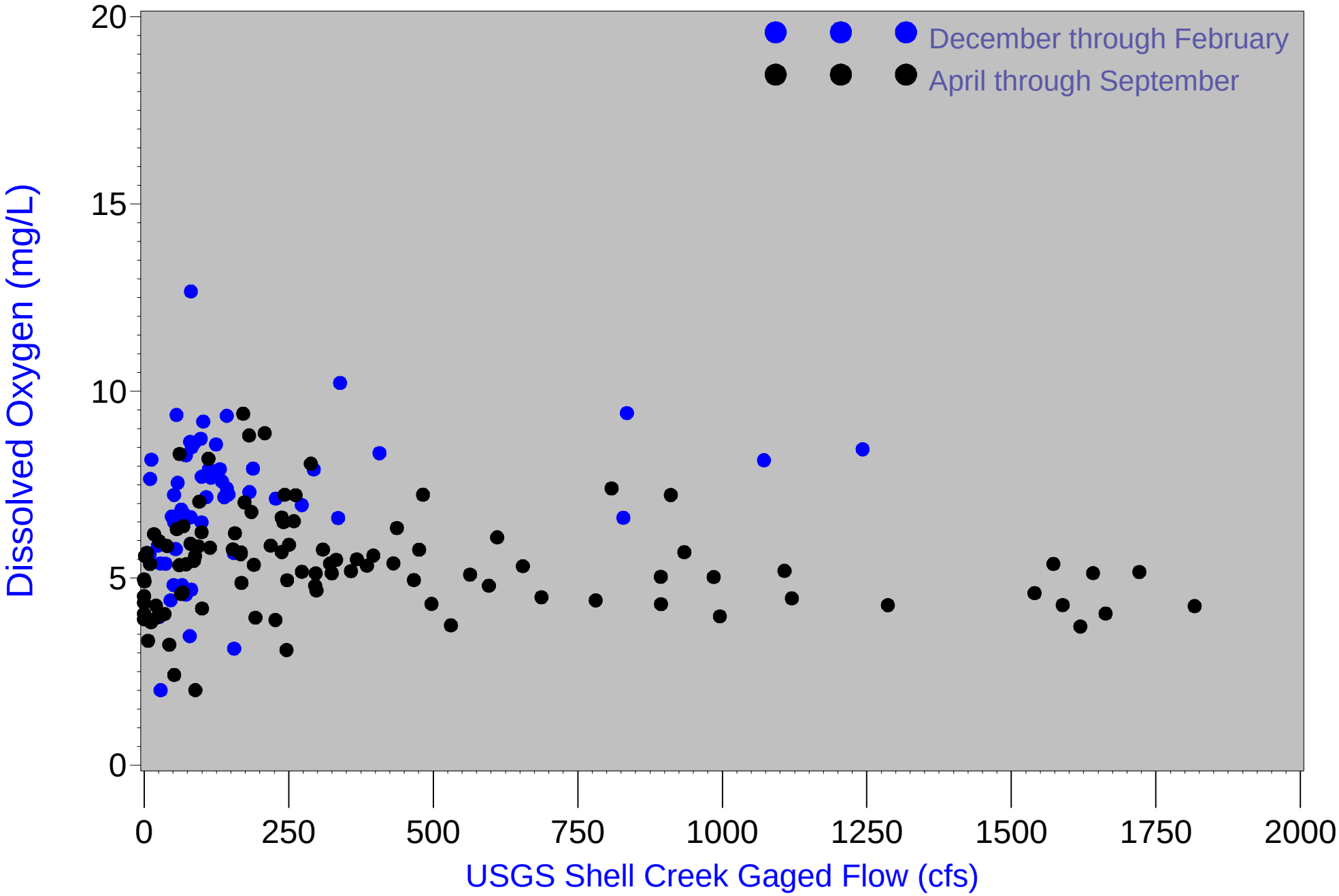


Figure 4.53c Mean D.O. at Station #4 (River Kilometer 8.74) versus 7-day average Shell Creek flow 1991-2009

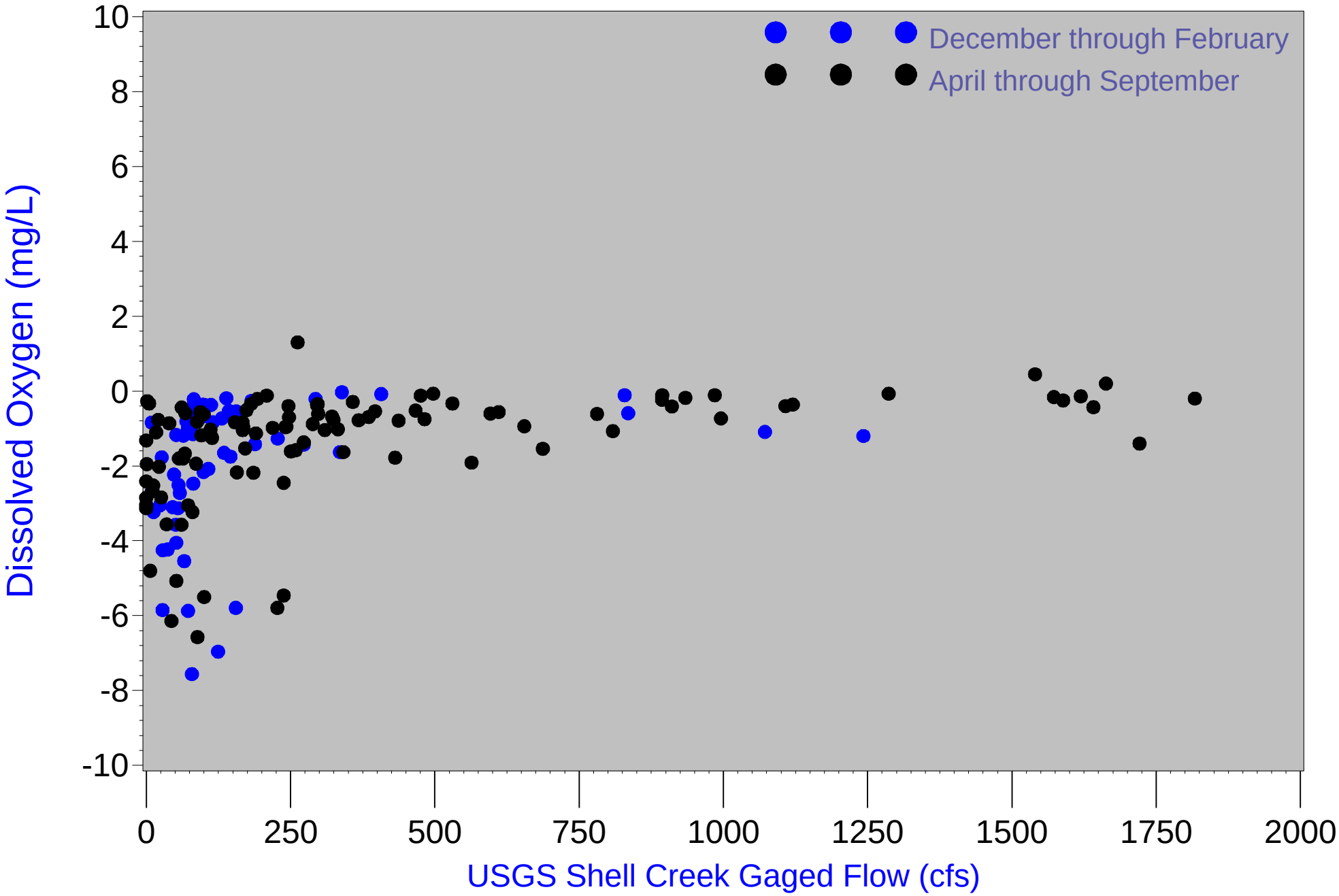


Figure 4.53d D.O. stratification at Station #4 (River Kilometer 8.74) versus 7-day average Shell Creek flow 1991-2009

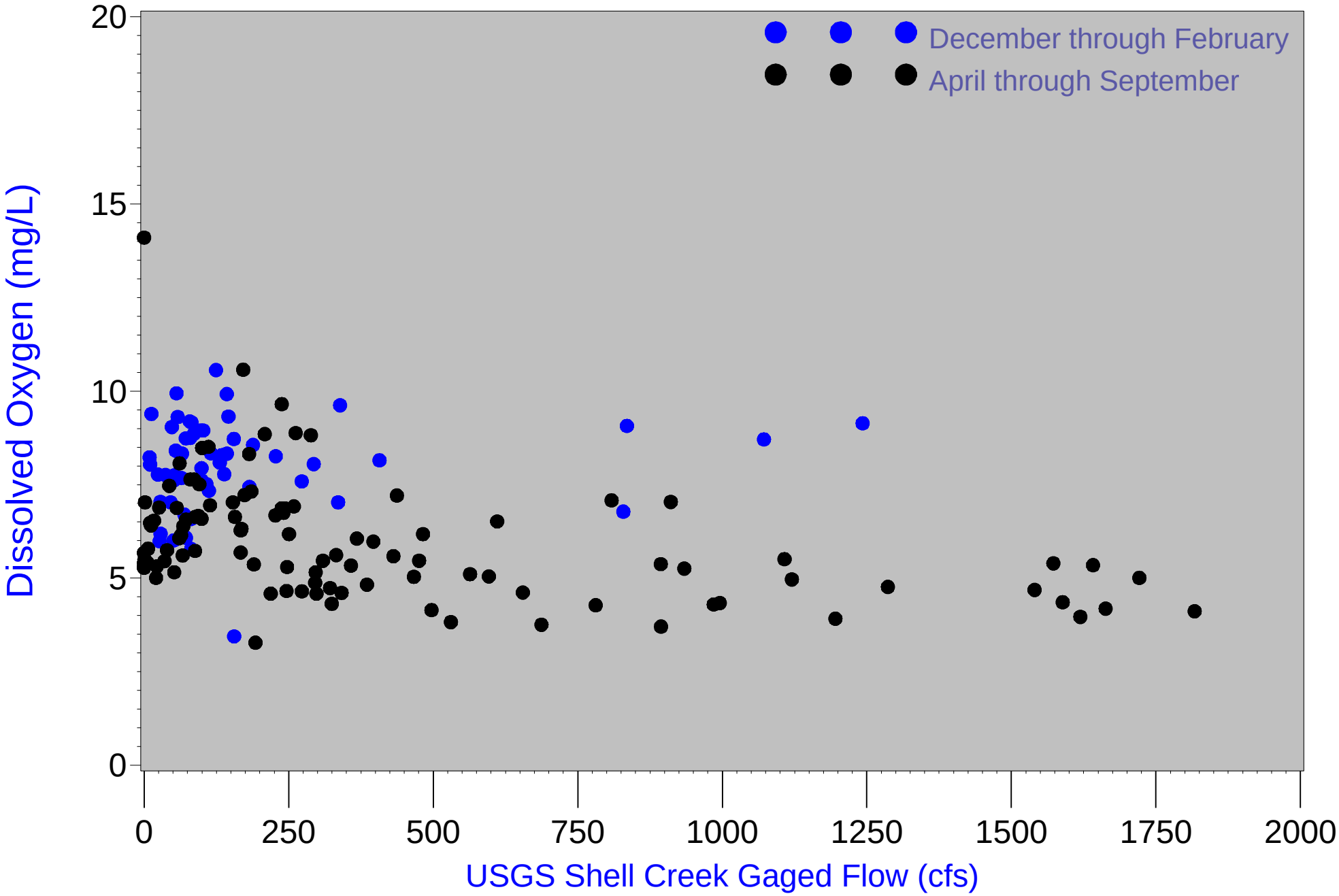


Figure 4.54a Surface D.O. at Station #5 (River Kilometer 6.72) versus 7-day average Shell Creek flow 1991-2009

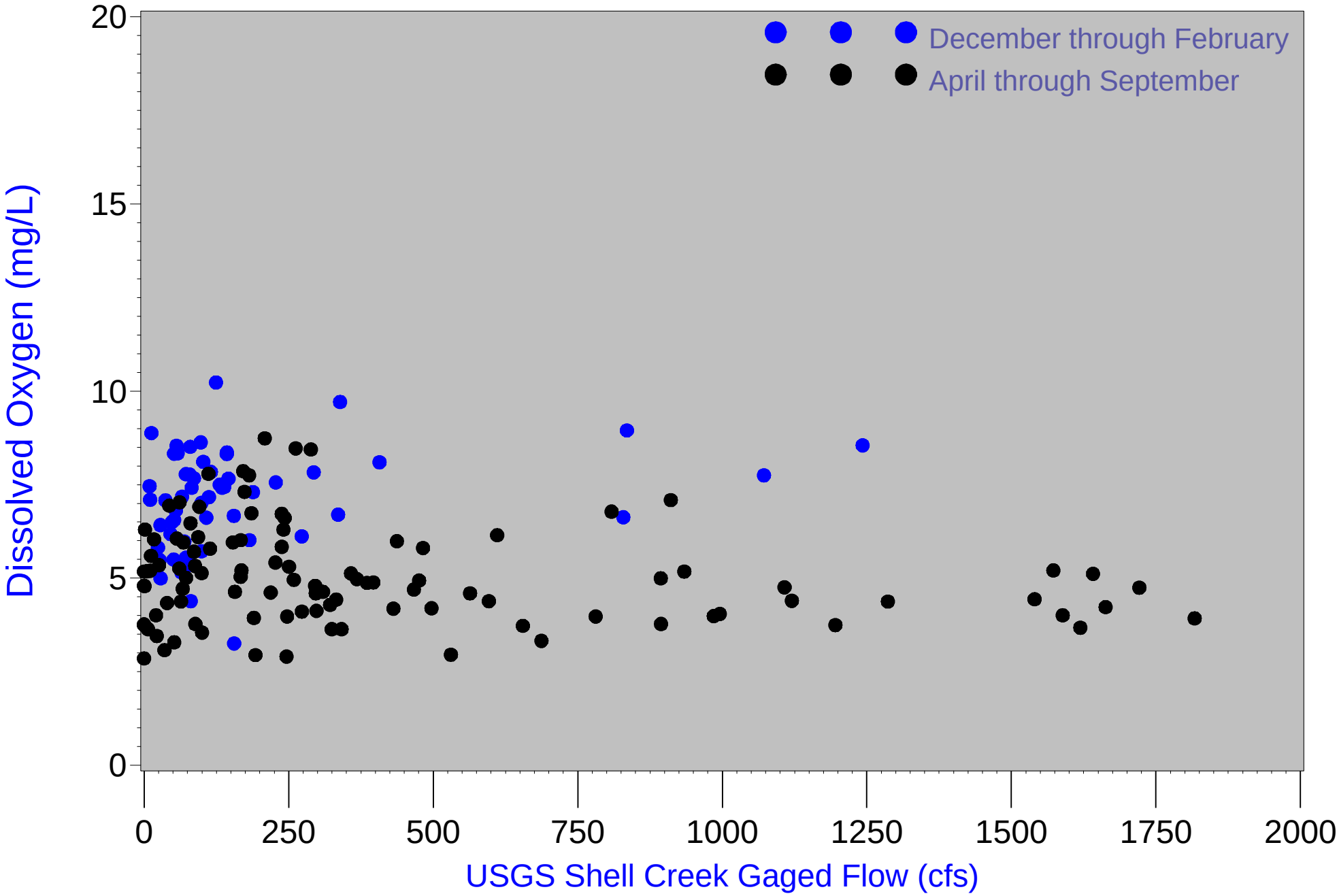


Figure 4.54b Bottom D.O. at Station #5 (River Kilometer 6.72) versus 7-day average Shell Creek flow 1991-2009

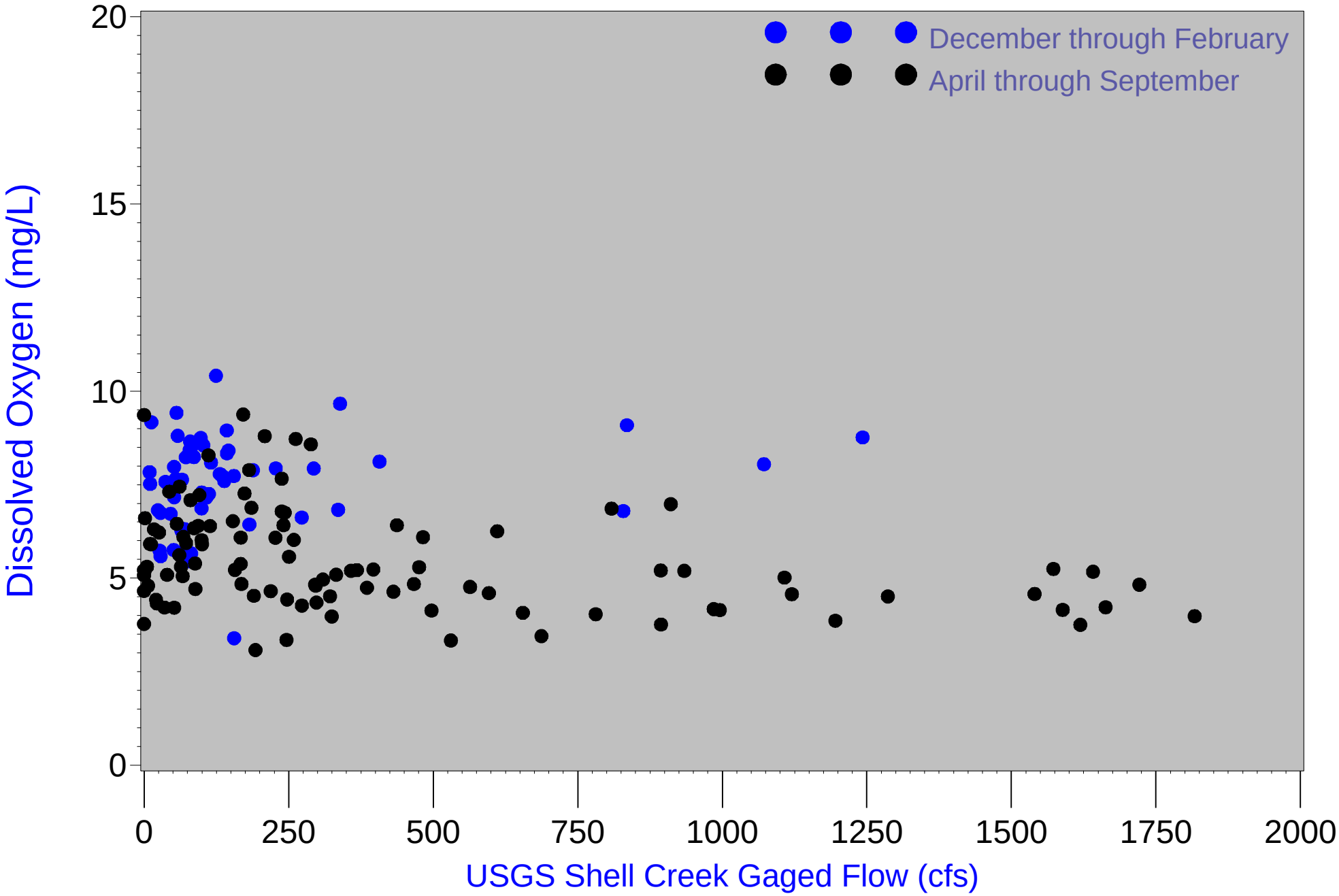


Figure 4.54c Mean D.O. at Station #5 (River Kilometer 6.72) versus 7-day average Shell Creek flow 1991-2009

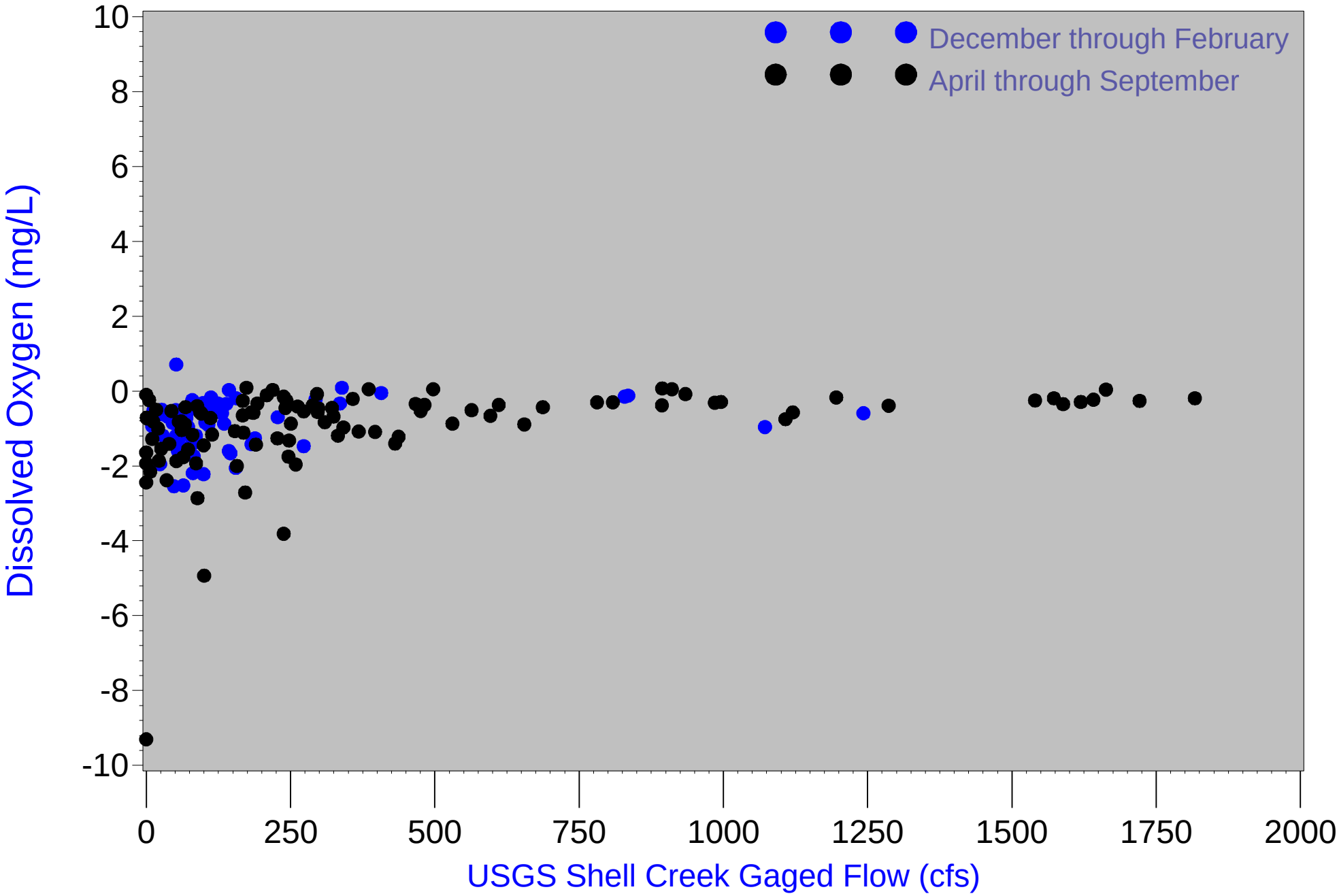


Figure 4.54d D.O. stratification at Station #5 (River Kilometer 6.72) versus 7-day average Shell Creek flow 1991-2009

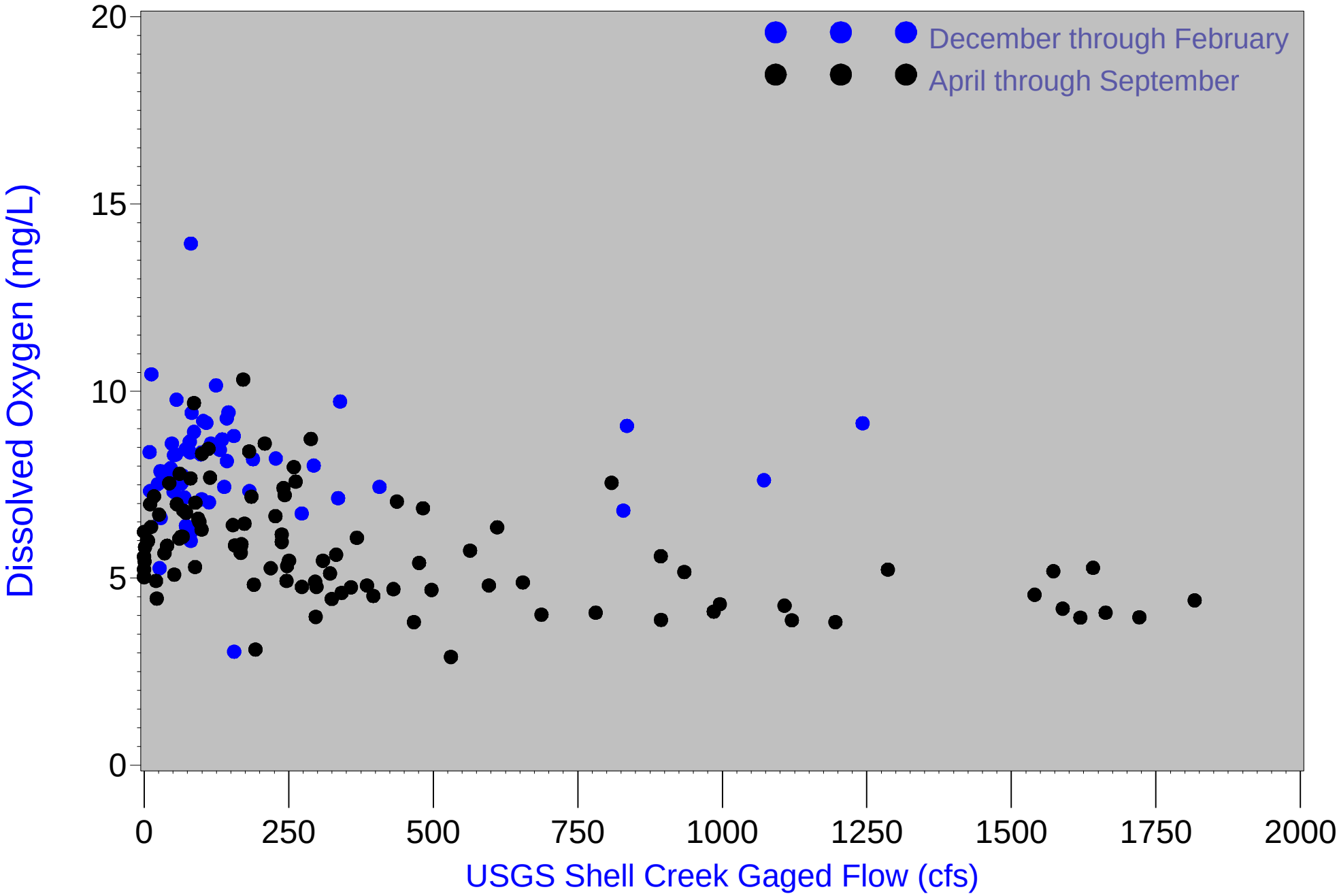


Figure 4.55a Surface D.O. at Station #6 (River Kilometer 4.61) versus 7-day average Shell Creek flow 1991-2009

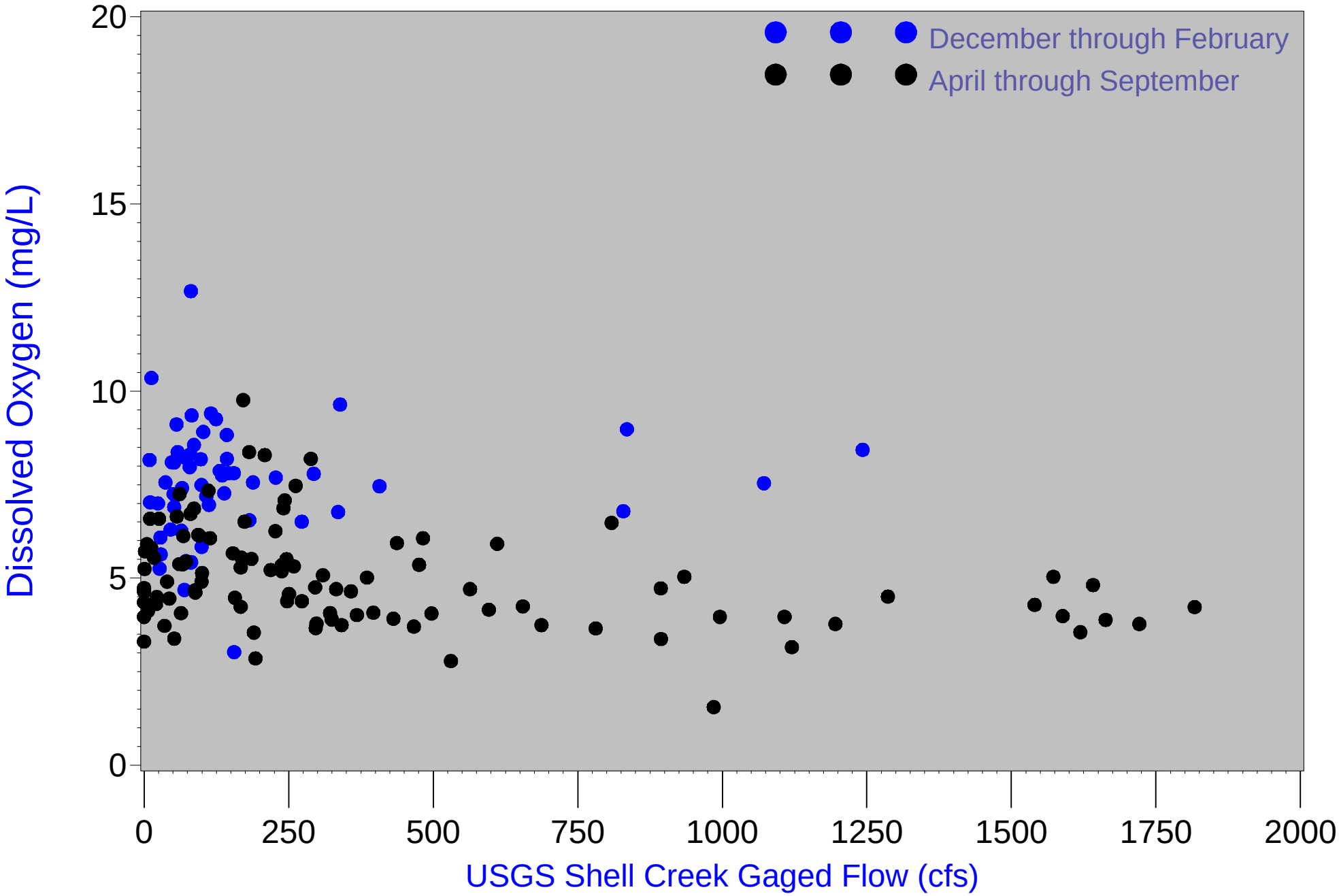


Figure 4.55b Bottom D.O. at Station #6 (River Kilometer 4.61) versus 7-day average Shell Creek flow 1991-2009

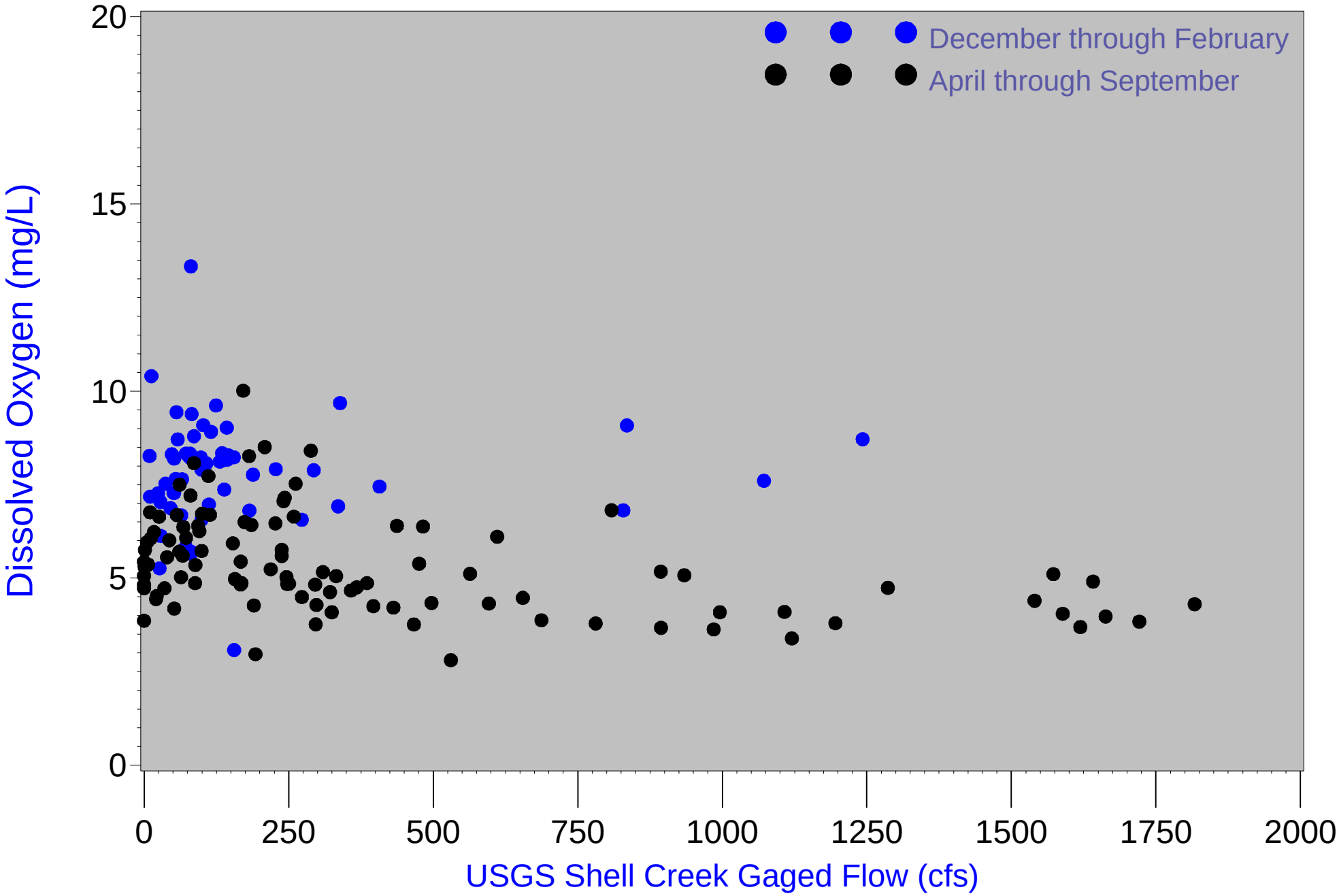


Figure 4.55c Mean D.O. at Station #6 (River Kilometer 4.61) versus 7-day average Shell Creek flow 1991-2009

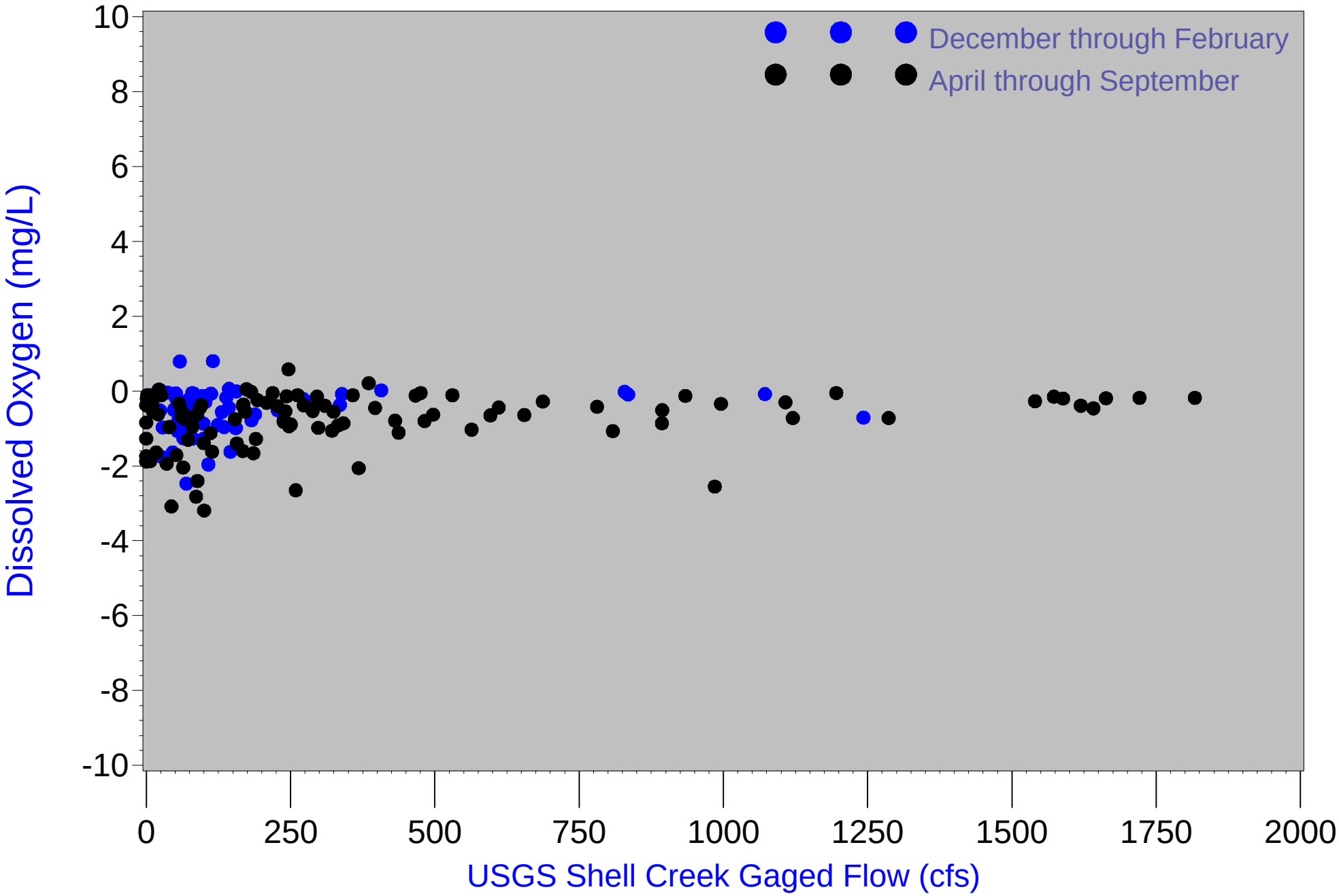


Figure 4.55d D.O. stratification at Station #6 (River Kilometer 4.61) versus 7-day average Shell Creek flow 1991-2009

