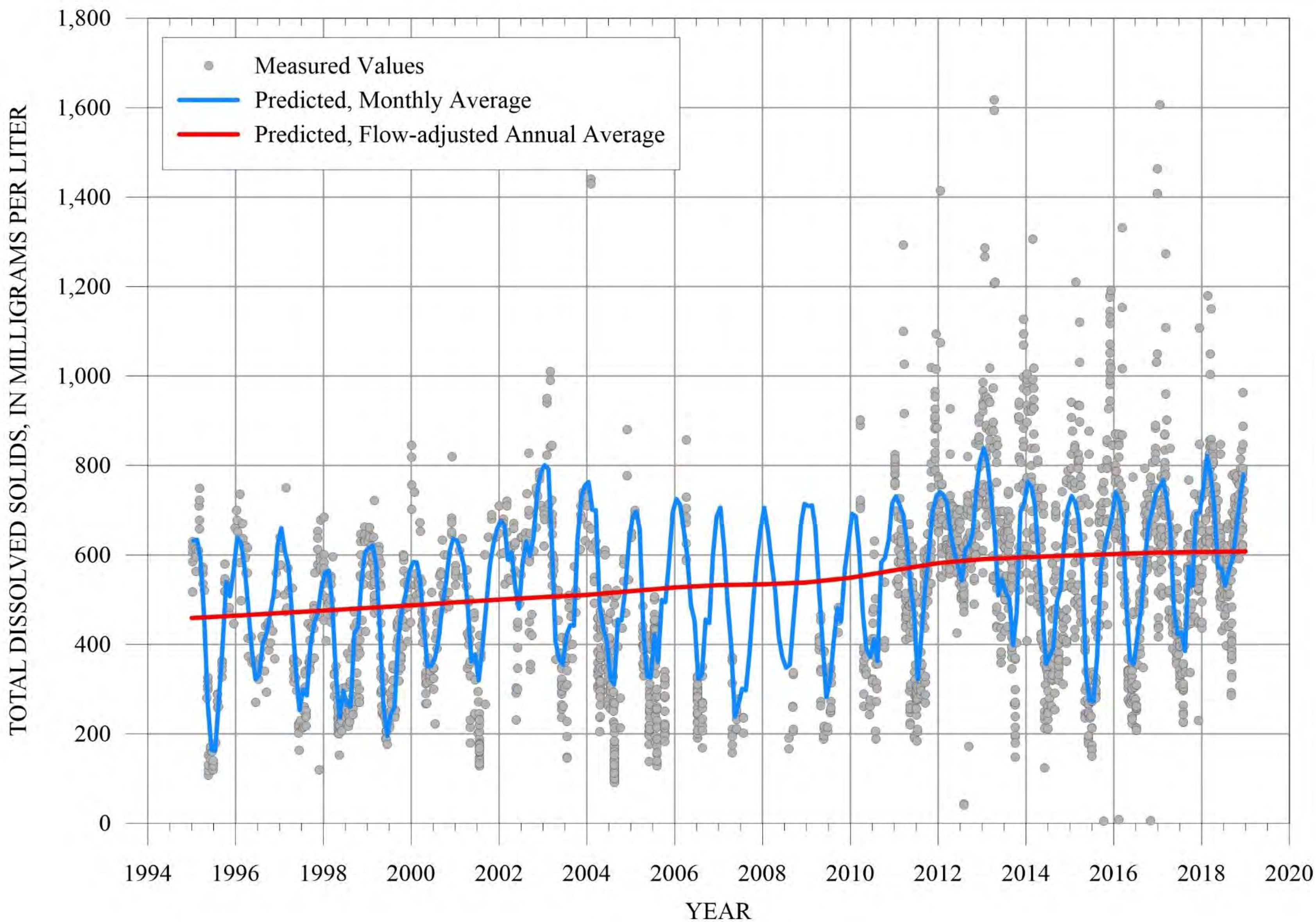

Figure 8-12. Flow-adjusted, average annual Total Dissolved Solids concentrations for Reach 2

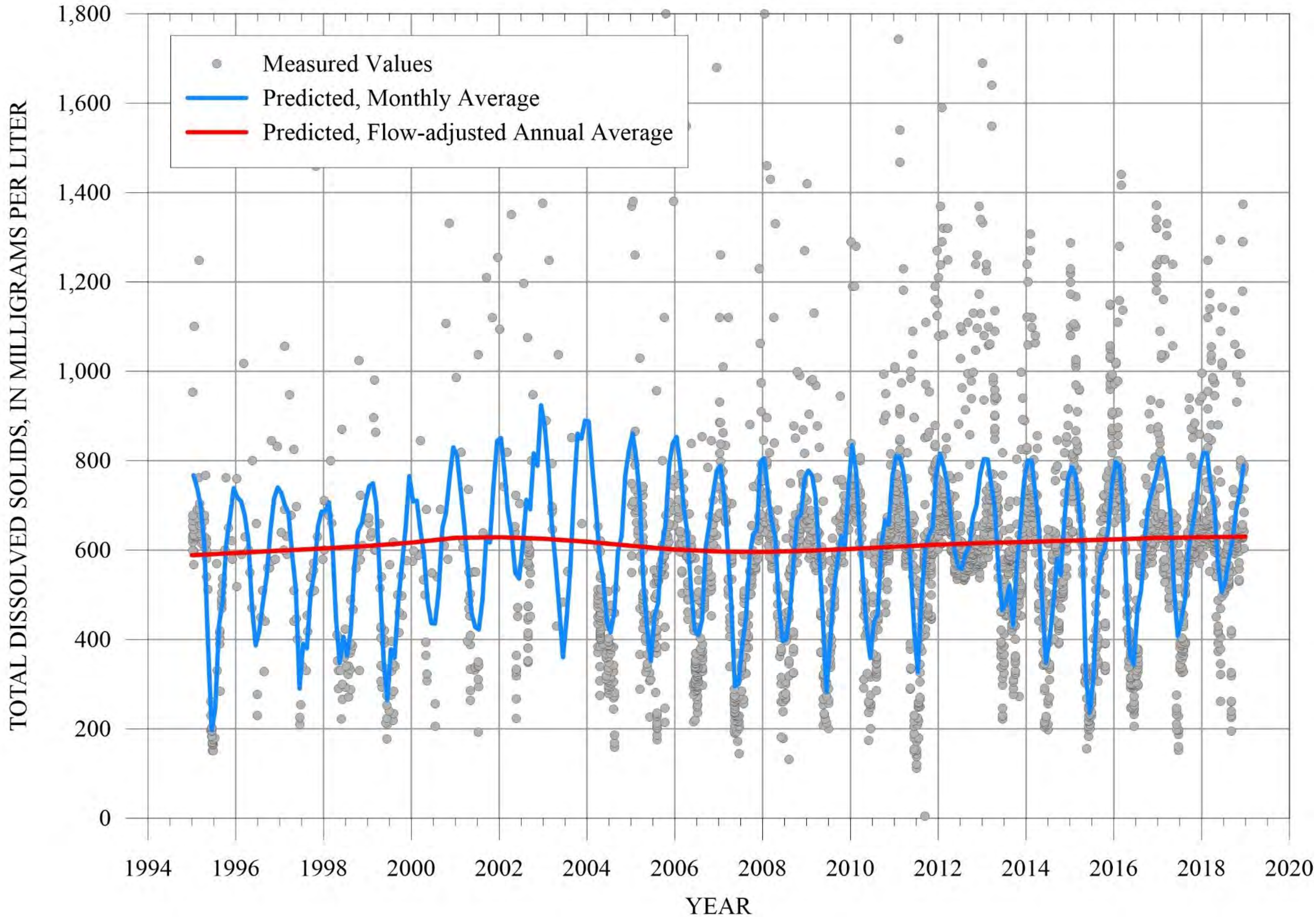

Figure 8-13. Flow-adjusted, average annual Total Dissolved Solids concentrations for Reach 3

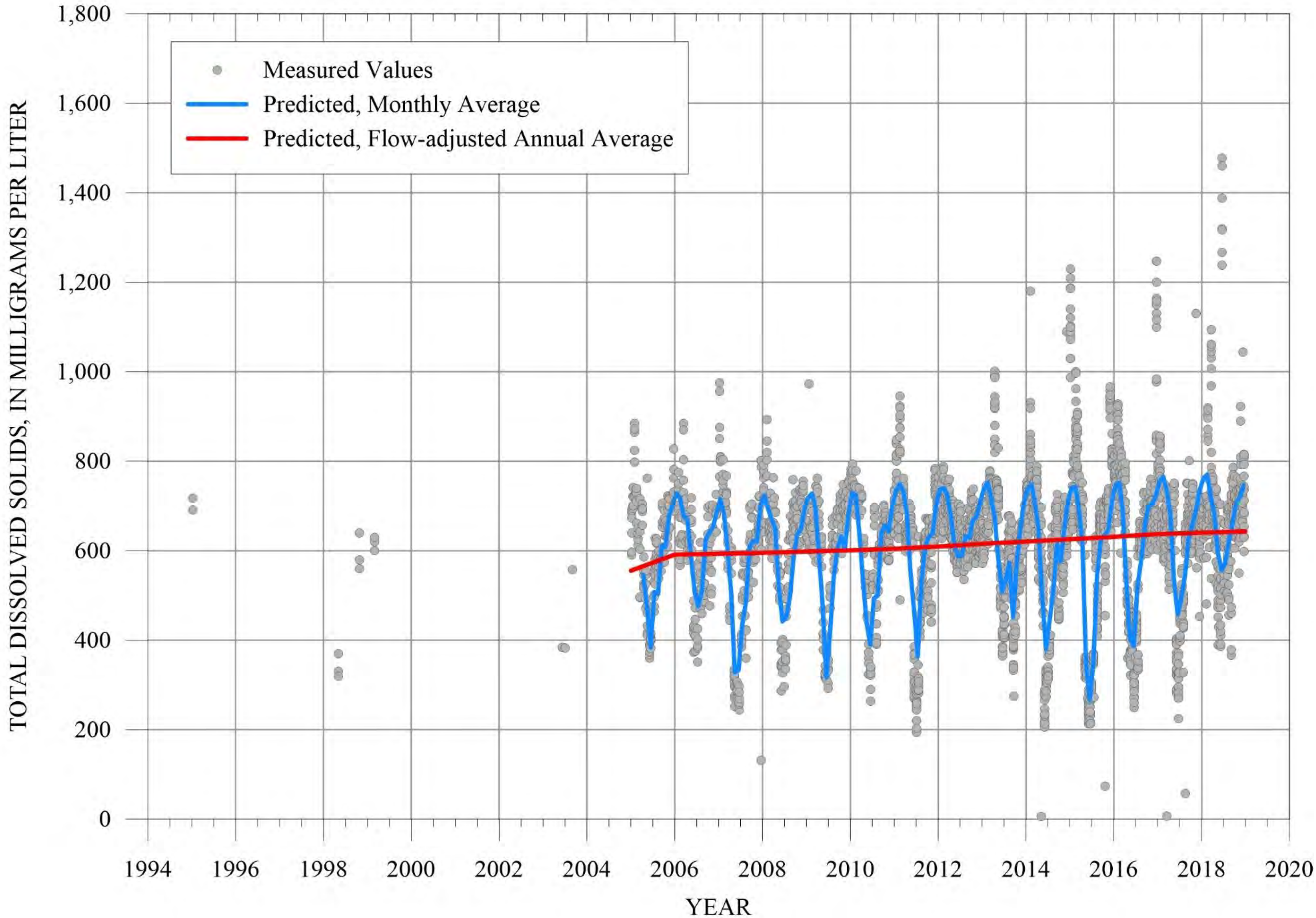

Figure 8-14. Flow-adjusted, average annual Total Dissolved Solids concentrations for Reach 4