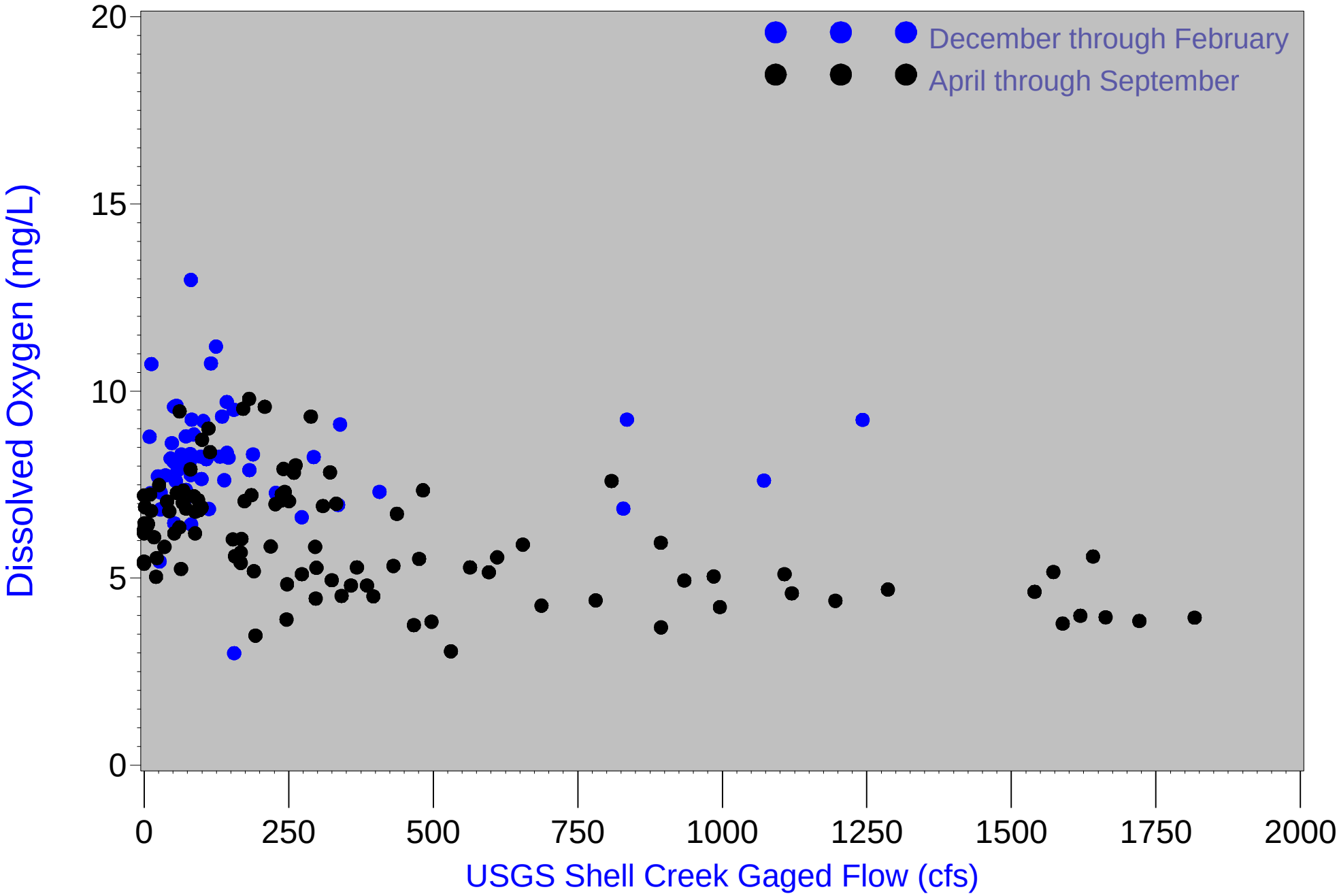


Figure 4.56a Surface D.O. at Station #7 (River Kilometer 2.35) versus 7-day average Shell Creek flow 1991-2009

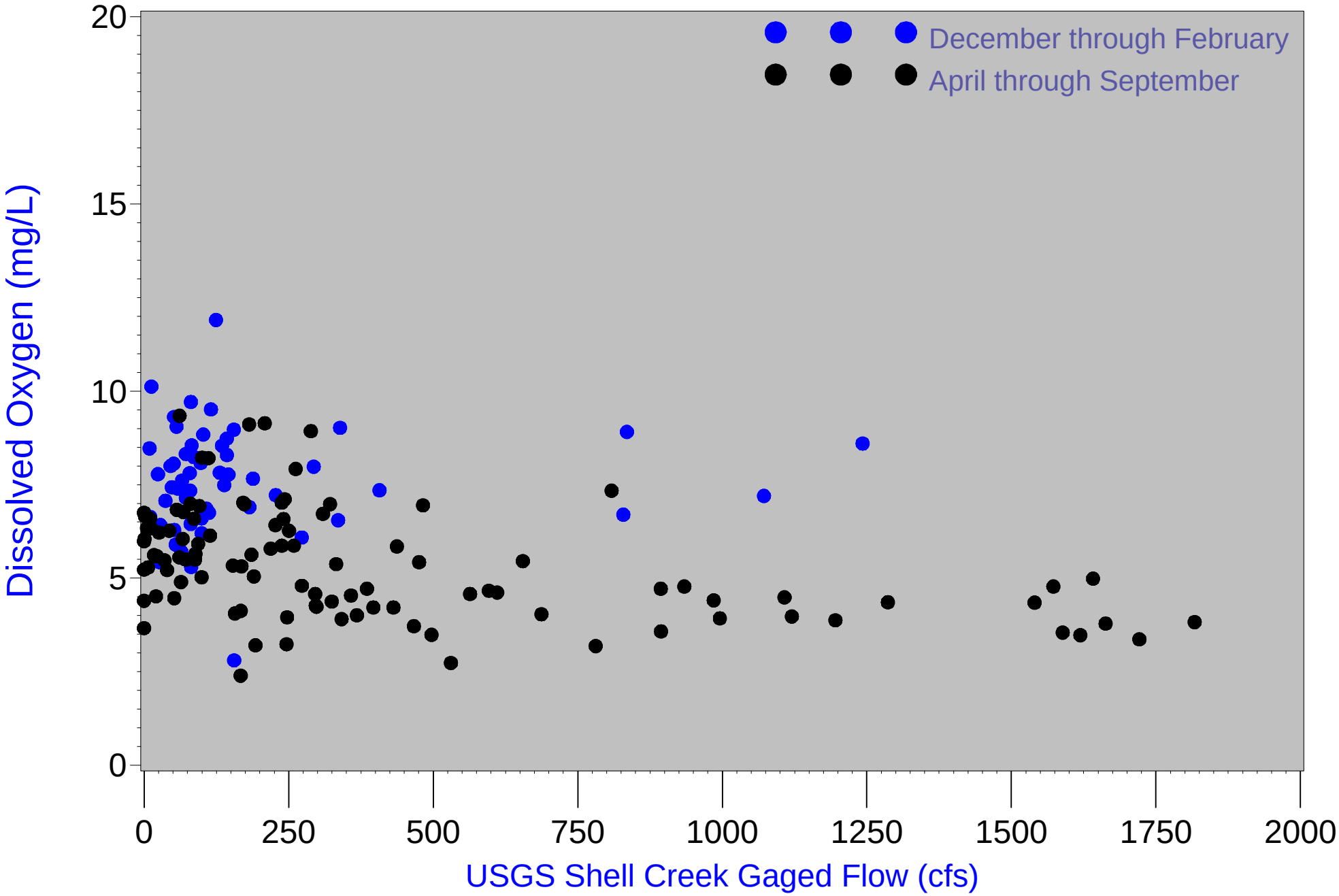


Figure 4.56b Bottom D.O. at Station #7 (River Kilometer 2.35) versus 7-day average Shell Creek flow 1991-2009

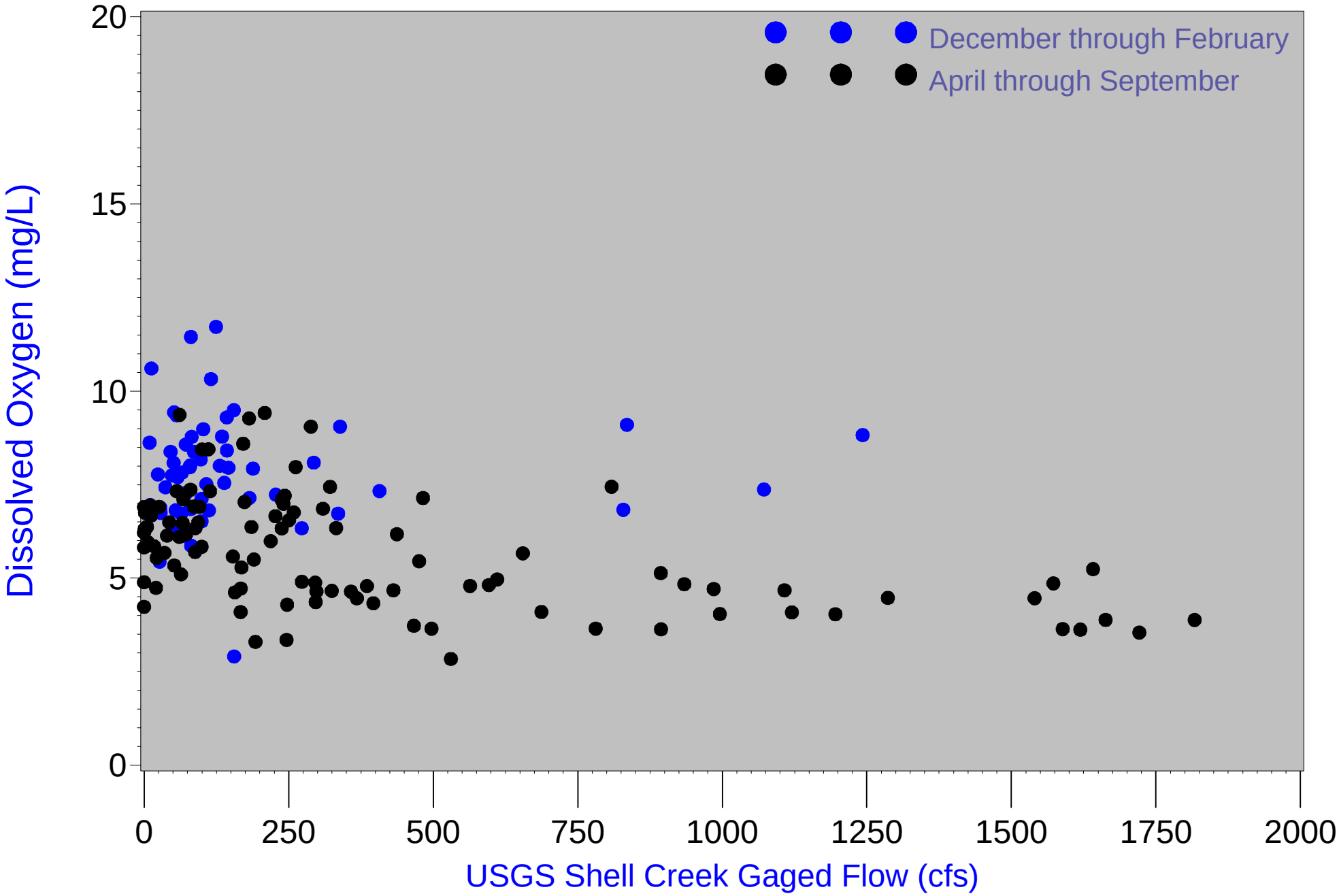


Figure 4.56c Mean D.O. at Station #7 (River Kilometer 2.35) versus 7-day average Shell Creek flow 1991-2009

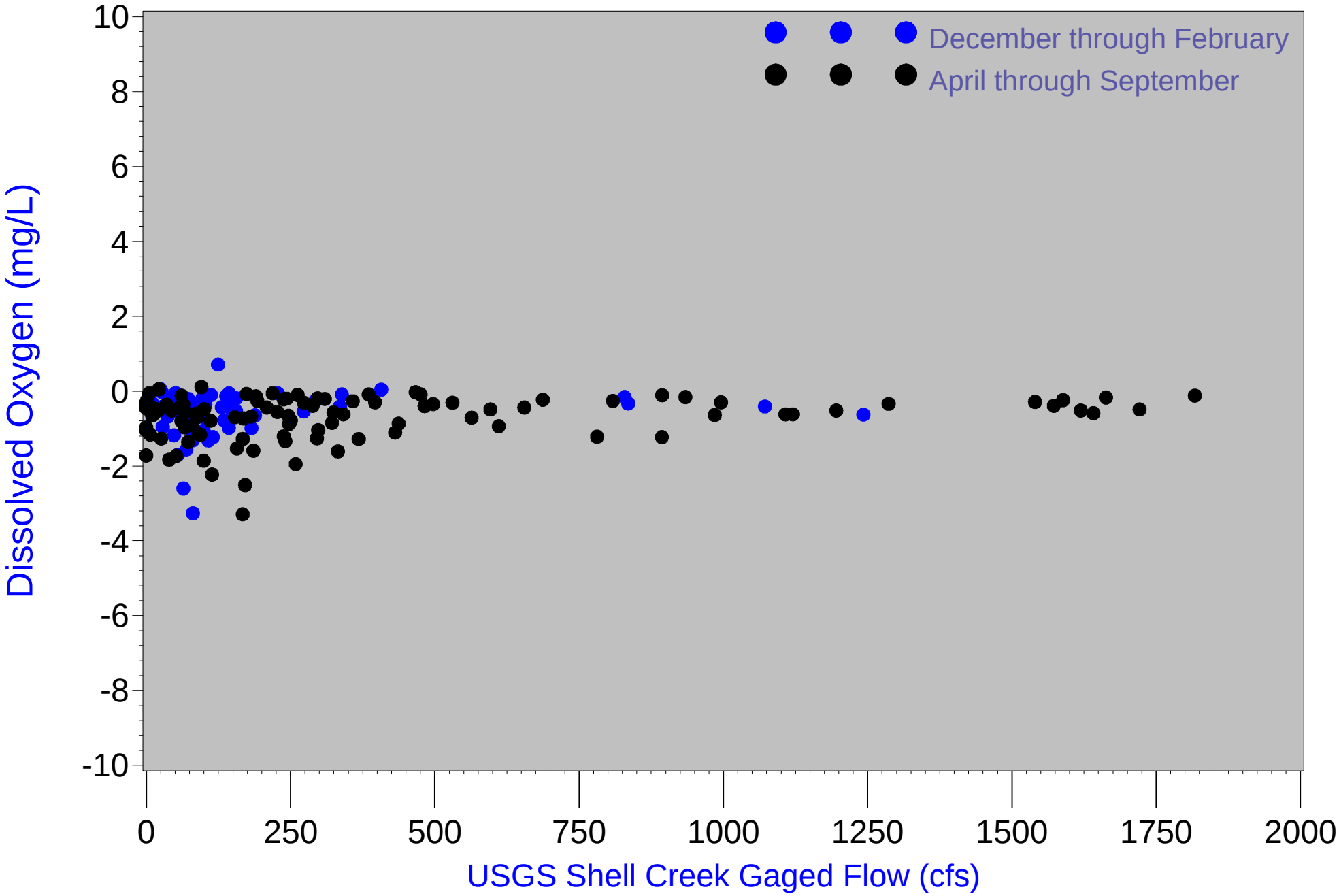


Figure 4.56d D.O. stratification at Station #7 (River Kilometer 2.45) versus 7-day average Shell Creek flow 1991-2009

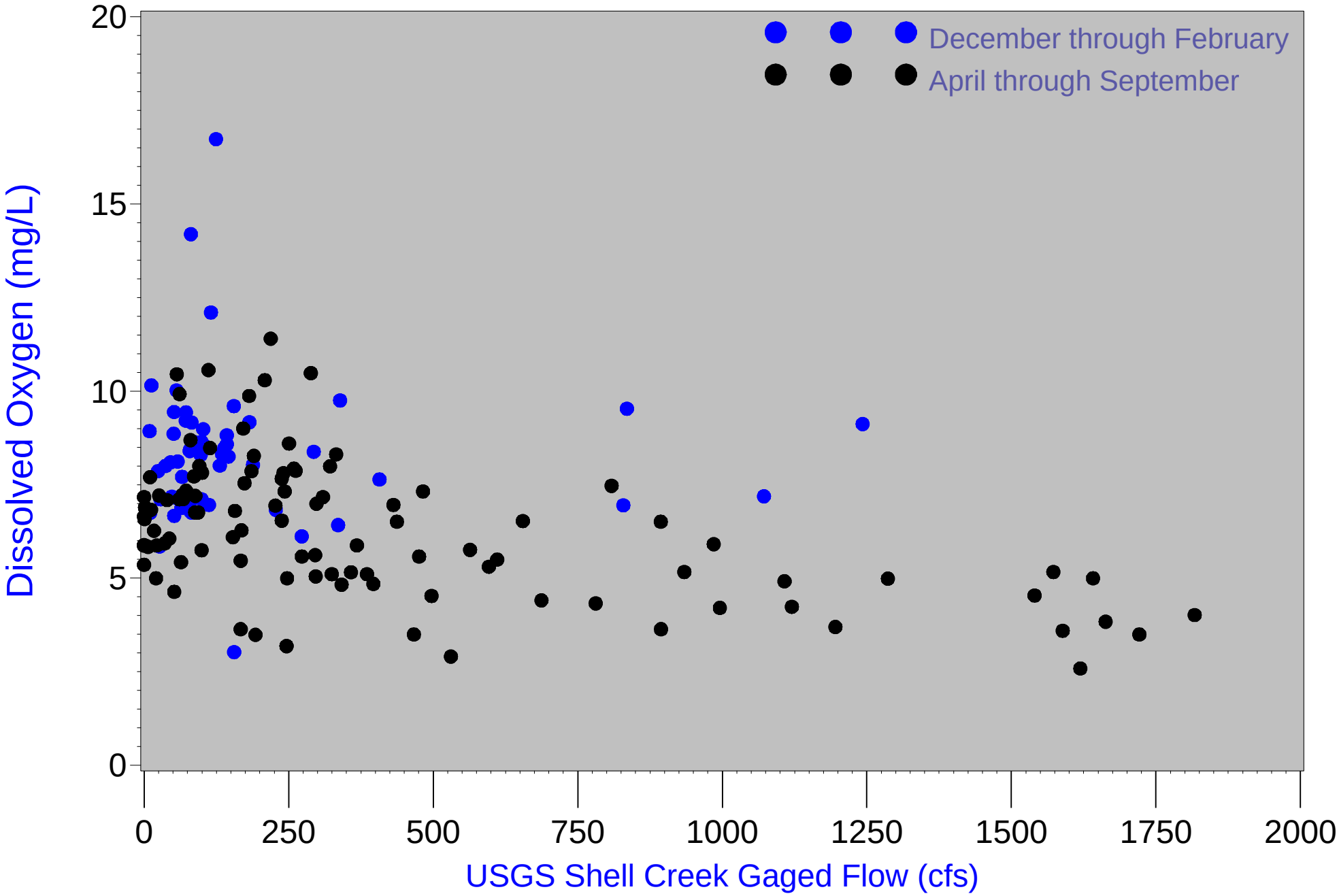


Figure 4.57a Surface D.O. at Station #16 (River Kilometer 1.26) versus 7-day average Shell Creek flow 1991-2009

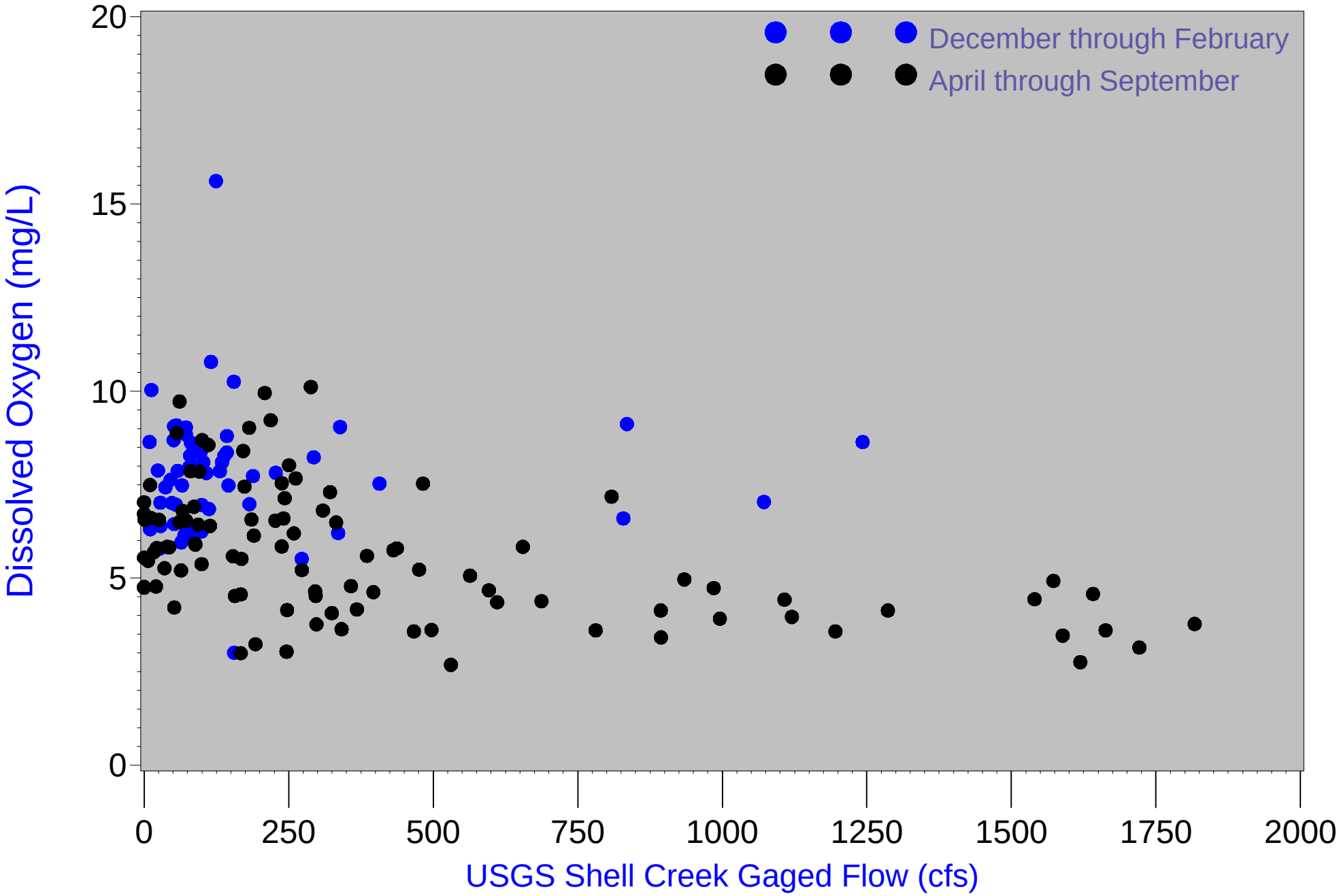


Figure 4.57b Bottom D.O. at Station #16 (River Kilometer 1.26) versus 7-day average Shell Creek flow 1991-2009

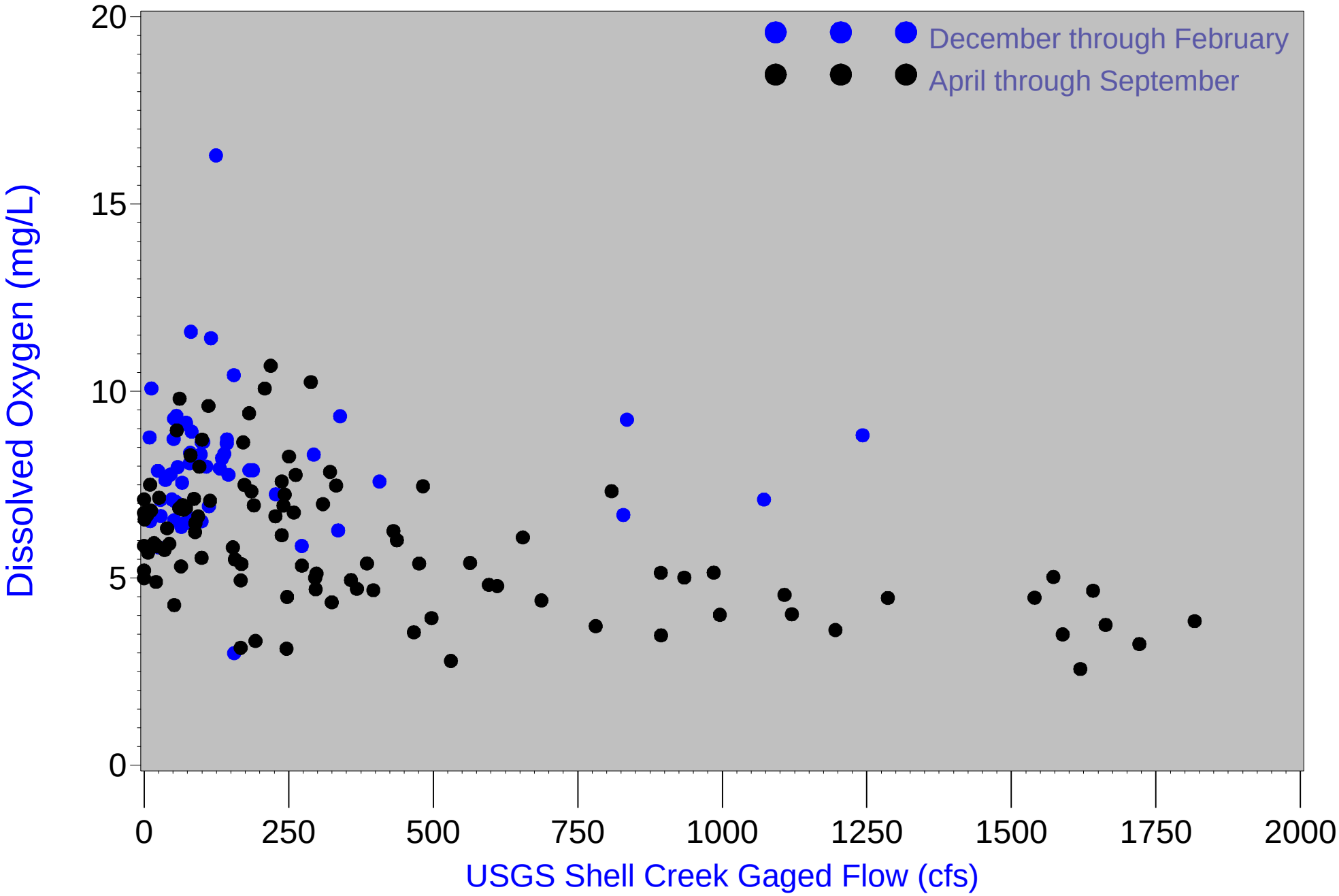


Figure 4.57c Mean D.O. at Station #16 (River Kilometer 1.26) versus 7-day average Shell Creek flow 1991-2009

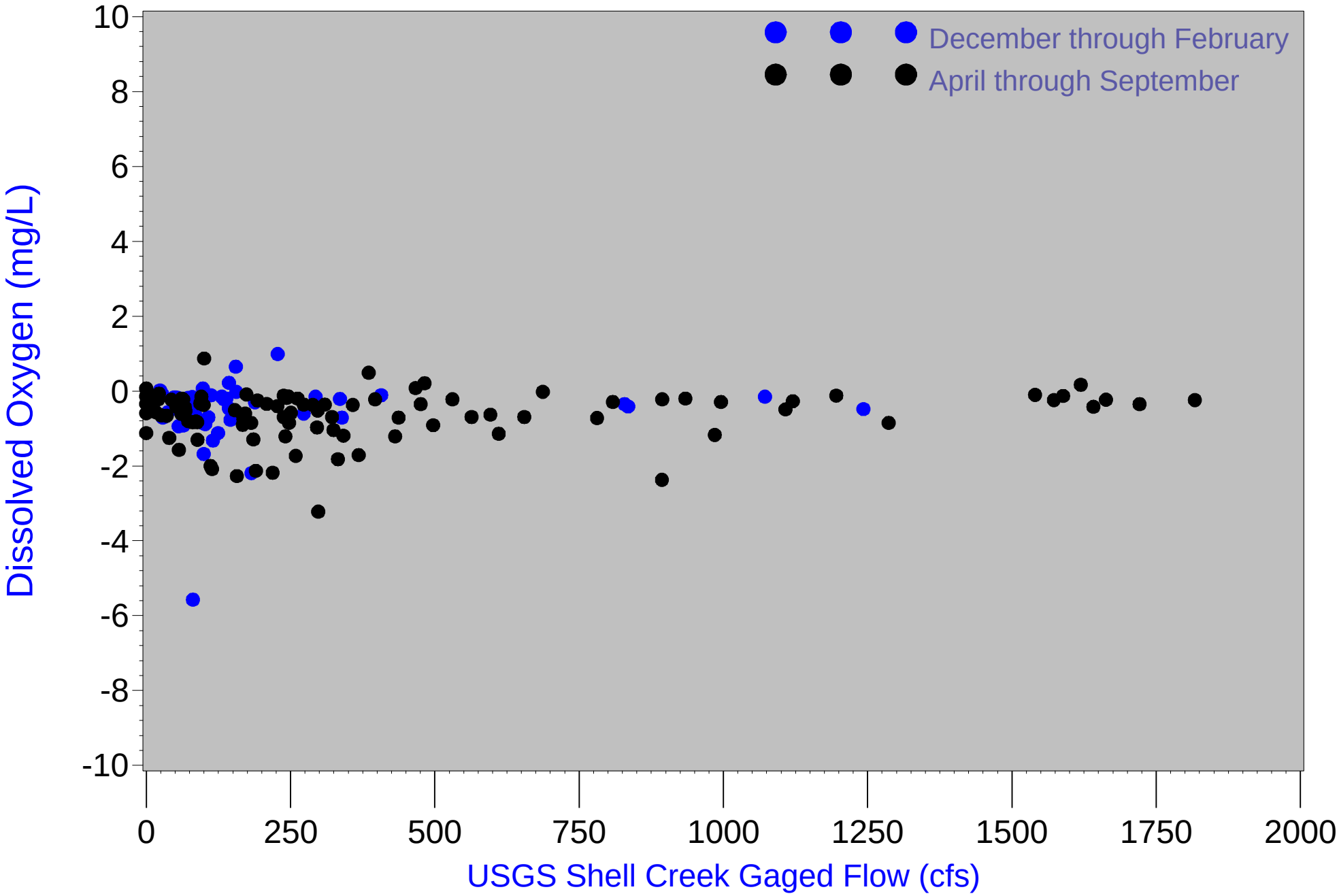


Figure 4.57d D.O. stratification at Station #16 (River Kilometer 1.26) versus 7-day average Shell Creek flow 1991-2009

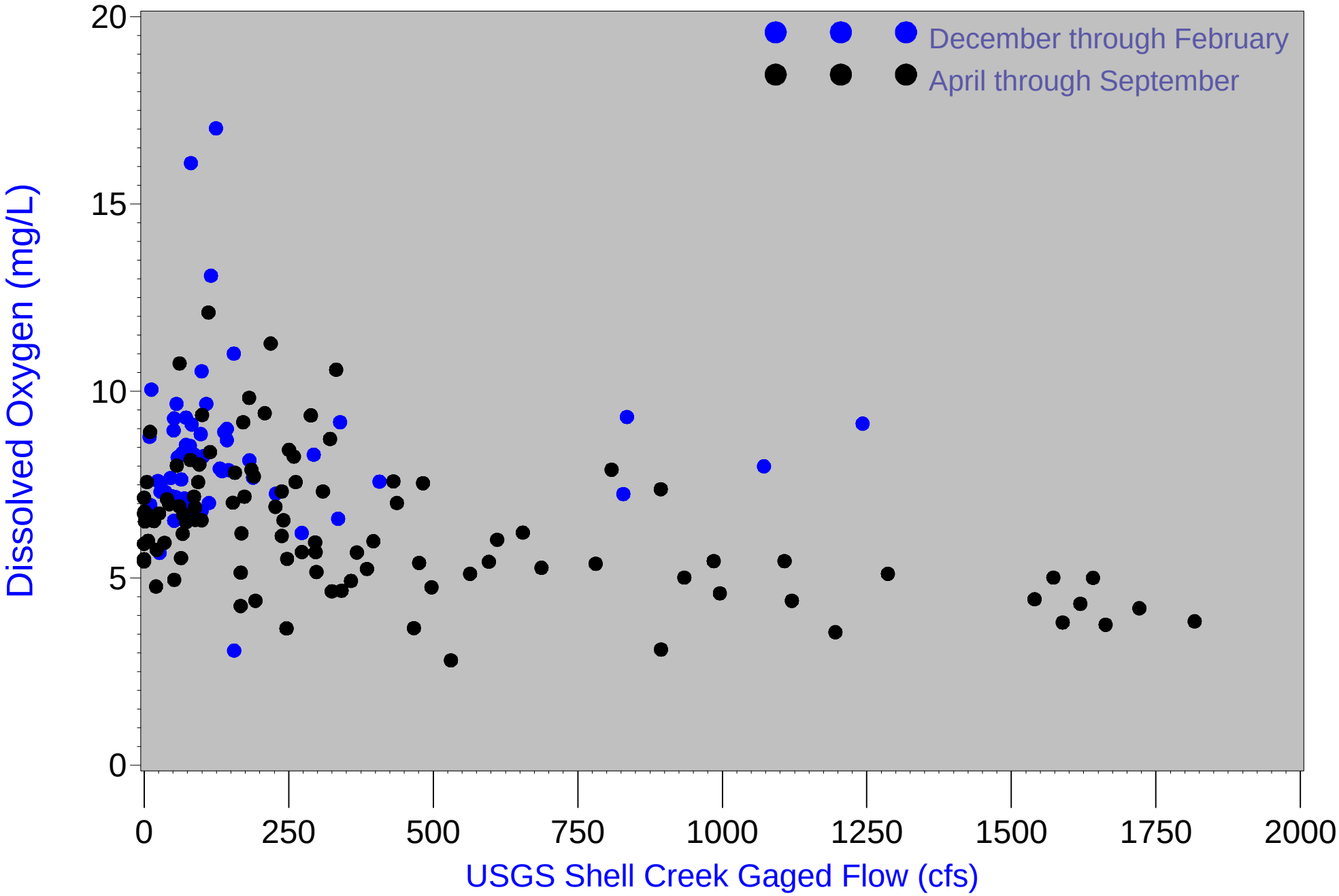


Figure 4.58a Surface D.O. at Station #17 (River Kilometer 0.43) versus 7-day average Shell Creek flow 1991-2009

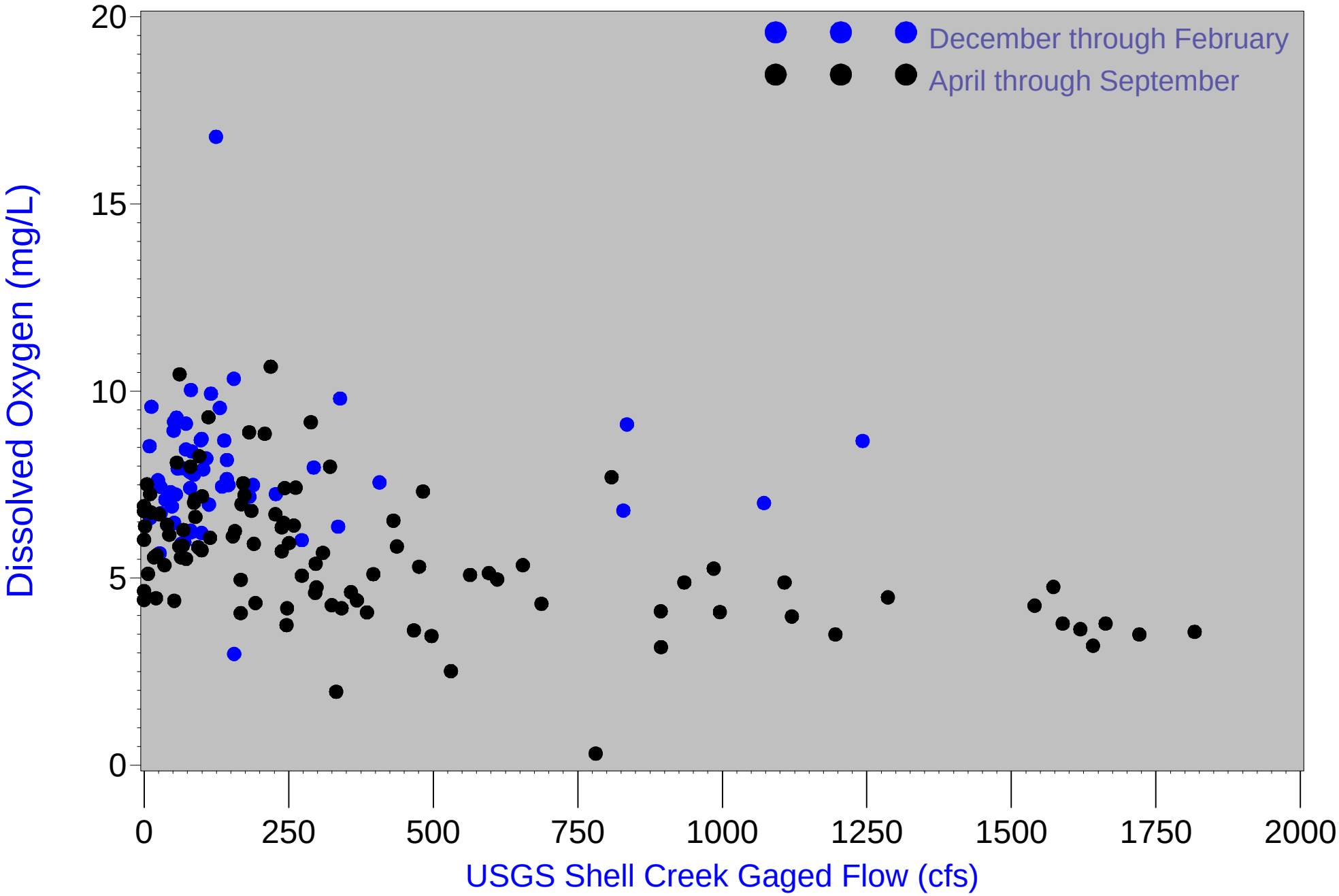


Figure 4.58b Bottom D.O. at Station #17 (River Kilometer 0.43) versus 7-day average Shell Creek flow 1991-2009

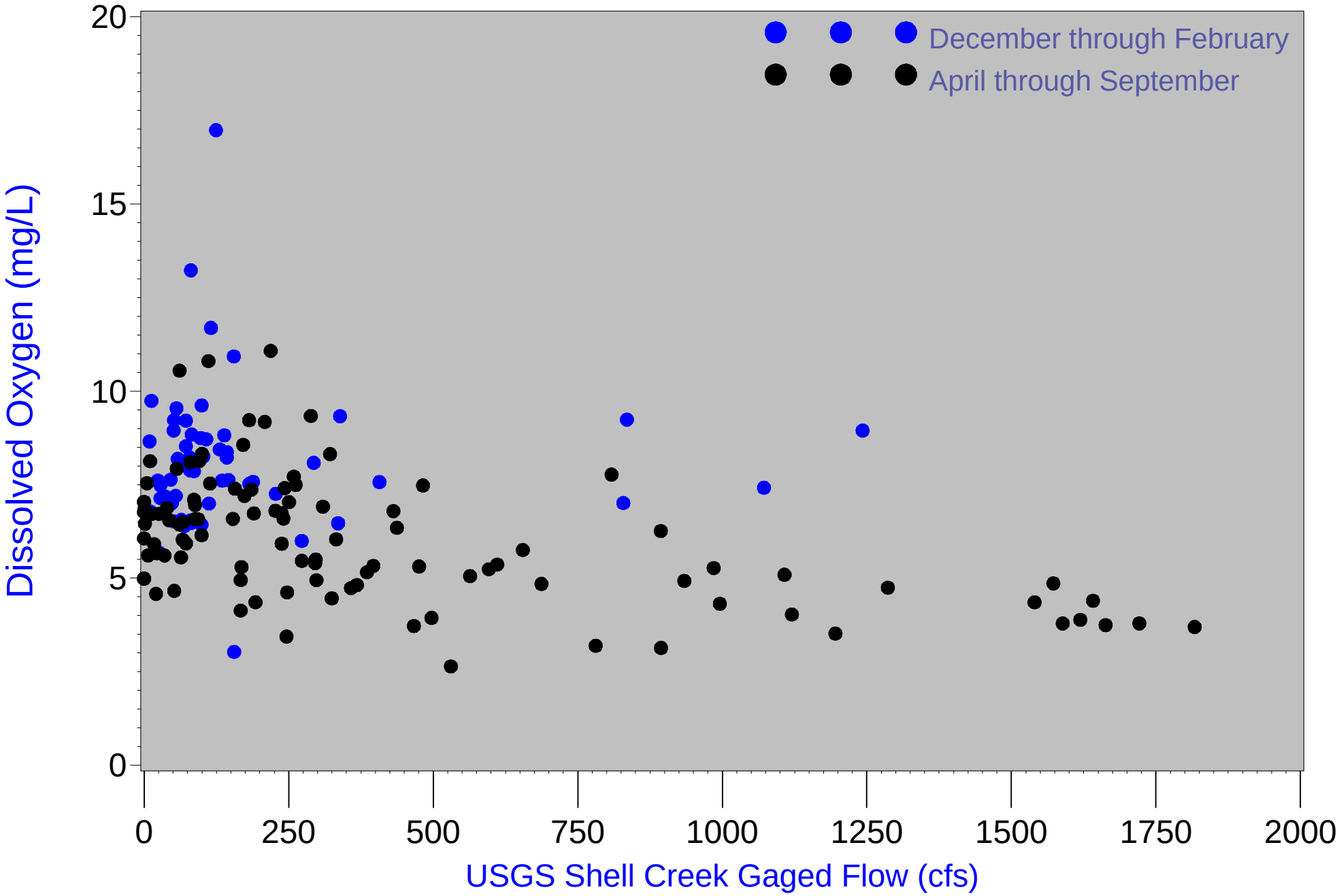


Figure 4.58c Mean D.O. at Station #17 (River Kilometer 0.43) versus 7-day average Shell Creek flow 1991-2009

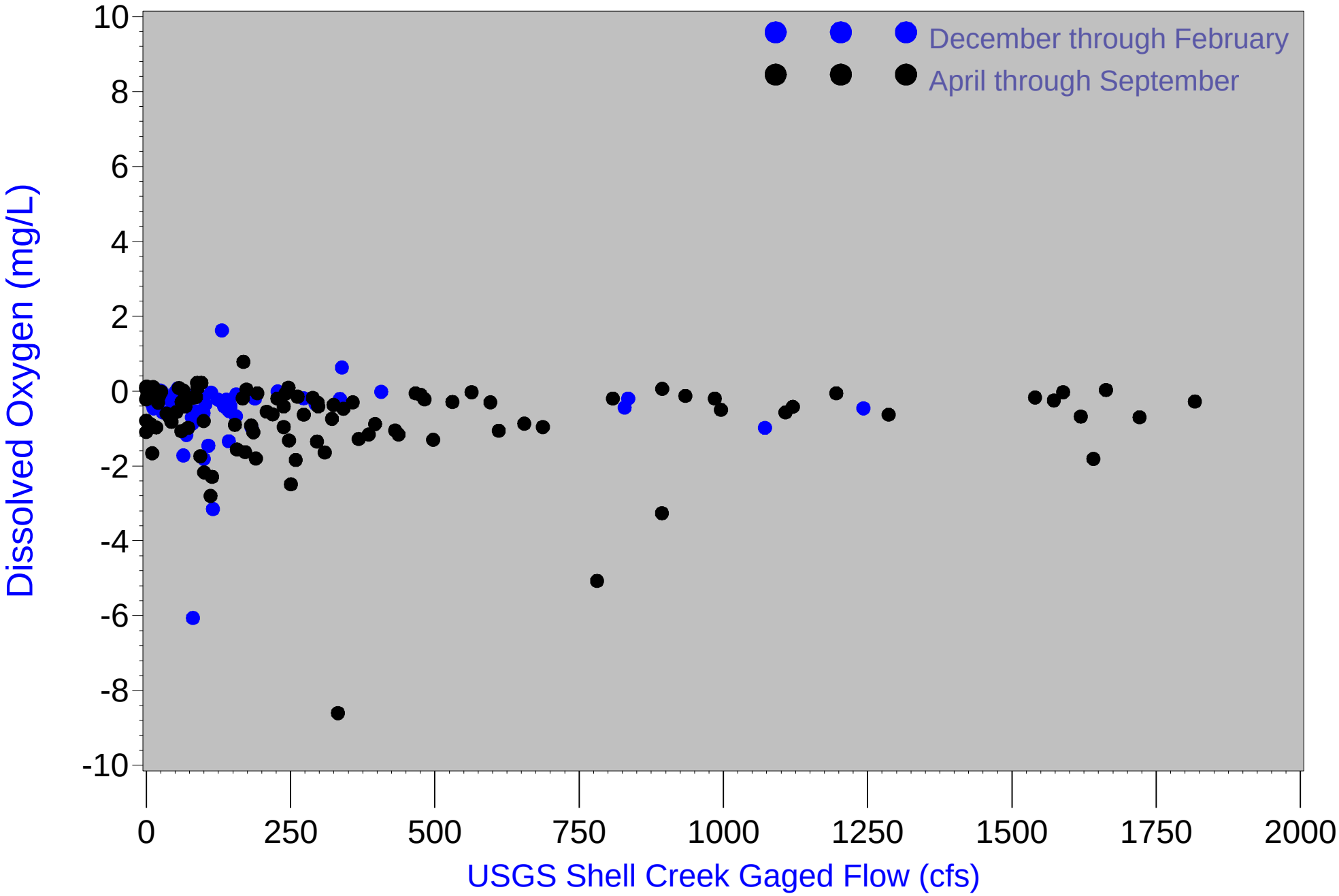


Figure 4.58d D.O. stratification at Station #17 (River Kilometer 0.43) versus 7-day average Shell Creek flow 1991-2009

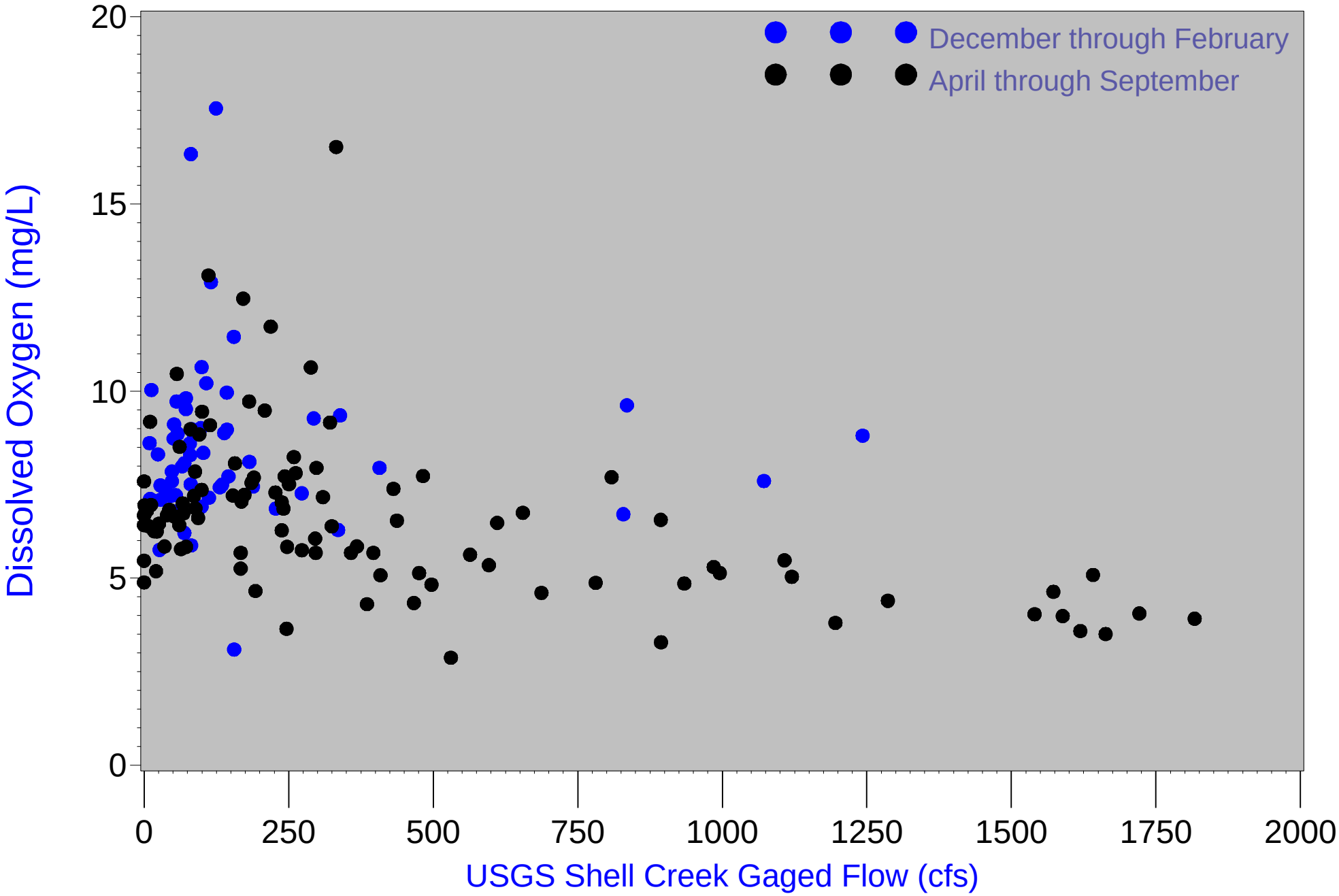


Figure 4.59a Surface D.O. at Station #9 (River Kilometer -0.37) versus 7-day average Shell Creek flow 1991-2009

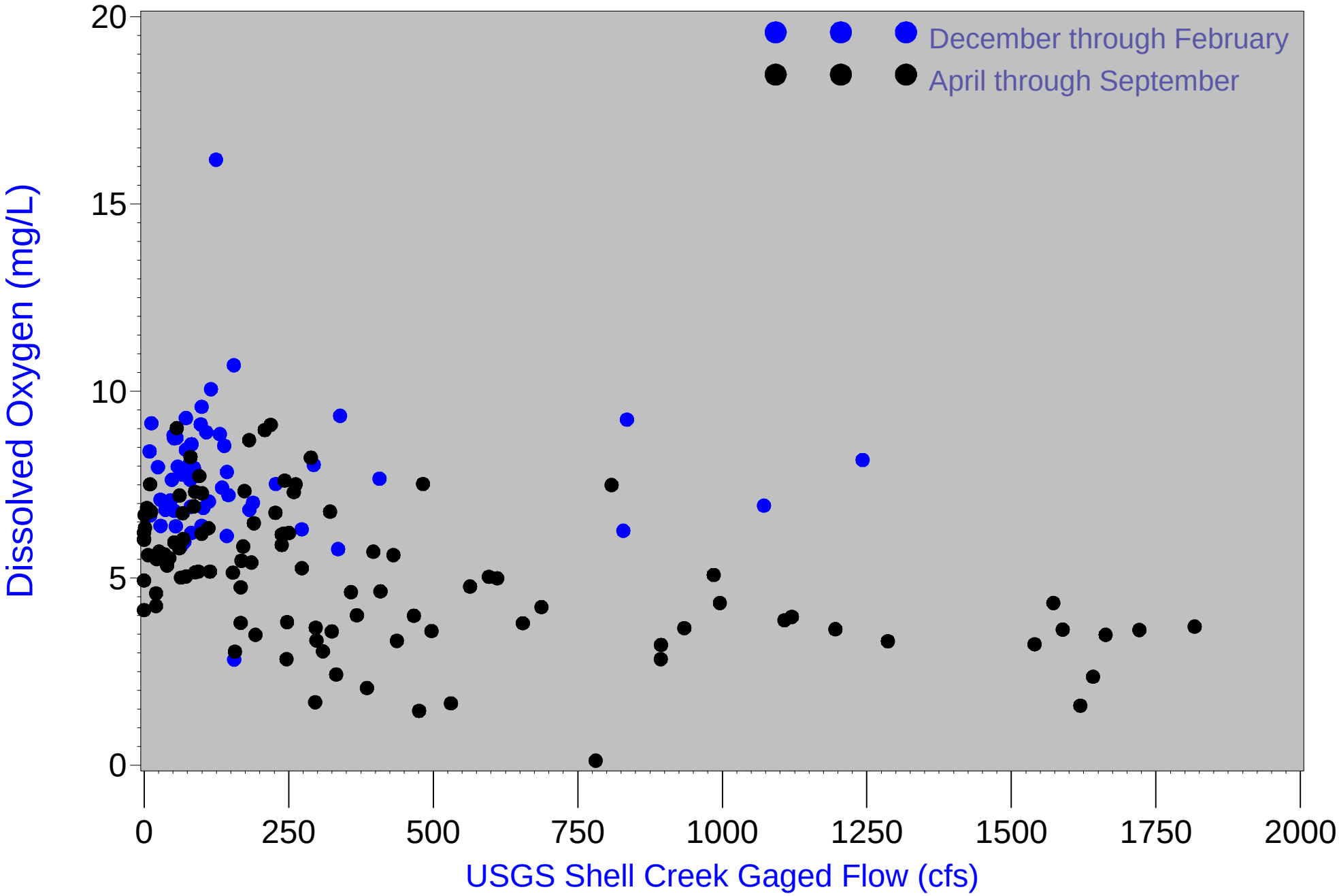


Figure 4.59b Bottom D.O. at Station #9 (River Kilometer -0.37) versus 7-day average Shell Creek flow 1991-2009

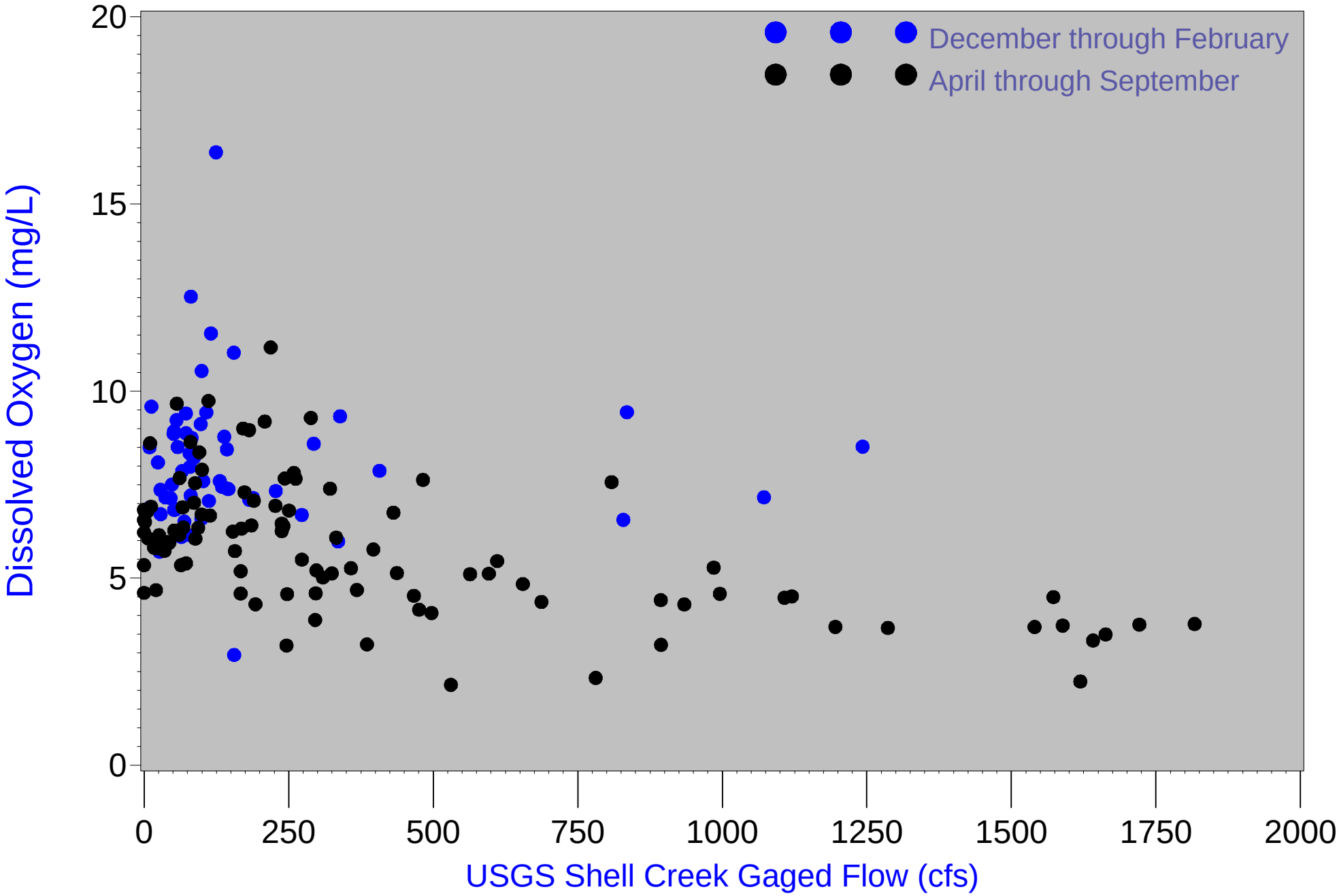


Figure 4.59c Mean D.O. at Station #9 (River Kilometer -0.37) versus 7-day average Shell Creek flow 1991-2009

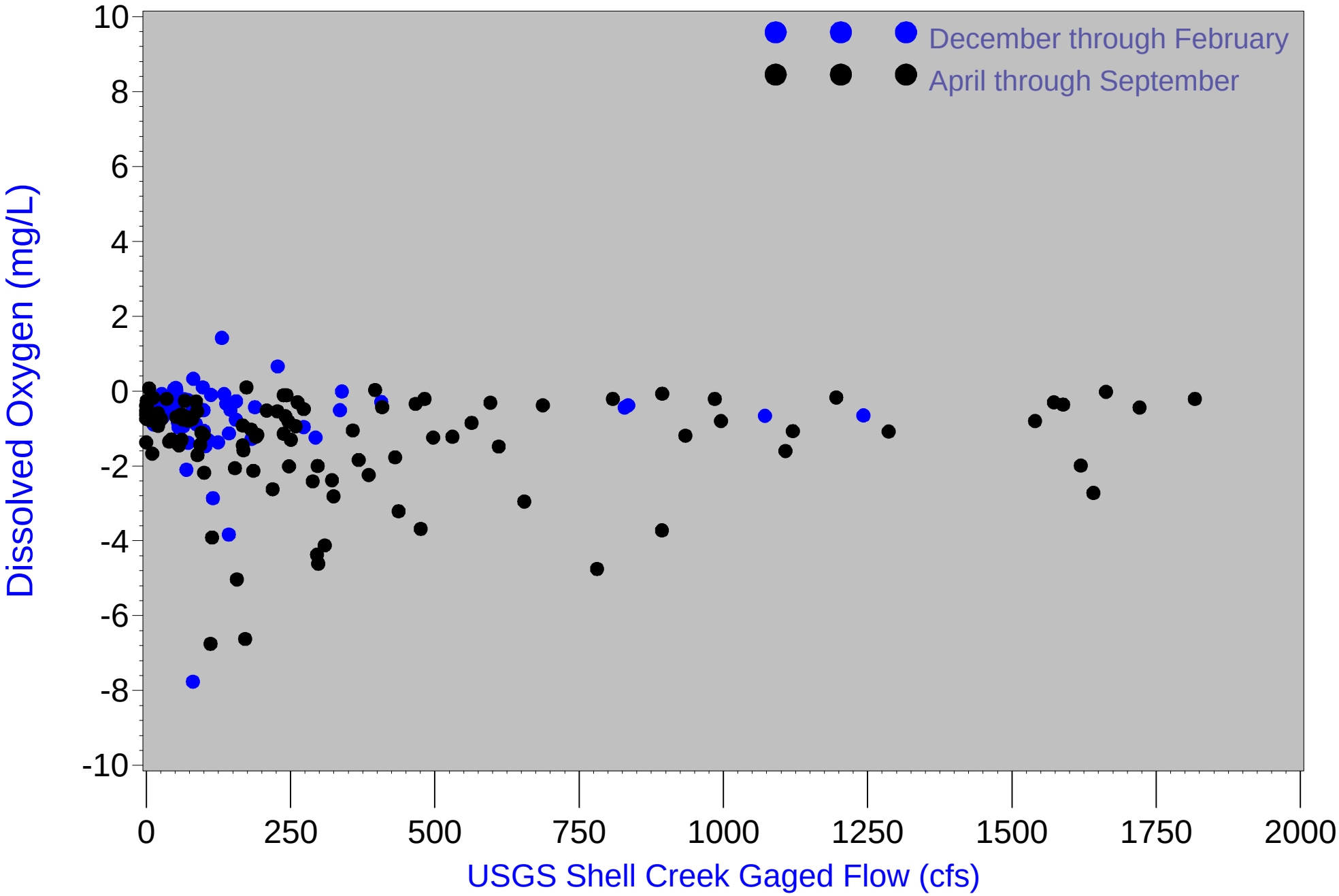


Figure 4.59d D.O. stratification at Station #9 (River Kilometer -0.37) versus 7-day average Shell Creek flow 1991-2009

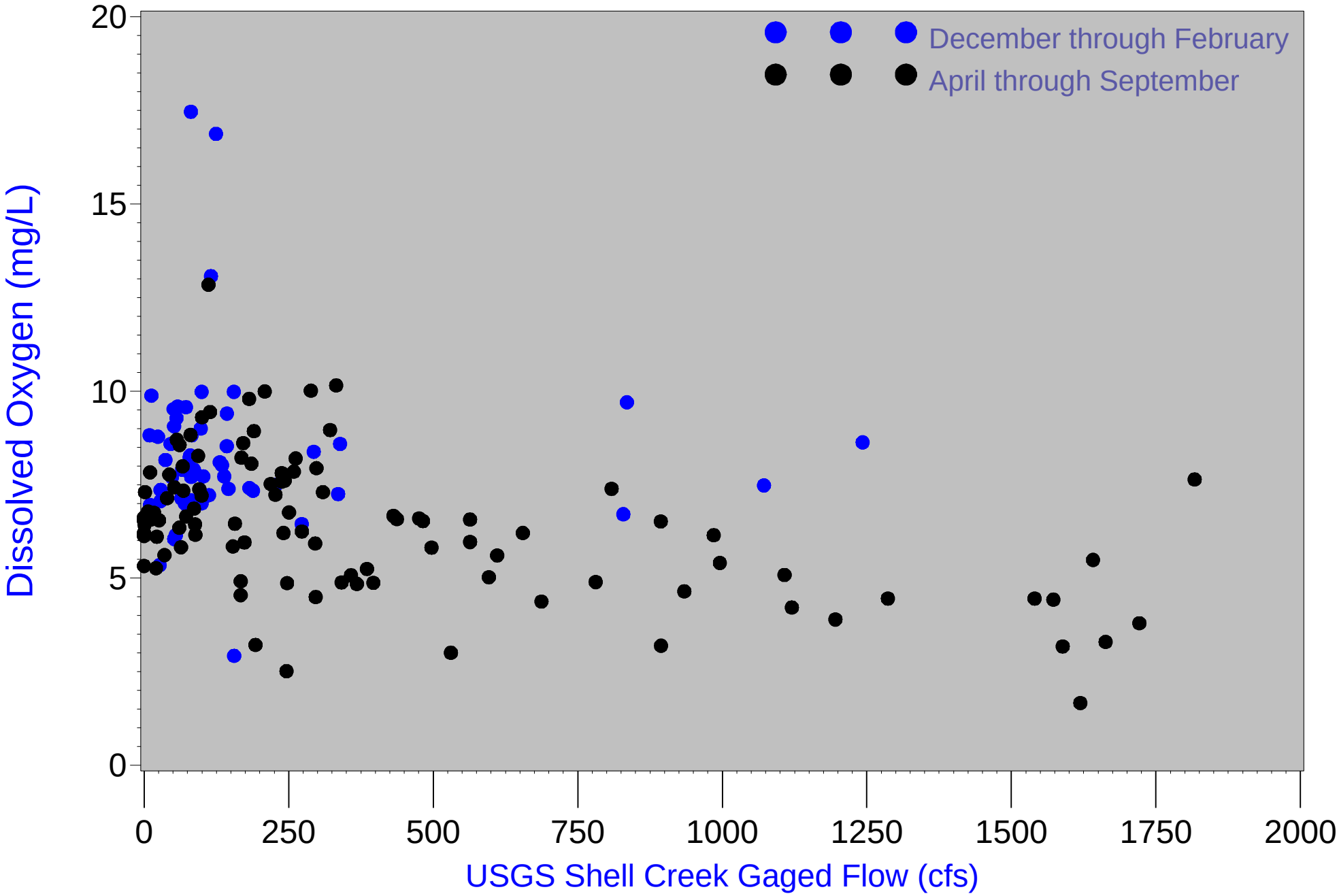


Figure 4.60a Surface D.O. at Station #8 in lower Peace River versus 7-day average Shell Creek flow 1991-2009

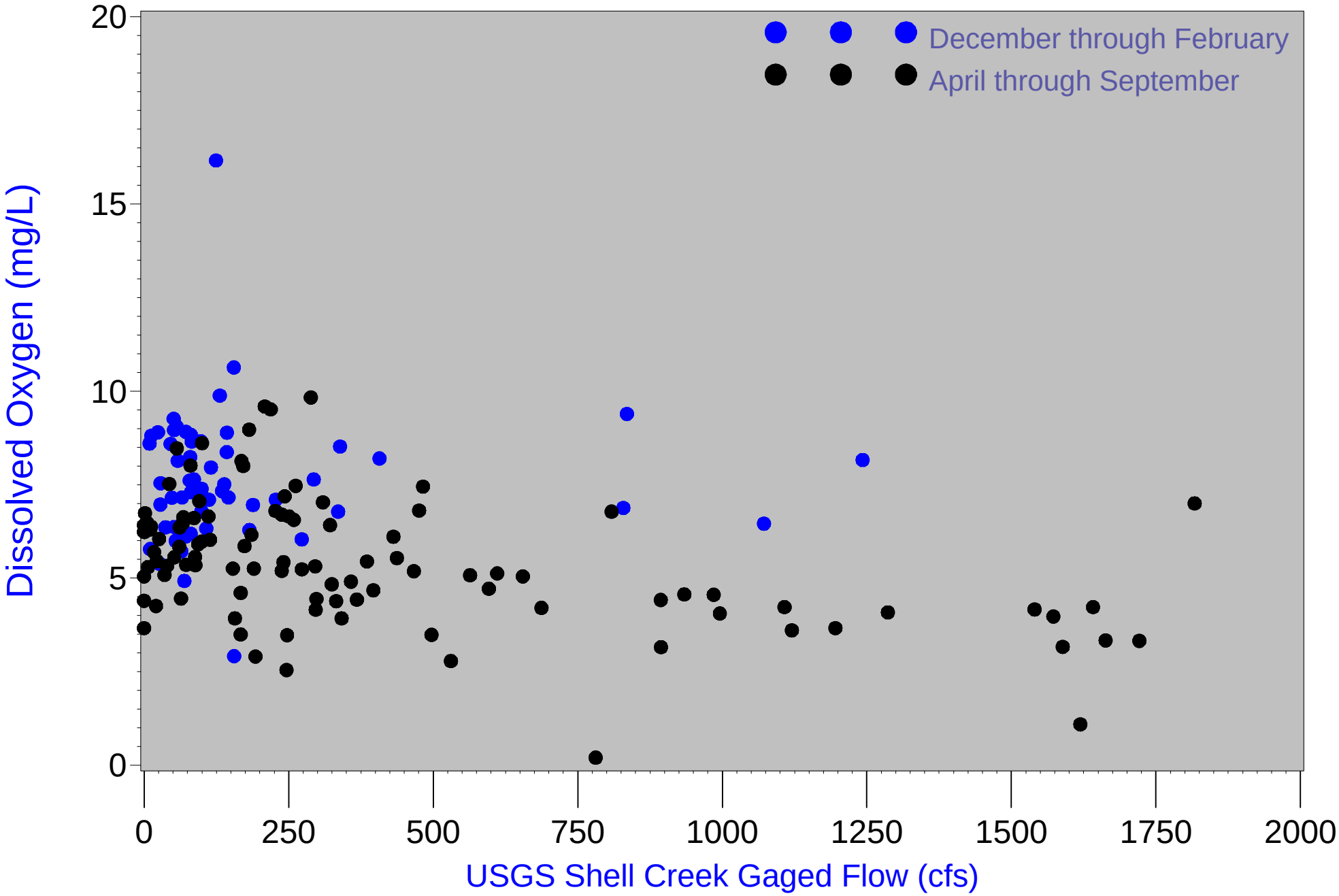


Figure 4.60b Bottom D.O. at Station #8 in lower Peace River versus 7-day average Shell Creek flow 1991-2009

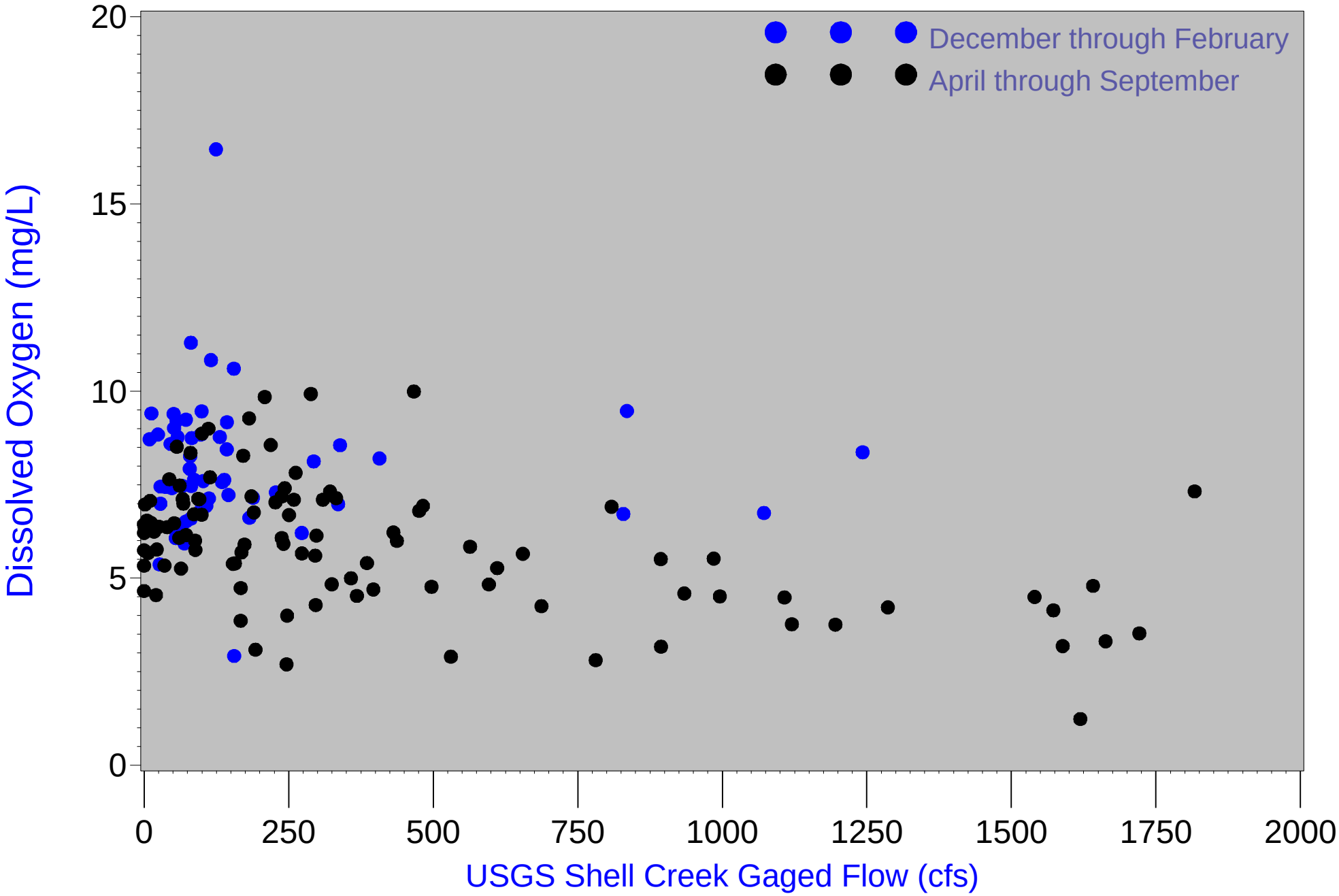


Figure 4.60c Mean D.O. at Station #8 in lower Peace River versus 7-day average Shell Creek flow 1991-2009

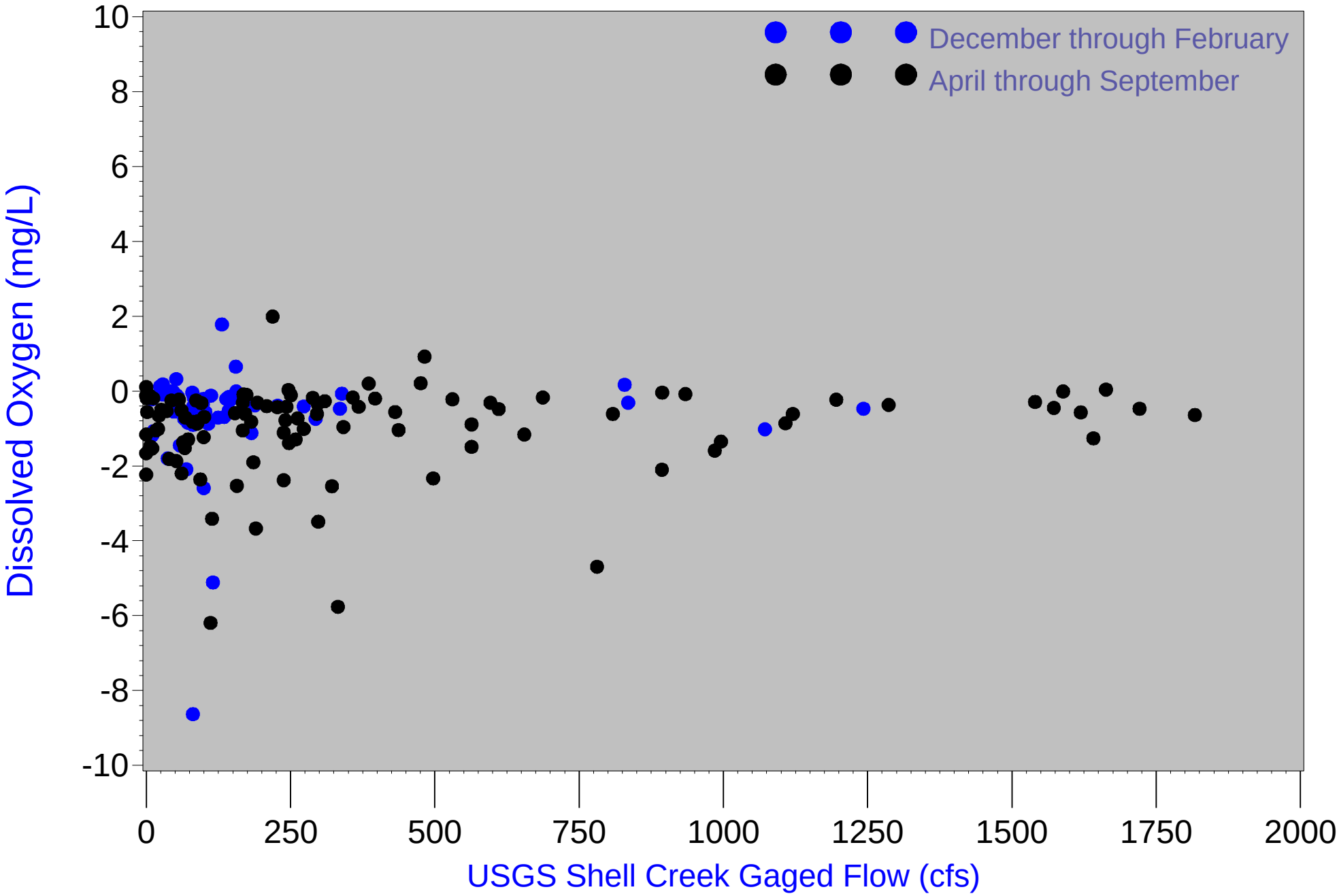


Figure 4.60d D.O. stratification at Station #8 in lower Peace River versus 7-day average Shell Creek flow 1991-2009

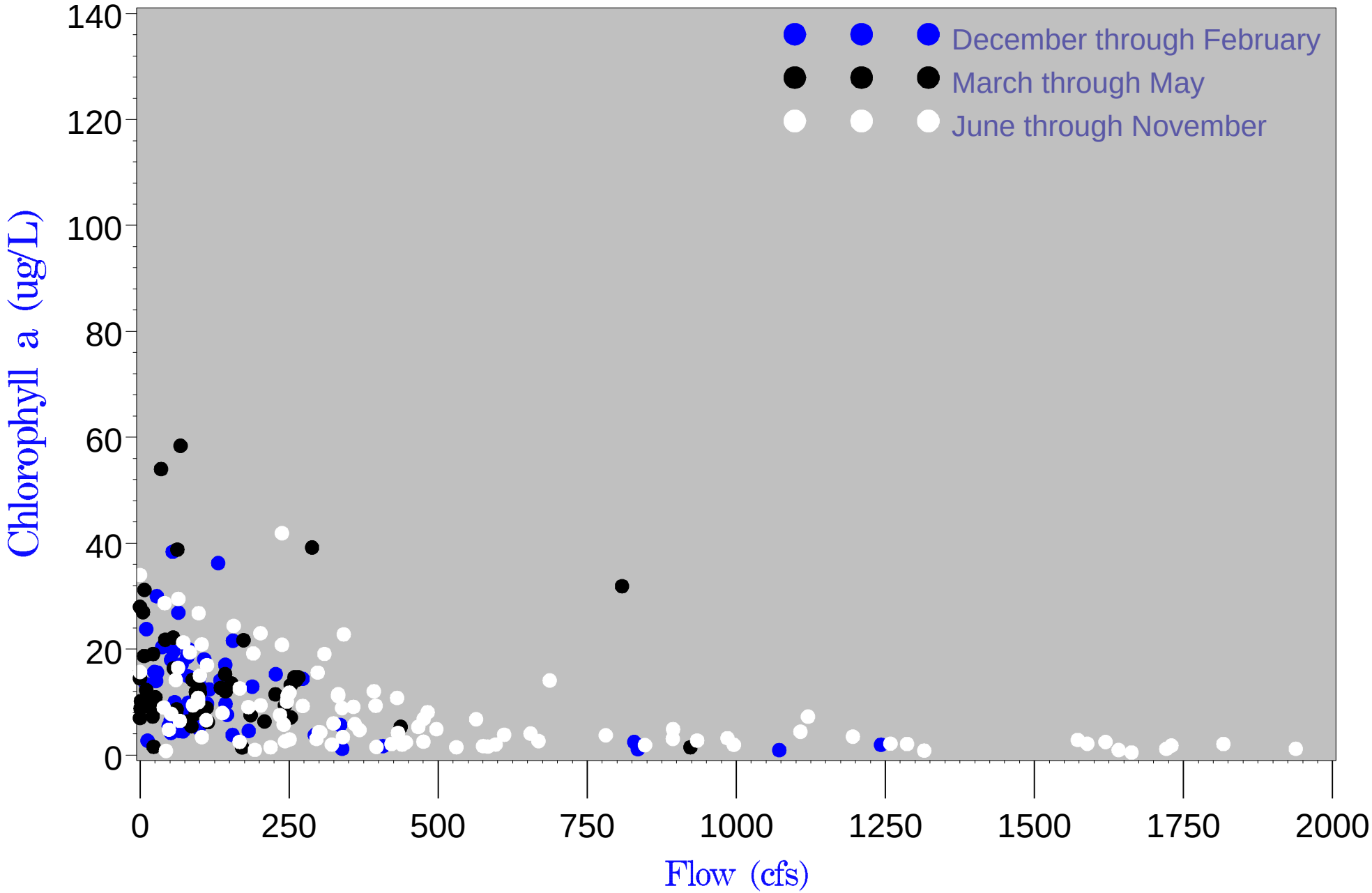


Figure 4.61 Mid-depth chlorophyll a versus 7-day average flow at Station #4 (River Kilometer 8.74), 1991-2009