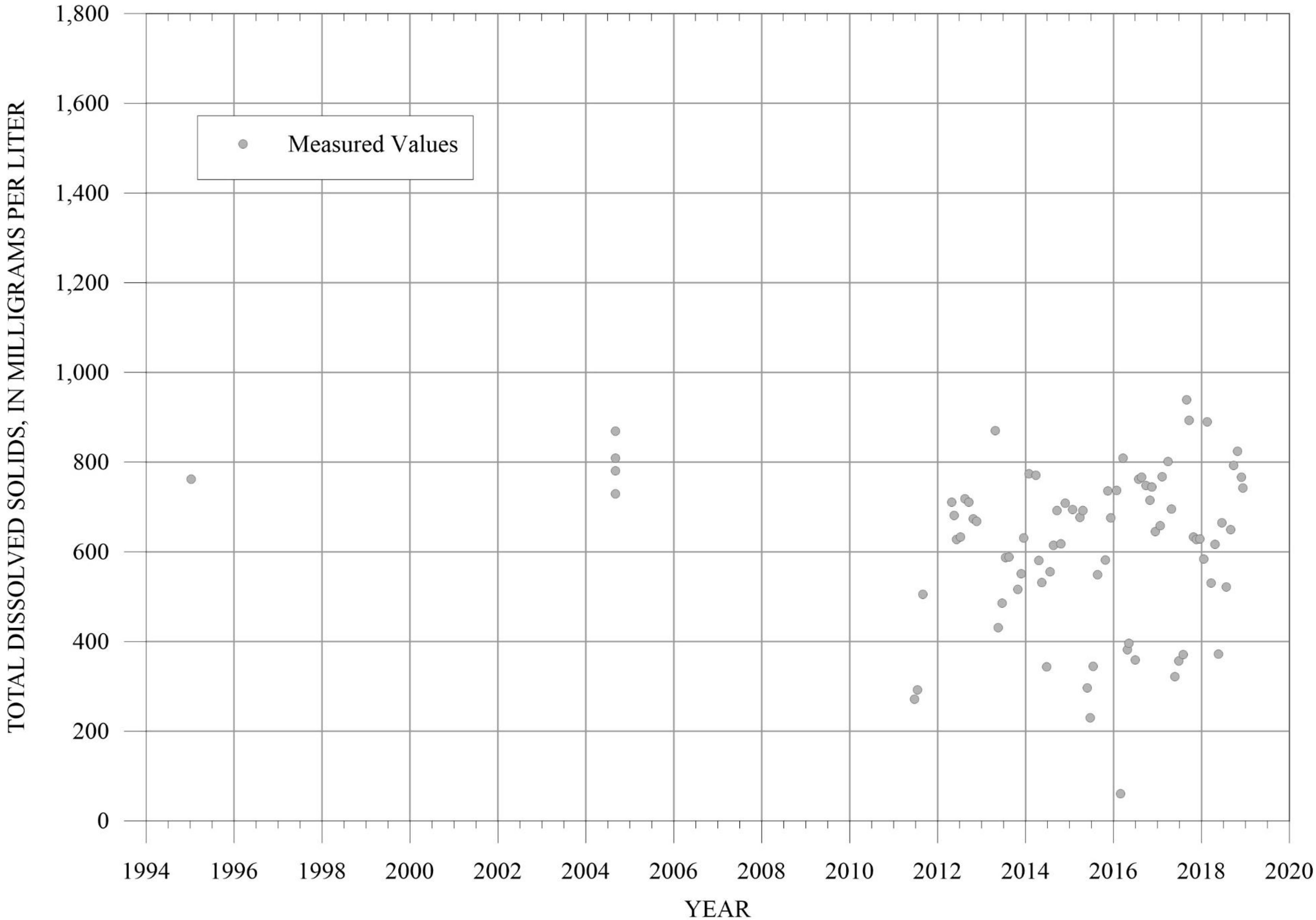

Figure 8-15. Total Dissolved Solids concentrations for Reach 5

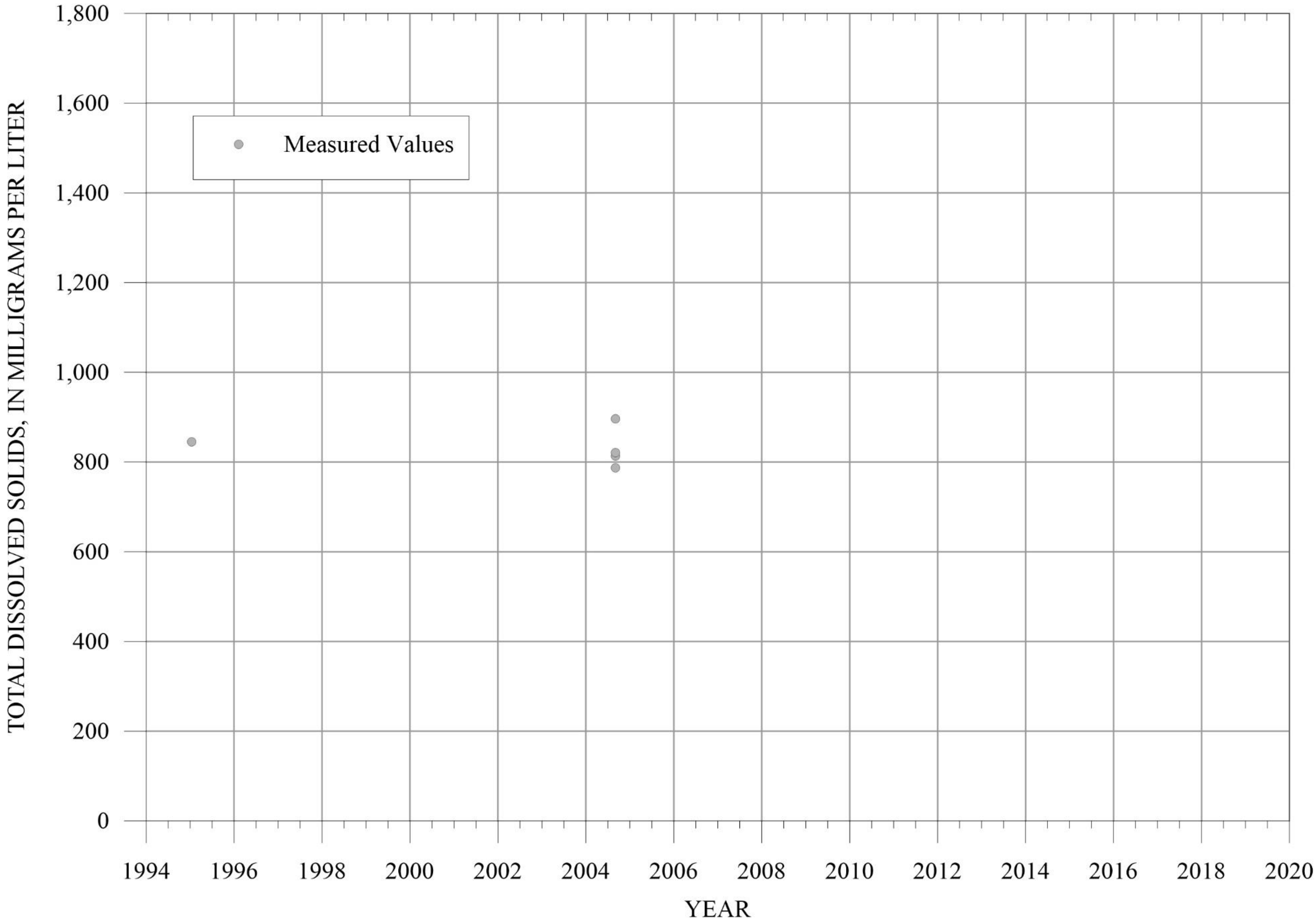

Figure 8-16. Total Dissolved Solids concentrations for Reach 6

The upper most reaches in the Denver Metro area, reaches 1 and 2, have rising salinity trends with average annual concentration increases of 150 to 200 mg/l (Figure 8-11 and Figure 8-12). The next downstream reaches, 3 and 4, have consistent to slightly increasing average annual concentrations. The middle reaches, 5 and 6, that receive inflow from Saint Vrain Creek and the Big Thompson River, do not have enough data for the WRTDS analysis (Figure 8-15 and Figure 8-16).

Average annual salinity concentrations in reaches 2, 3, and 4 have been steadily increasing. Average annual concentrations exceed 600 mg/l after the river flows through the Denver Metro area. Salinity concentrations of 1,800 mg/l have been measured in these upper reaches, with numerous measurements over 1,200 mg/l, which is twice the annual average.

Although the salinity steadily increases with downstream distance Reach 7, 8, and 9, have overall declining salinity trends since 1995 (Figure 8-17, Figure 8-18, and Figure 8-19). The average annual concentration in Reach 7 has decreased from about 900 mg/l to 750 mg/l since 1995. Reach 8 has declined from about 1,100 mg/l in 1995 to 850 mg/l in 2018. Annual concentrations in Reach 9 have decreased slightly from 1,100 mg/l in 2012 to over 1,000 mg/l in 2018. In 2012, the monitoring frequency in Reach 9 increased and although this is a limited period for analysis, these are the best data available. These lower reaches also have had extreme salinity concentrations measured with over 1,400 mg/l in Reach 8 and over 1,600 mg/l in Reach 9.

The Saint Vrain, Big Thompson, and Cache la Poudre tributaries were investigated to see if they were influencing salinity in the lower reaches of the South Platte River. The Saint Vrain and Big Thompson have sparse and sporadic measurements, but they were included in the analysis since these data form the current understanding of their salinity conditions.

The Saint Vrain trend is flat with concentrations of about 775 mg/l (Figure 8-20). The Big Thompson flow-adjusted annual average concentrations are similar to the LOWESS trend line on Figure 8-9. Concentrations in 1995 were about 1,500 mg/l and declined to about 900 mg/l by 2012. After 2012 the trend reversed to slightly upward (Figure 8-21). The number of salinity measurements increased in 2017-18 and future data collection will aid in clarifying current trends.

The Cache la Poudre River has abundant data from 2003-2018, except for 2011 (Figure 8-22). Northern Water has routine monitoring sites near the confluence with the South Platte River (Figure 5-3). The salinity trend has been consistent or slightly decreasing from about 750 to 700 mg/l.

Other tributaries, like Cherry Creek, Clear Creek, and Sand Creek had higher salinity than the Denver Metro area from 1990 into the early 2000's (Haby, 2011). Although trends in these tributaries were mixed, they also appeared to have an overall decreasing trend. General improvements in water treatment since the 1990's may be contributing to the decreasing trends. Tributary concentratons suggest that they are significant salinity contributors to the South Platte River. It is reasonable to expect the tributaries to influence the South Platte River.

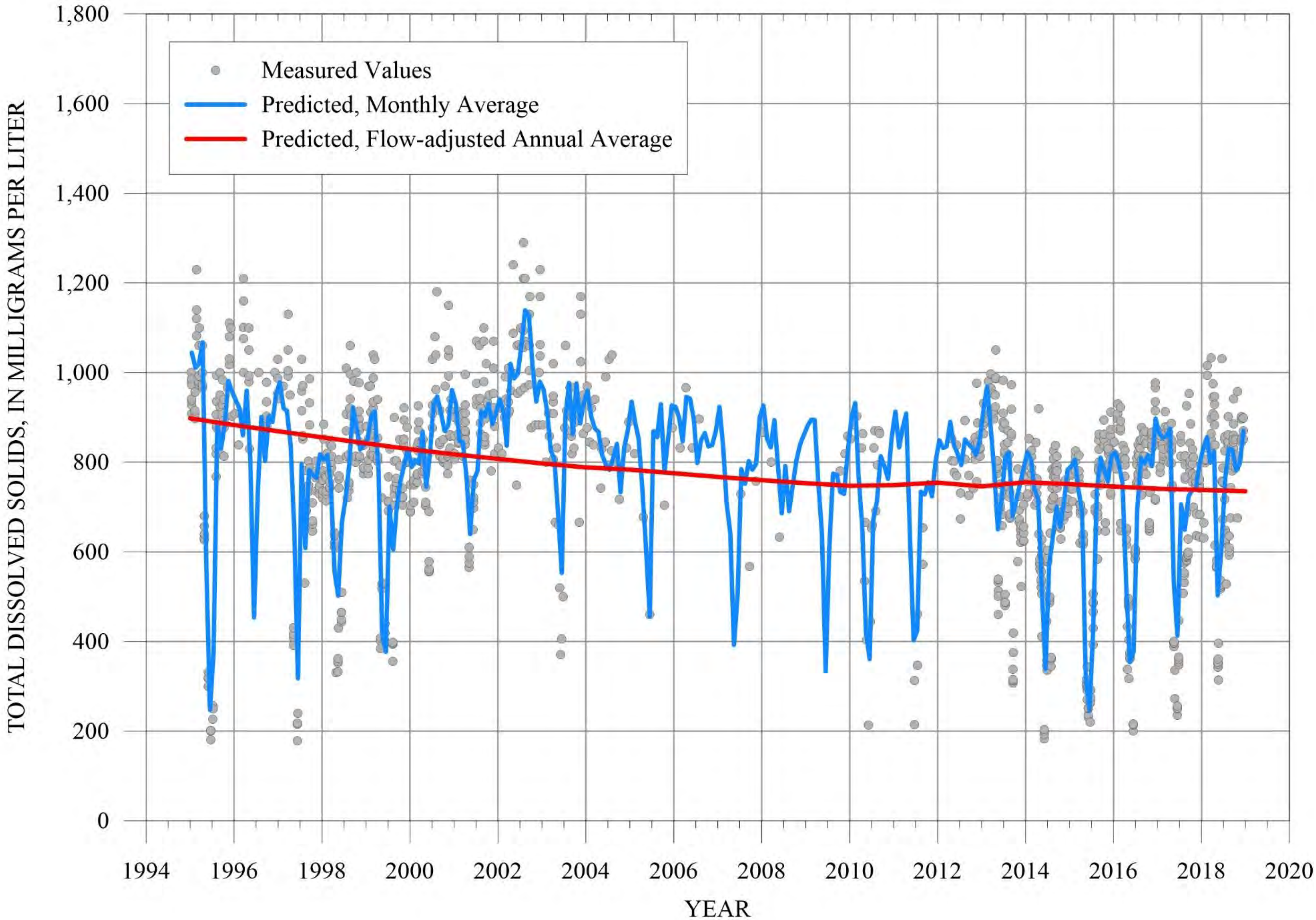

Figure 8-17. Flow-adjusted, average annual Total Dissolved Solids concentrations for Reach 7

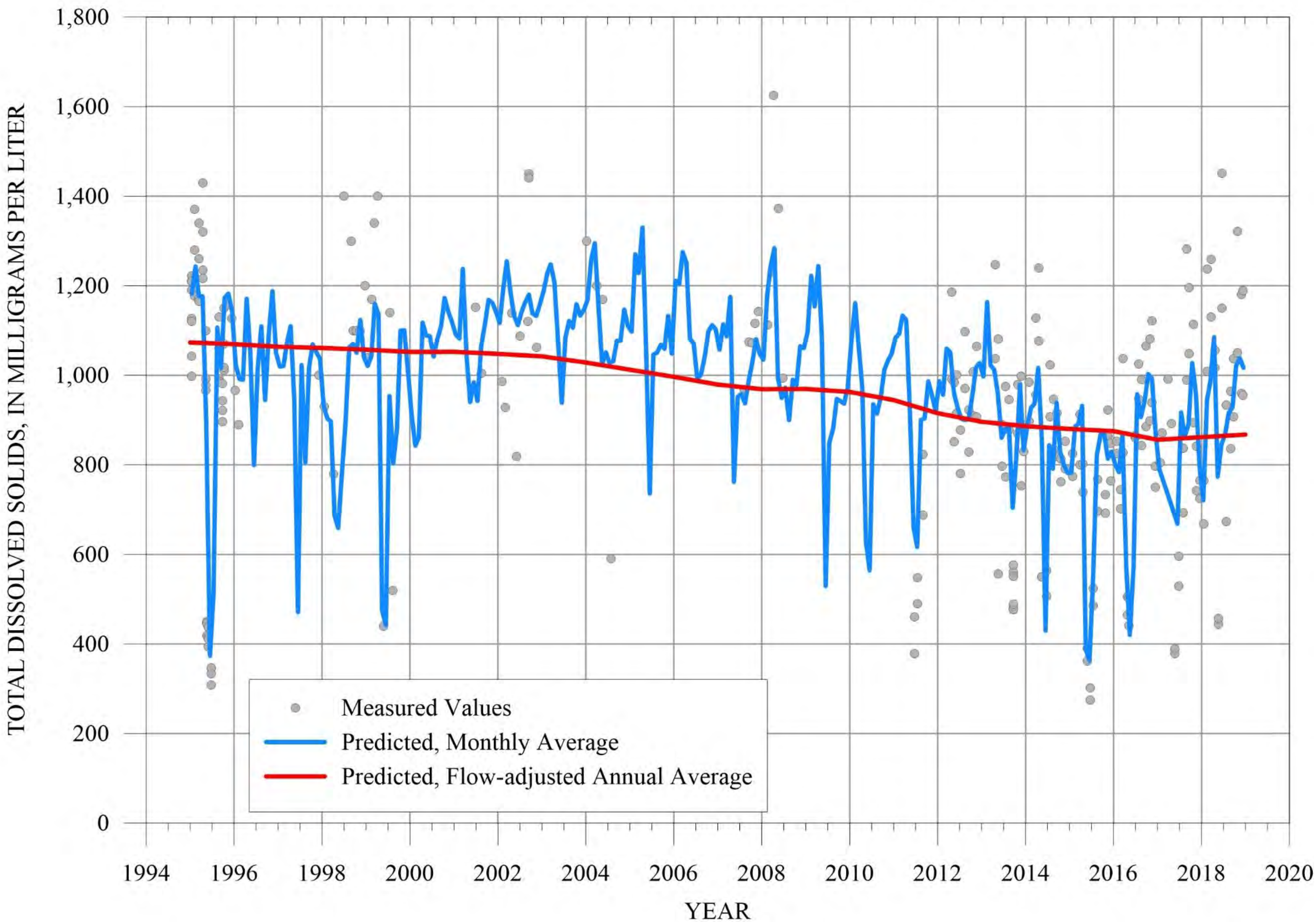

Figure 8-18. Flow-adjusted, average annual Total Dissolved Solids concentrations for Reach 8