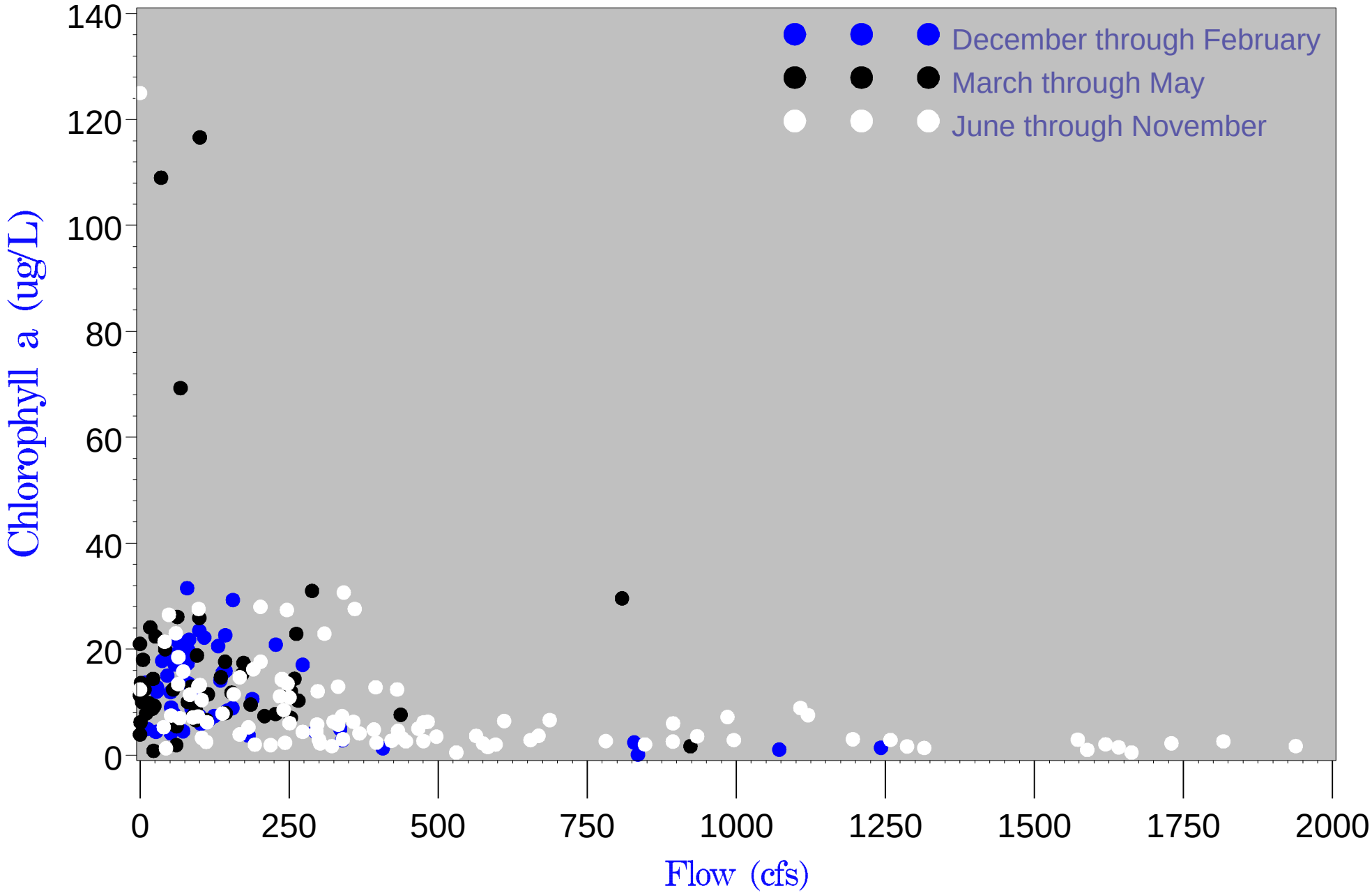


Figure 4.62 Mid-depth chlorophyll a versus 7-day average flow at Station #5 (River Kilometer 6.72), 1991-2009

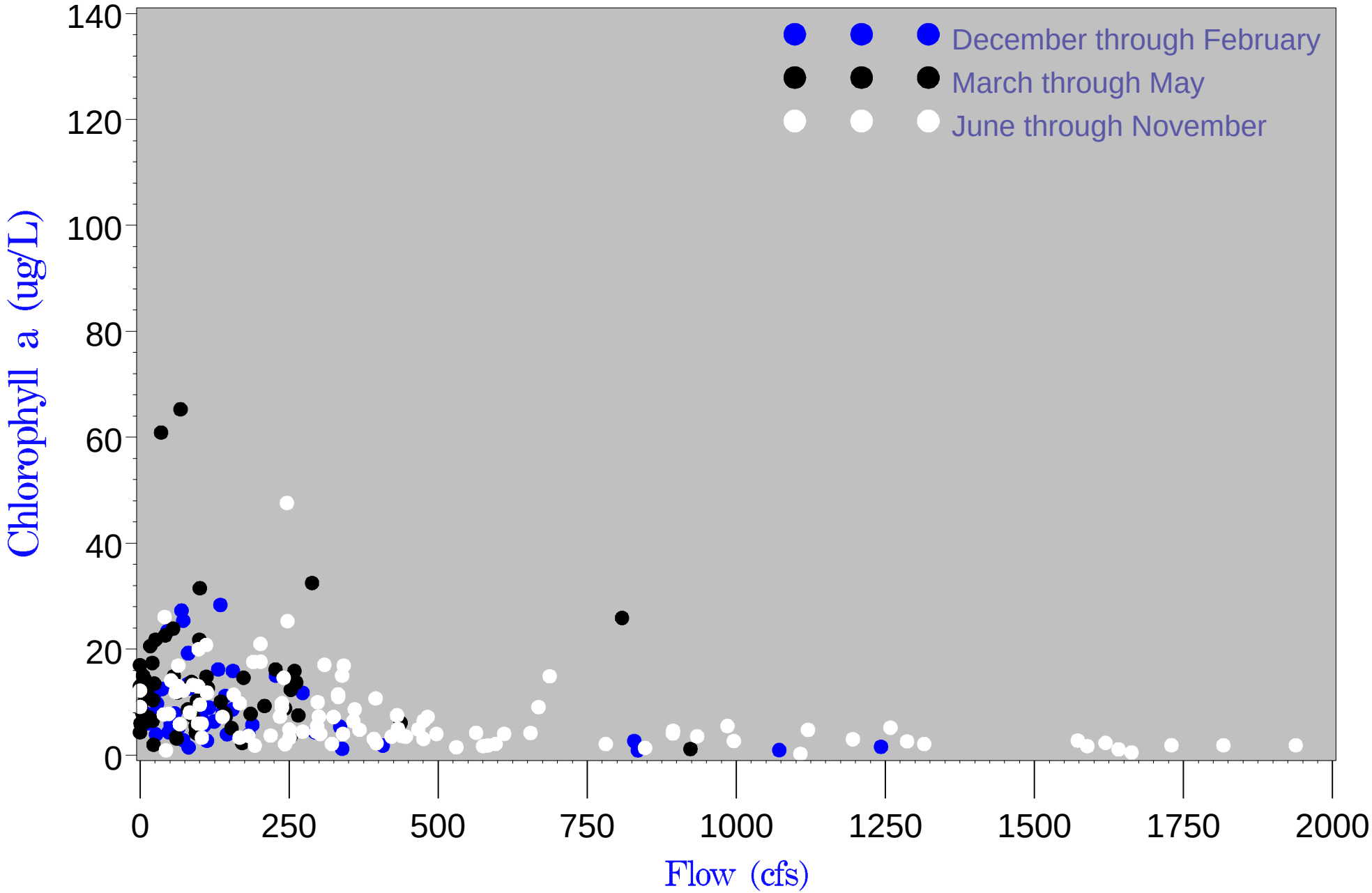


Figure 4.63 Mid-depth chlorophyll a versus 7-day average flow at Station #6 (River Kilometer 4.61), 1991-2009

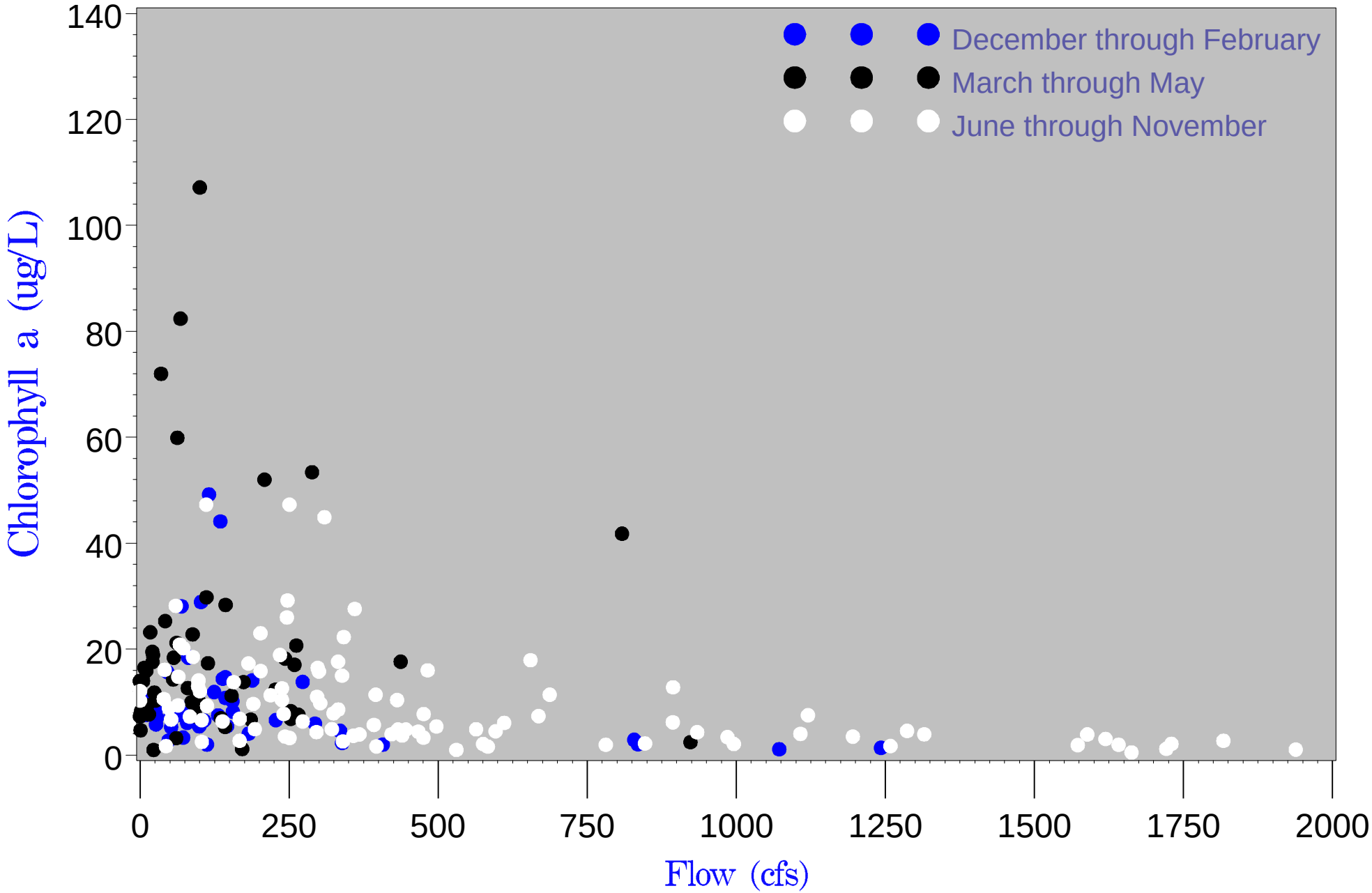


Figure 4.64 Mid-depth chlorophyll a versus 7-day average flow at Station #7 (River Kilometer 2.35), 1991-2009

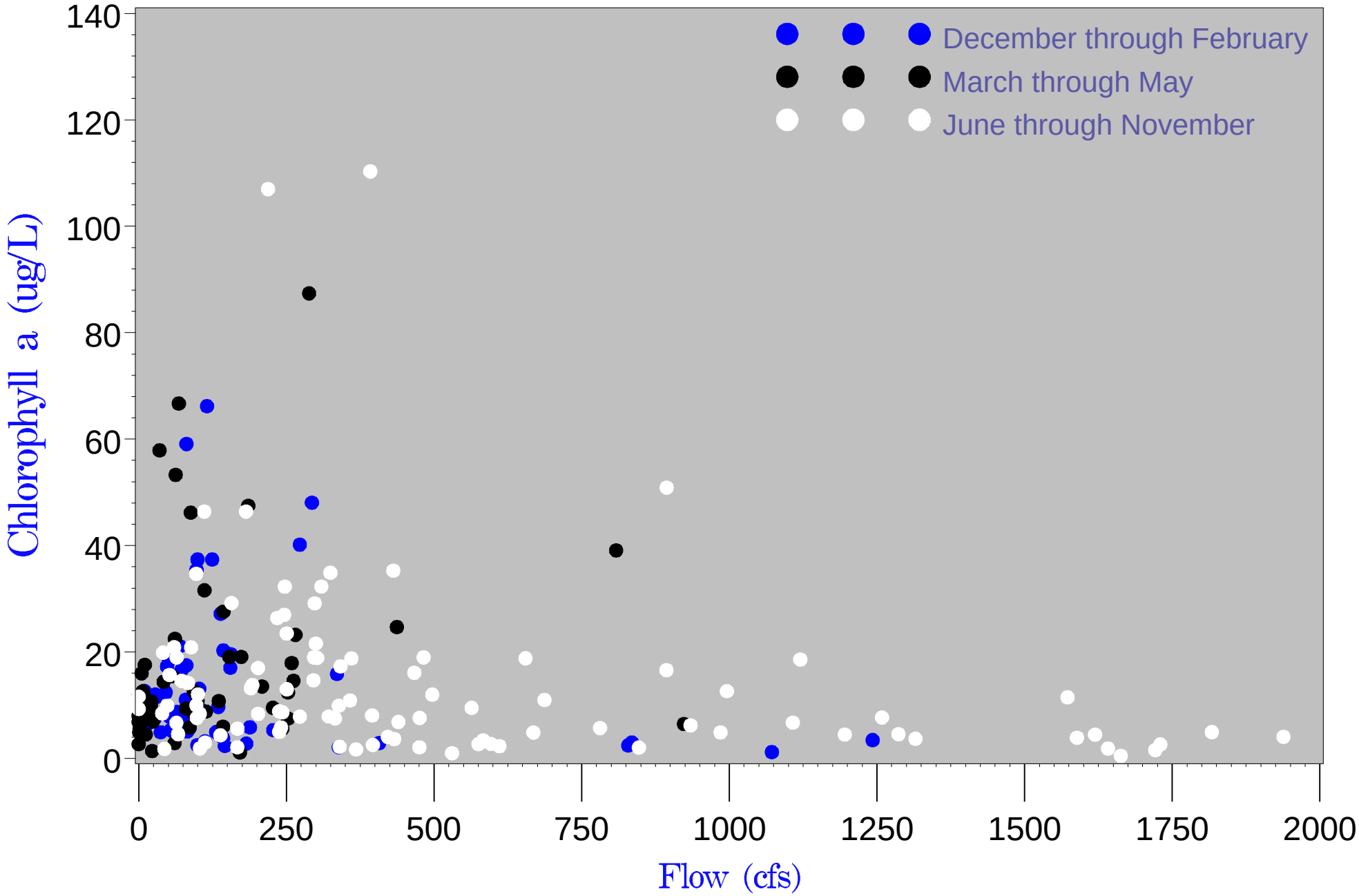


Figure 4.65 Mid-depth chlorophyll a versus 7-day average flow at Station #9 (River Kilometer -0.37), 1991-2009

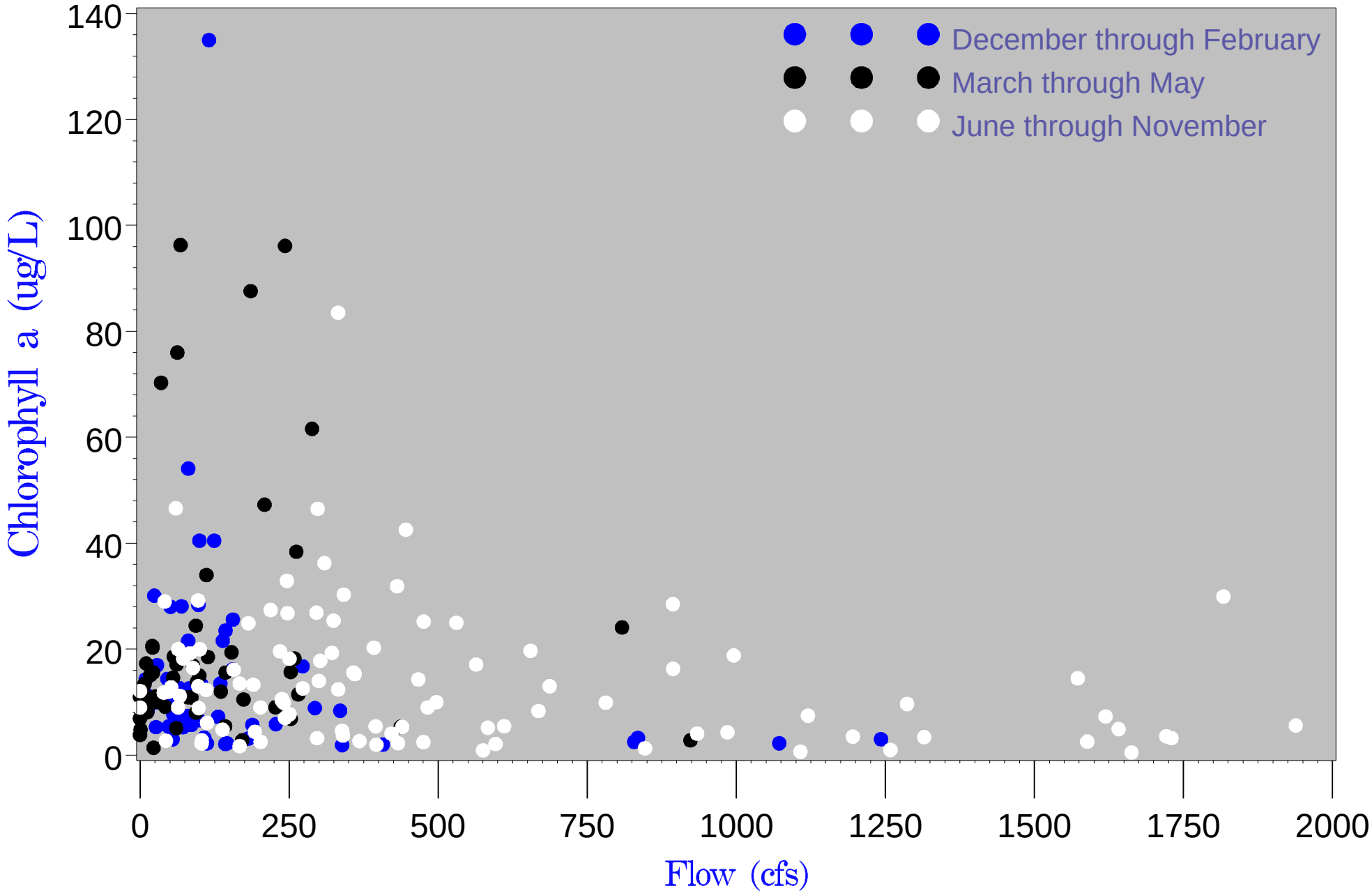


Figure 4.66 Mid-depth chlorophyll a versus 7-day average flow at Station #8 (Lower Peace River), 1991-2009

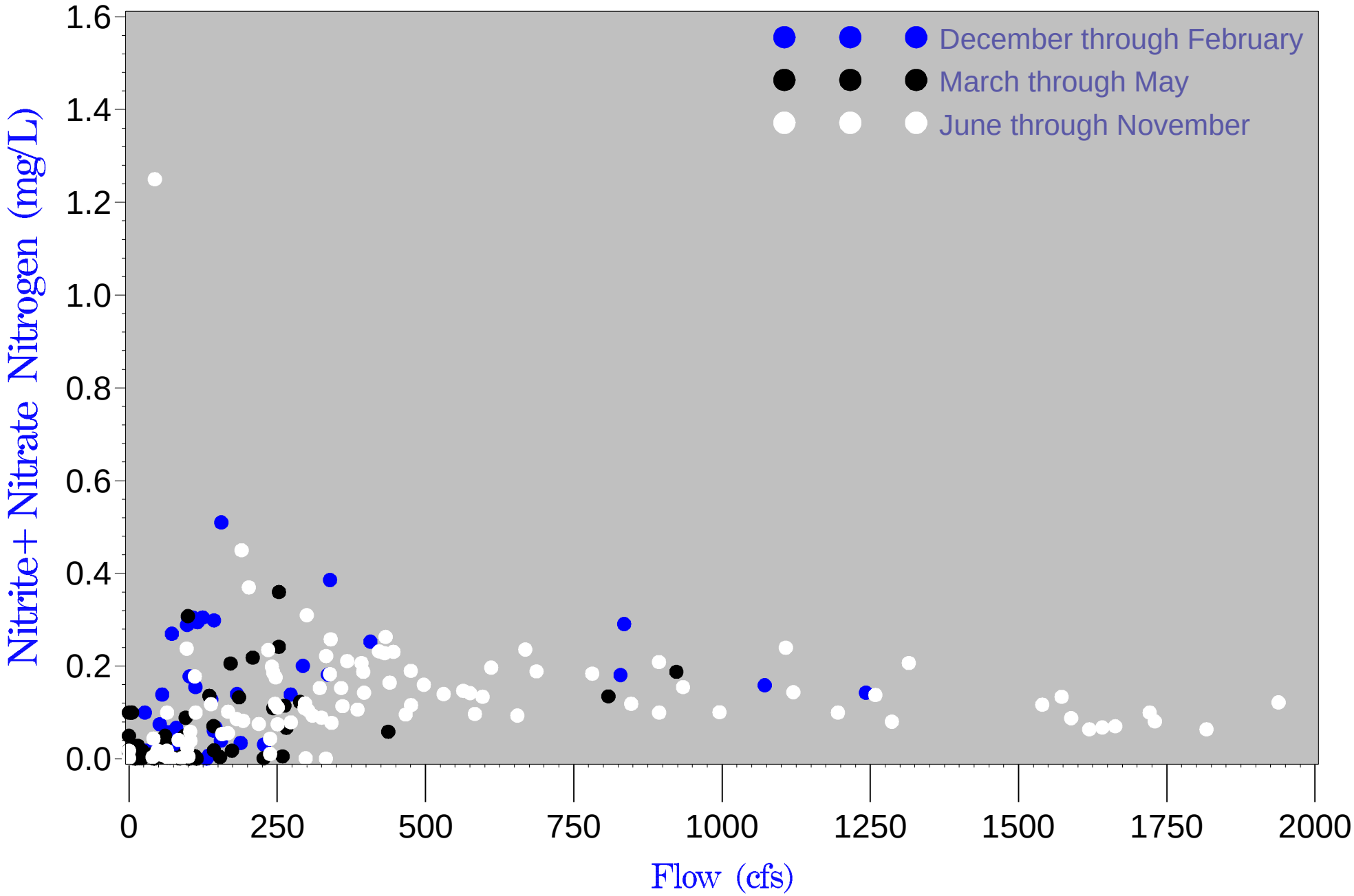


Figure 4.67 Mid-depth nitrite+nitrate nitrogen versus 7-day average flow at Station #4 (River Kilometer 8.74), 1991-2009

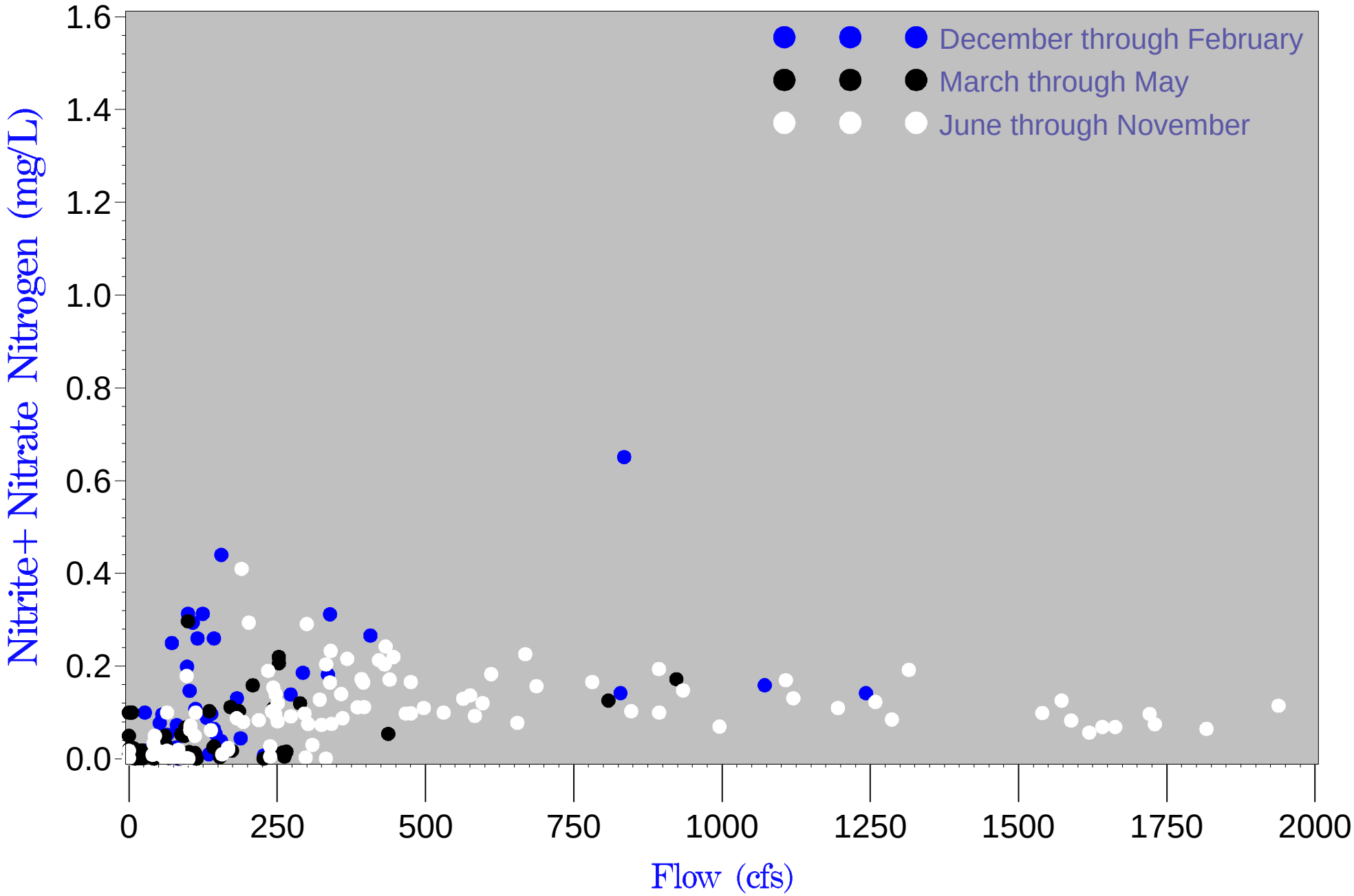


Figure 4.68 Mid-depth nitrite+nitrate nitrogen versus 7-day average flow at Station #5 (River Kilometer 6.72), 1991-2009

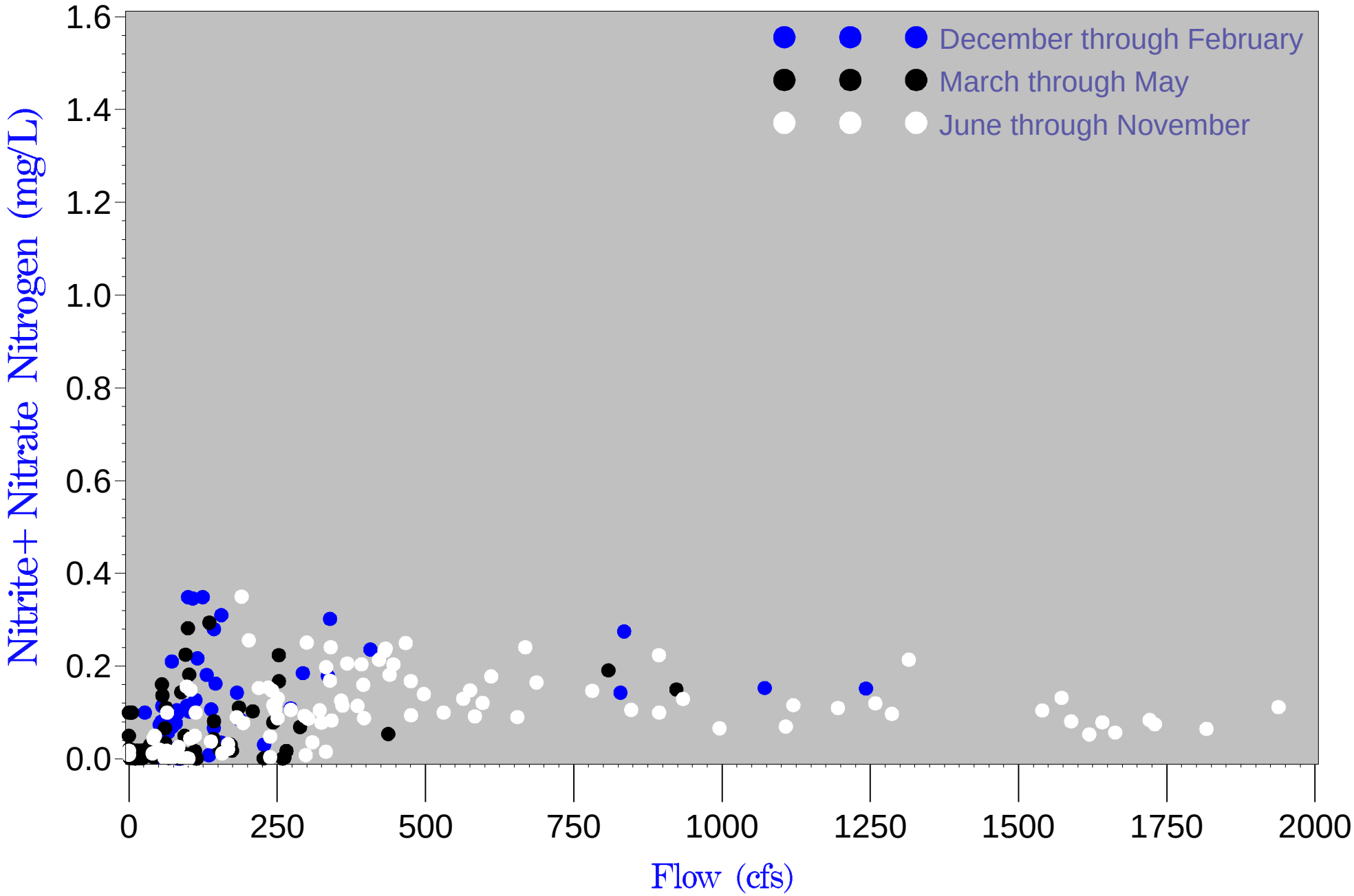


Figure 4.69 Mid-depth nitrite+nitrate nitrogen versus 7-day average flow at Station #6 (River Kilometer 4.61), 1991-2009

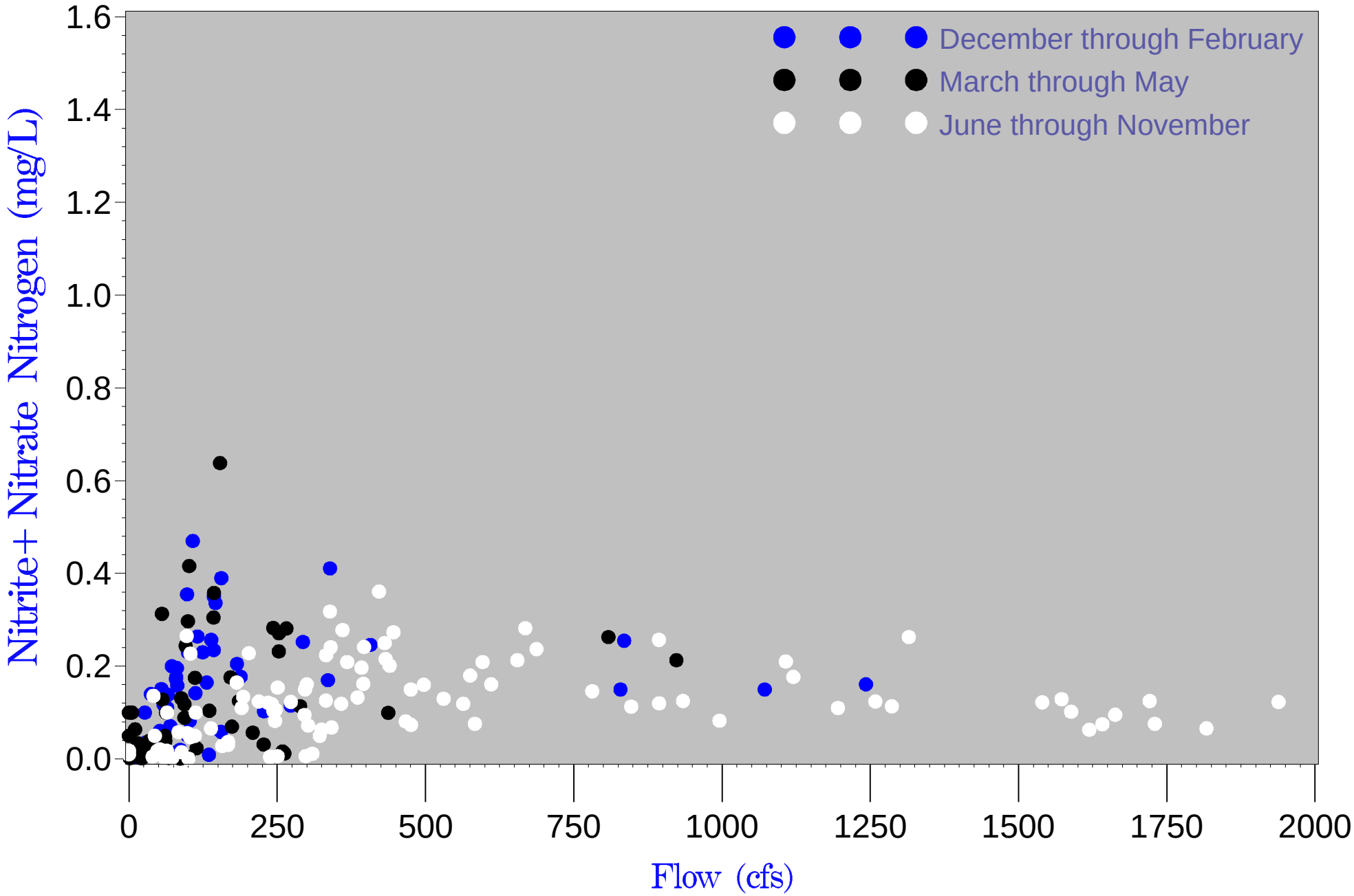


Figure 4.70 Mid-depth nitrite+nitrate nitrogen versus 7-day average flow at Station #7 (River Kilometer 2.35), 1991-2009

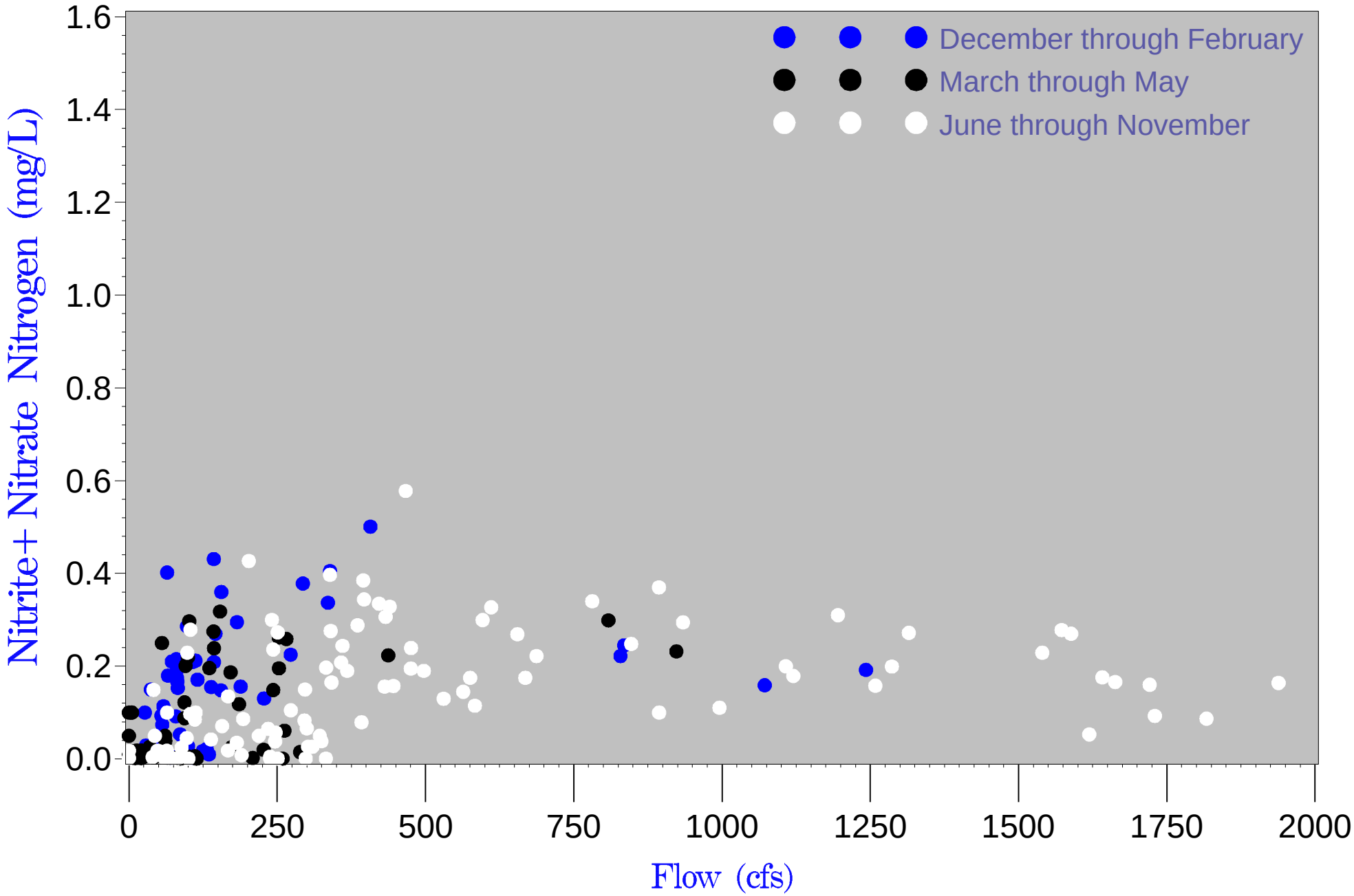


Figure 4.71 Mid-depth nitrite+nitrate nitrogen versus 7-day average flow at Station #9 (River Kilometer -0.37), 1991-2009

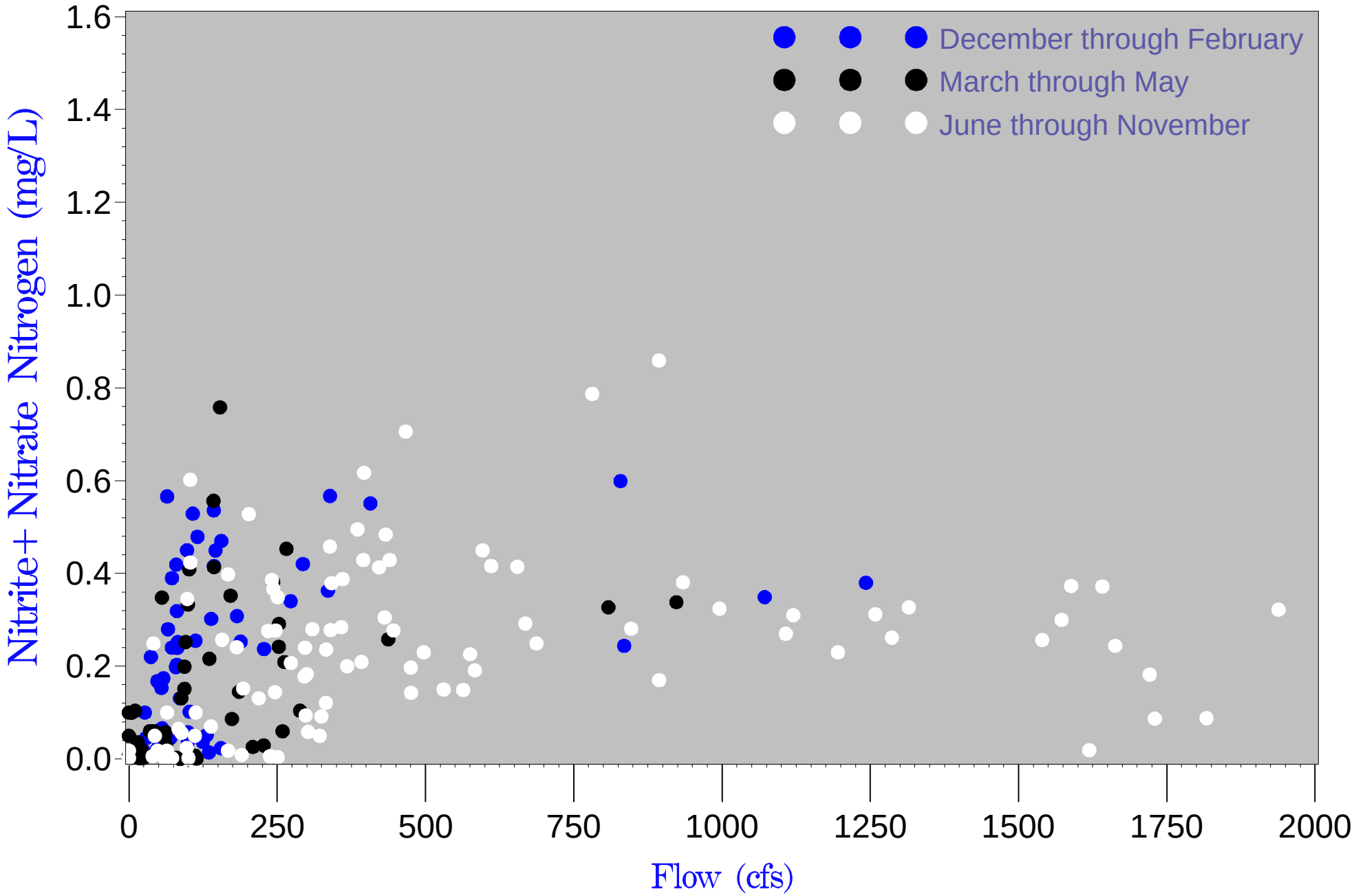


Figure 4.72 Mid-depth nitrite+nitrate nitrogen versus 7-day average flow at Station #8 (Lower Peace River), 1991-2009

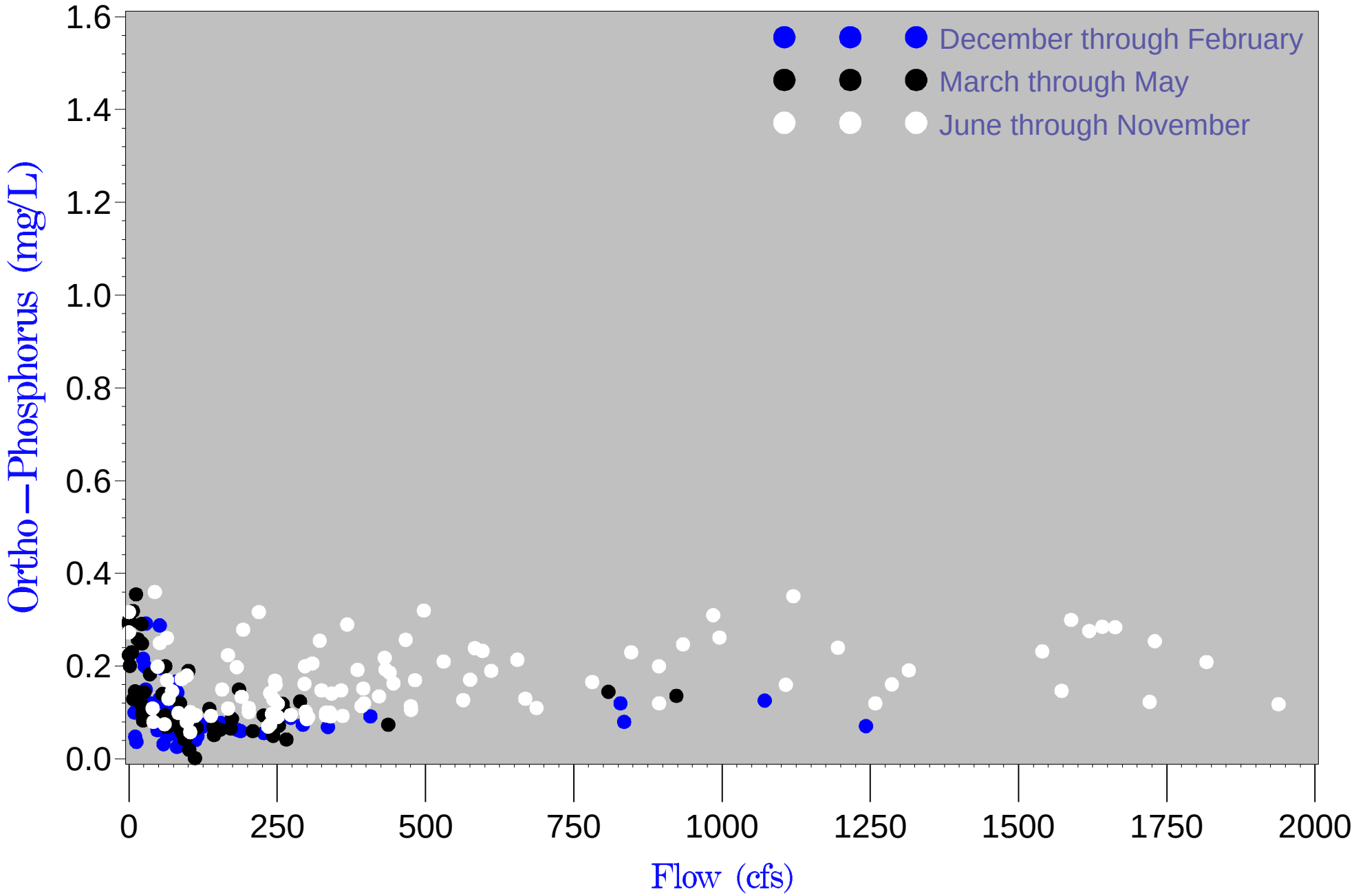


Figure 4.73 Mid-depth ortho-phosphorus versus 7-day average flow at Station #4 (River Kilometer 8.74), 1991-2009

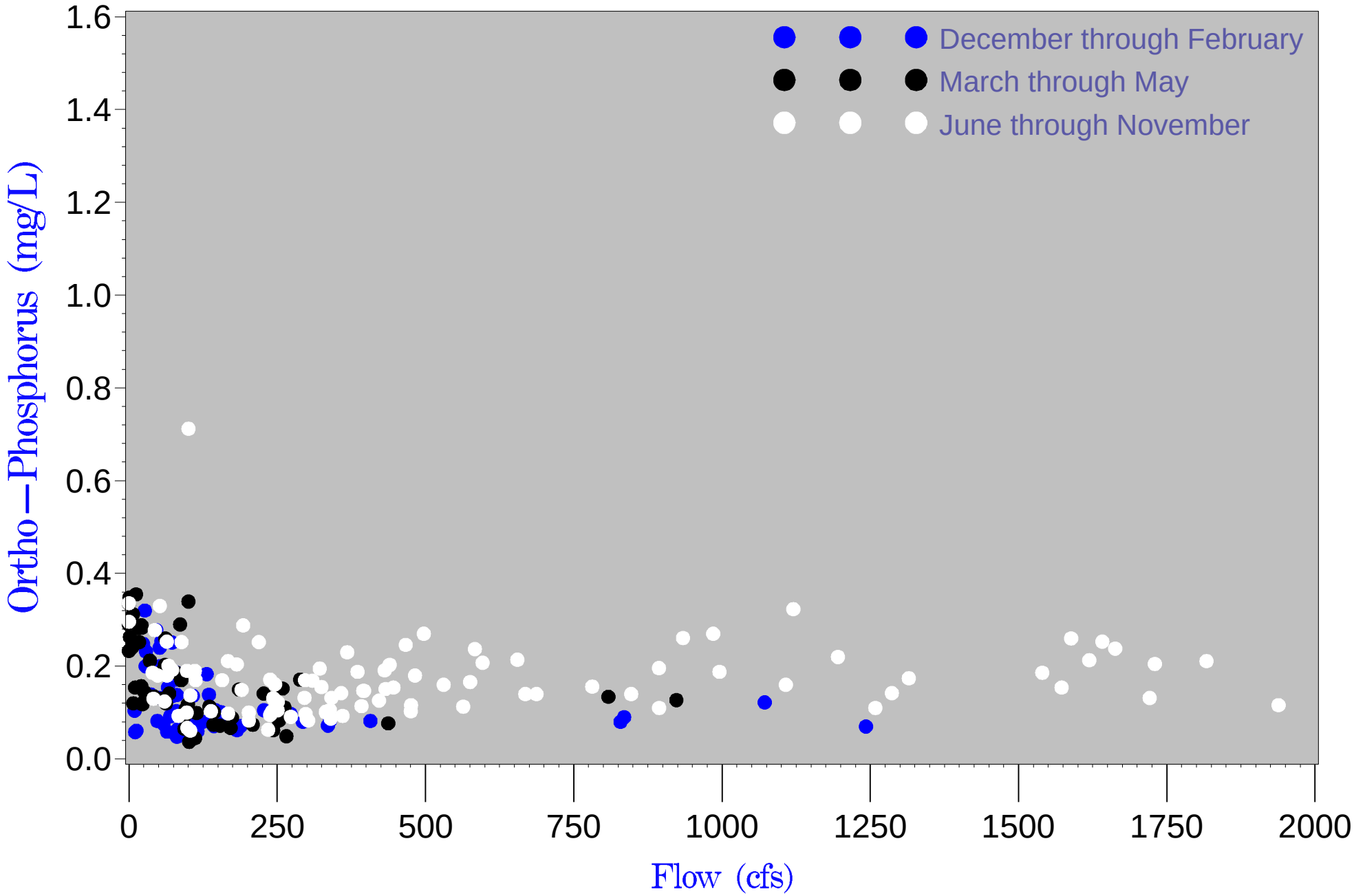


Figure 4.74 Mid-depth ortho-phosphorus versus 7-day average flow at Station #5 (River Kilometer 6.72), 1991-2009

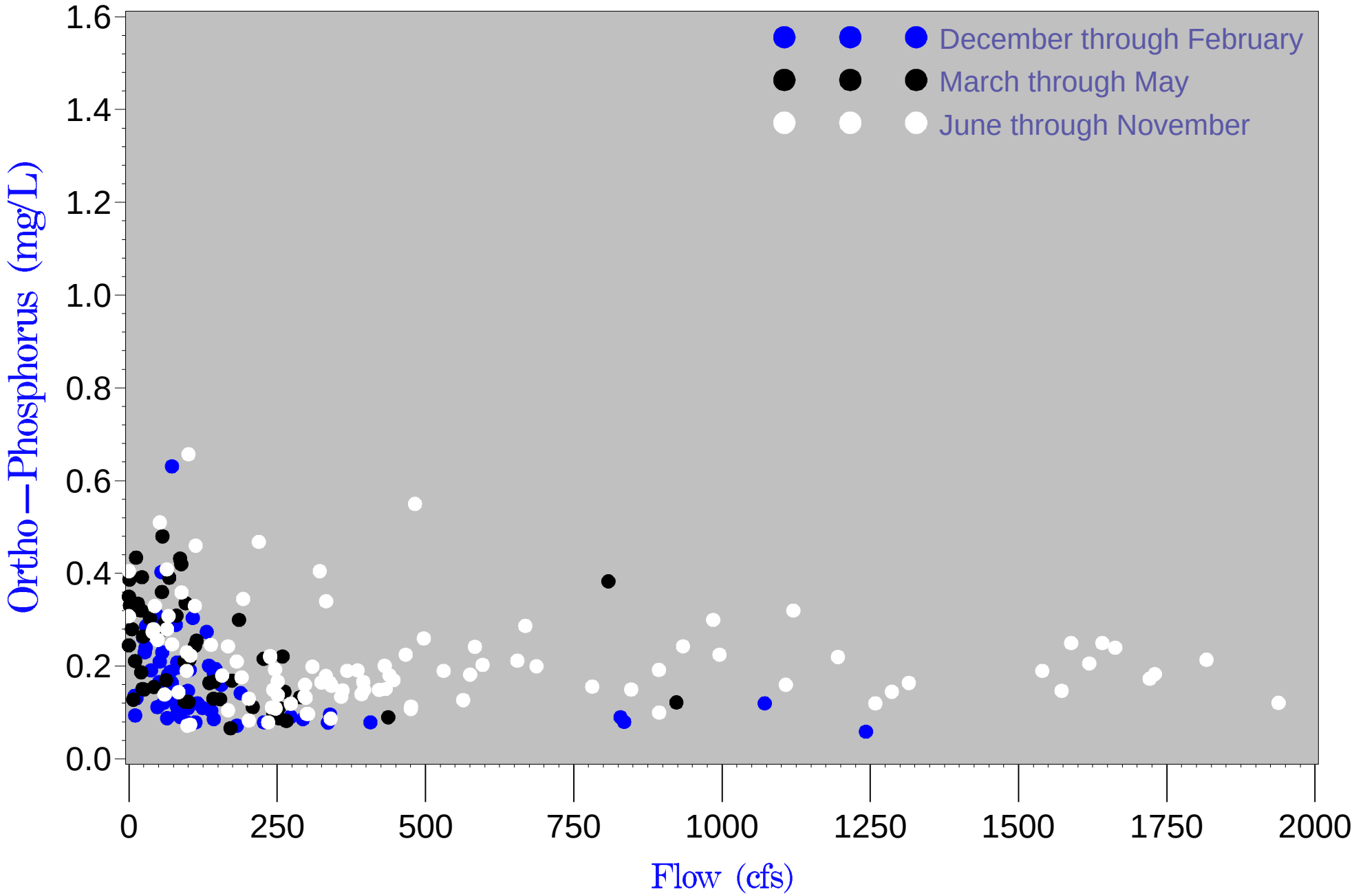


Figure 4.75 Mid-depth ortho-phosphorus versus 7-day average flow at Station #6 (River Kilometer 4.61), 1991-2009

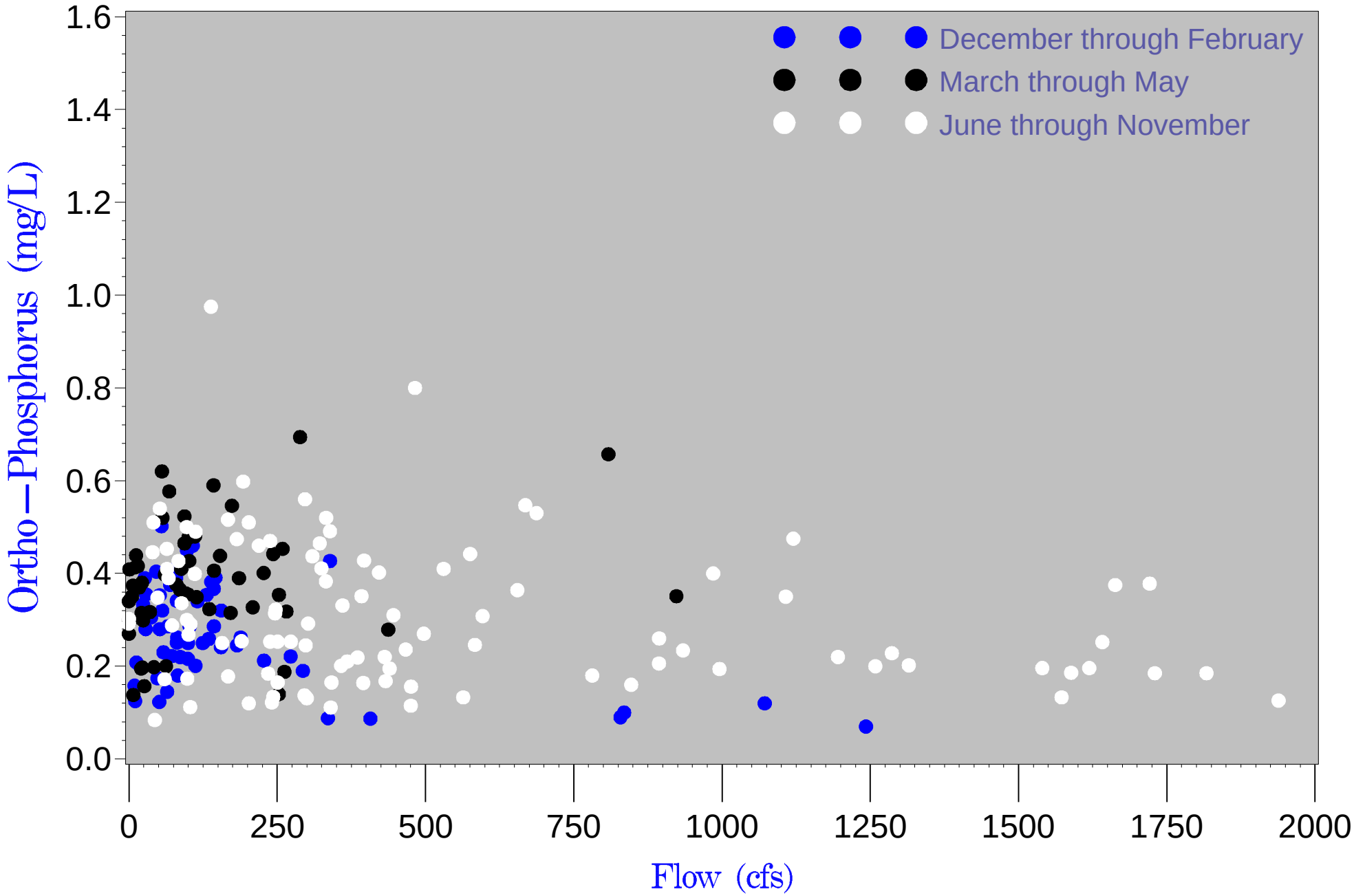


Figure 4.76 Mid-depth ortho-phosphorus versus 7-day average flow at Station #7 (River Kilometer 2.35), 1991-2009

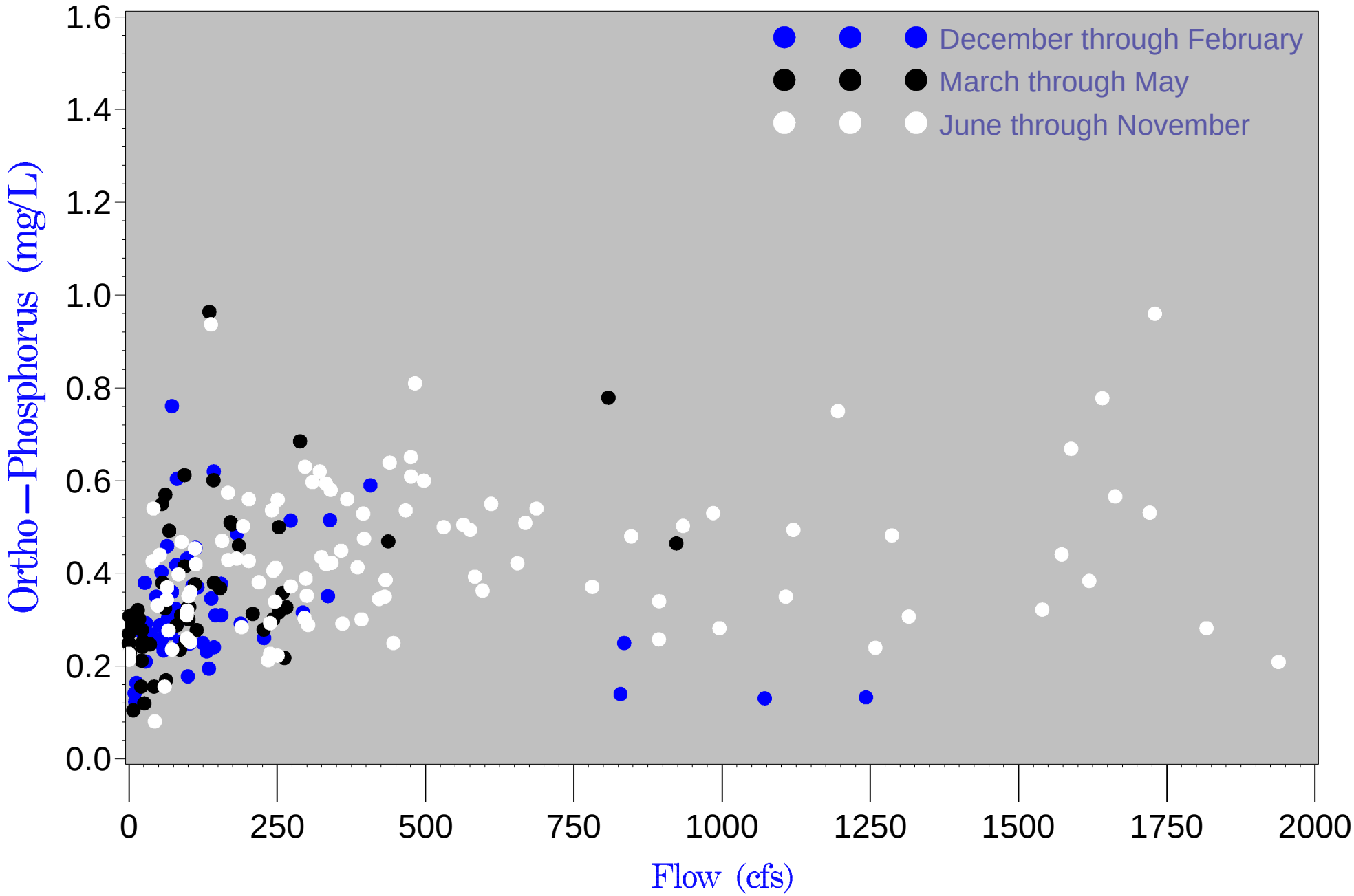


Figure 4.77 Mid-depth ortho-phosphorus versus 7-day average flow at Station #9 (River Kilometer -0.37), 1991-2009

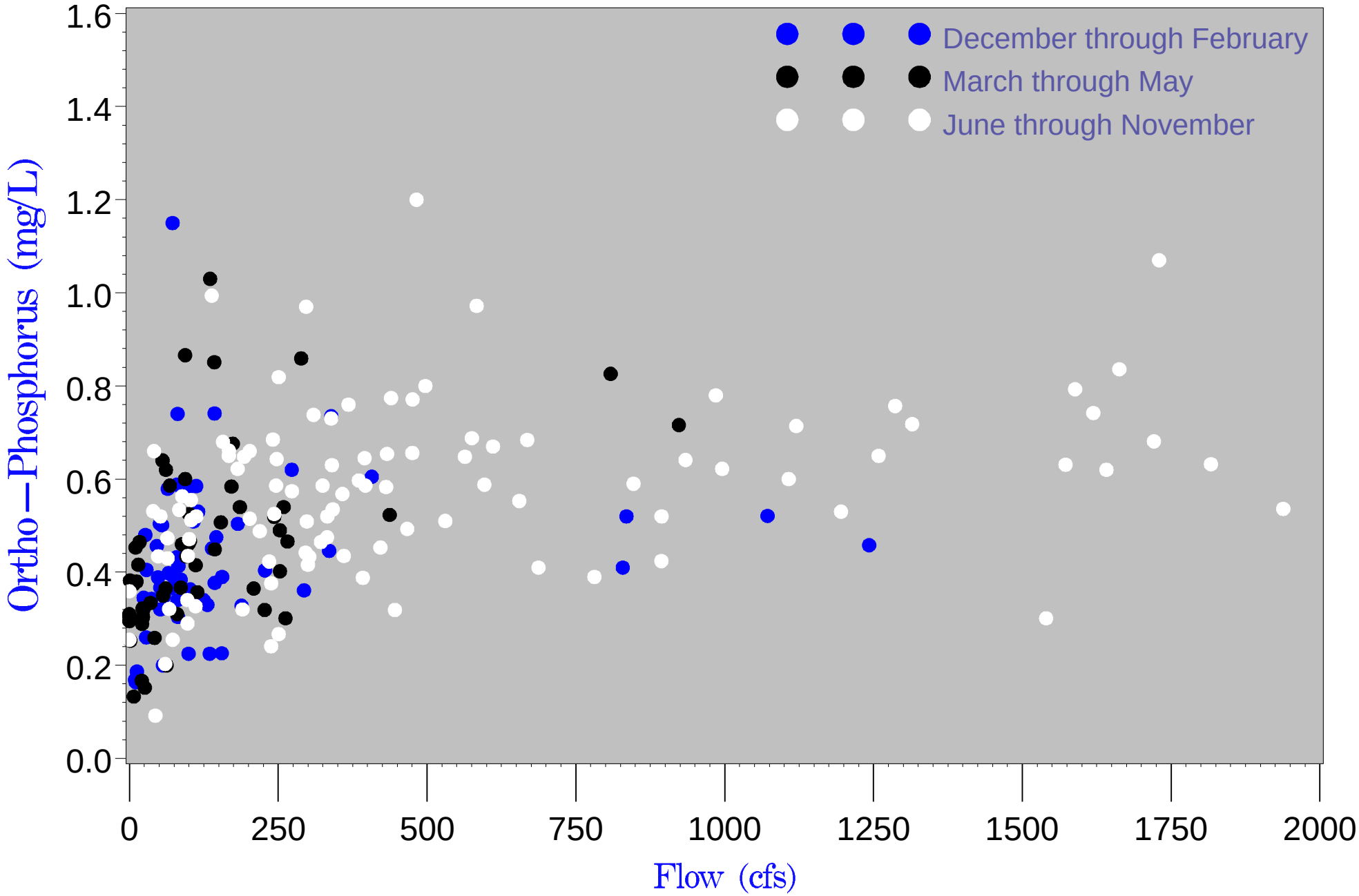


Figure 4.78 Mid-depth ortho-phosphorus versus 7-day average flow at Station #8 (Lower Peace River), 1991-2009

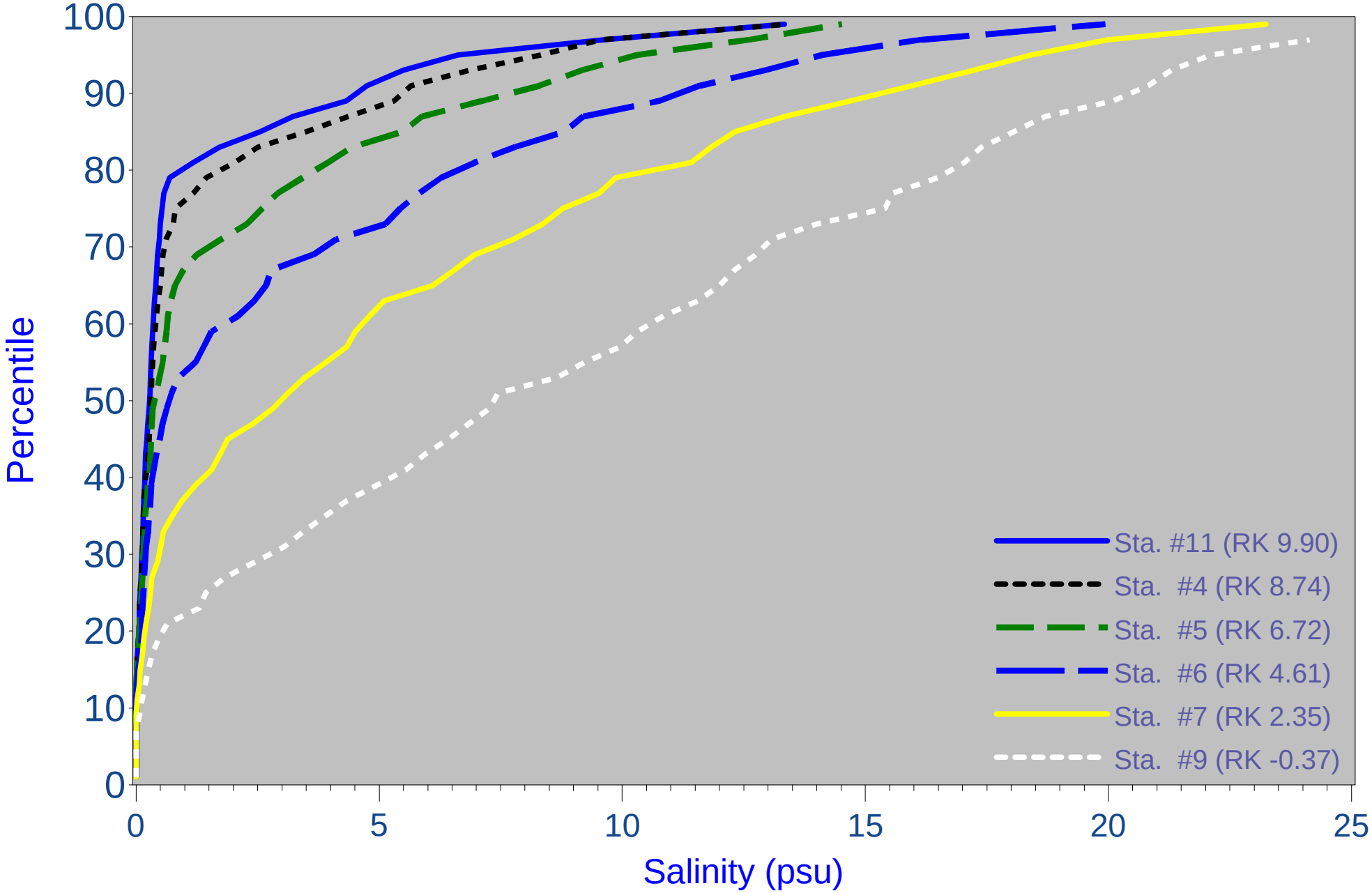


Figure 4.79 CDF plots of surface salinity among selected Shell Creek transect locations

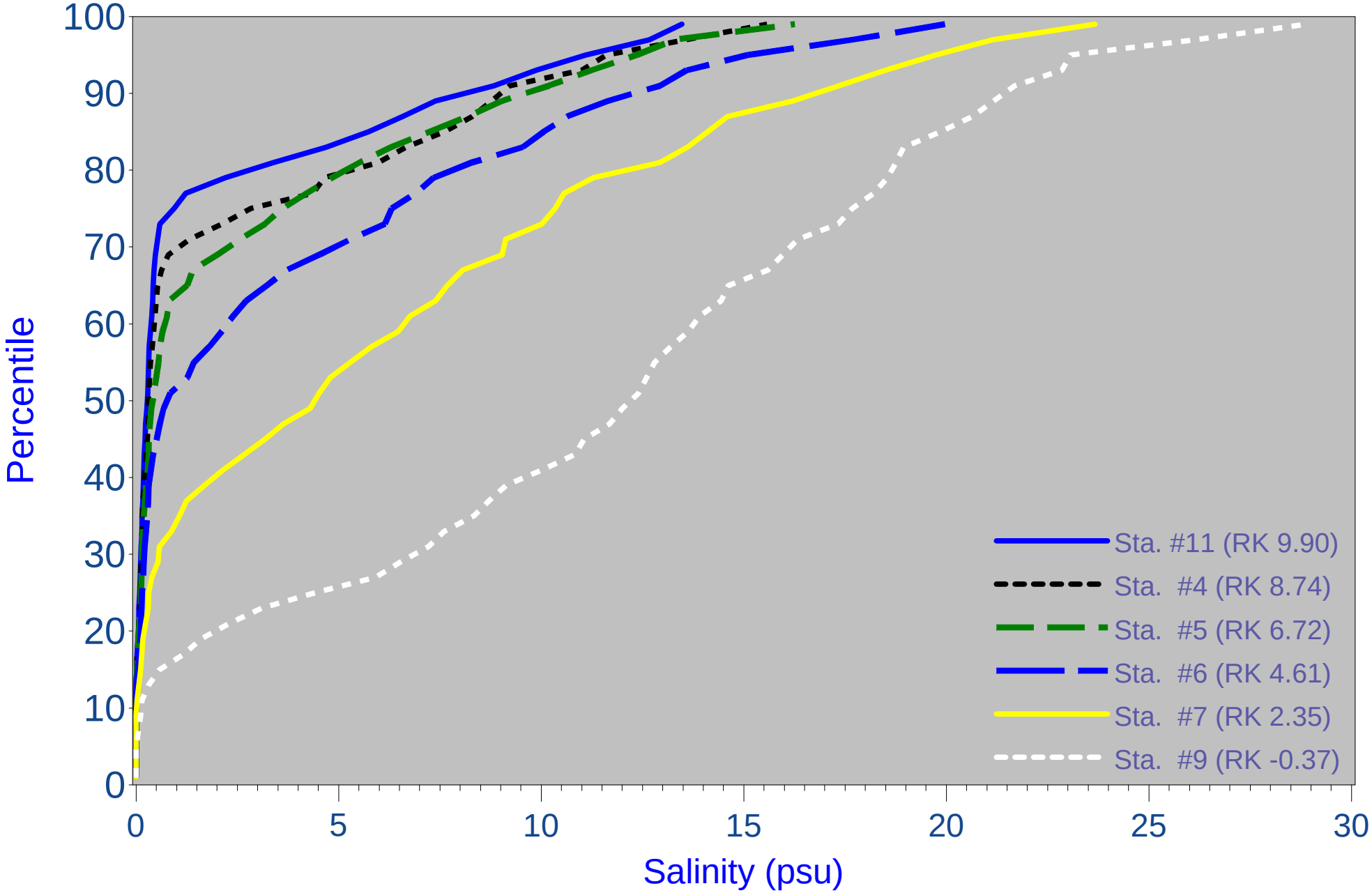


Figure 4.80 CDF plots of bottom salinity among selected Shell Creek transect locations

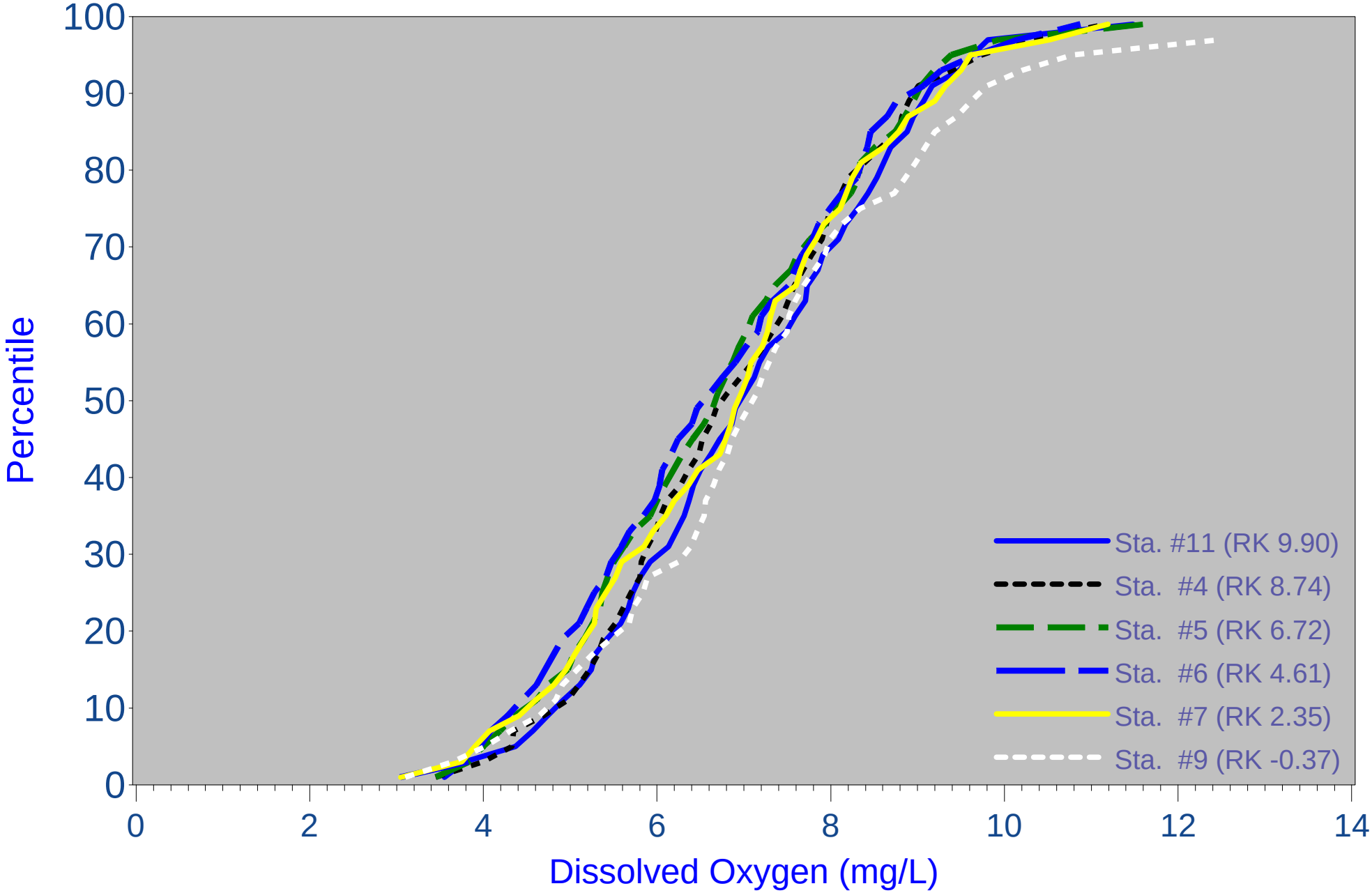


Figure 4.81 CDF plots of surface dissolved oxygen among selected Shell Creek transect locations

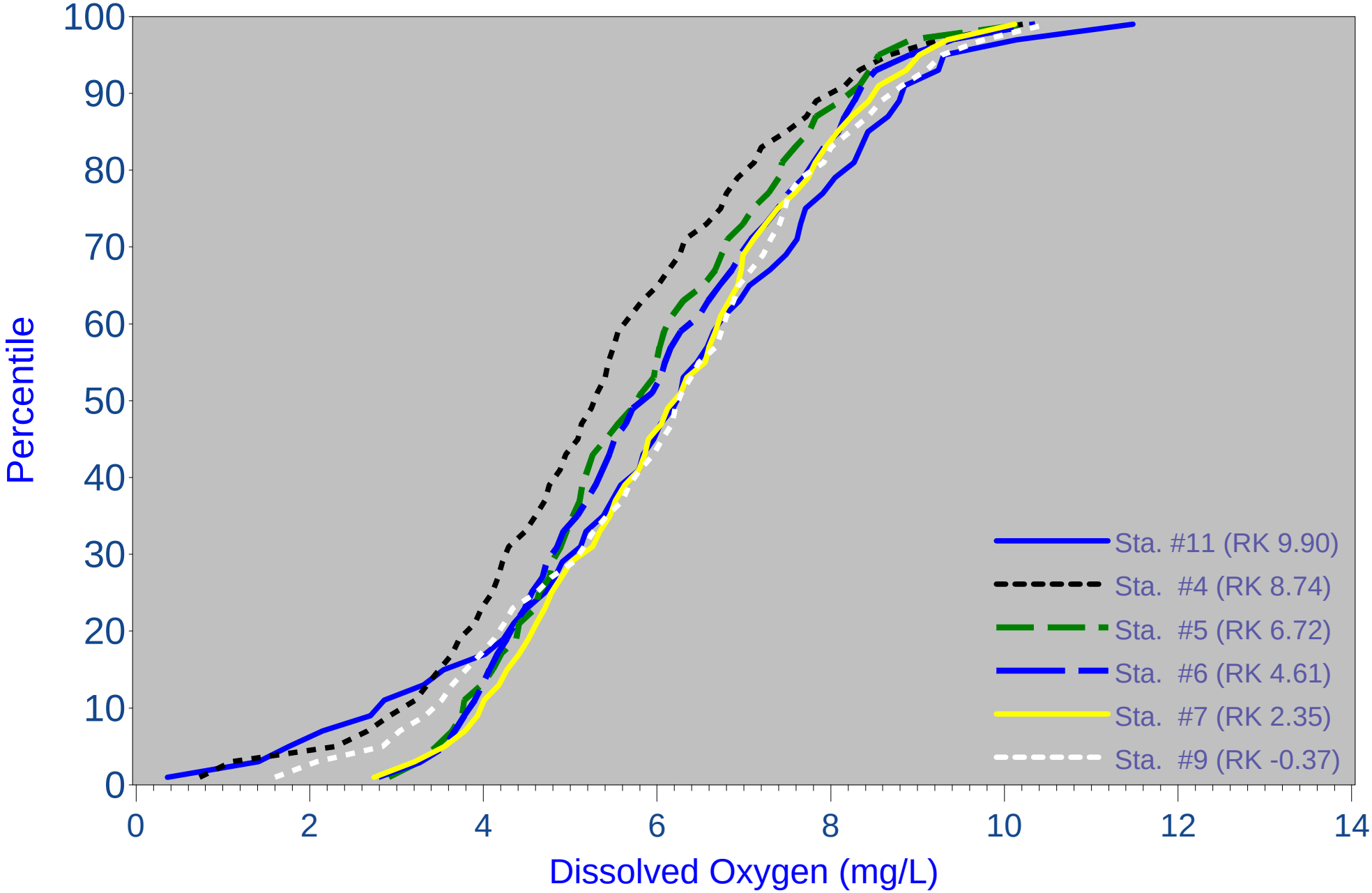


Figure 4.82 CDF plots of bottom dissolved oxygen among selected Shell Creek transect locations