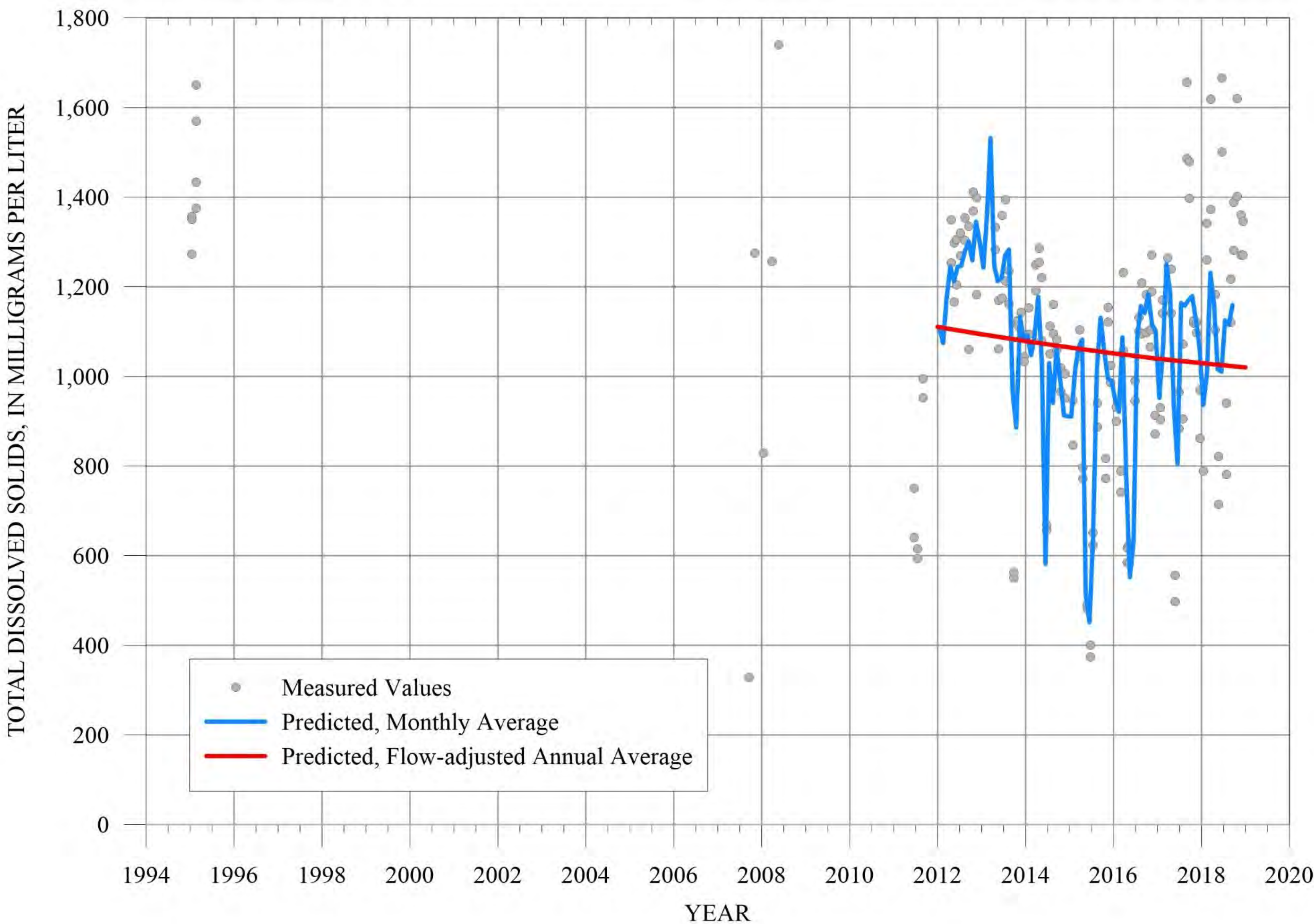

Figure 8-19. Flow-adjusted, average annual Total Dissolved Solids concentrations for Reach 9

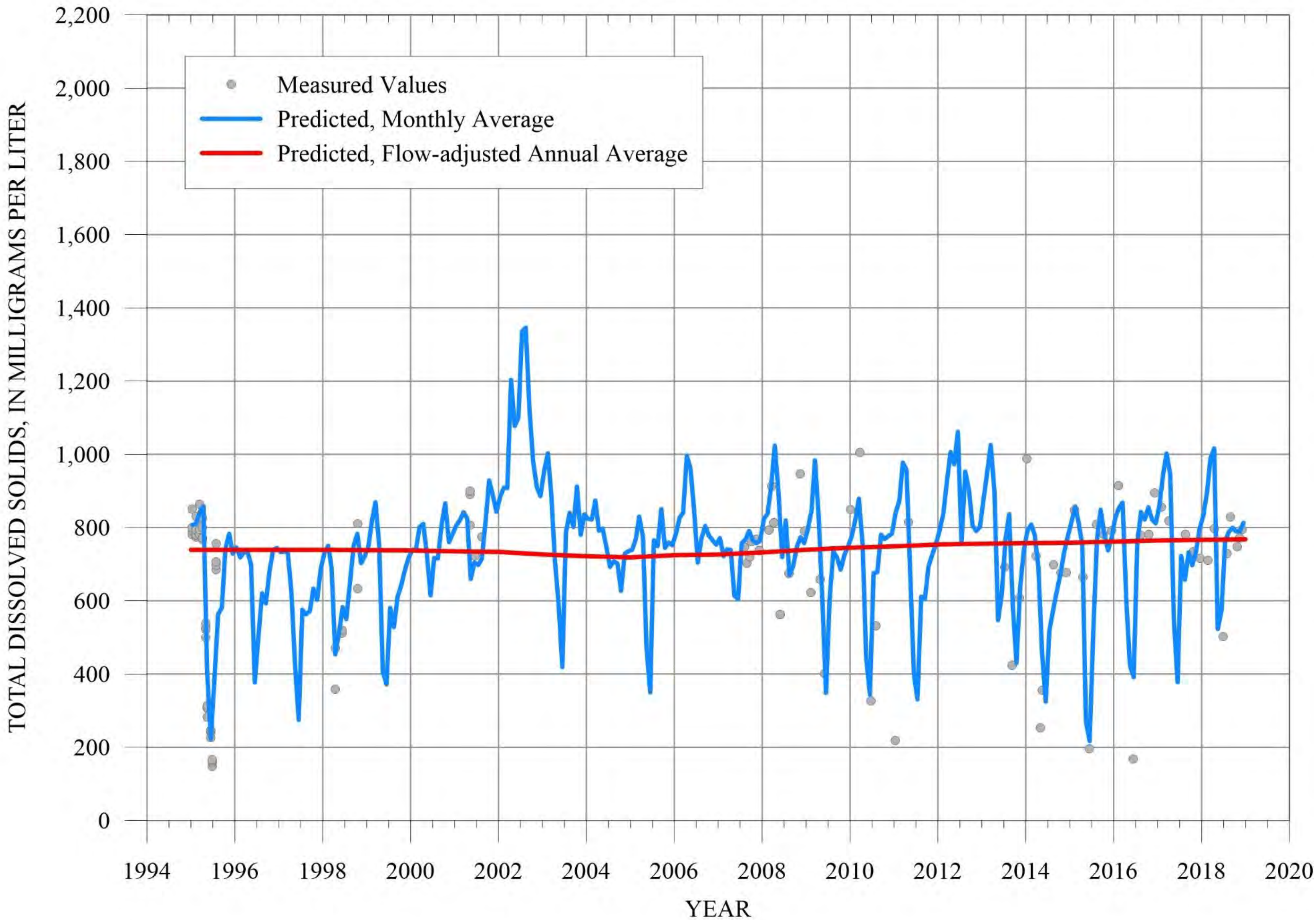

Figure 8-20. Flow-adjusted, average annual Total Dissolved Solids concentrations for Saint Vrain Creek

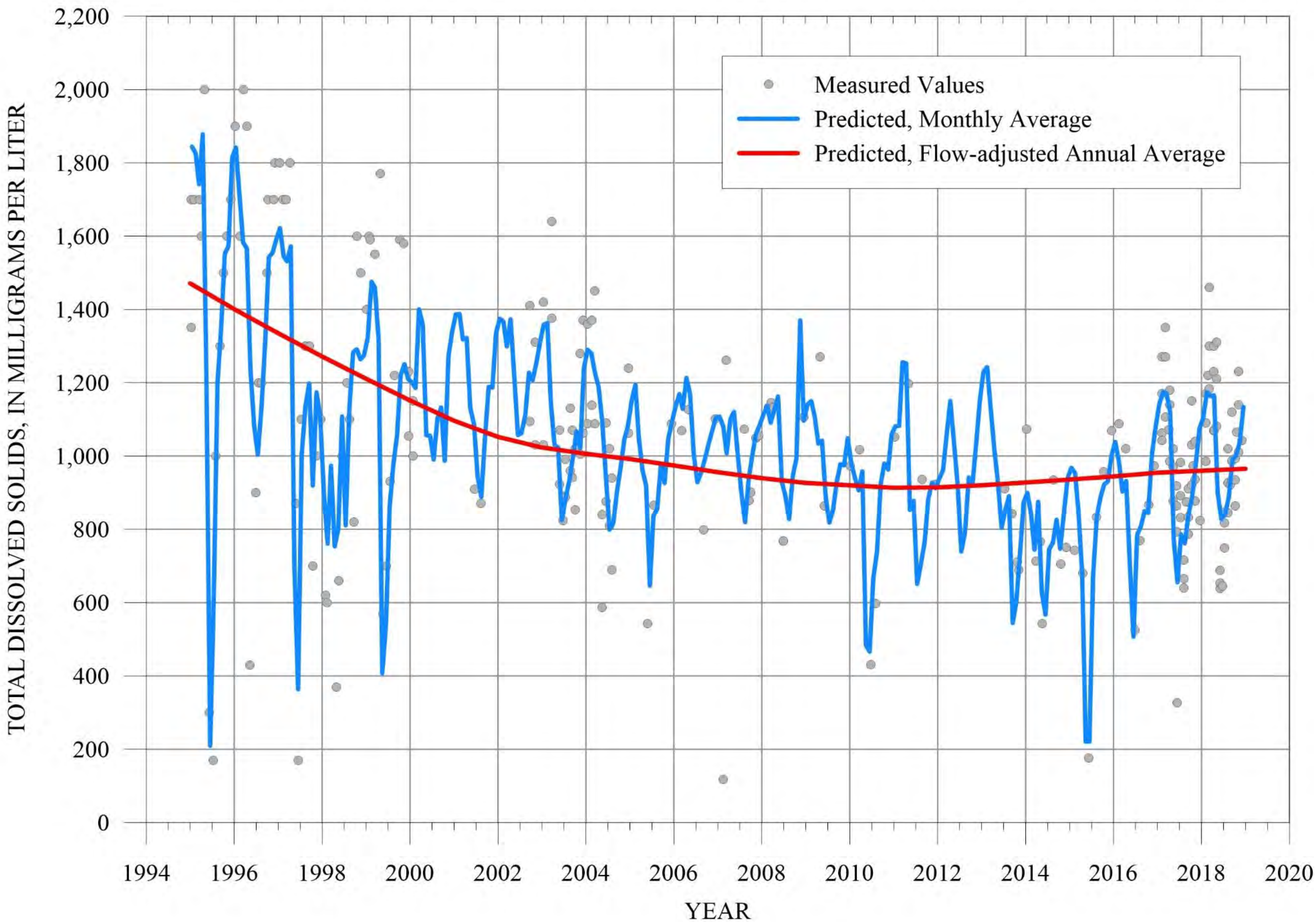

Figure 8-21. Flow-adjusted, average annual Total Dissolved Solids concentrations for the Big Thompson River

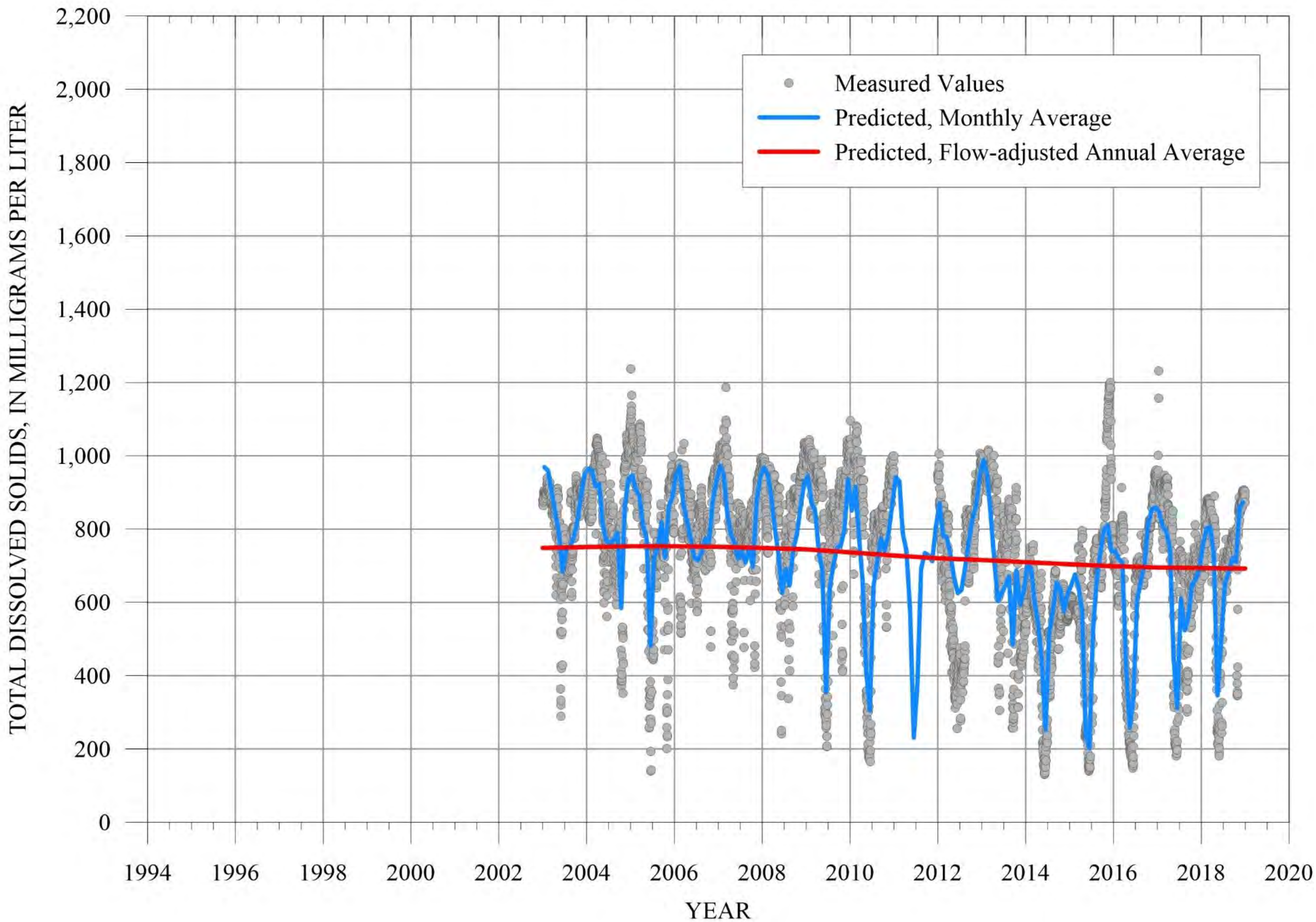

Figure 8-22. Flow-adjusted, average annual Total Dissolved Solids concentrations for the Cache la Poudre River

Salinity concentrations and trends in the lower South Platte River reaches reflect the net effect of salinity loading in the upper reaches, the tributaries, and groundwater inflow. A large portion of the flow from the upper reaches is diverted into ditches, so the water can be used for crop irrigation. The remaining South Platte River flow mixes with the tributary inflow. The portion of irrigation water that is not lost to crop transpiration and evaporation, returns to the South Platte River as return flow in the ditches or as groundwater flow. Freshwater is removed by crop transpiration and evaporation processes, but the salts remain, which increases the salinity of the return flow.

The South Platte River flow has a net decrease through reaches 4, 5, and 6 due to numerous ditch diversions. These diversion losses are largely replaced by tributary and groundwater inflow. The salinity concentrations in the South Platte River become a blend of the upper reach flow and the tributary inflow. The salinity input from the tributaries increases the salinity from about 650 mg/l in Reach 4 to 750 mg/l in Reach 7. The contribution of tributary inflow appears to influence the salinity trends in the lower reaches.

The average annual salinity in upper reaches 1-5 are shown on Figure 8-23. Salinity increases with downstream distance as additional salt loading is added to the river. Salinity has also been increasing with time. Since 2012 the average annual salinity in reaches 2-5 has been essentially the same and following the same trends. These equivalent concentrations may indicate that after 2012 the river flow in these reaches became dominated by wastewater effluent.

The salinity in the tributaries has been gradually decreasing and following similar trends, which are shown on Figure 8-24. The increasing salinity trend since 2015 may be due to lower streamflow. Future salinity and streamflow monitoring will clarify whether this trend is due to a change in salt loading or due to river discharge.

Salinity trends in the tributaries are reflected in the lower reaches as shown on Figure 8-25. In 2018, the Cache la Poudre salinity was about 700 mg/l, the Saint Vrain was about 800 mg/l, and the Big Thompson was about 1,000 mg/l. These tributaries are adding higher salinity water and about as much flow as the South Platte River, which results in higher South Platte salinity.