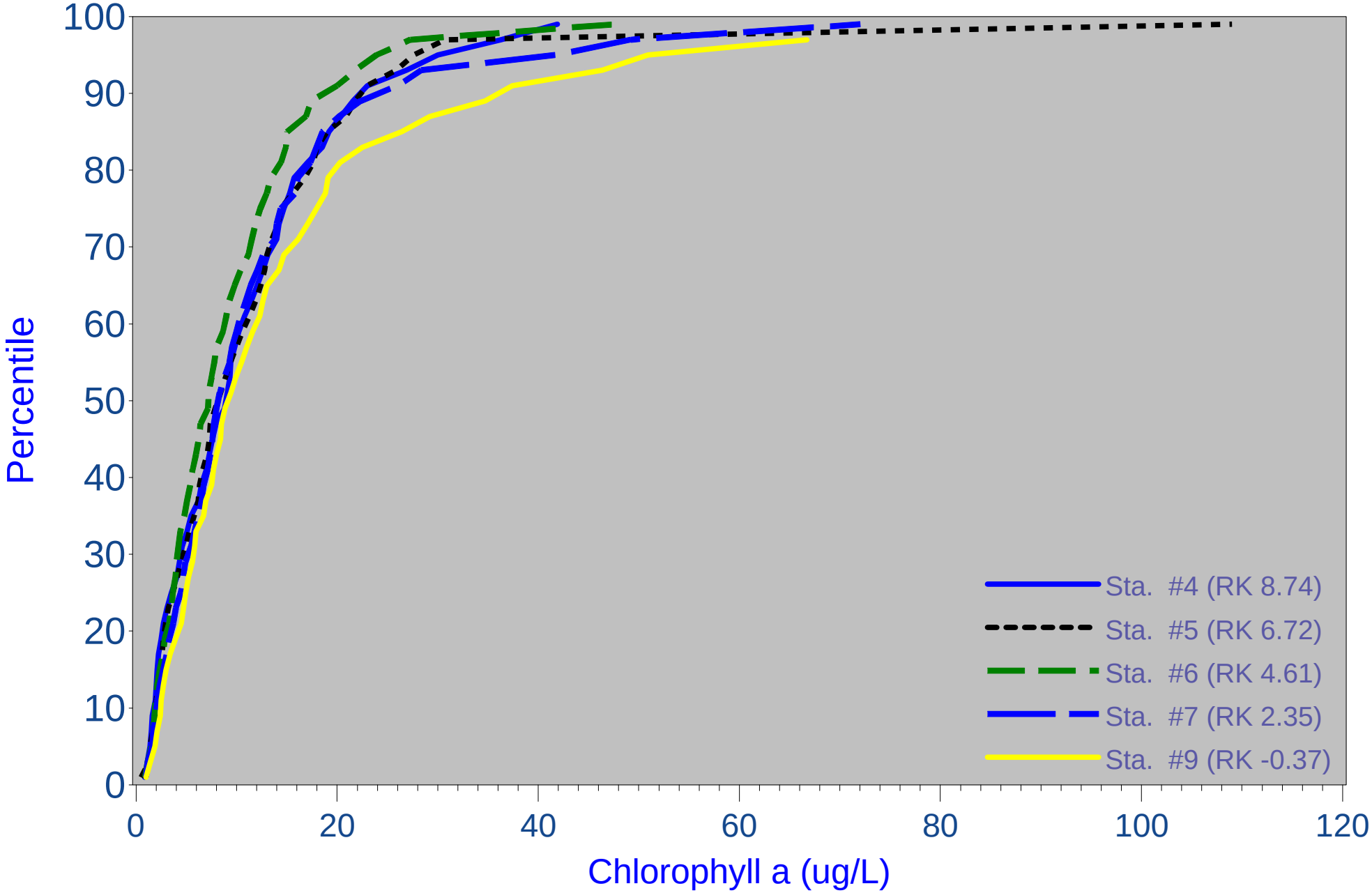


Figure 4.83 CDF plots of mid-depth chlorophyll among selected Shell Creek transect locations

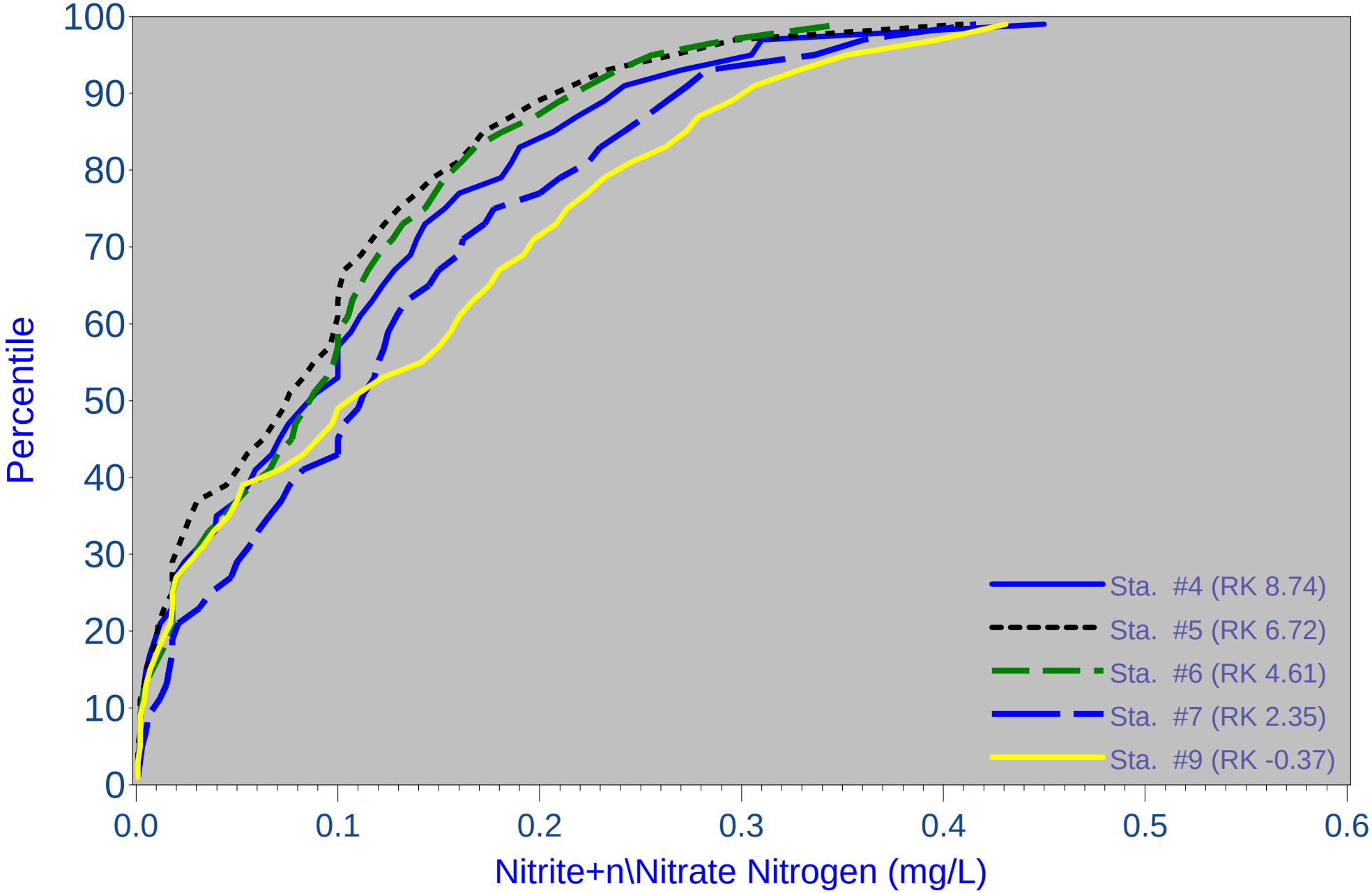


Figure 4.84 CDF plots of mid-depth nitrite+nitrate nitrogen among selected Shell Creek transect locations

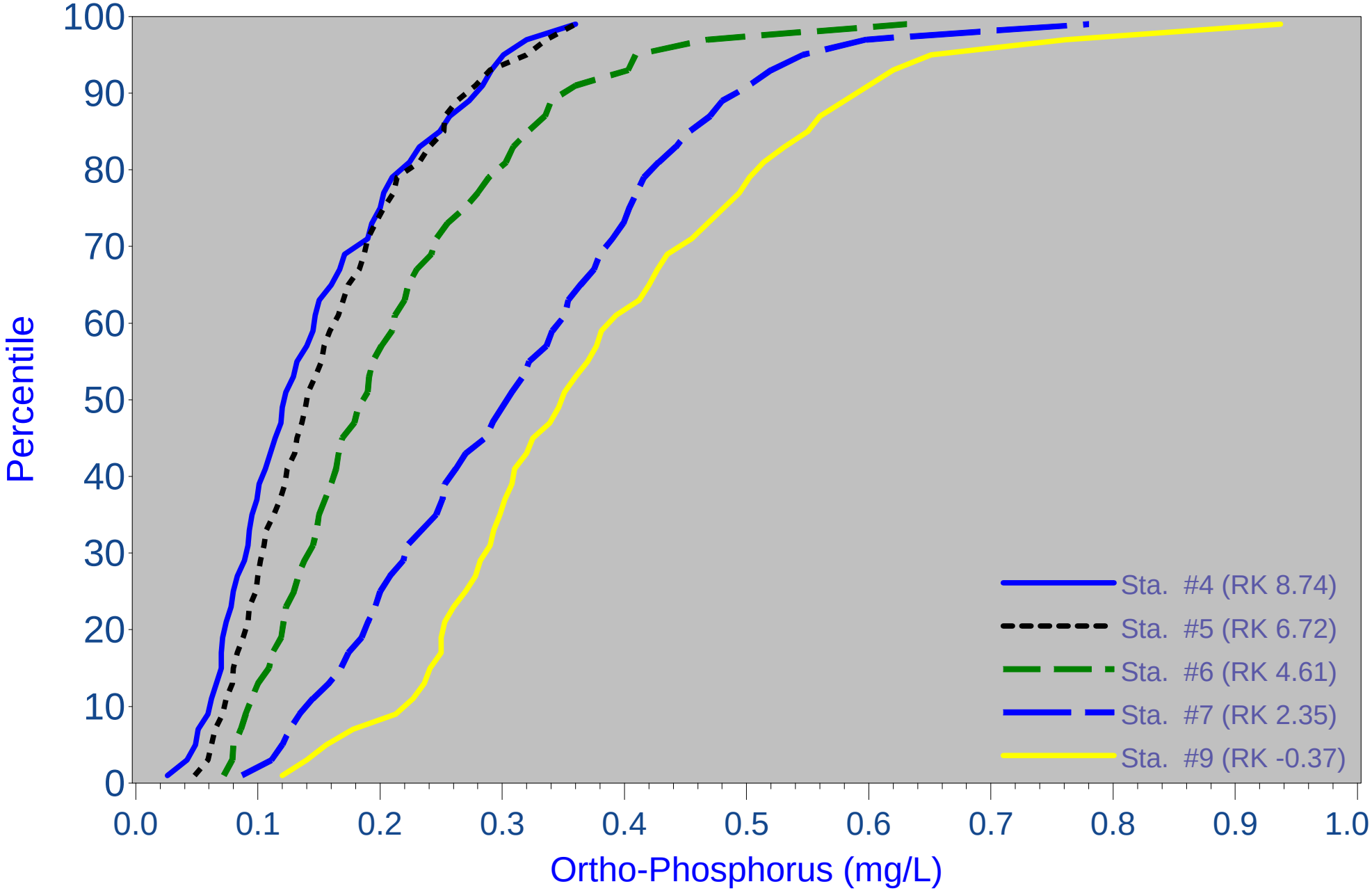


Figure 4.85 CDF plots of mid-depth ortho-phosphorus among selected Shell Creek transect locations

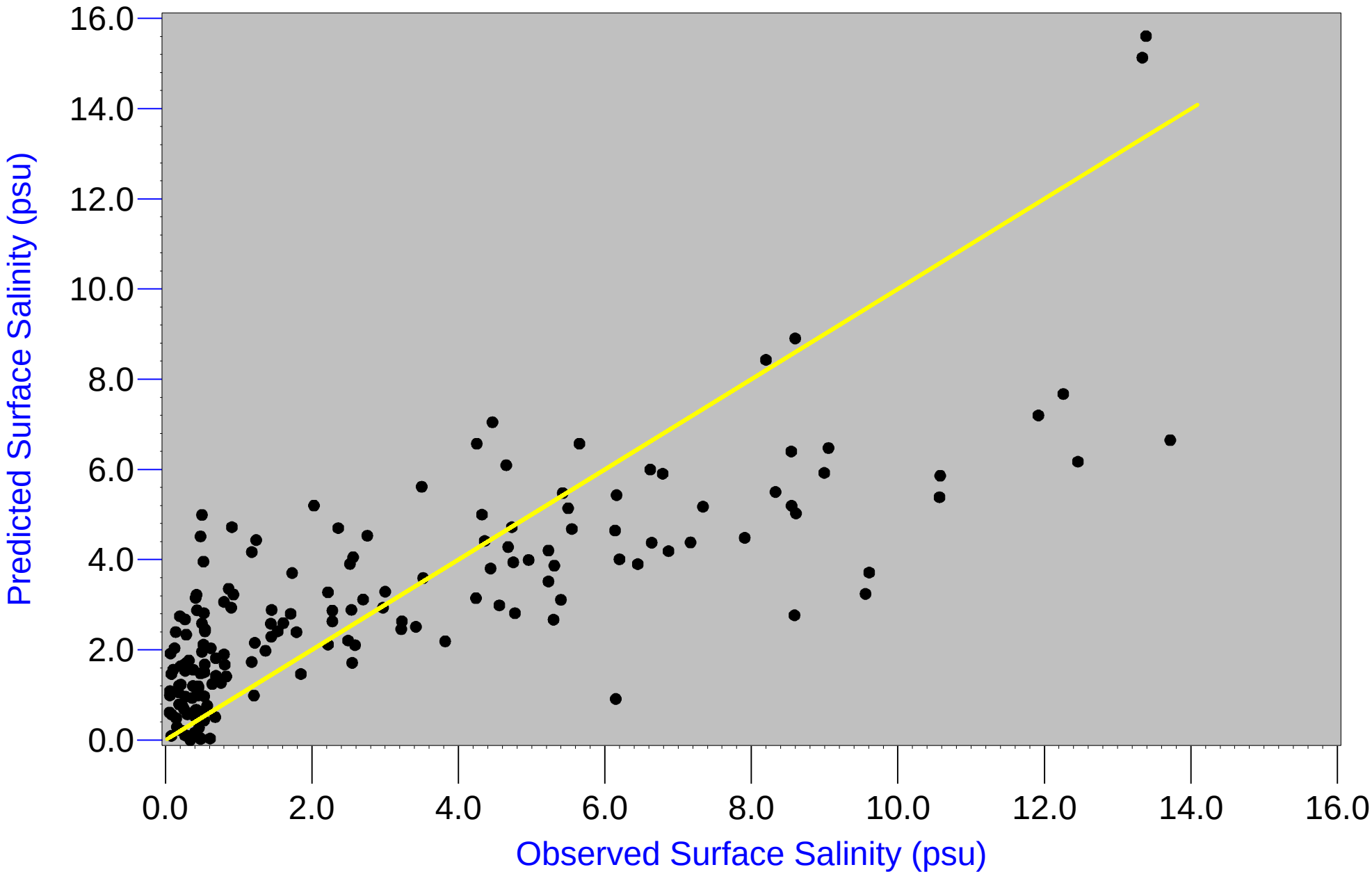


Figure 4.86a Predicted versus observed of modeled Shell Creek surface salinity Group A (0-120 cfs)

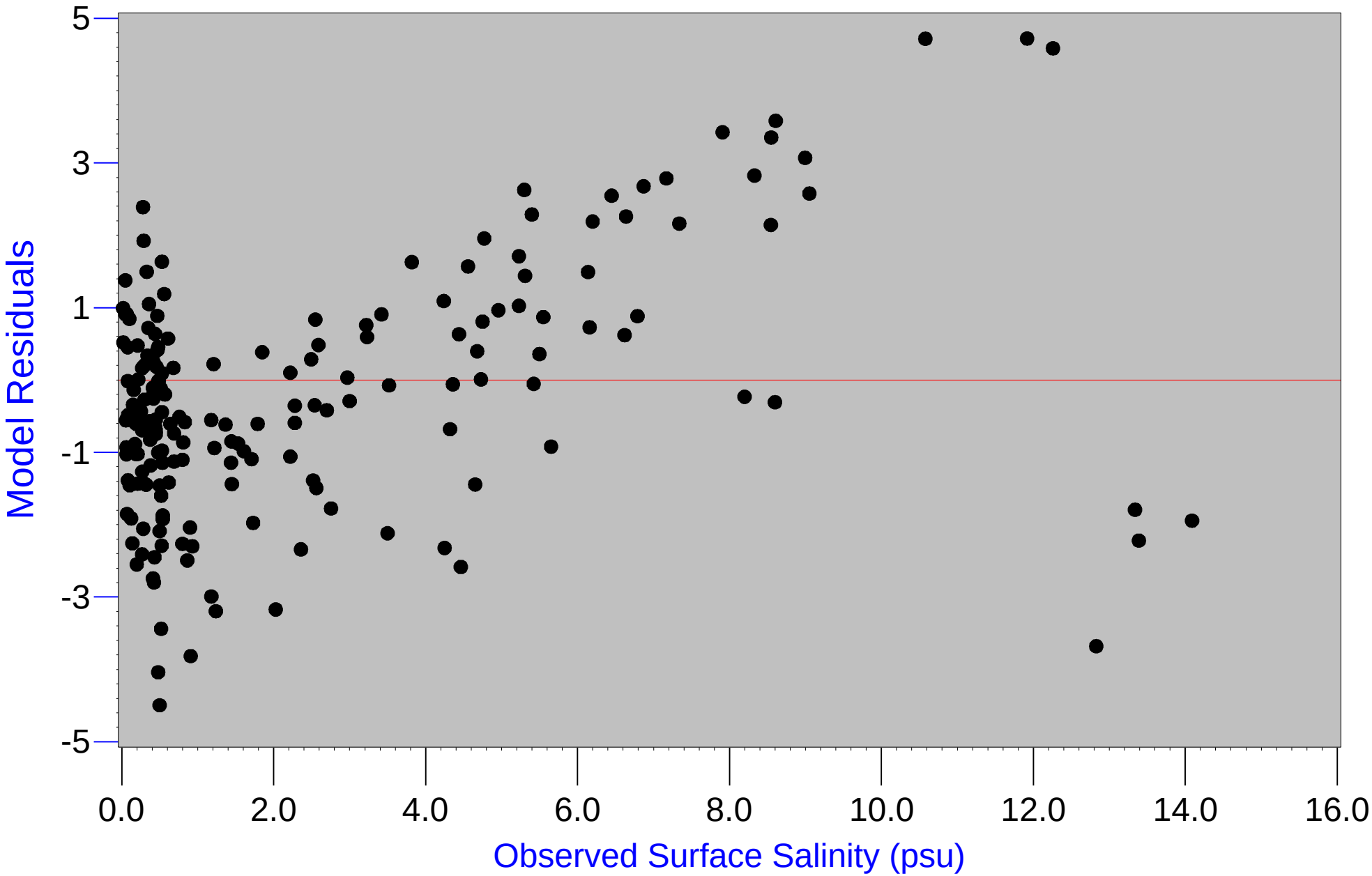


Figure 4.86b Model residuals versus observed of Shell Creek surface salinity Group A (0-120 cfs)

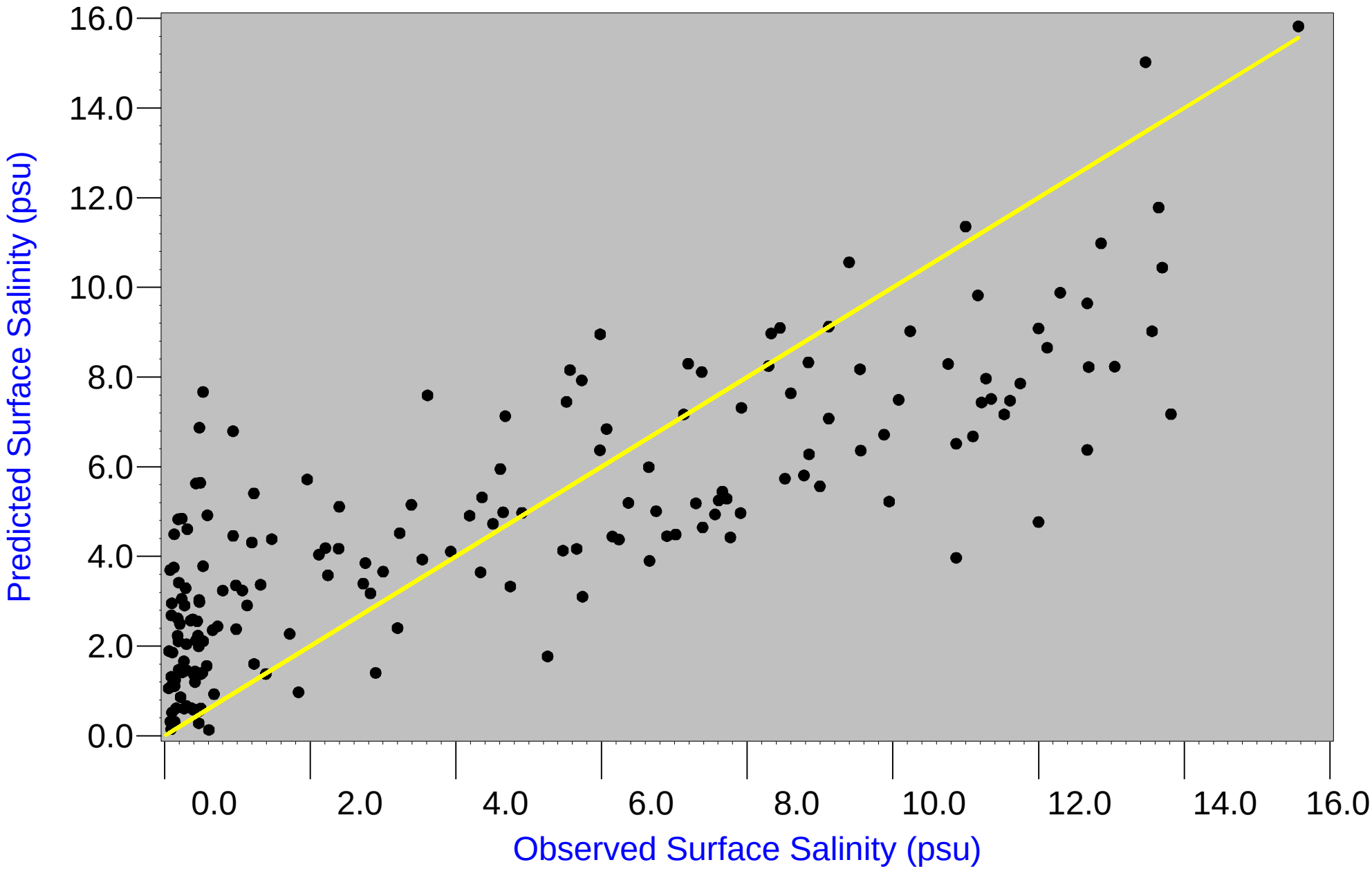


Figure 4.87a Predicted versus observed of modeled Shell Creek bottom salinity Group A (0-150 cfs)

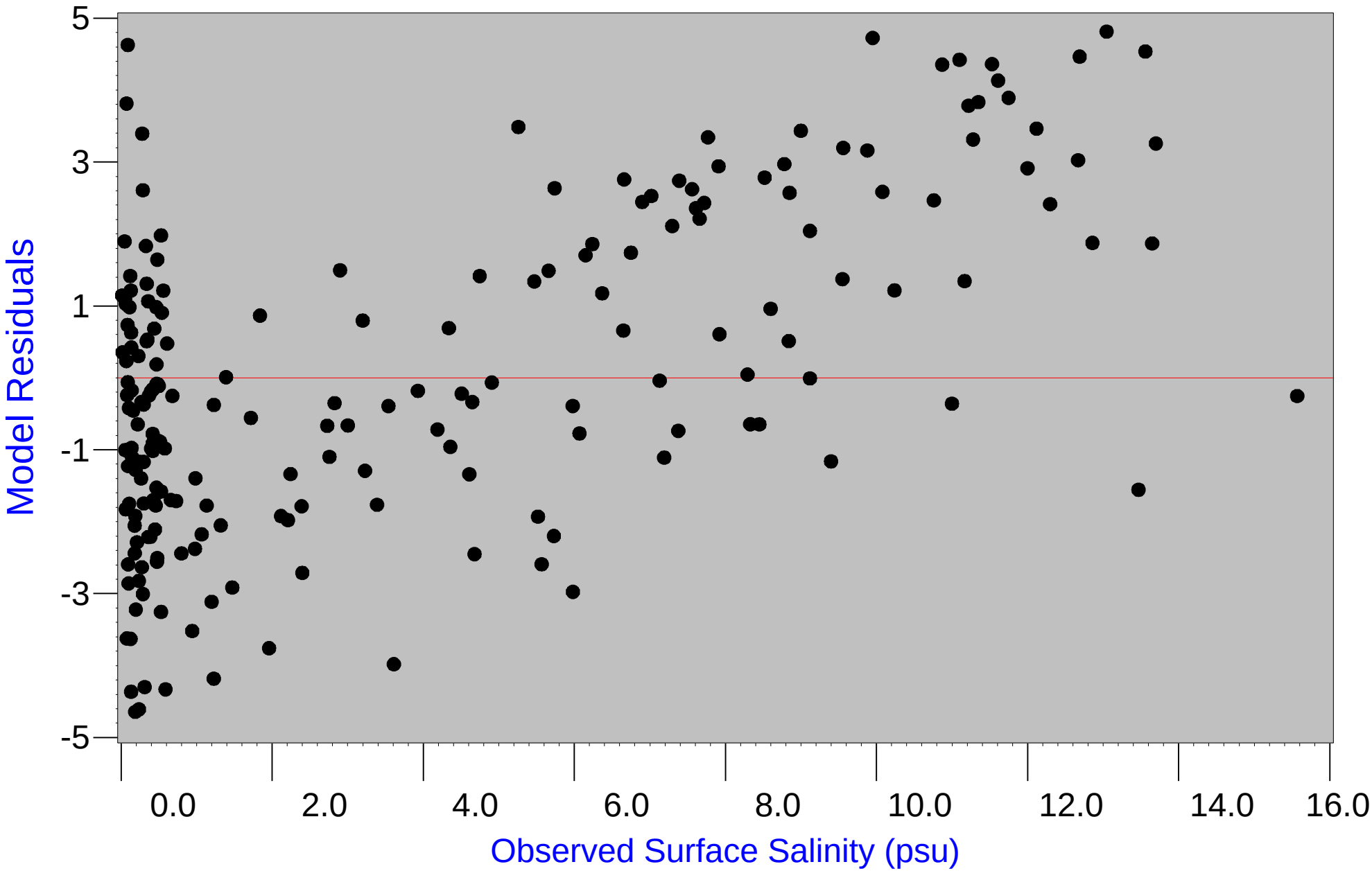


Figure 4.87b Model residuals versus observed of Shell Creek bottom salinity Group A (0-150 cfs)

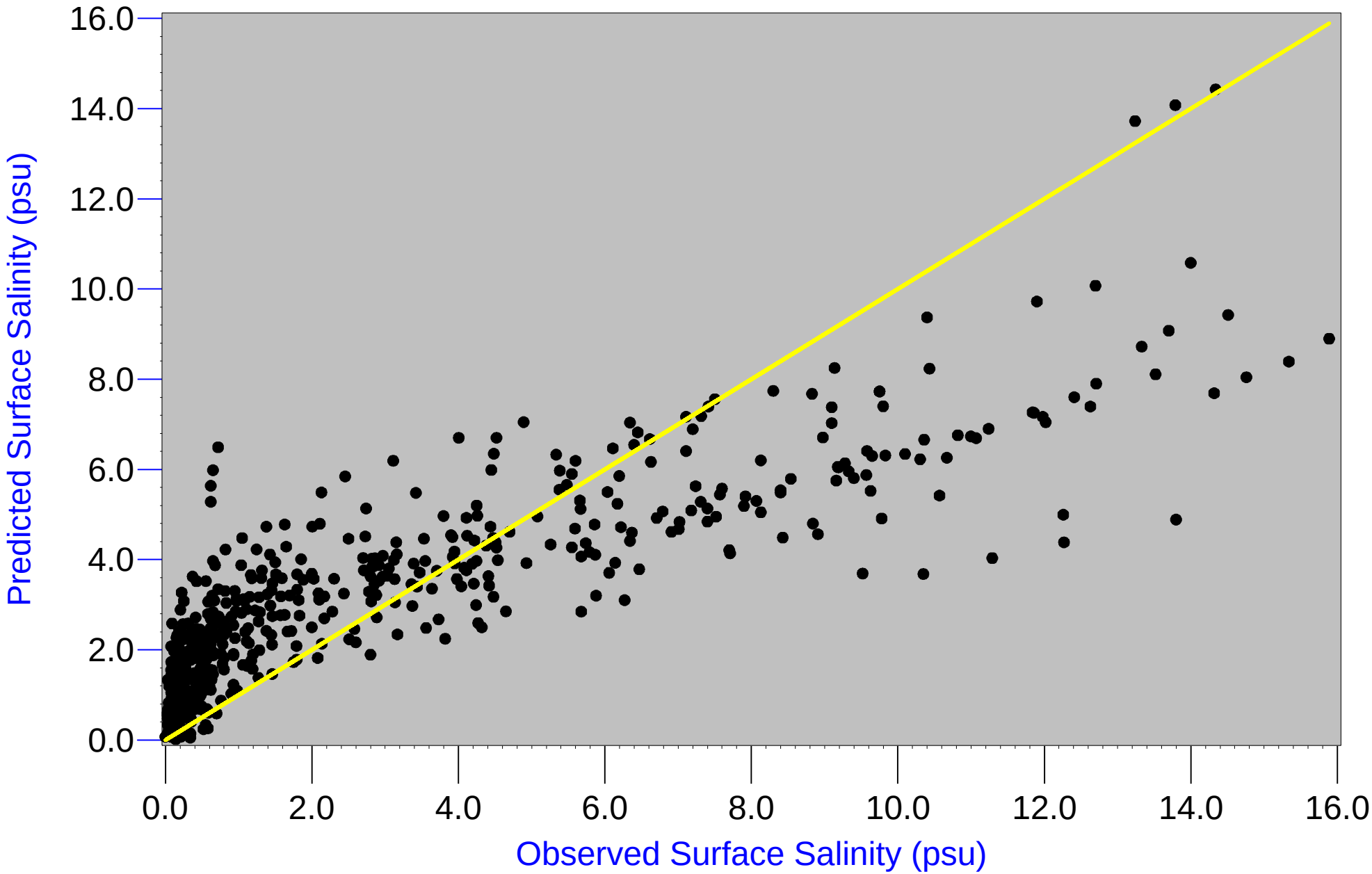


Figure 4.88a Predicted versus observed of modeled Shell Creek surface salinity Group B (0-350 cfs)

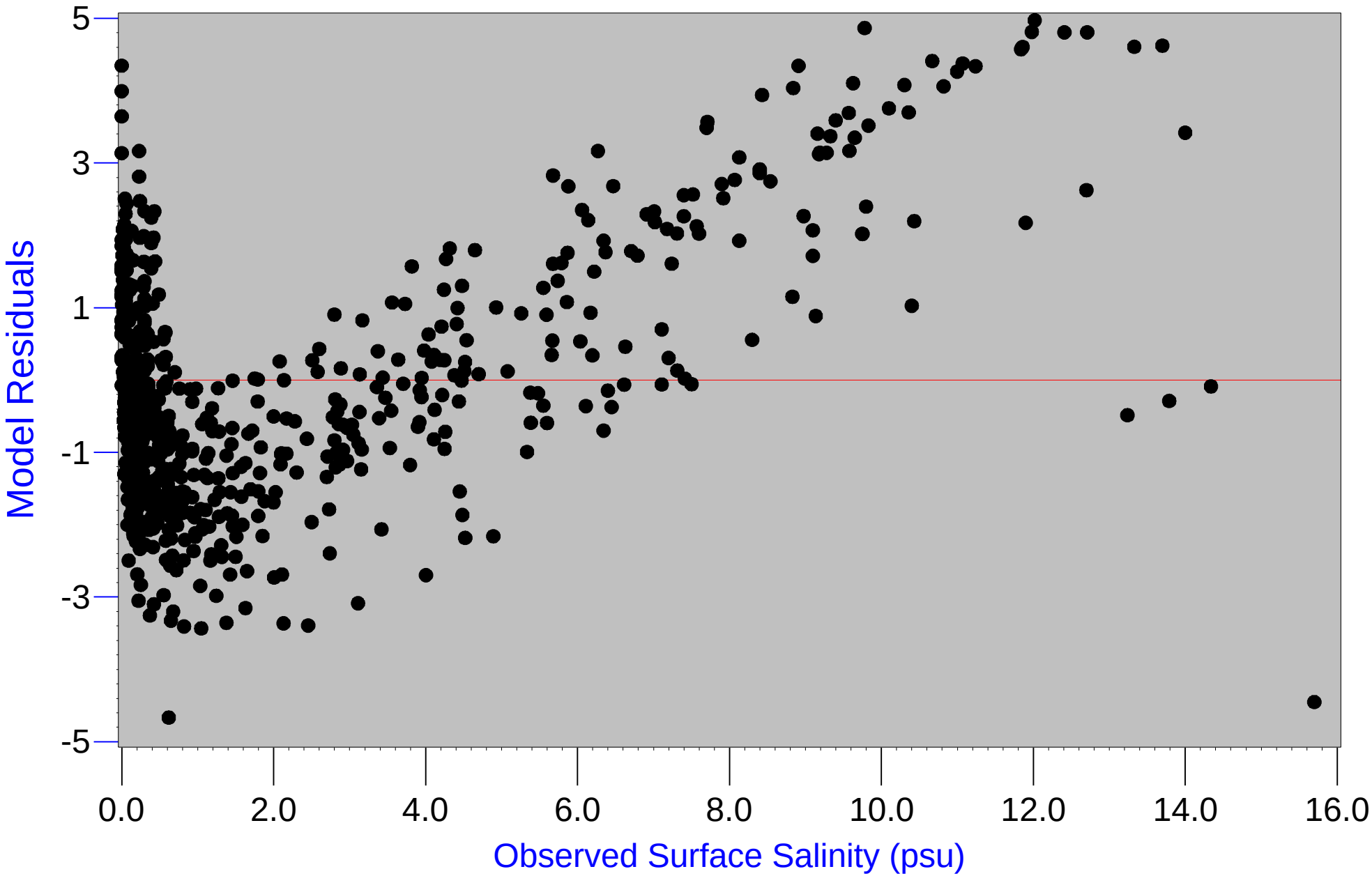


Figure 4.88b Model residuals versus observed of Shell Creek surface salinity Group B (0-350 cfs)

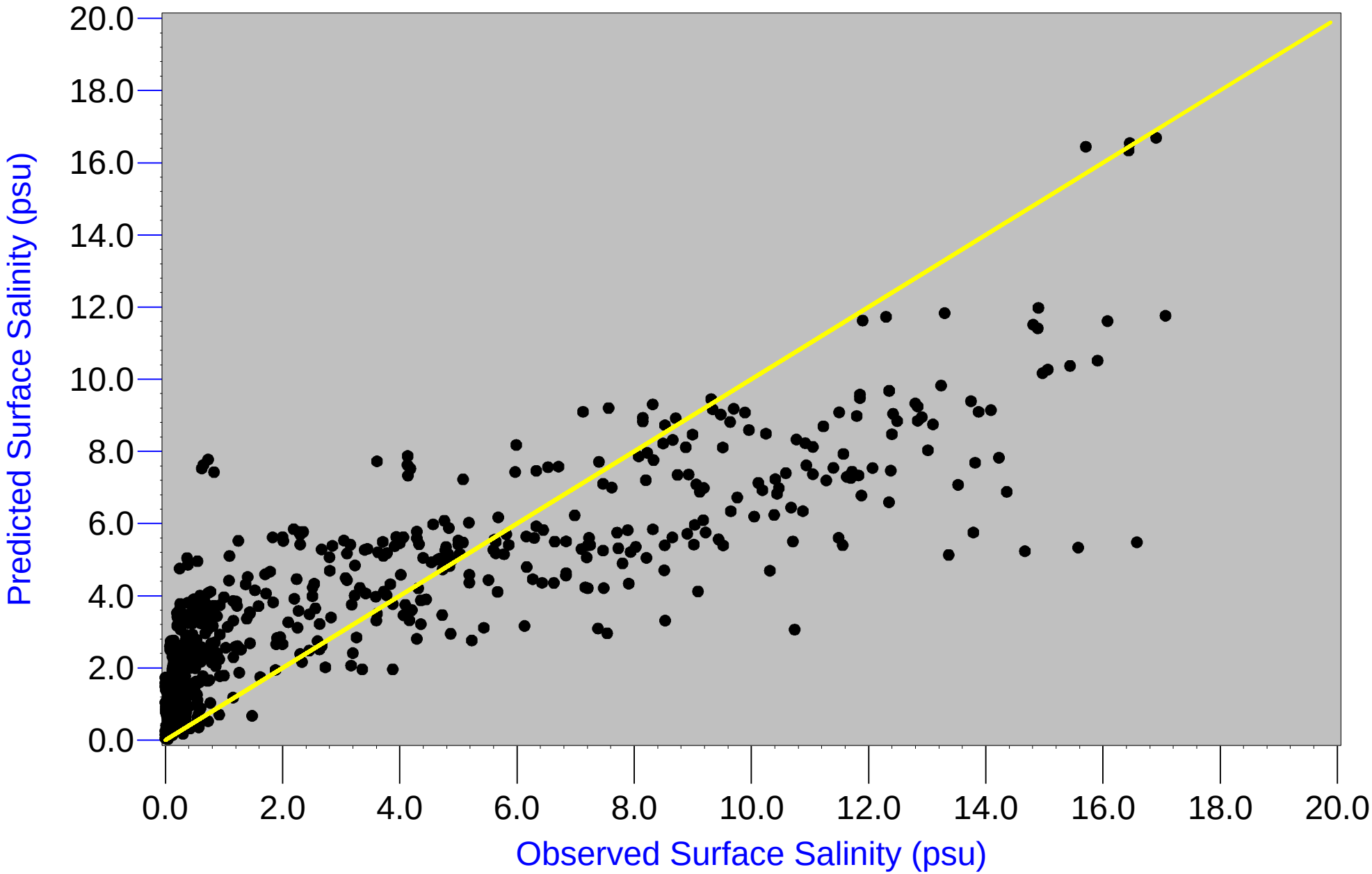


Figure 4.89a Predicted versus observed of modeled Shell Creek bottom salinity Group B (0-400 cfs)