Salinity steadily increases downstream in the lower reaches, from about 750 mg/l in Reach 7, to 950 mg/l in Reach 8, to 1,175 mg/l in Reach 9 (2018 averages; Figure 8-25). The numerous irrigation diversions throughout the basin distribute water to farmland and the alluvial aquifer. Water that is not consumed by plants or evaporation returns to the river with higher salinity concentrations. As water is repeatedly reused as it flows downstream it contributes to the increasing downstream salinity.

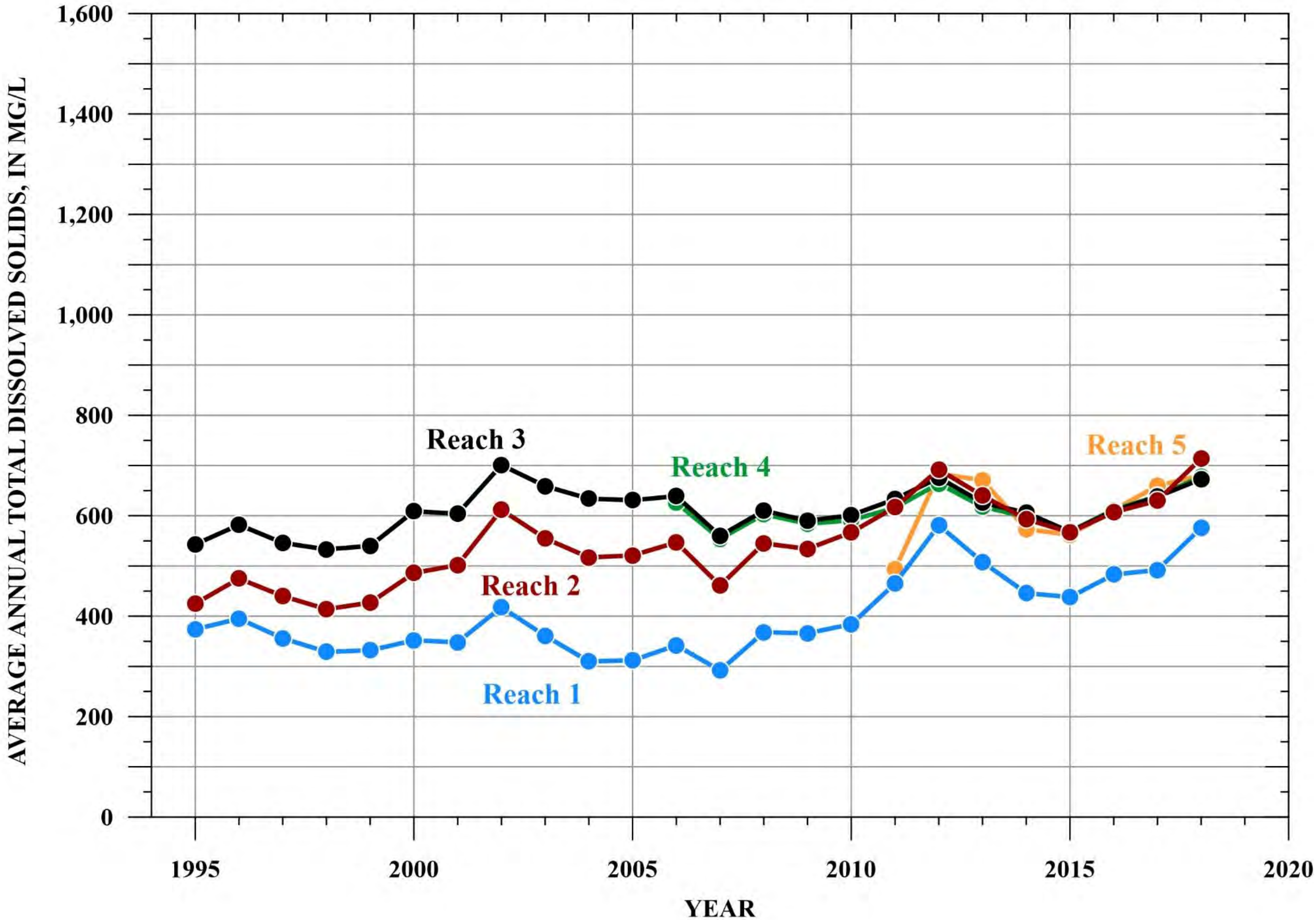

Figure 8-23. Average annual salinity trends in the upper South Platte River Reaches

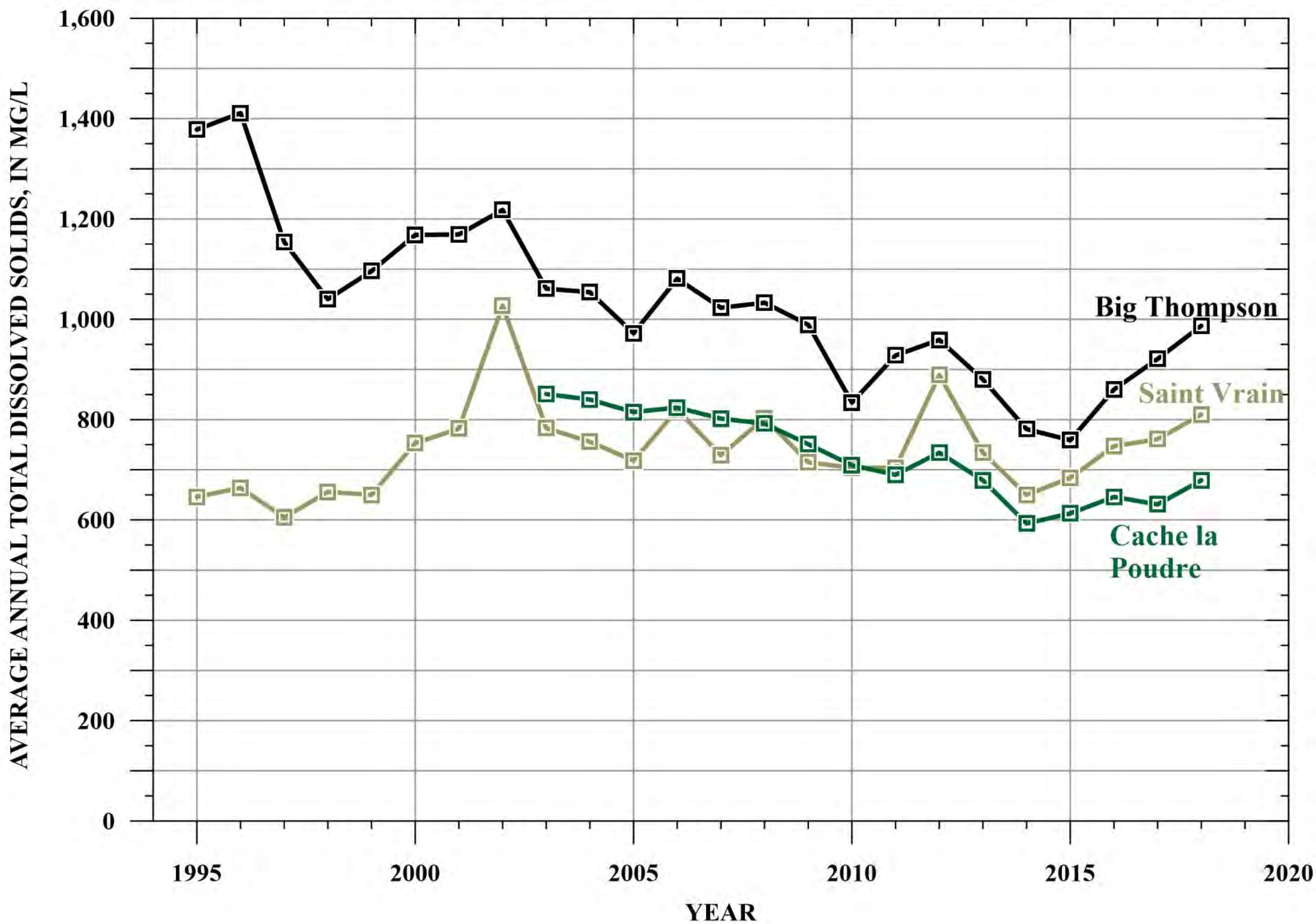

Figure 8-24. Average annual salinity trends in tributary rivers

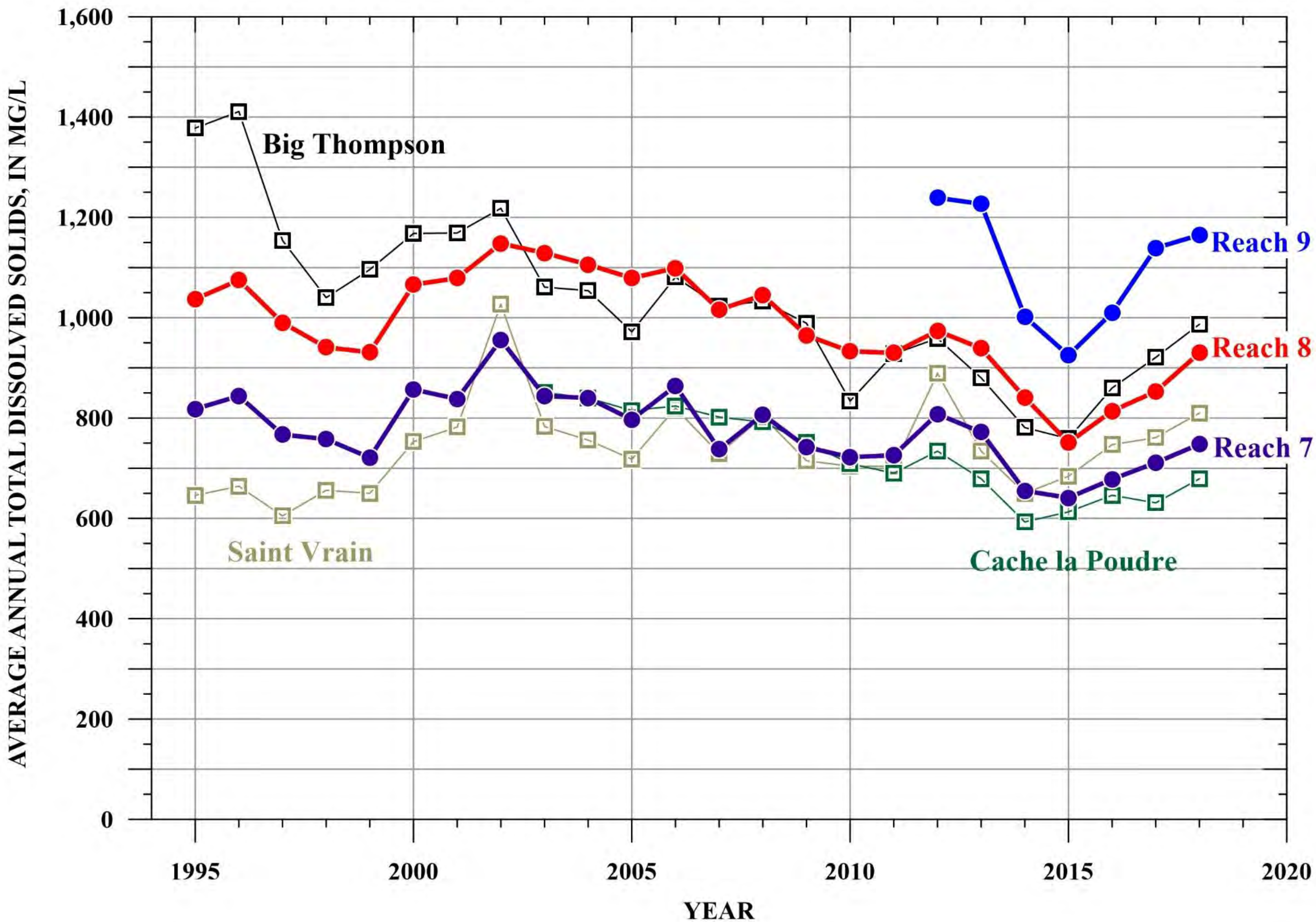

Figure 8-25. Average annual salinity trends in the lower South Platte River reaches reflect tributary inflow

9. SALT LOADING

The South Platte River Total Dissolved Solids and electrical conductivity measurements are the most readily available indicators of the salinity severity and its related hazards and concerns. These data represent the amount of salt moving through the hydrologic system.

The salt load is the physical amount of salt in the river that is transported to farmland and other users. If the river water was evaporated there would be a pile of residue, which includes salts. The load, or flux, is provided in units of mass per time, like tons per year. This load varies depending on the salinity concentration and the flow rate. Loads increase as concentrations and/or flow rates increase.

Daily salt loads were estimated for each river reach. The daily concentrations estimated by the WRTDS analysis were multiplied by the daily flow volume to obtain the salt load, in tons per day. The daily loads were then summed to obtain annual salt loads. Since this method uses daily concentrations and average daily flows it is more representative than estimates using monthly averages or other more general approximations.

9.1 Irrigated Fields

Salt loading is important to irrigated crop lands because salt can reduce crop yields and damage soils. If salts added to soils by irrigation water are not flushed through the root zone the soils can become impermeable, which prevents drainage and can prevent crops from accessing soil moisture. The effect of irrigation water on crops and soil is discussed further in Section 3.1.

The amount of salt applied to irrigated fields can be calculated based on flow rates and salinity concentrations. The pounds of salt applied to fields for each inch of irrigation water applied per acre (pounds per acre inch) is calculated as follows (Bauder and others, 2014):

> Multiply the source water TDS (mg/l) by 0.23[4] to obtain pounds per acre inch and then multiply by the inches of water applied.
>
> For example, assuming water has TDS of 1,000 mg/l (EC = 1.6 dS/m)
>
> > Total Dissolved solids (TDS) = 1,000 mg/l
> >
> > 1,000 mg/l x 0.23 = 230 pounds per acre inch.
>
> Considering seasonal irrigation of 24 inches, there would be:
>
> > 230 pounds per acre inch x 24 inches = 5,520 pounds salt per acre

Diversions that remove South Platte River flow also remove salts. The salt is transported by ditches and canals for crop irrigation. Water that is not consumed by the crops or lost to evaporation,

[4] For every 1 mg/l TDS there is 0.23 pounds of salt per acre-inch of water. Water with TDS of 740 mg/l (EC = 1.15 dS/m) contains approximately 2,000 pounds of salt for every acre foot of water (Bauder and others, 2014).

infiltrates and reaches the groundwater system. Some salt may remain in the soil and some is transported with the groundwater.

Groundwater tends to concentrate salts and has been shown to have higher salinity concentrations than the South Platte River (Dennehy and others, 1998). This higher salinity groundwater can be pumped by irrigators and re-applied to crops. As this irrigation water reuse process is repeated the salinity can exceed that of the originally diverted water. Salt loading to groundwater irrigated fields may, therefore, be higher than surface-water irrigated fields.

The cumulative effect of applying salt to soils over repeated irrigation seasons without flushing the salts through the soil column can cause permanent damage to the soil structure. If left unmanaged this damage can become irreversible and render the soil unusable for irrigated agriculture.

9.2 Load Estimates

Salt loads generally increase as the South Platte River flows through the basin. The river flow increases due to contributions from tributaries, wastewater effluent, groundwater, and return flows. Each of these sources also contributes salt. The salt load in each reach was calculated using the WRTDS model, which estimates the daily salinity concentration, and the gaged streamflow in each reach. The numerous diversions that remove water and salt from the river were not explicitly considered.

In 2018, the salt load was 448,500 tons in Reach 7, which was the largest loading estimate in the South Platte River. The salt load in Reach 7 includes the loads from the Denver Metro area and the major tributaries. The 2018 salt loads and the average annual load for each reach from 1995 through 2018 are provided in Table 9-1. Streamflow was below normal in 2018, so the salt loads were less than the historical average.