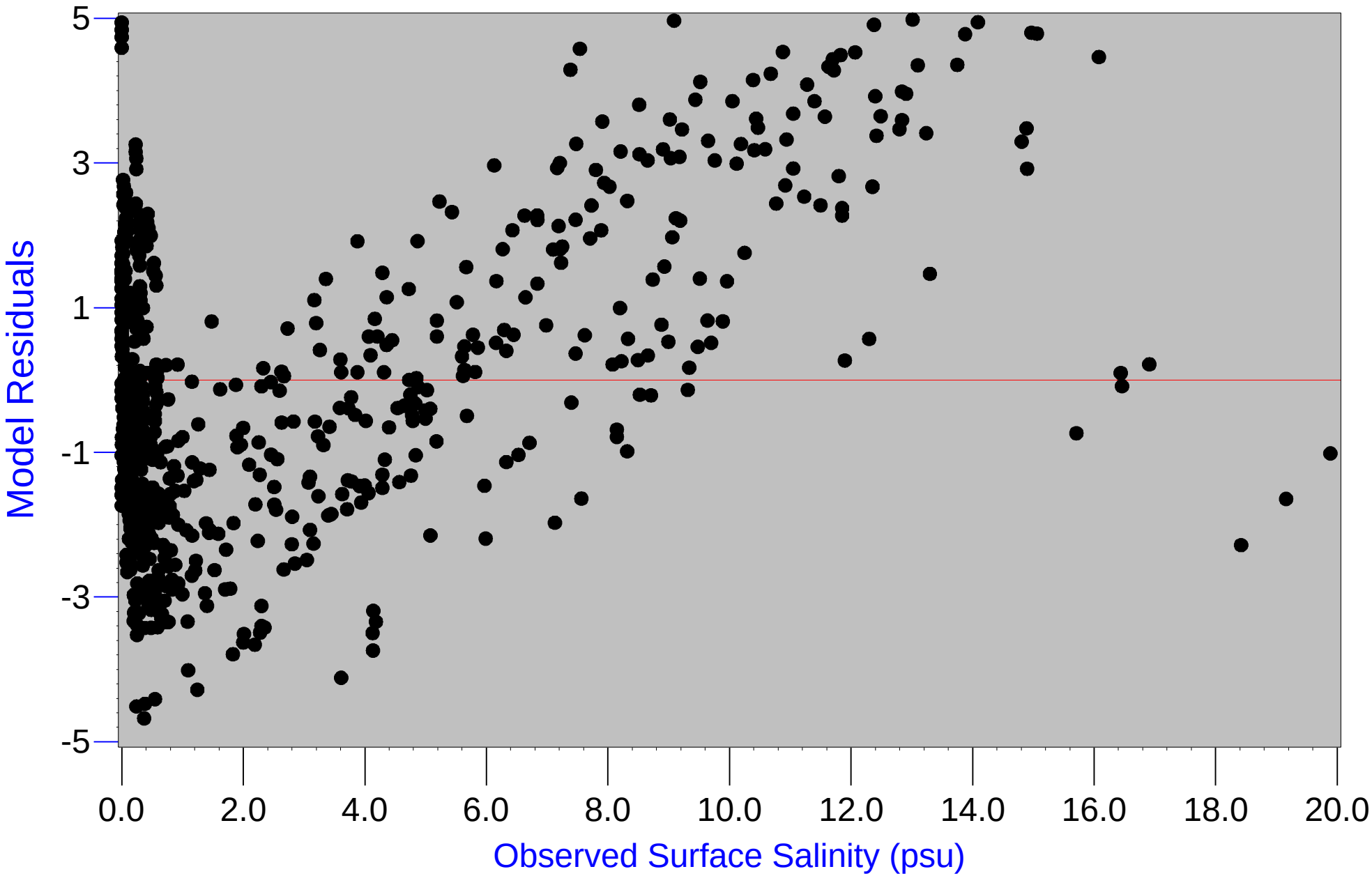


Figure 4.89b Model residuals versus observed of Shell Creek salinity Group B (0-400 cfs)

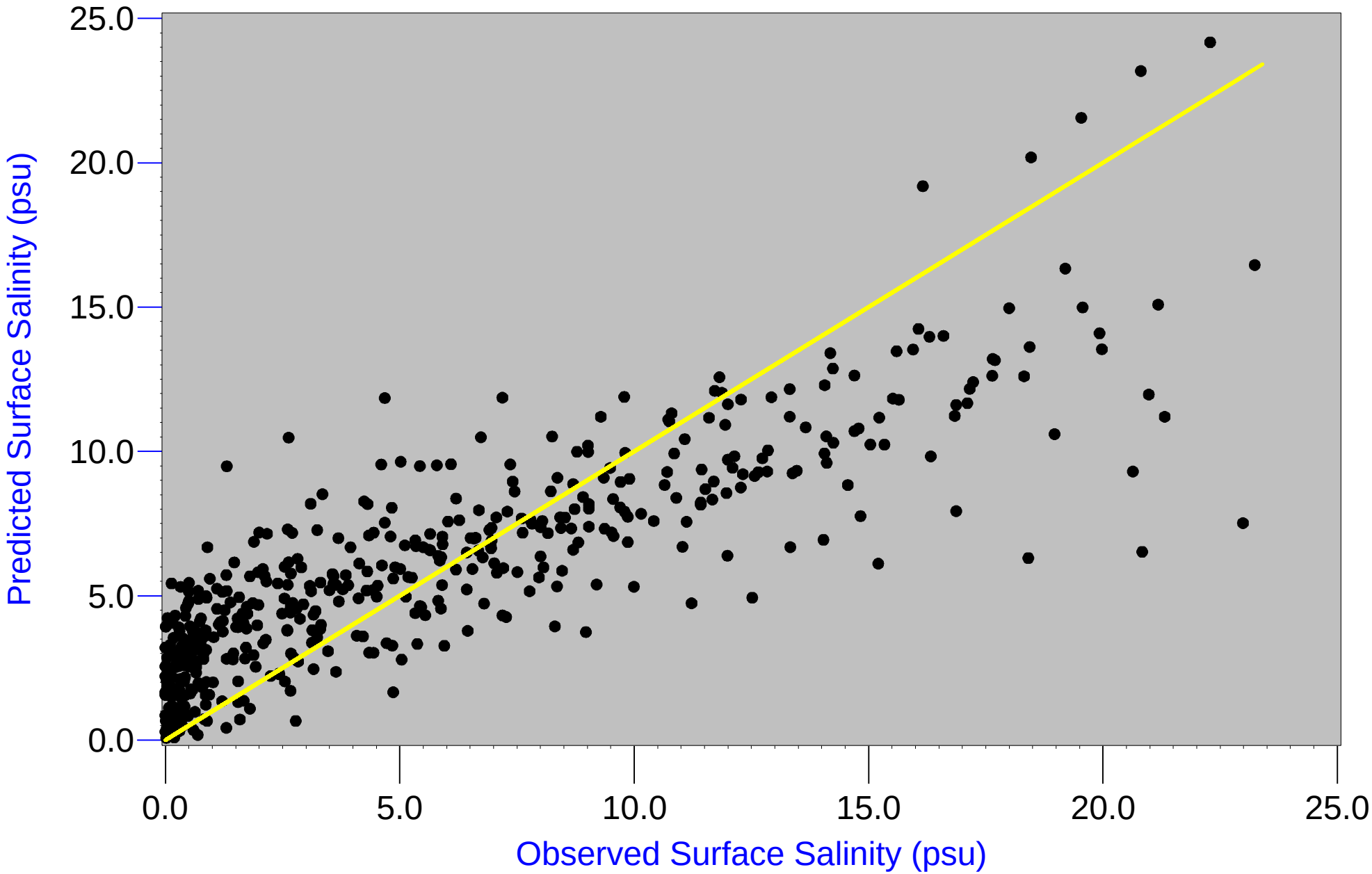


Figure 4.90a Predicted versus observed of modeled Shell Creek surface salinity Group C (0-600 cfs)

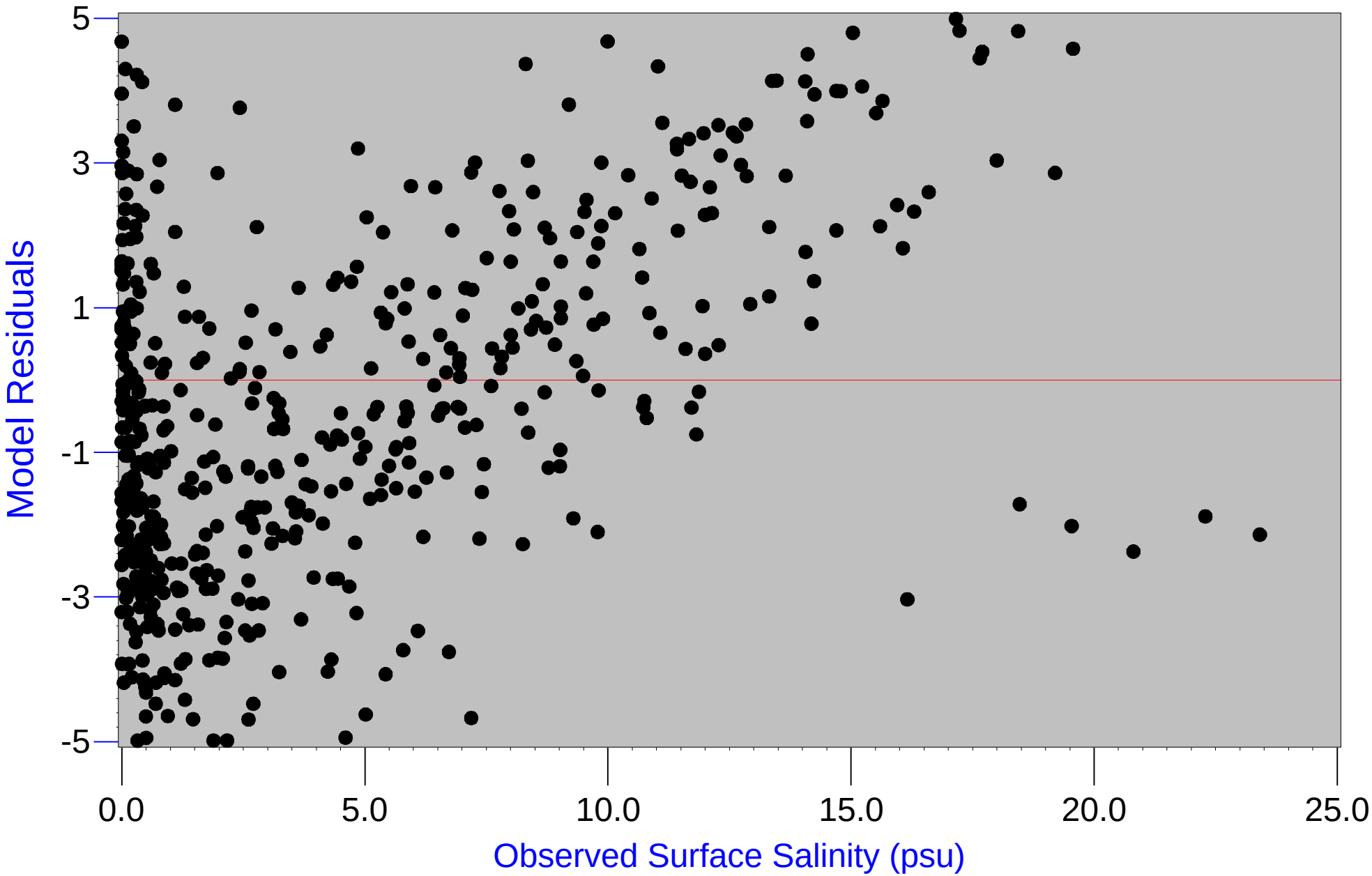


Figure 4.90b Model residuals versus observed of Shell Creek surface salinity Group C (0-600 cfs)

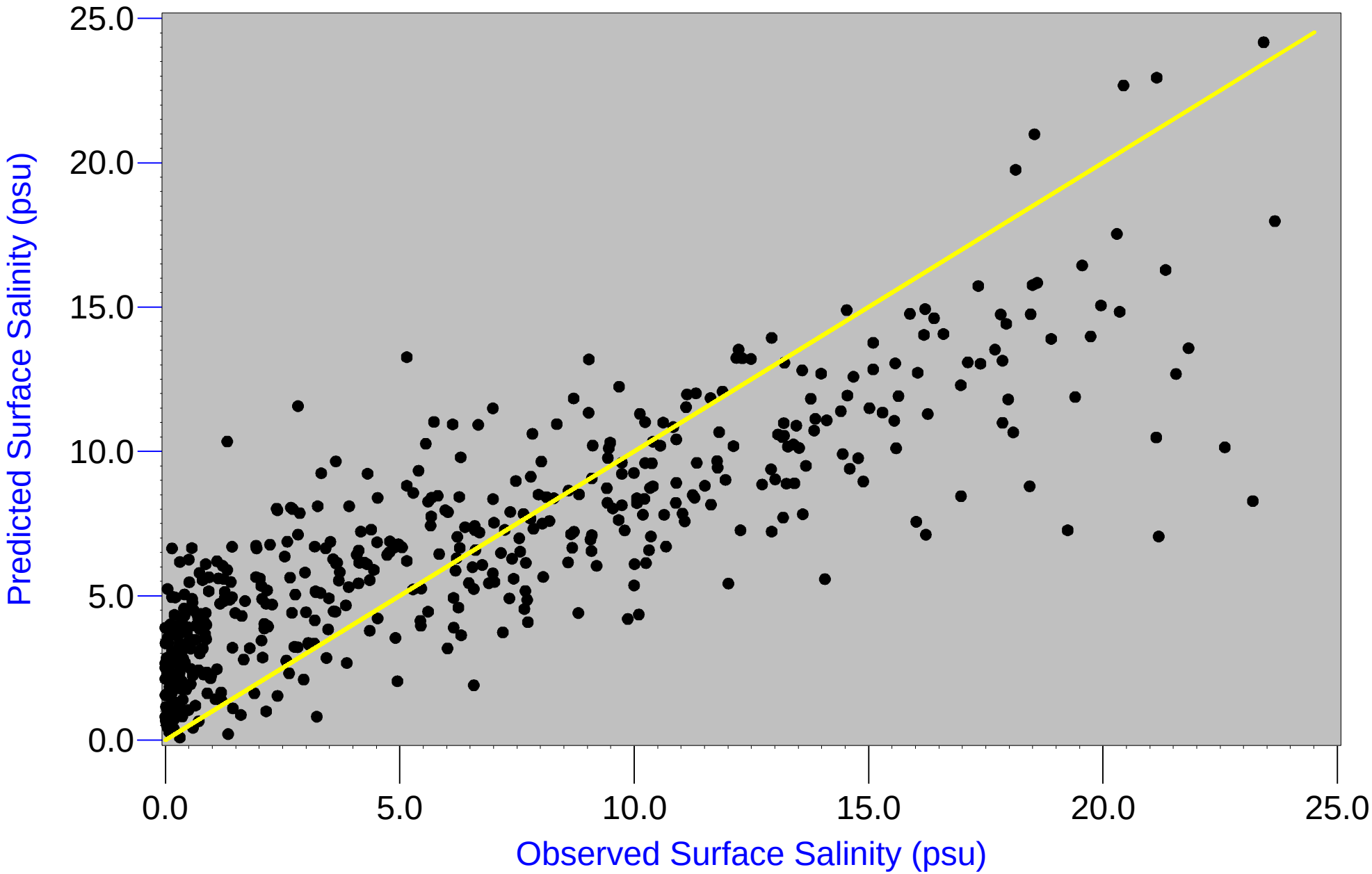


Figure 4.91a Predicted versus observed of modeled Shell Creek bottom salinity Group C (0-650 cfs)

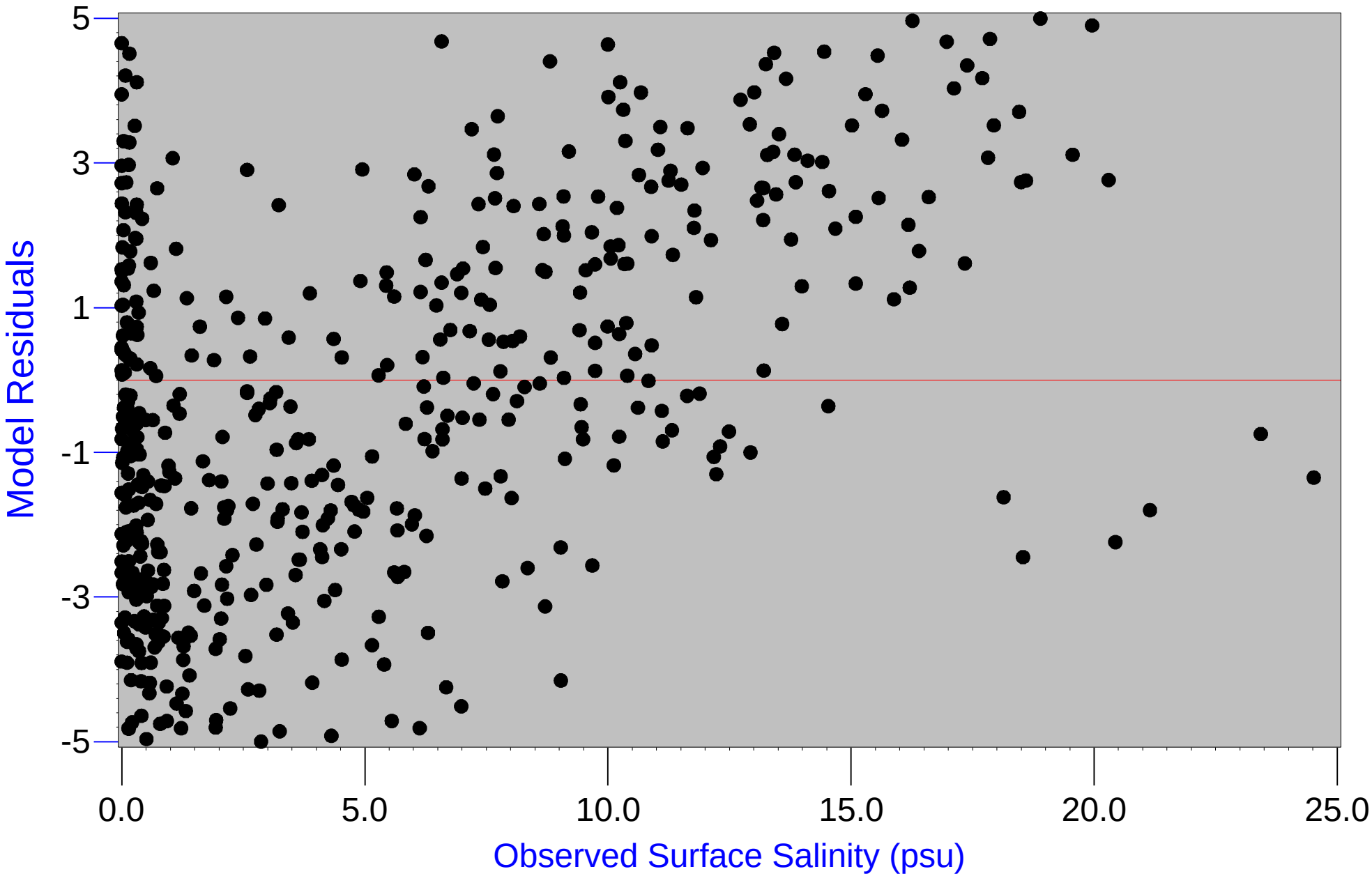


Figure 4.91b Model residuals versus observed of Shell Creek bottom salinity Group C (0-650 cfs)

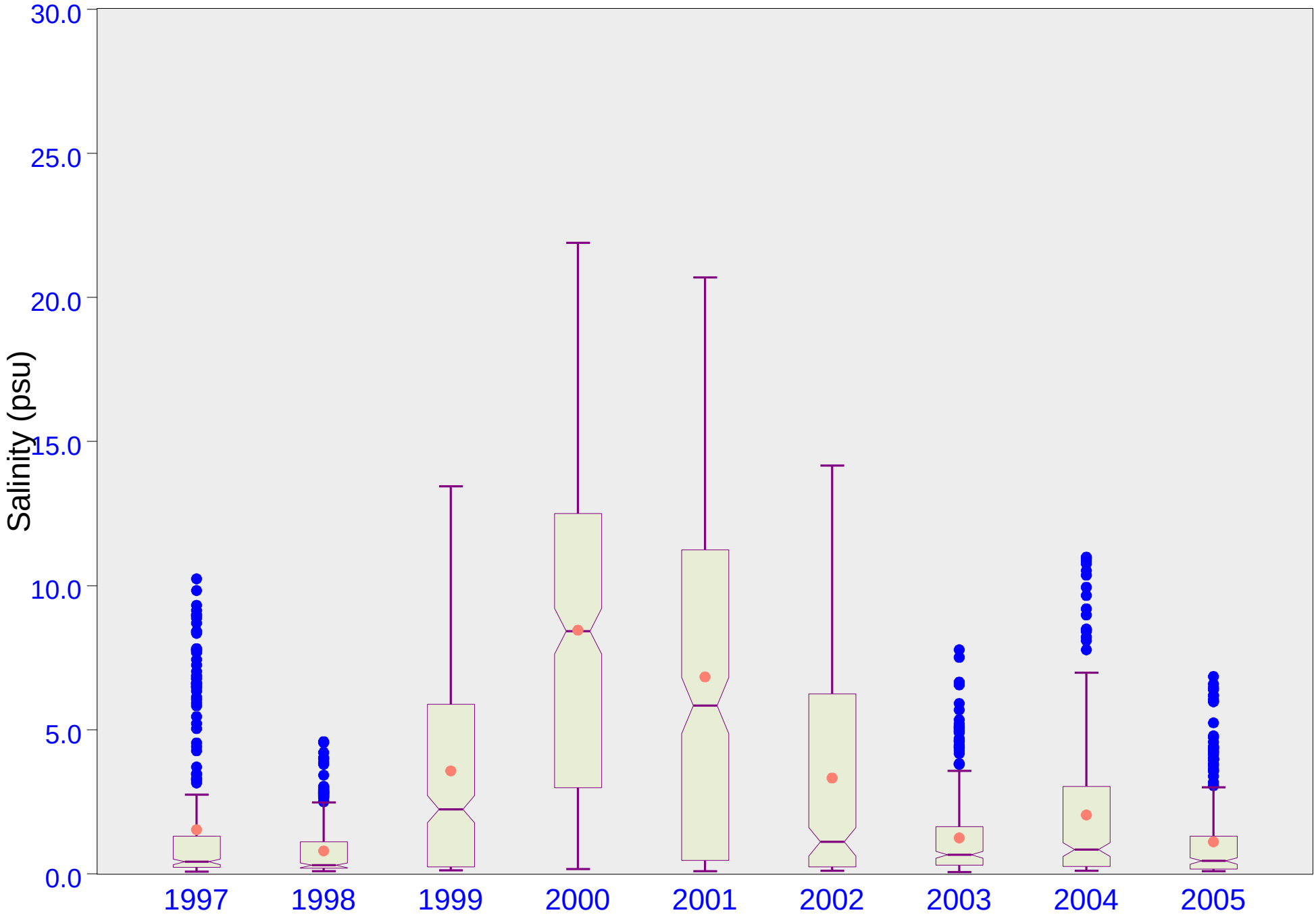


Figure 4.92a Annual variability in daily average surface salinity at USGS continuous recorder site on Shell Creek (RK 4.6)

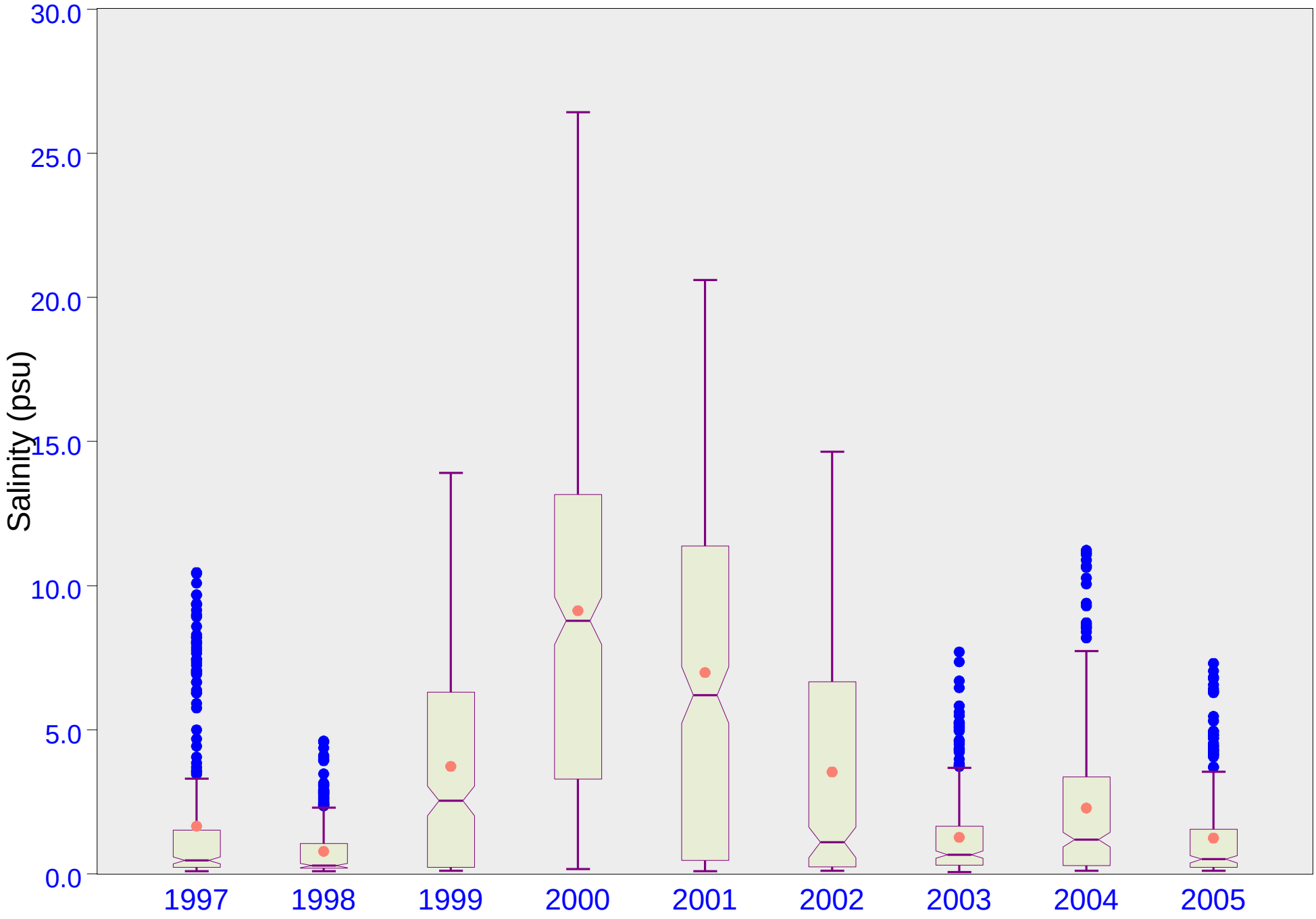


Figure 4.92b Annual variability in daily average bottom salinity at USGS continuous recorder site on Shell Creek (RK 4.6)

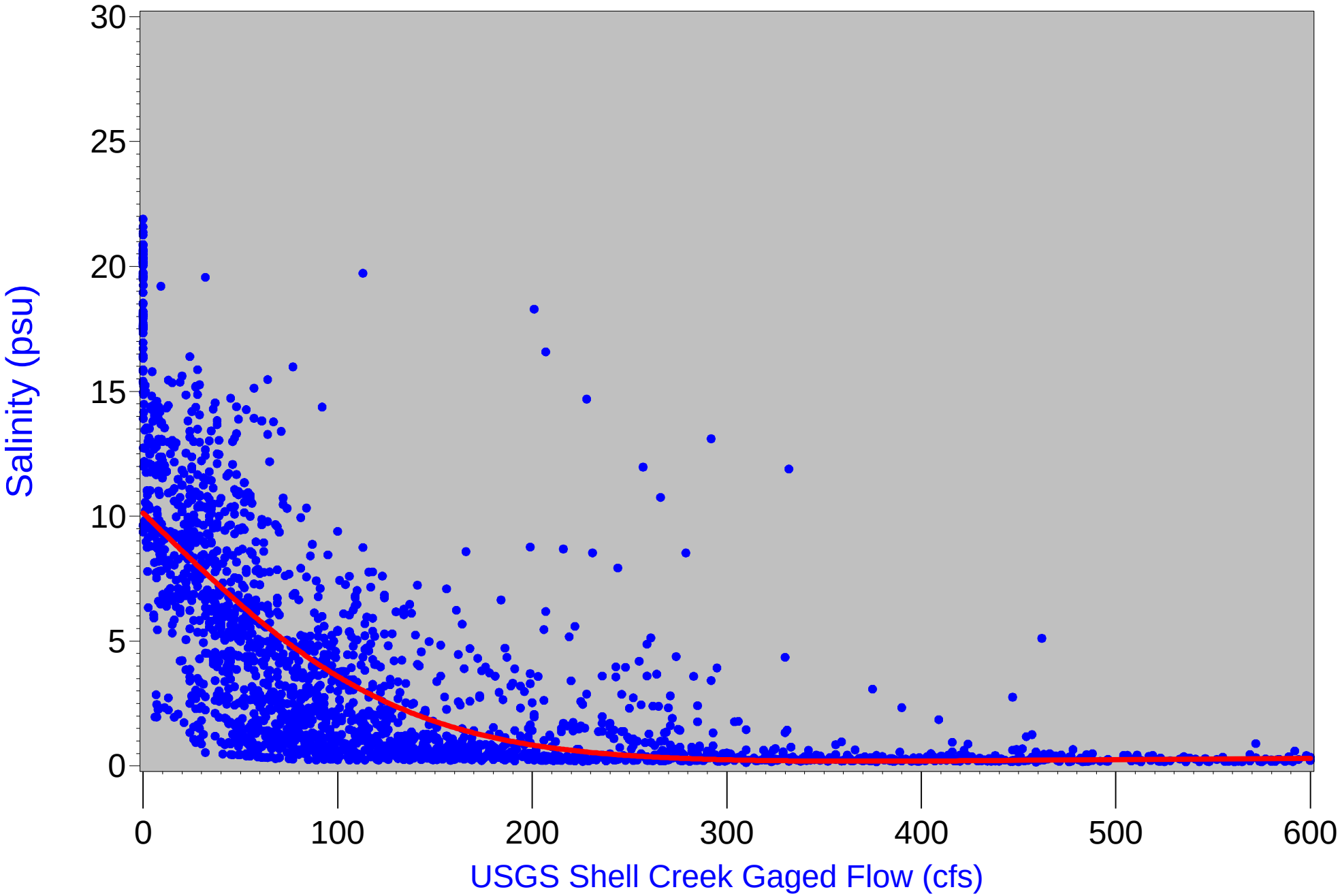


Figure 4.93a Average dailiy surface salinity at USGS continuous recorder site (River Kilometer 4.6) versus Shell Creek flow

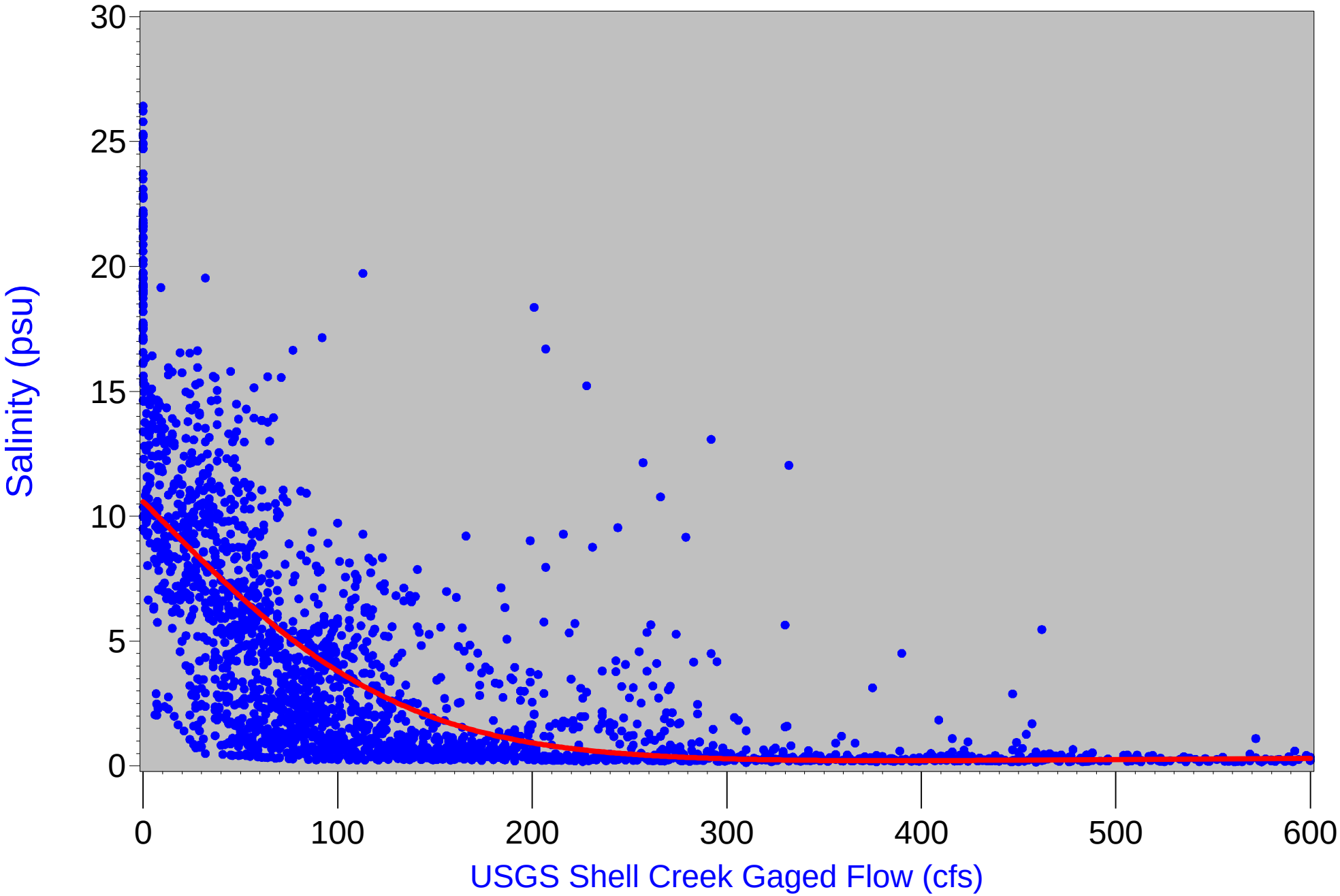


Figure 4.93b Average daily bottom salinity at USGS continuous recorder site (River Kilometer 4.6) versus Shell Creek flow

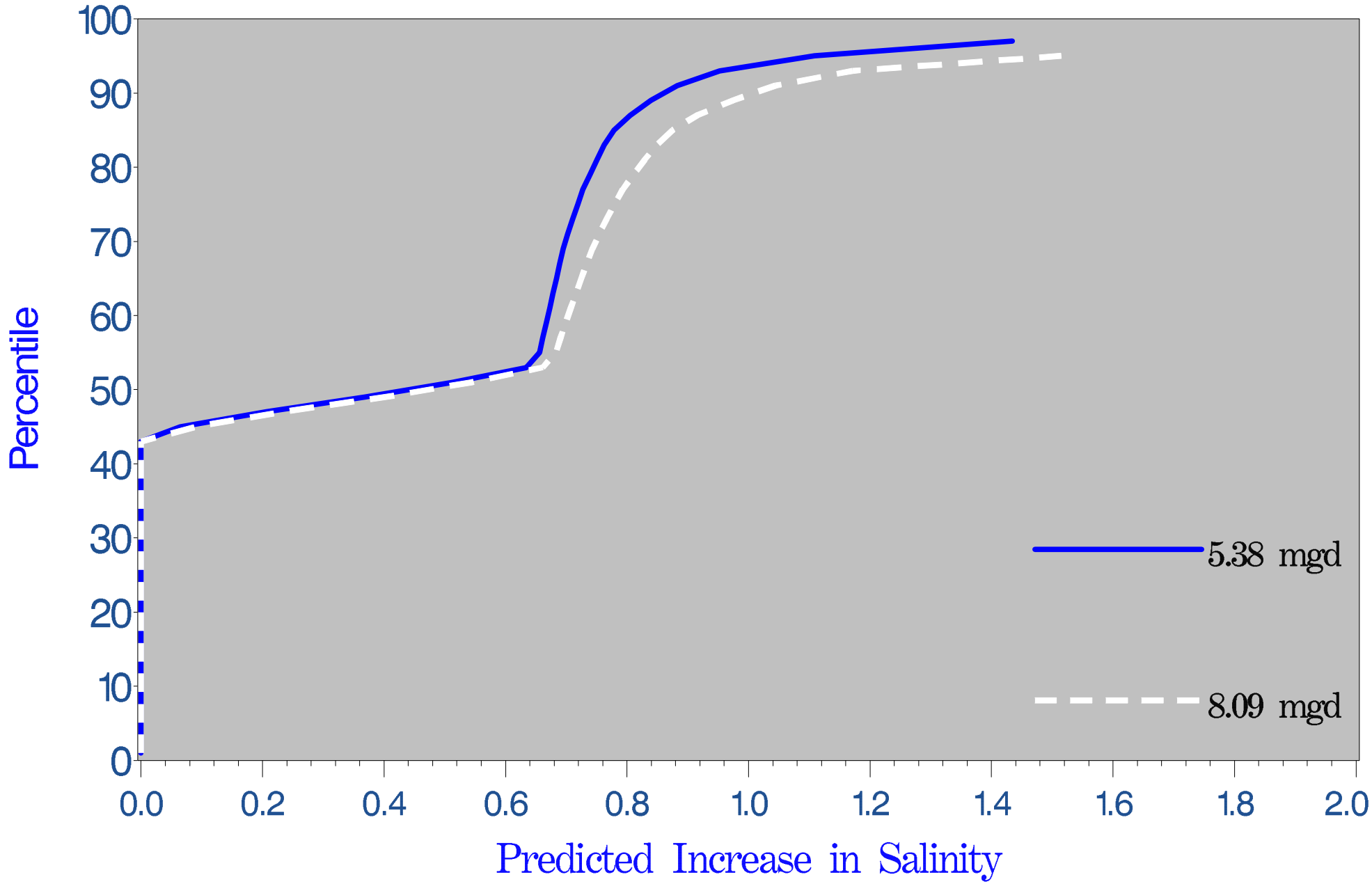


Figure 4.94a CDF of predicted change in Segment A surface salinities due to difference in withdrawals