There are several large diversions in Reaches 7 and 8 that remove flow and salt. This results in lower loading in Reach 8 (Table 9-1). However, in Reach 9 salt loading has historically been the highest of any reach. This occurs without any major surface-water tributary inflow. The increase in salt load and salt concentrations is partly due to groundwater inflow from the alluvial aquifer that surrounds the South Platte River and, if not fully consumed, agricultural ditch return flows. This increase in salt load occurs even though South Platte River flows are decreasing from Reach 7 to 8 to 9. This occurs due to the significant increase in salinity concentrations in Reach 9.

Salt loading follows the concentration trends discussed in Section 8.5 Flow-Adjusted Trends and the discharge trends discussed in Section 6. Annual average salt loading, flow-adjusted trends, and loading variations due to streamflow are provided in Appendix D.

Table 9-1. South Platte River salt loading in 2018 and average since 1995 (in tons per year)

Reach	2018 Salt Loading (tons per year)	Long-term Average Salt Loading (tons per year)
1	38,800	70,000
2	101,800	137,300
3	180,400	248,900
4	192,300	276,200
5	--	--
6	--	--
7	448,500	636,600
8	216,000	454,200
9	292,900	653,600
Saint Vrain Creek	126,300	134,500
Big Thompson River	46,400	64,800
Cache la Poudre River	85,000	99,000

-- = no discharge data available in this reach and not enough salinity data for WRTDS analysis

10. SPROWG CONSTITUENTS

The South Platte Regional Opportunities Working Group (SPROWG) is conducting a Water Development Concept Feasibility Study (Feasibility Study) that is evaluating four water-supply development concepts. These concepts include water storage facilities and additional conveyance capacity throughout the Basin. These water supplies would be delivered to meet municipal, agricultural, environmental, and recreational demands.

This section presents data compiled for the Feasibility Study Water Treatment Strategies task, which intends to identify water-treatment approaches. The goal of these treatment strategies is to meet the municipal use water-quality standards, which are the most restrictive standards of the possible uses. The source water quality will dictate the constituents that require treatment and the most appropriate treatment methods.

The Feasibility Study identified water-quality constituents, in addition to salinity, that are important for evaluating water treatment. The constituents compiled to support the SPROWG study are provided in Table 10-1. Several forms of nitrogen were evaluated individually including nitrate, nitrite, mixed forms, and organic nitrogen.

Table 10-1. SPROWG feasibility study constituents

Calcium	Alkalinity
Magnesium	Bromide
Hardness	Manganese
Carbonate	Iron
Bicarbonate	Total Organic Carbon
Phosphorous	Turbidity
Nitrogen	Temperature
pH	

Scatter plots for each water-quality constituent, by reach, are provided in Figure 10-1 through Figure 10-15 10-20. The plots for each constituent have the same axis range for all reaches. This aids comparison of concentration changes downstream. A LOWESS trend line has been added to aid trend visualization. Boxplots that visually illustrate the statistical distribution and yearly changes are provided in Appendix E. Statistics used to create the boxplots are provided in tabular form in Appendix E.

A summary of the constituent trends is provided in Table 10-2. The upper reaches have more data availability than the lower reaches. Reaches 5 and 6 have little if any data for most constituents. Although this data set represents the best publicly available data, few constituents have been sampled consistently over time or along the entire South Platte River.

Table 10-2. Summary of SPROWG constituent trends

Constituent	Trends	Notes
Calcium	Steadily increasing downstream with concentrations less than 200 mg/l	Usual range in irrigation water less than 400 mg/l (Ayers and Westcot, 1994)
Magnesium	Steadily increasing downstream with concentrations greater than 60 mg/l in Reach 9	Usual range in irrigation water less than 60 mg/l (Ayers and Westcot, 1994)
Hardness	Increasing concentrations downstream with greater than 180 mg/l in Reach 1 and greater than 600 mg/l in Reach 9	Greater than180 mg/l is considered very hard. Water hardness is generally the amount of dissolved calcium and magnesium in water. In hard water, soap reacts with the calcium to form "soap scum". and more soap or detergent is needed for cleaning.
Carbonate	Limited data available. Maximum concentrations greater than 3 mg/l in Reach 2 and Reach 7	Usual range in irrigation water less than 3 mg/l (Ayers and Westcot, 1994)
Bicarbonate	Limited data available. Increasing concentrations downstream with all reaches less than 610 mg/l	Usual range in irrigation water less than 610 mg/l (Ayers and Westcot, 1994)
Nitrate	Decreasing concentrations downstream and decreasing trend since 2015. All reaches with less than 10 mg/l	Usual range in irrigation water less than 10 mg/l (Ayers and Westcot, 1994). Nitrate and Nitrite below drinking water standards in all reaches
Phosphate	Decreasing concentrations downstream and decreasing trend since 2015. Reaches 2, 3, and 4 have had concentrations greater than 2 mg/l. Since 2015 all reaches monthly average less than 2 mg/l	Usual range in irrigation water less than 2 mg/l (Ayers and Westcot, 1994)
pH	Increasing over time and downstream. Extreme values (greater than 90th percentile) exceed 8.5	Usual range in irrigation water 6.0-8.5 (Ayers and Westcot, 1994)

Table 10-2. Summary of SPROWG constituent trends - Continued

Constituent	Trends	Notes
Nitrogen forms	Concentrations generally decreasing downstream	
Alkalinity	Lower Reaches (7-9) about 250 mg/l	
Bromide	Essentially no data available in any reach at any time	
Manganese	All reaches with less than 0.5 mg/l	Secondary drinking water standard 0.05 mg/l
Iron	Limited data available, no data in reaches 3-9 from 2010-18	Secondary drinking water standard 0.3 mg/l
Total Organic Carbon	Limited data available, no consistent trends between reaches or over time	
Turbidity	Limited data available, no data since 2013 in all reaches except Reach 7	

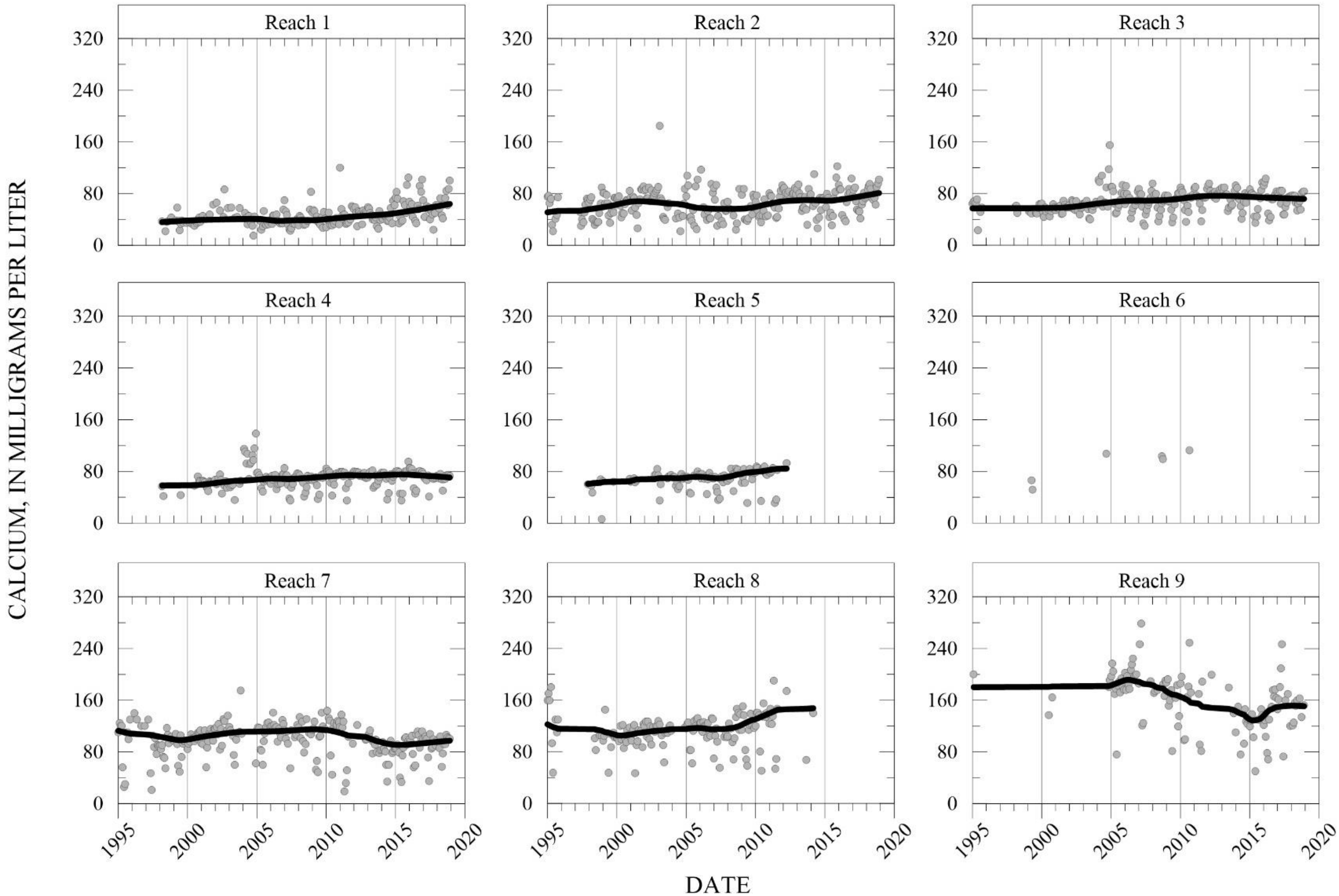

Figure 10-1. South Platte River average monthly calcium concentrations with LOWESS trend line

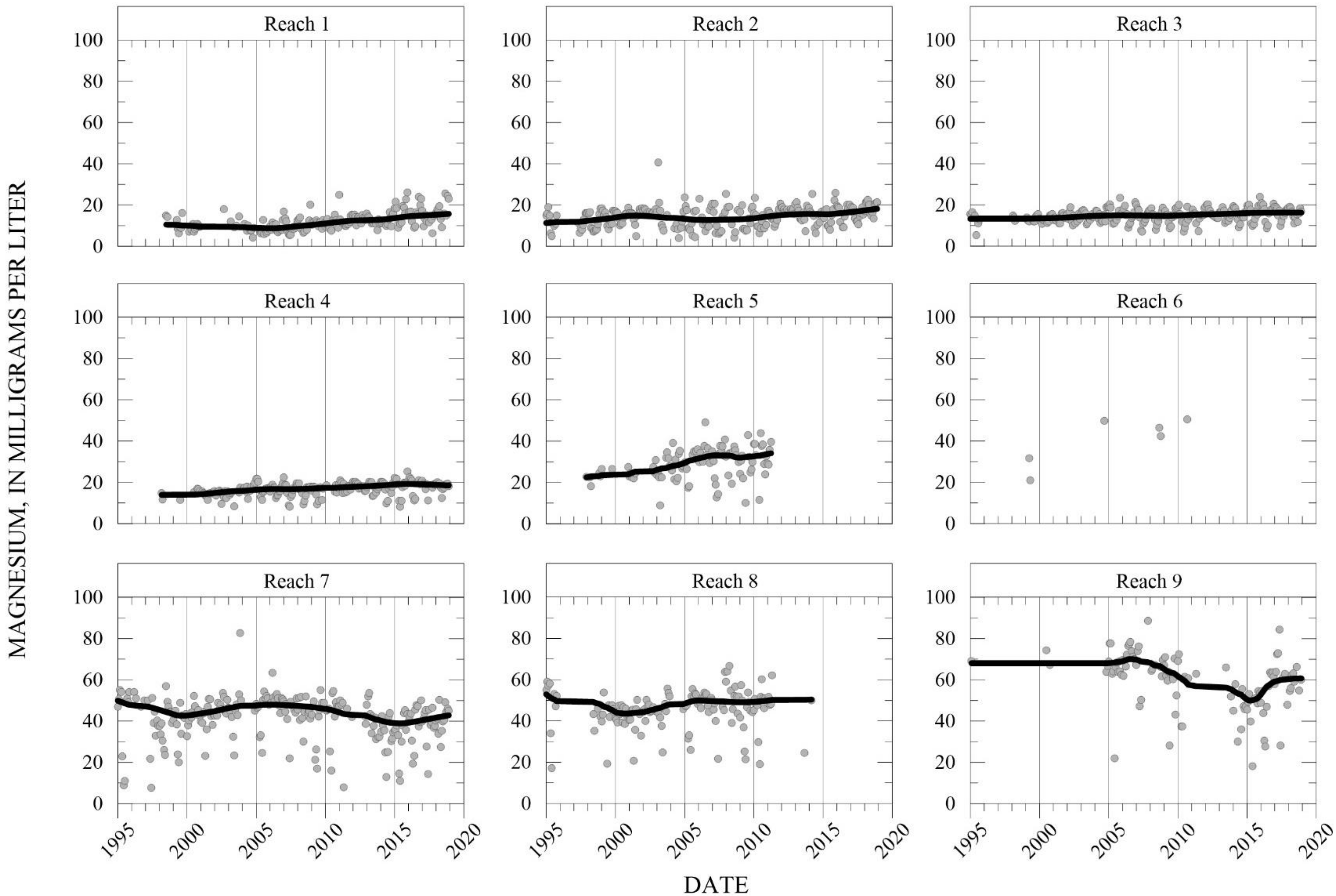

Figure 10-2. South Platte River average monthly magnesium concentrations with LOWESS trend line

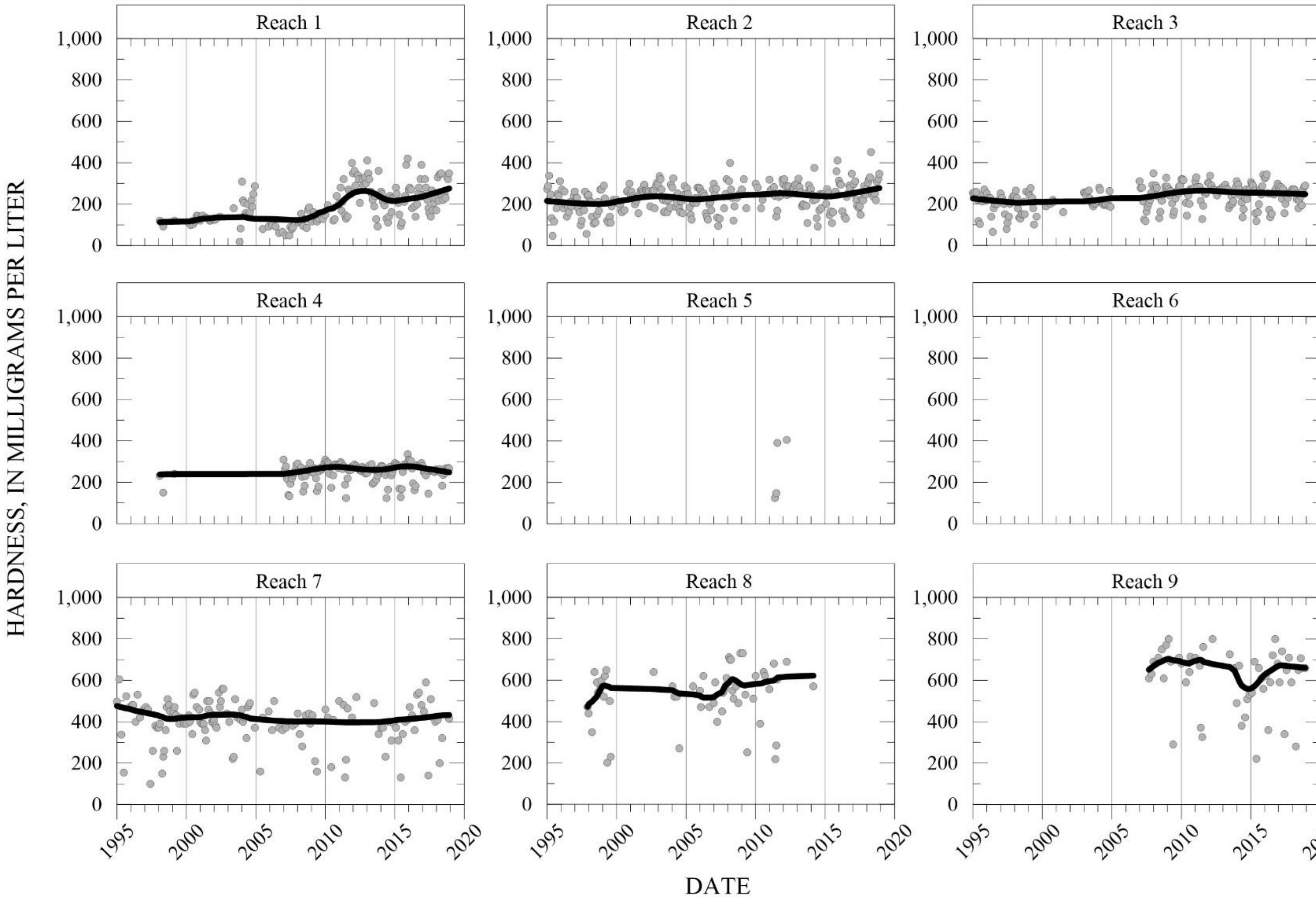

Figure 10-3. South Platte River average monthly hardness concentrations with LOWESS trend line