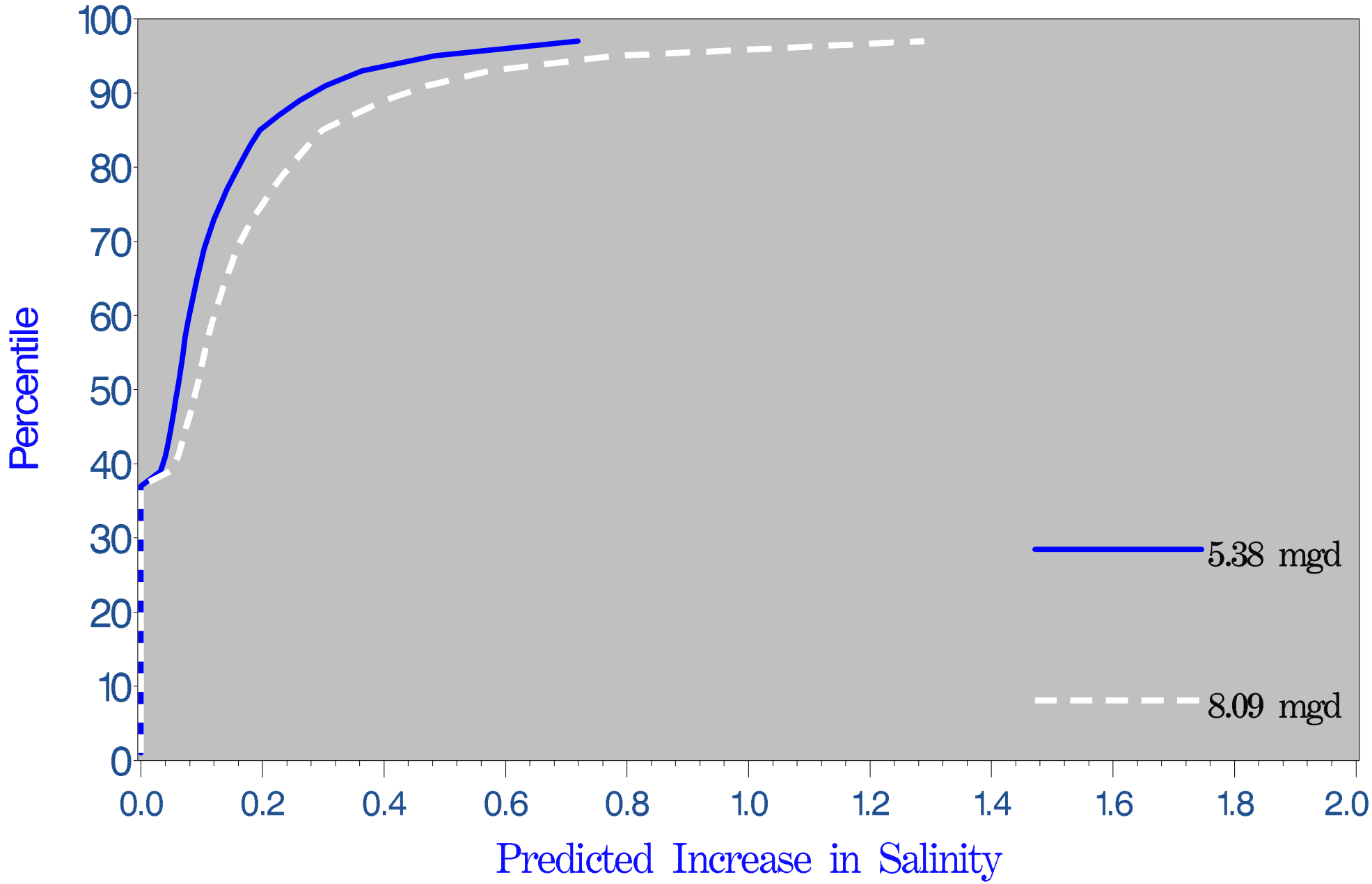


Figure 4.94b CDF of predicted change in Segment A bottom salinities due to difference in withdrawals

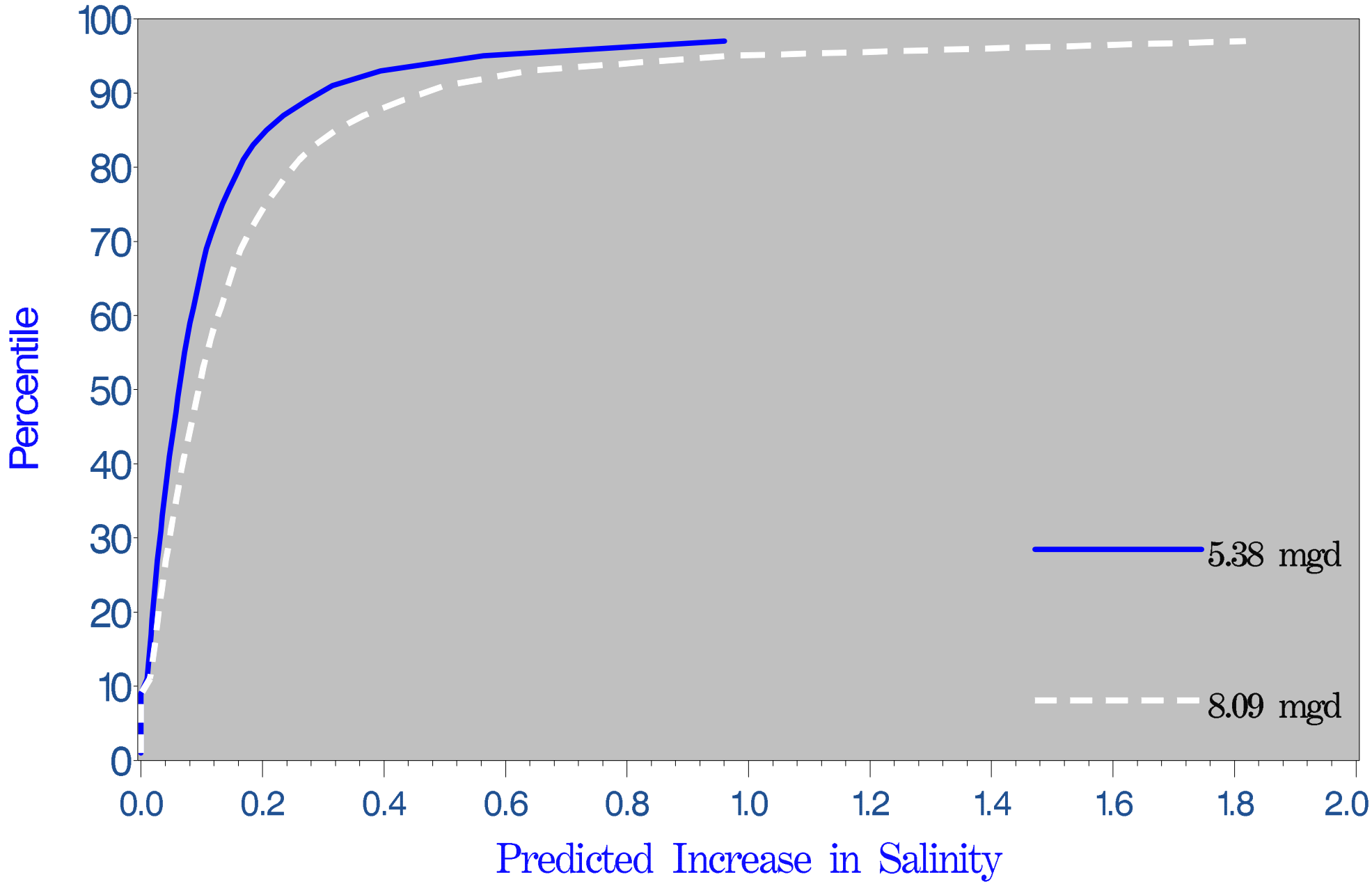


Figure 4.95a CDF of predicted change in Segment B surface salinities due to difference in withdrawals

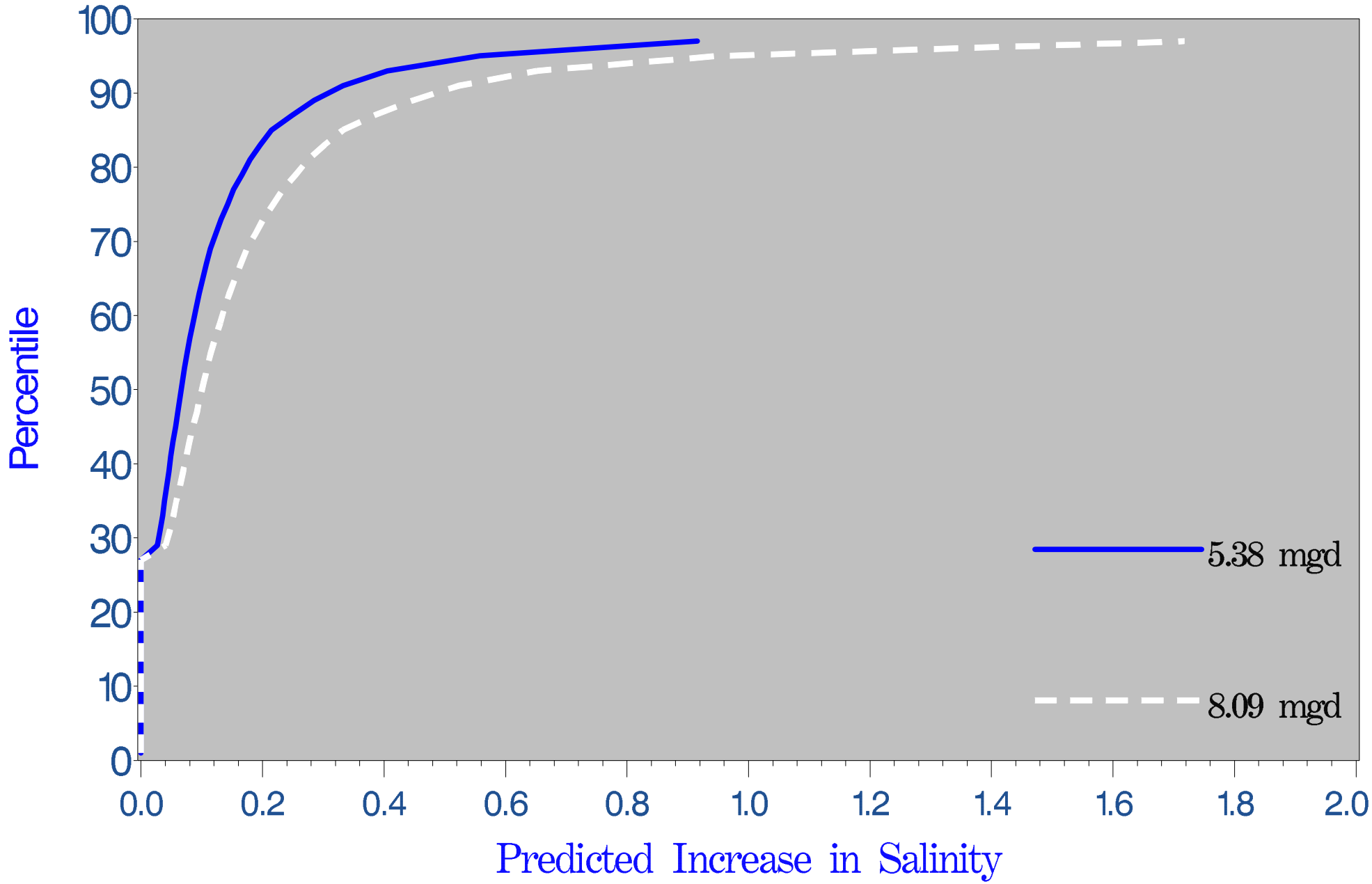


Figure 4.95b CDF of predicted change in Segment B bottom salinities due to difference in withdrawals

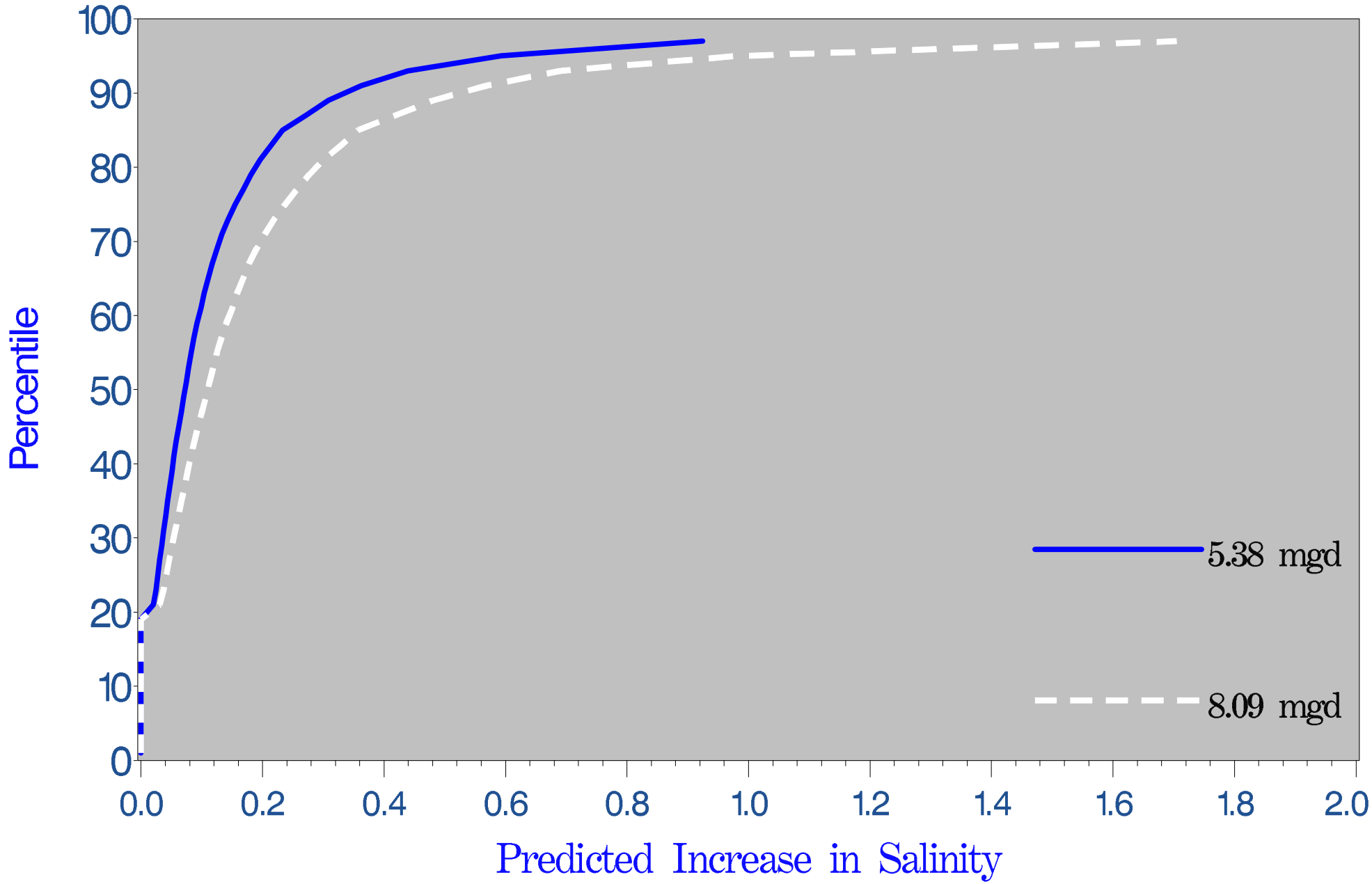


Figure 4.96a CDF of predicted change in Segment C surface salinities due to difference in withdrawals

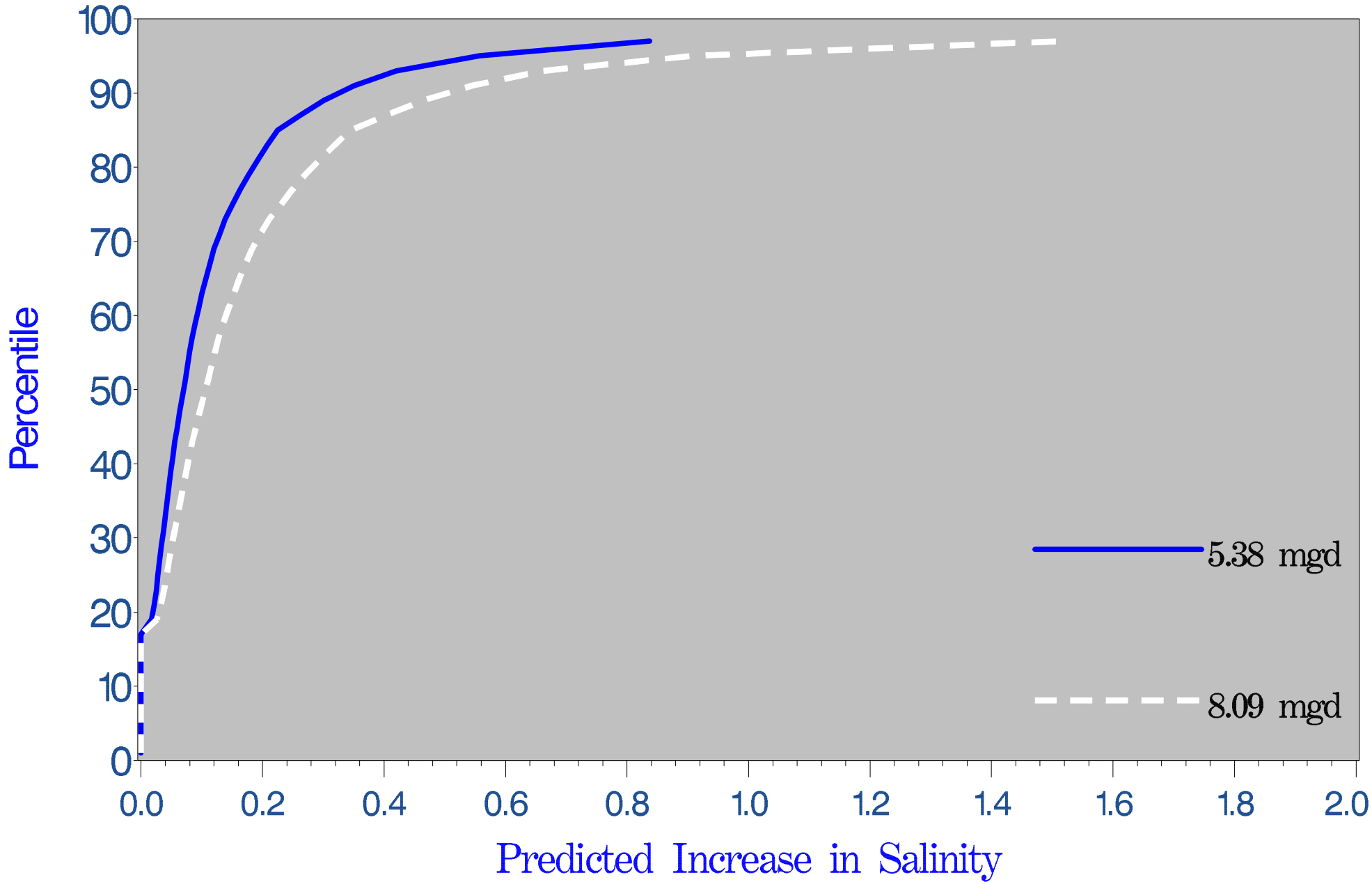


Figure 4.96b CDF of predicted change in Segment C bottom salinities due to difference in withdrawals

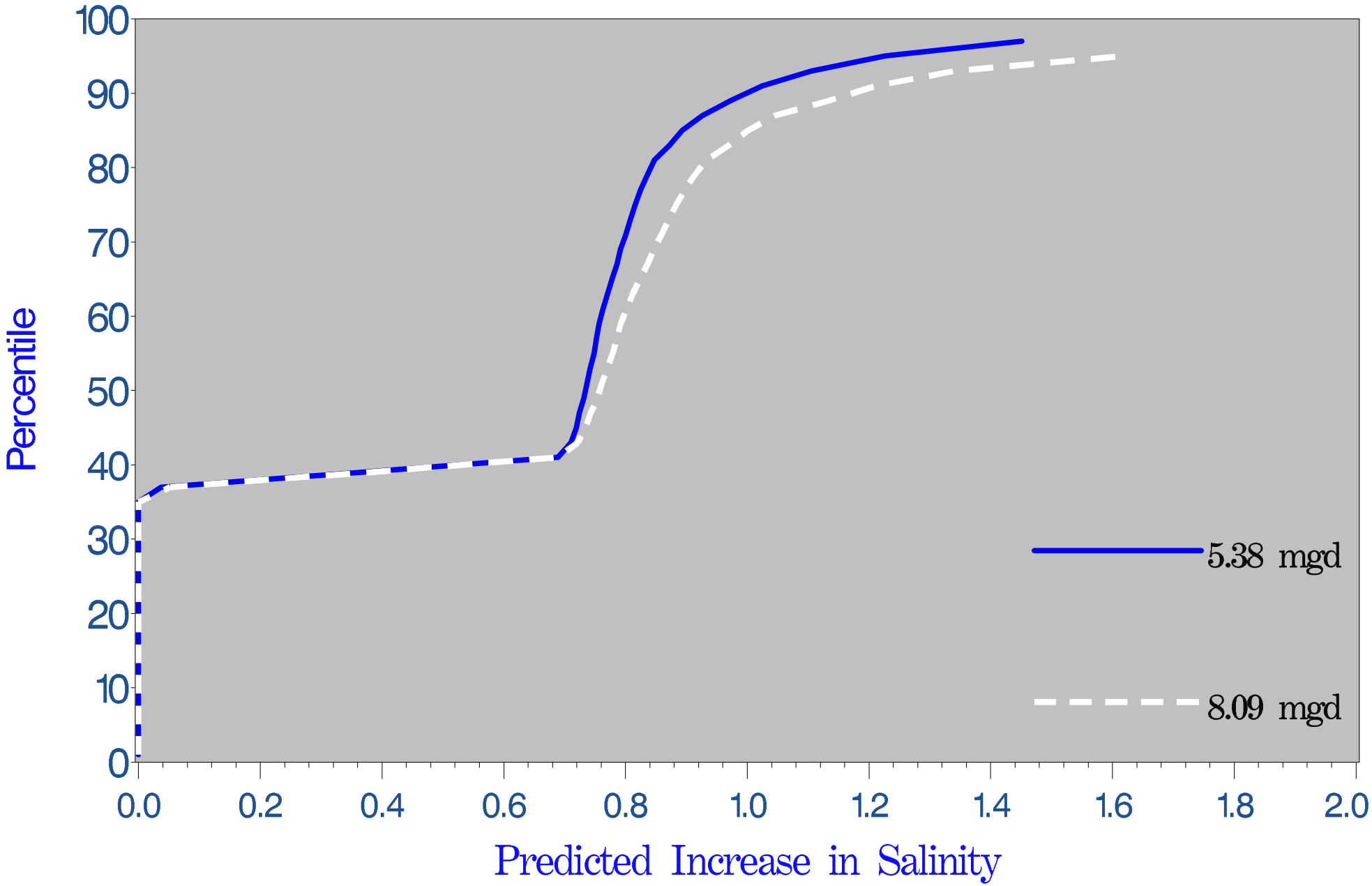


Figure 4.97a CDF of predicted change in surface salinities at USGS continuous recorder due to difference in withdrawals

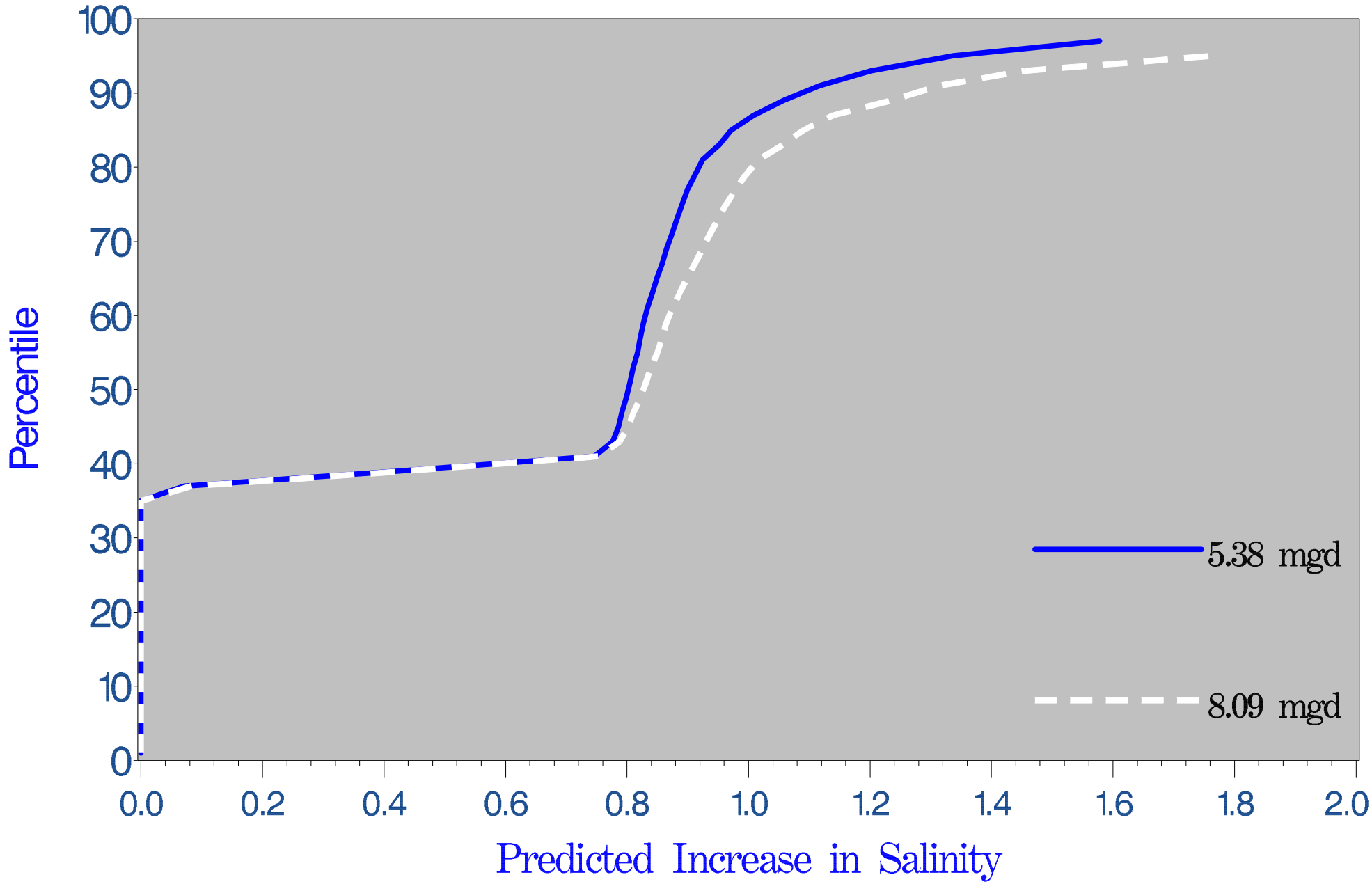
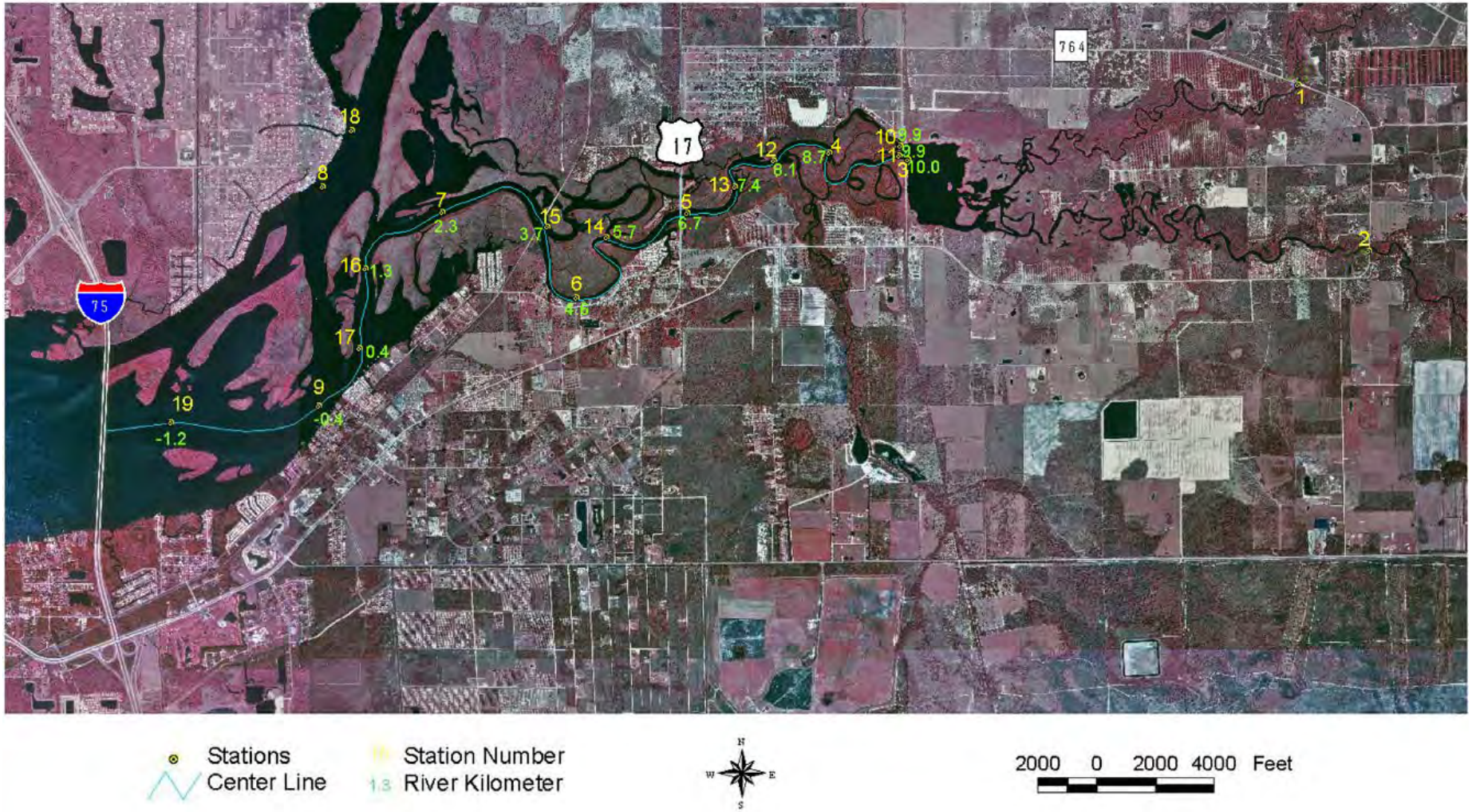


Figure 4.97b CDF of predicted change in bottom salinities at USGS continuous recorder due to difference in withdrawals

HBMP Report Maps

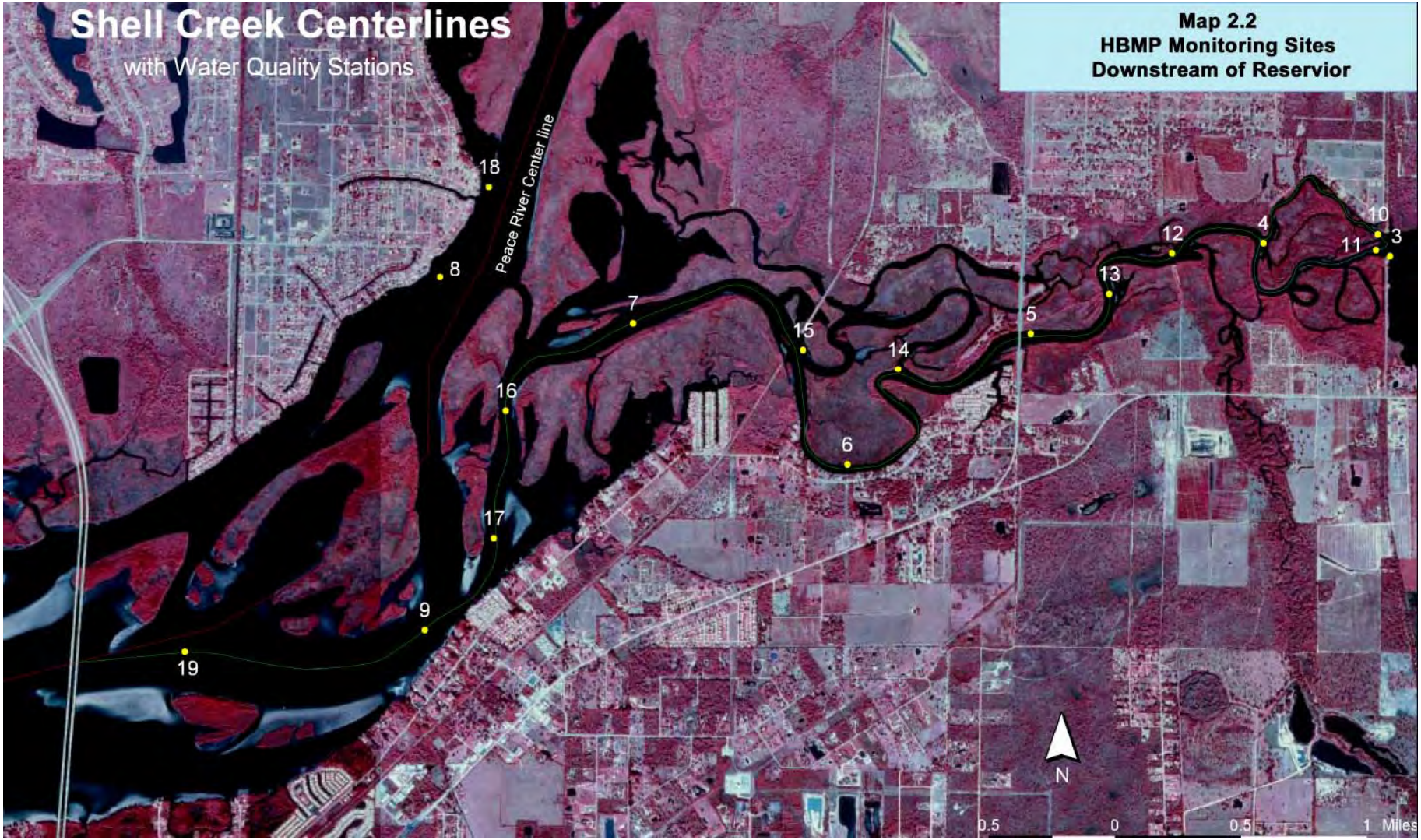
- **Chapter 2 – Description of the Existing Monitoring Program**
- **Chapter 3 – Status and Trends in the Shell Creek/Lower Peace River Estuary**
- **Chapter 4 – Influences of Withdrawals on Flow Characteristics**

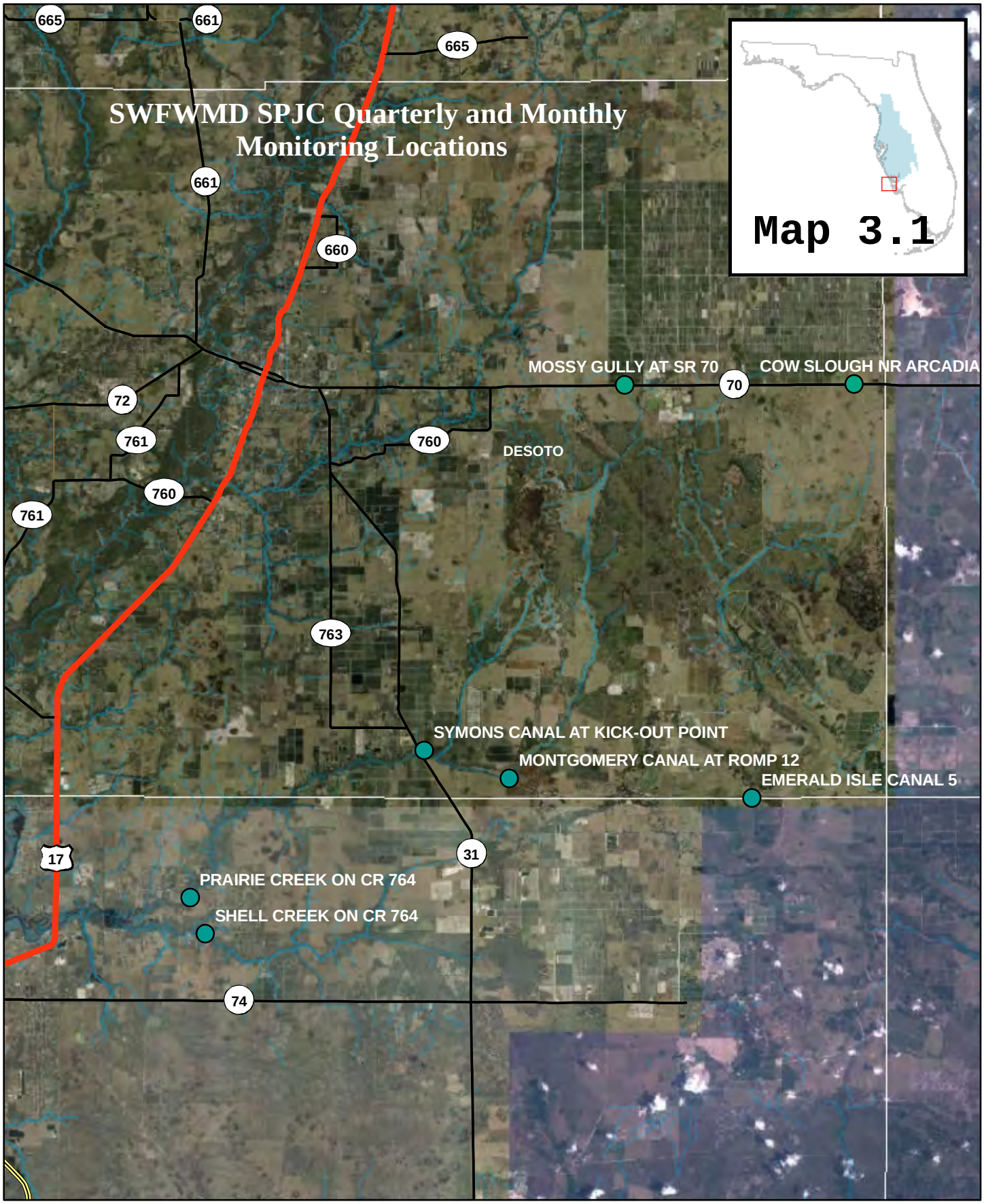
Map 2.1
HBMP Monitoring Sites and River Kilometers



Stations
Center Line
Station Number
1.3 River Kilometer

2000 0 2000 4000 Feet


Shell Creek Centerlines
with Water Quality Stations
Map 2.2
HBMP Monitoring Sites
Downstream of Reservior
Peace River Center line
18
8
7
16
17
9
19
15
14
6
5
13
12
4
10
11
3
N
0.5
0
0.5
1 Miles



Water Quality Monitoring Locations

0 1.25 2.5 5 7.5 10 Miles

N
W E
S

Map 4.1
Location of USGS Continuous Recorder 1997-2005

SAS Data Sets

The data used in this report are contained in the data sets summarized in the following table.

Data Set Name	Time Period	Brief Description
SAS Data Sets		
SHELL_HBMP.sd2	1931-2009	Historic daily flow data for: Peace at Bartow, Fort Meade, Zolfo Springs and Arcadia. Daily tributary flows for: Horse Creek near Arcadia; Joshua Creek near Nocatee; Prairie Creek near Ft. Ogden; and Shell Creek near Punta Gorda. Historic daily Peace River and Shell Creek Water Treatment Facility withdrawals. Theoretical values without withdrawals and under maximum 2008 permitted amounts. All values in cfs.
SC9109.sd2	1991-2009	Mid-depth water quality at the Shell Creek HBMP sampling locations. Relative locations reflect distances from the river mouth in kilometers.
SH9109.sd2	1991-2009	Monthly hydrolab *in situ* water quality measurements taken at 0.5 meter intervals at each of the HBMP station locations. Relative locations reflect from the river mouth in kilometers.
District.sd2	2002-2009	Water quality data from the District's background water quality monitoring program in the Prairie/Shell Creek Watershed.
USGS.sd2	2004-2009	Conductivity data from the USGS continuous recorders in the Prairie/Shell Creek Watershed.
City_Data.sd2	2001-2009	Daily City of Punta Gorda conductivity and chloride data from the reservoir.