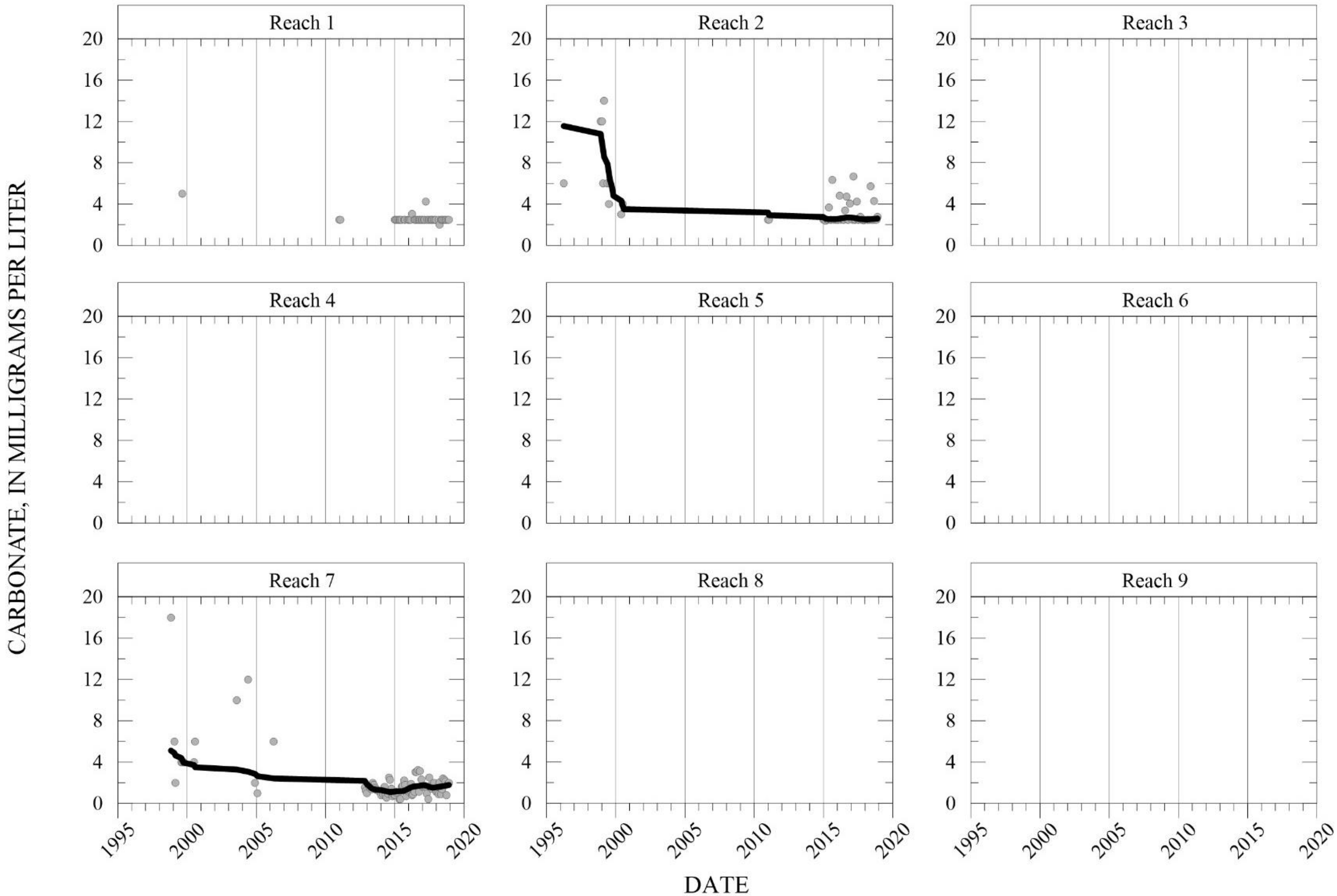

Figure 10-4. South Platte River average monthly carbonate concentrations with LOWESS trend line

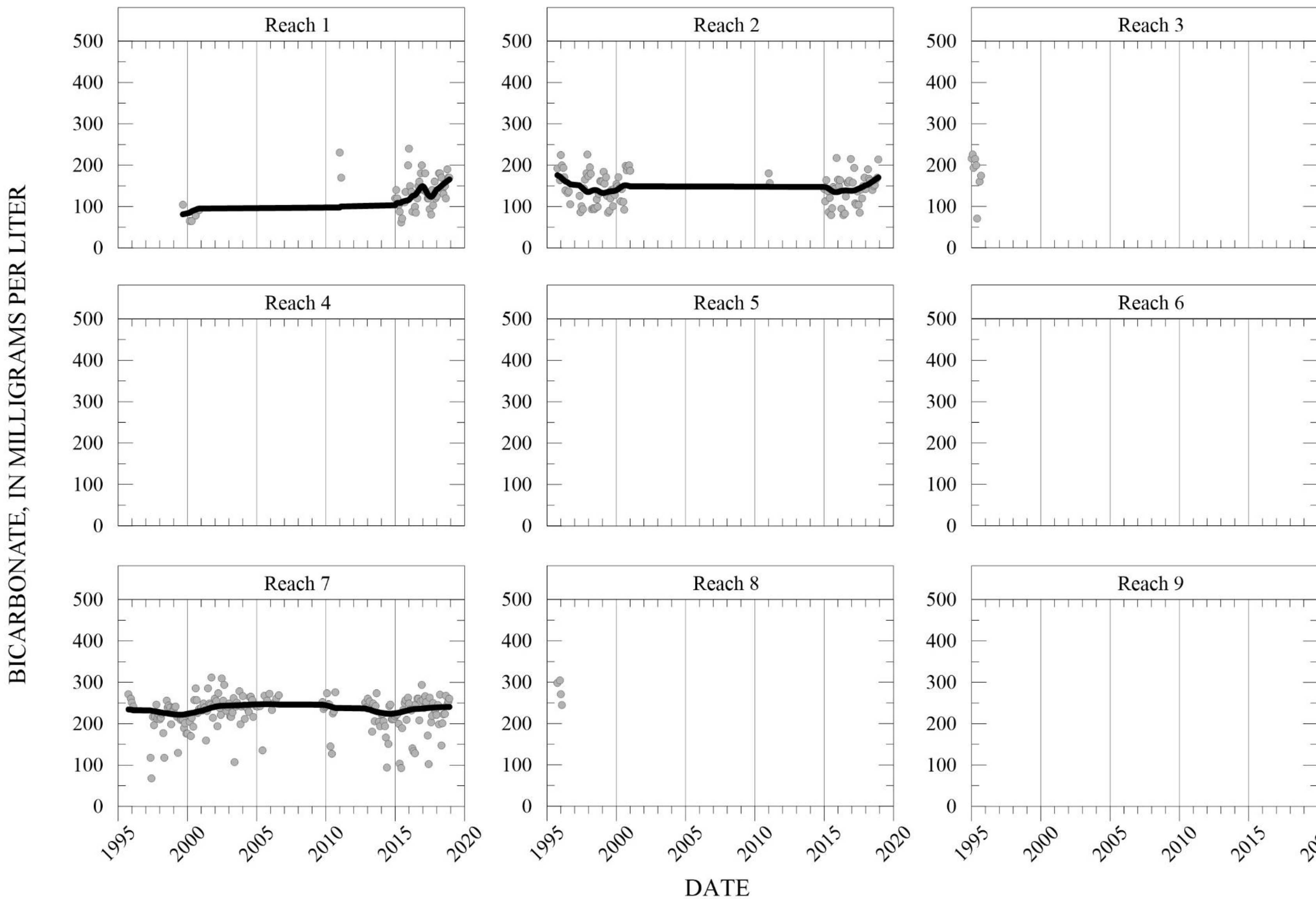

Figure 10-5. South Platte River average monthly bicarbonate concentrations with LOWESS trend line

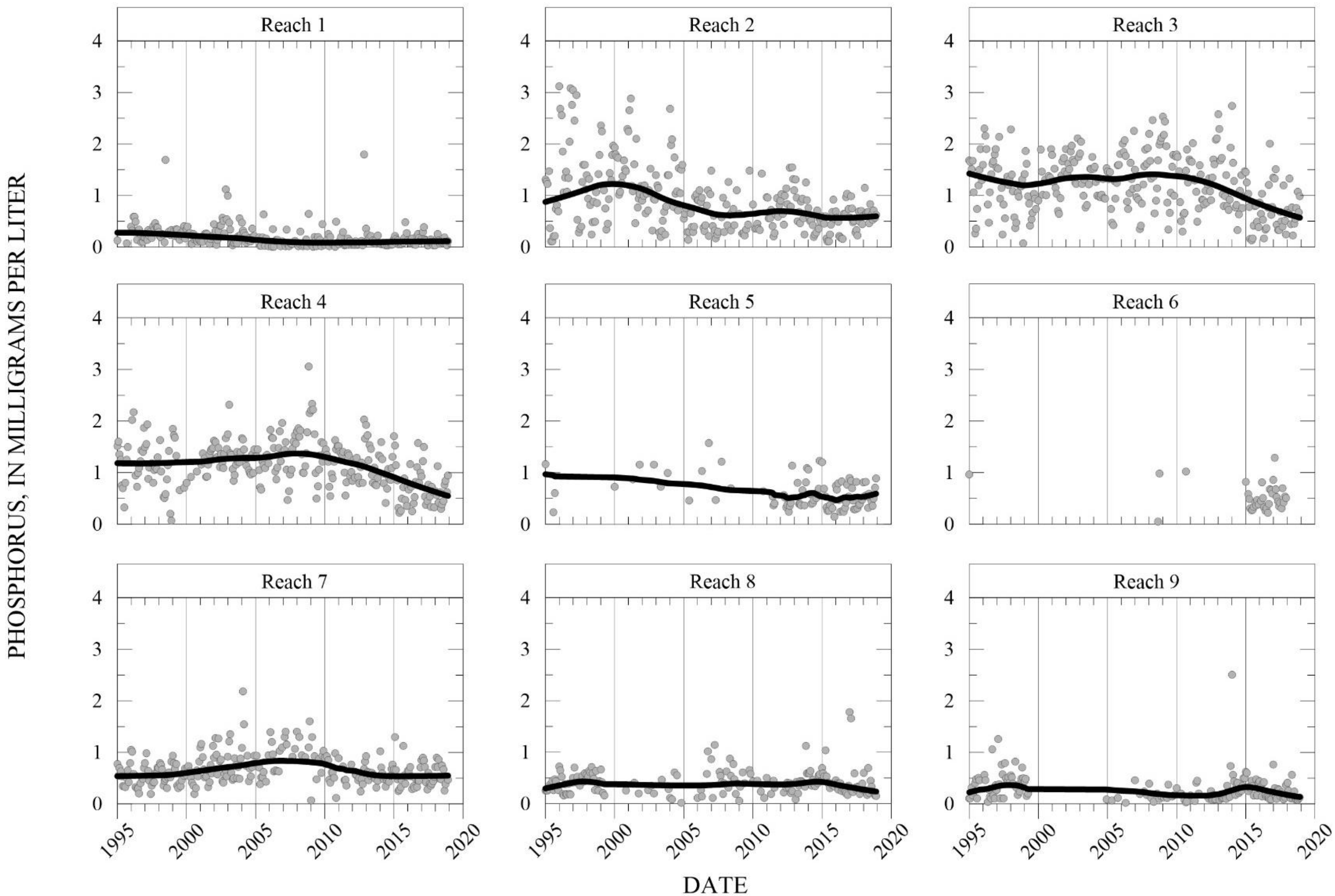

Figure 10-6. South Platte River average monthly phosphorous concentrations with LOWESS trend line

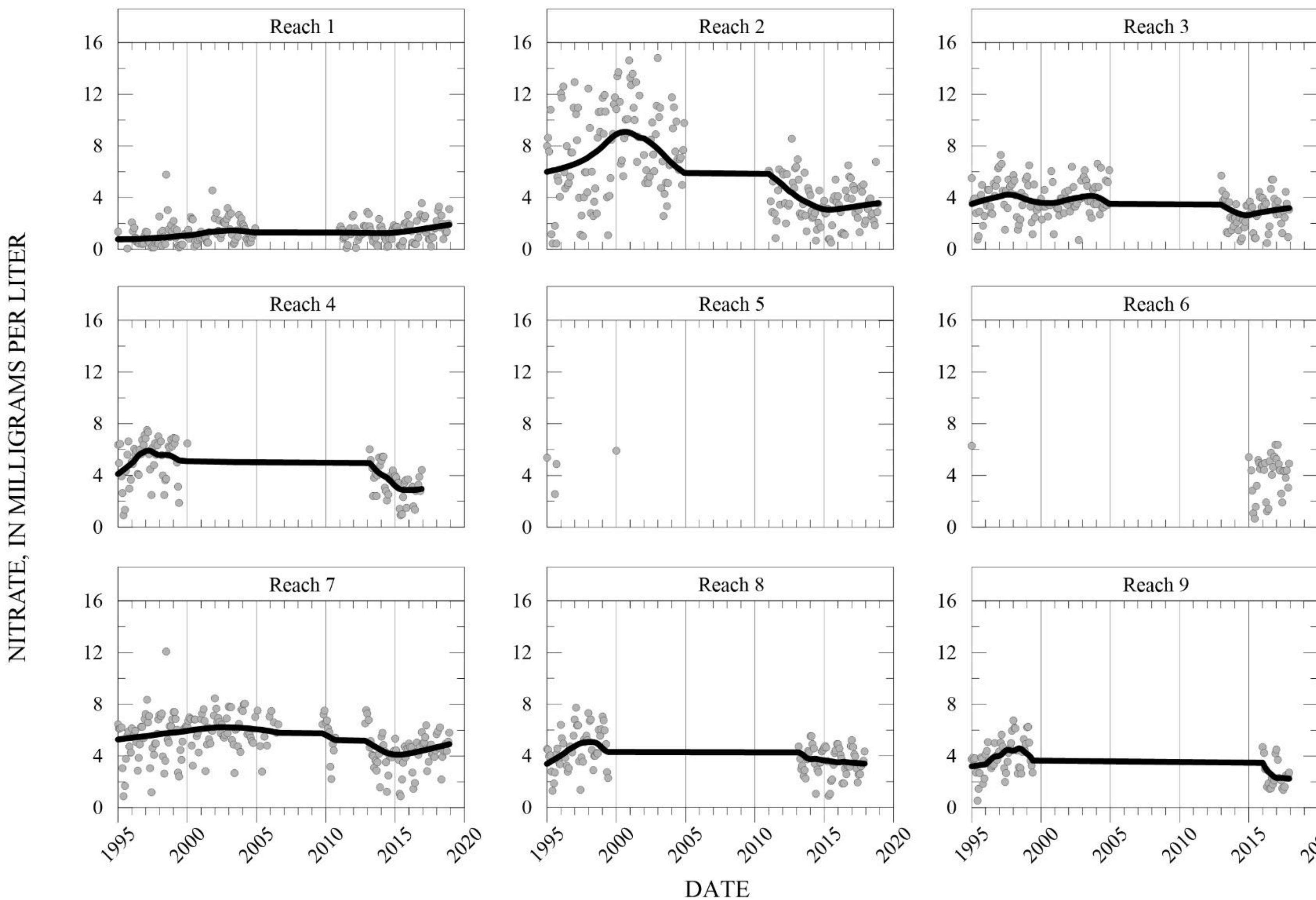

Figure 10-7. South Platte River average monthly nitrate concentrations with LOWESS trend line

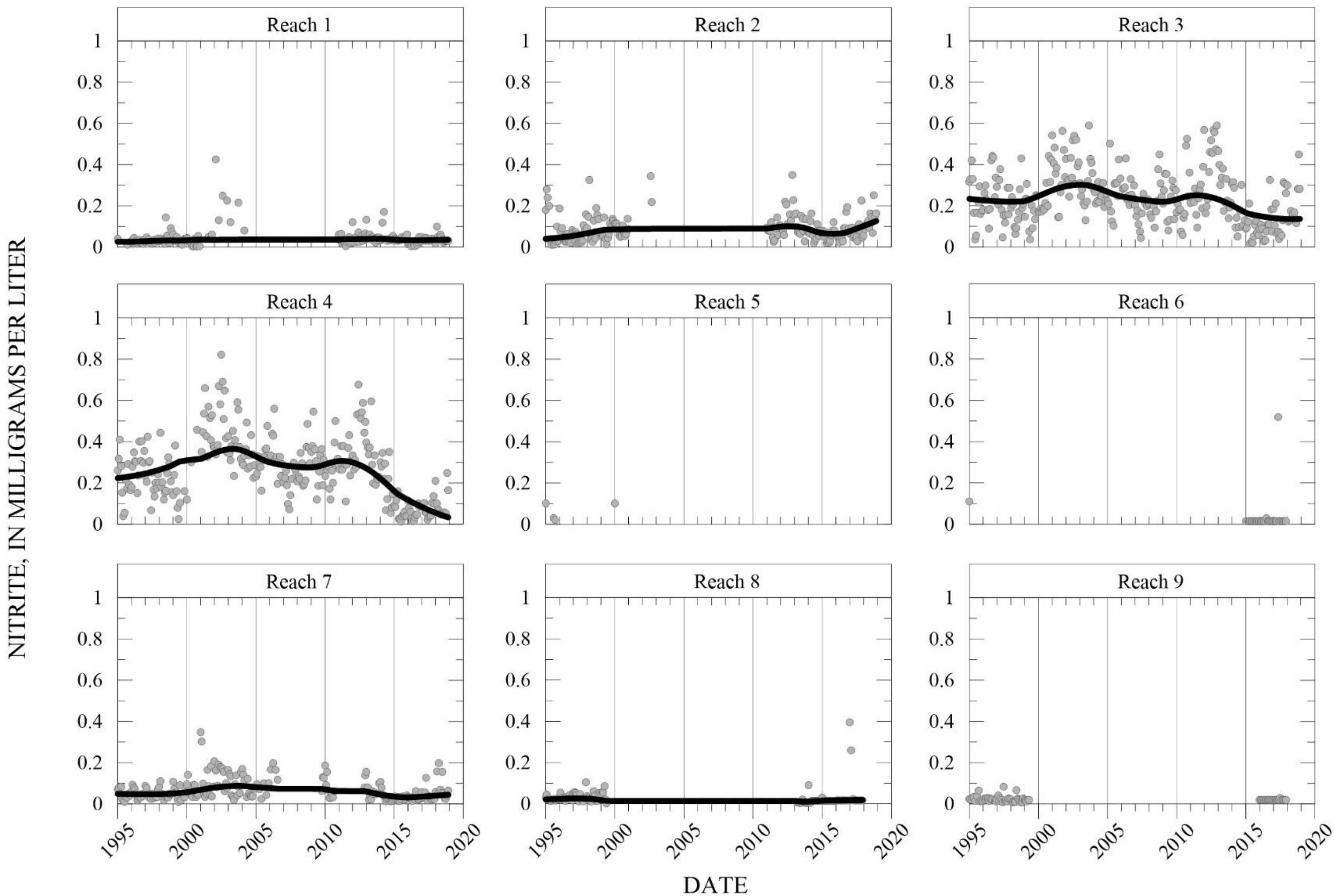

Figure 10-8. South Platte River average monthly nitrite concentrations with LOWESS trend line

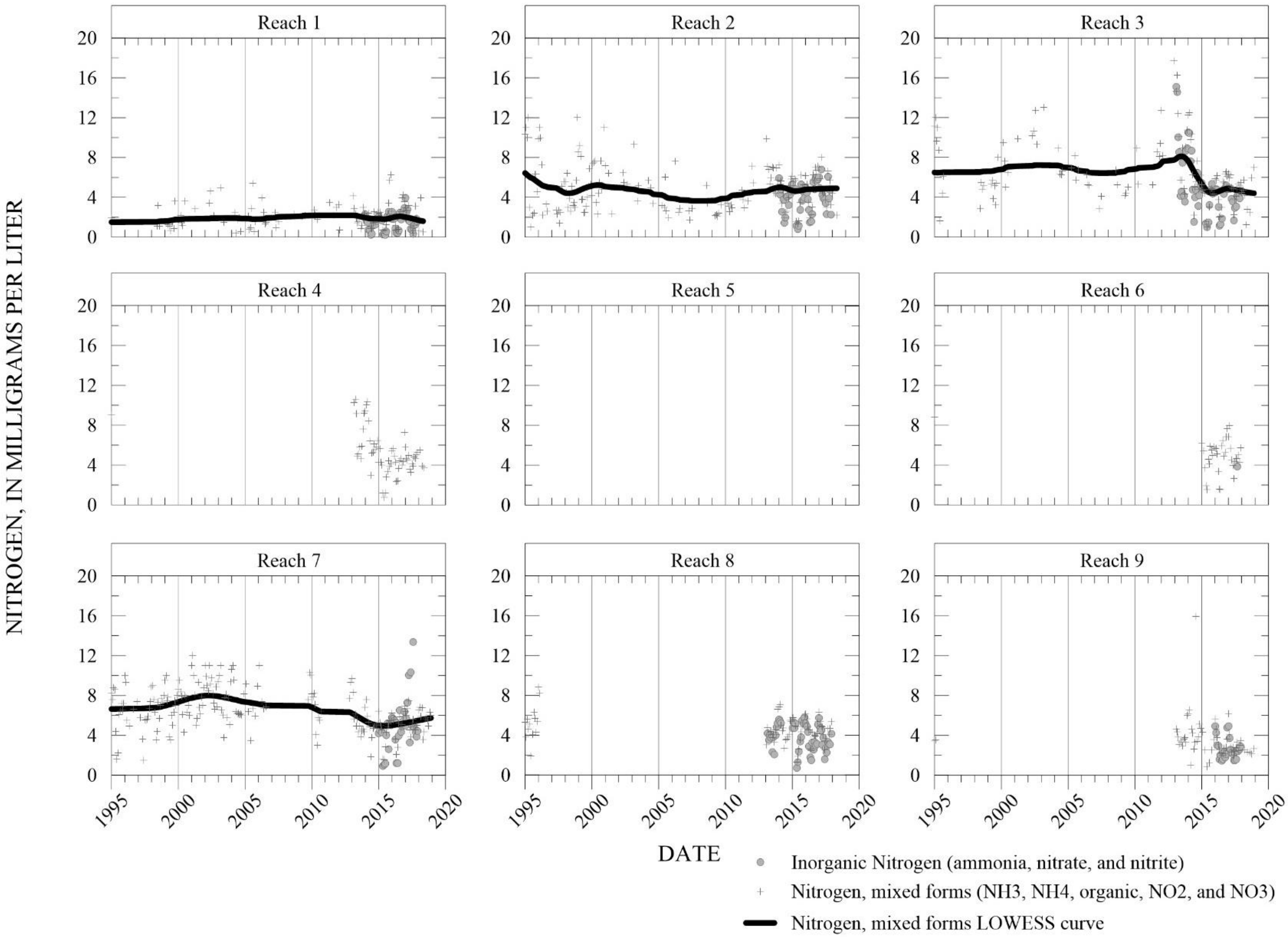

Figure 10-9. South Platte River average monthly nitrogen concentrations with LOWESS trend line

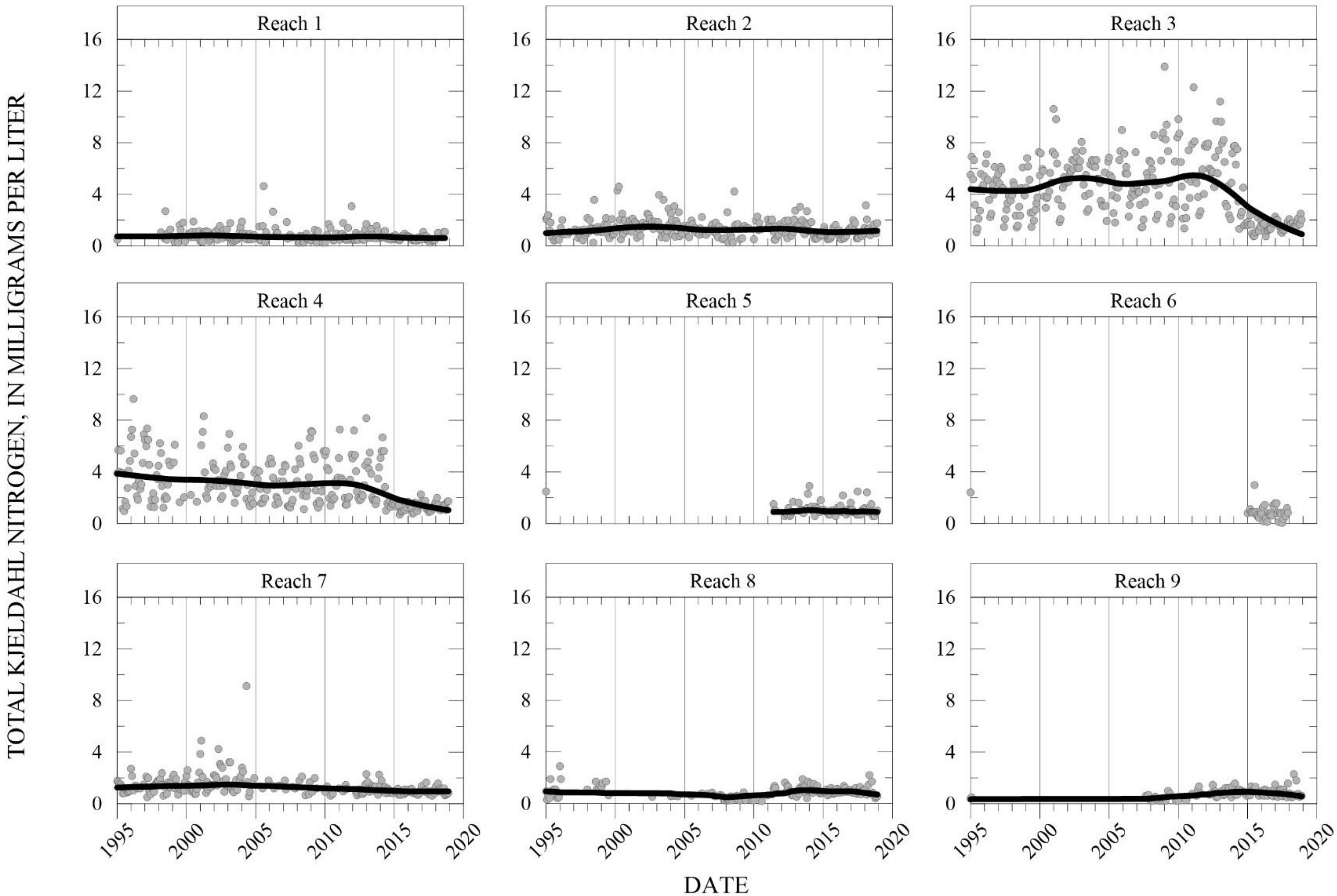

Figure 10-10. South Platte River average monthly Total Kjeldahl Nitrogen concentrations with LOWESS trend line

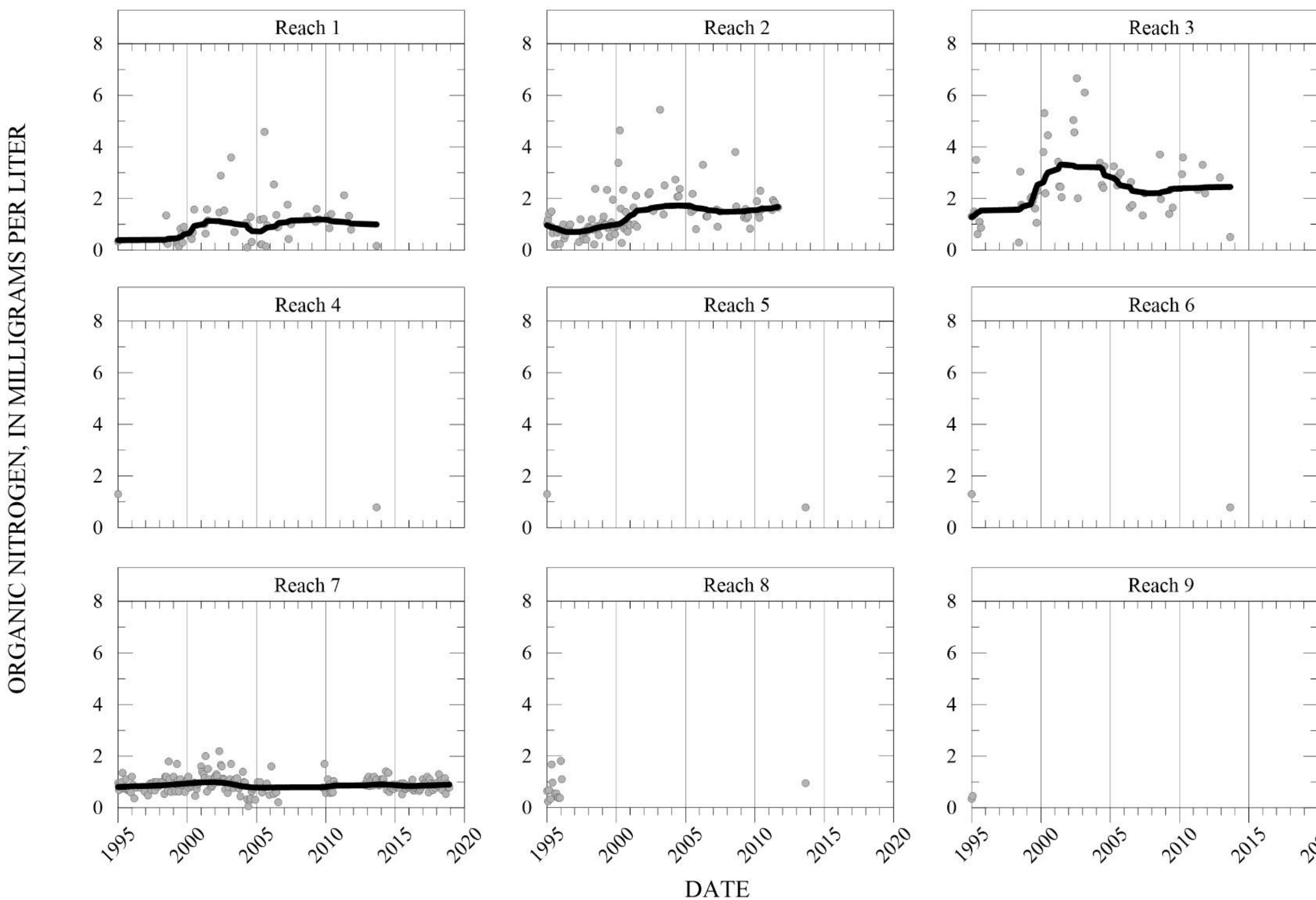

Figure 10-11. South Platte River average monthly organic nitrogen concentrations with LOWESS trend line

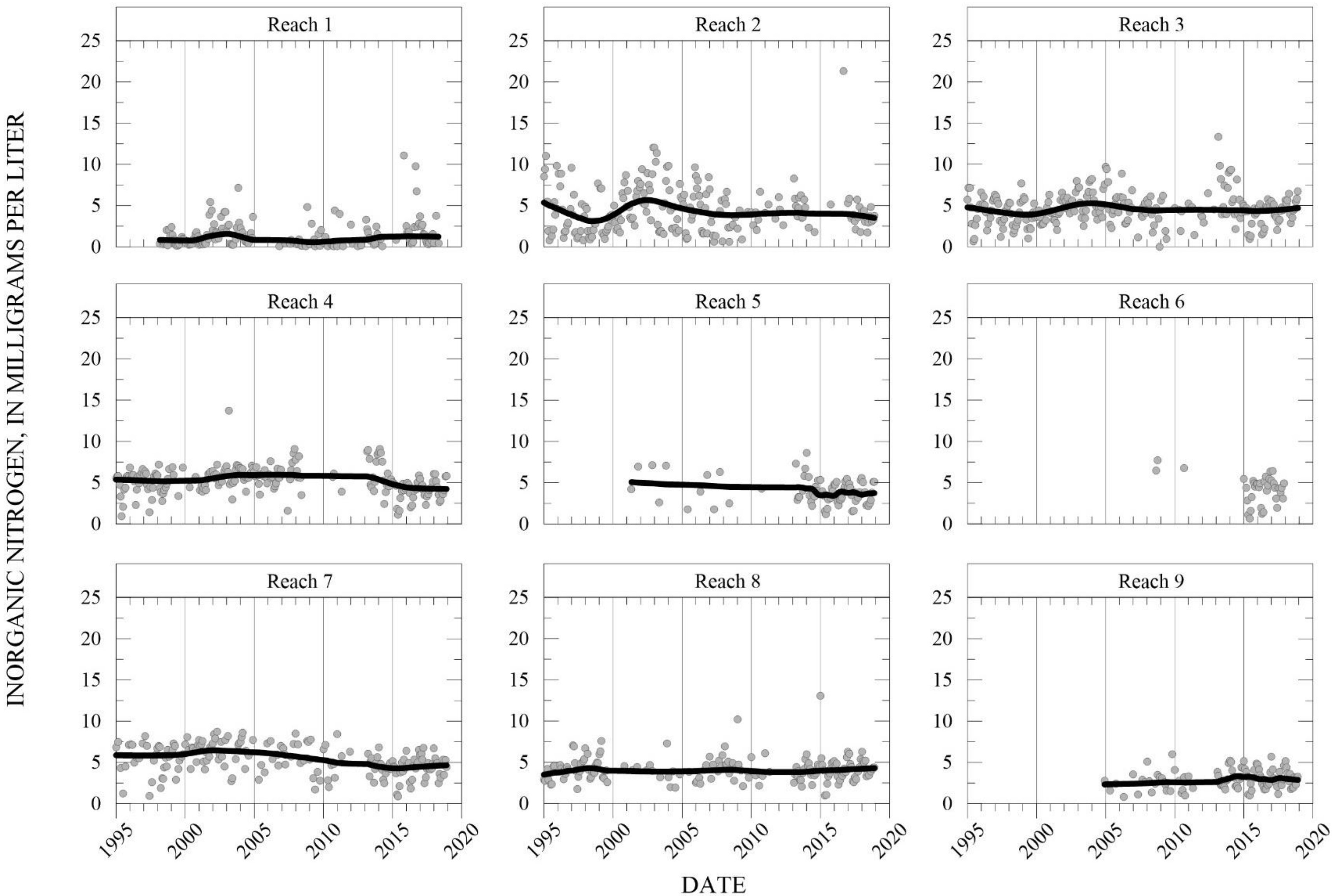

Figure 10-12. South Platte River average monthly inorganic nitrogen concentrations with LOWESS trend line

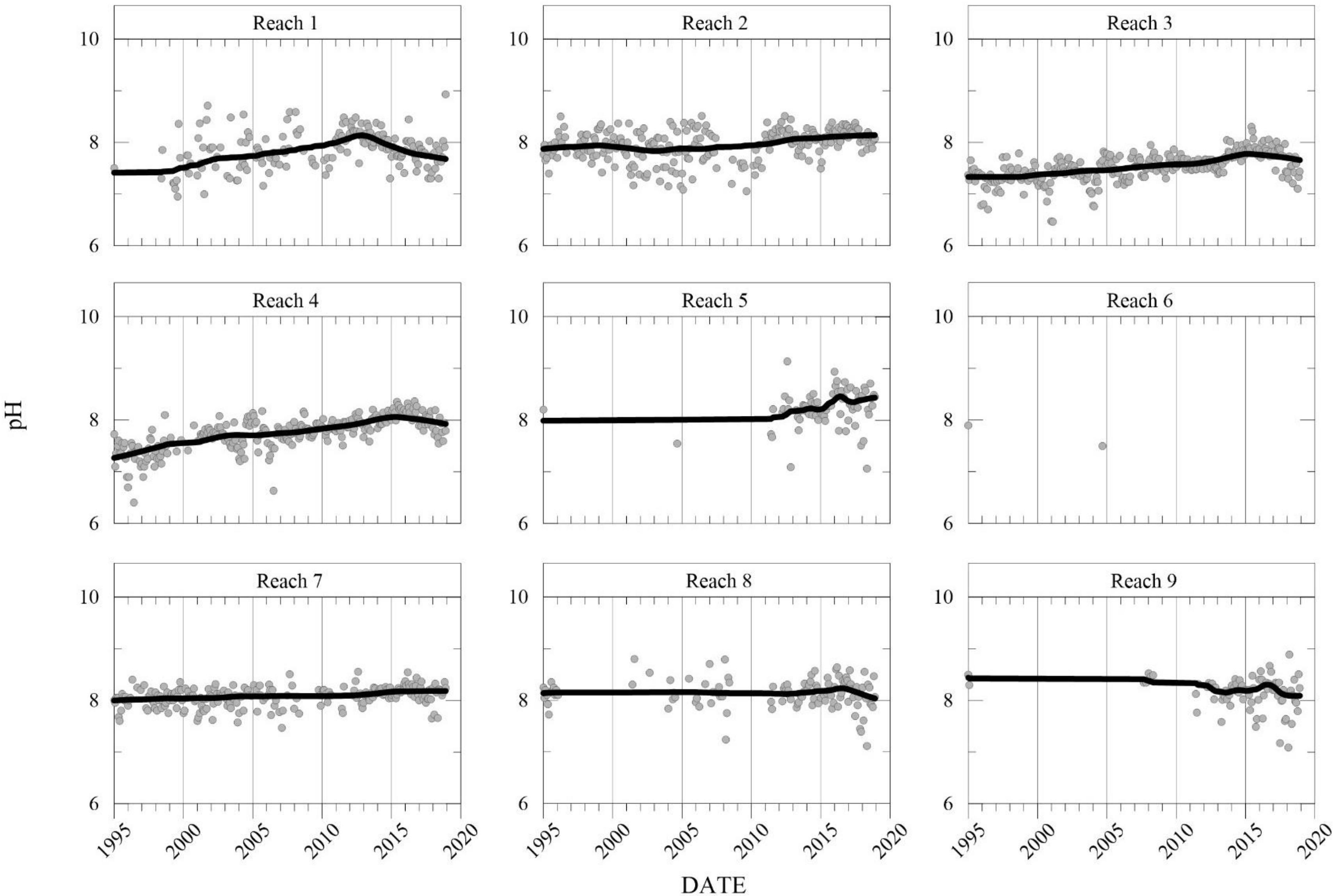

Figure 10-13. South Platte River average monthly pH with LOWESS trend line

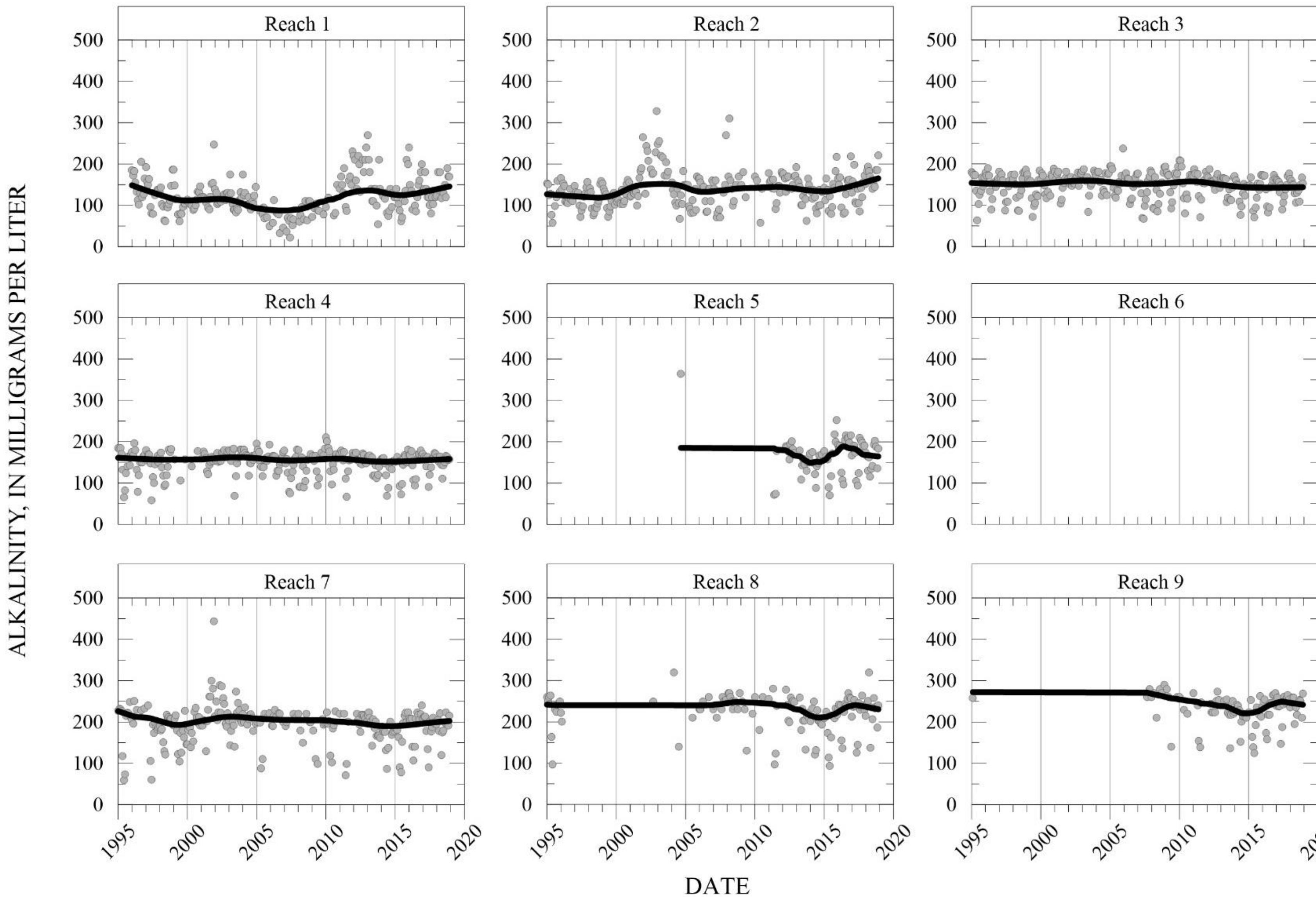

Figure 10-14. South Platte River average monthly alkalinity concentrations with LOWESS trend line

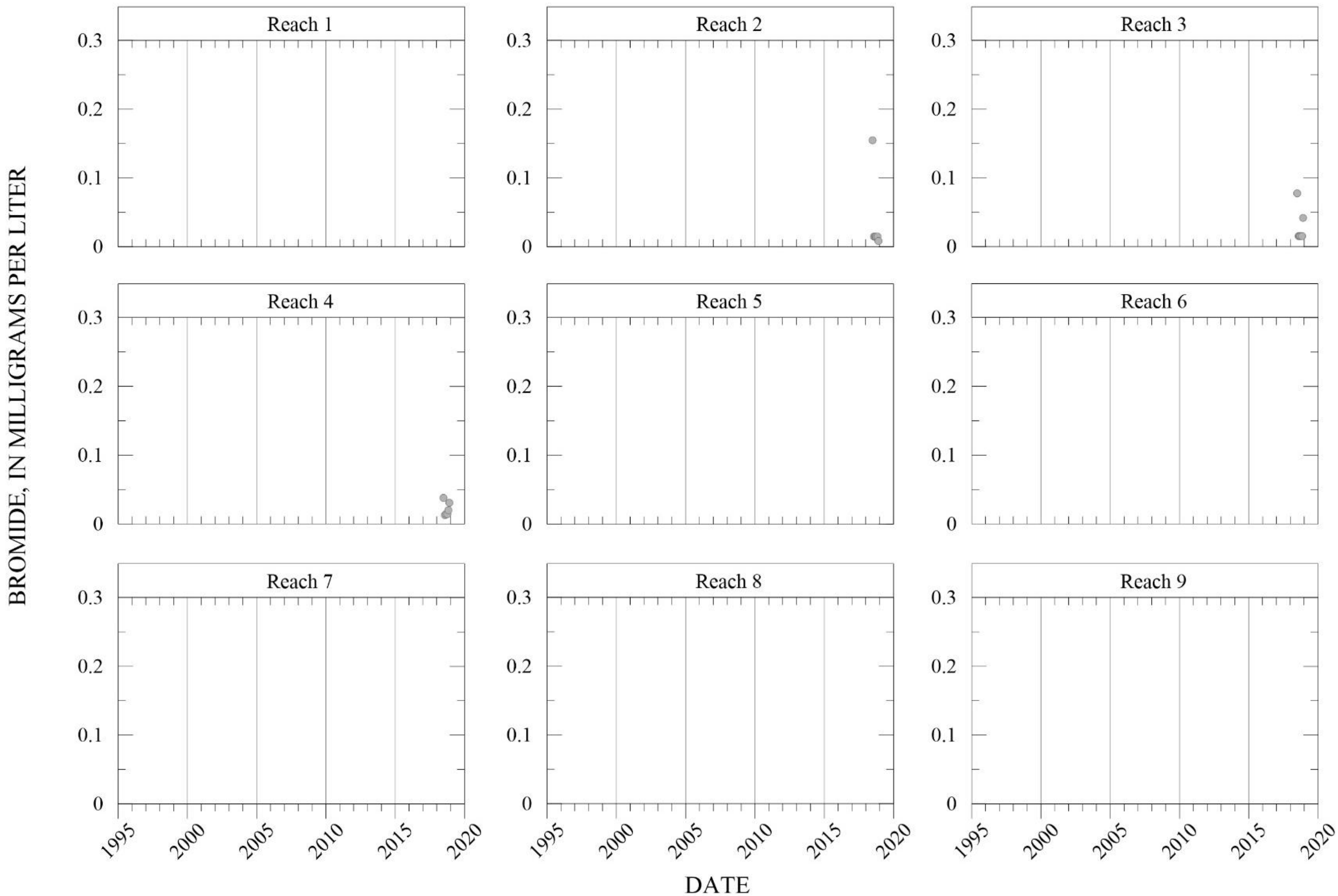

Figure 10-15. South Platte River average monthly bromide concentrations with LOWESS trend line

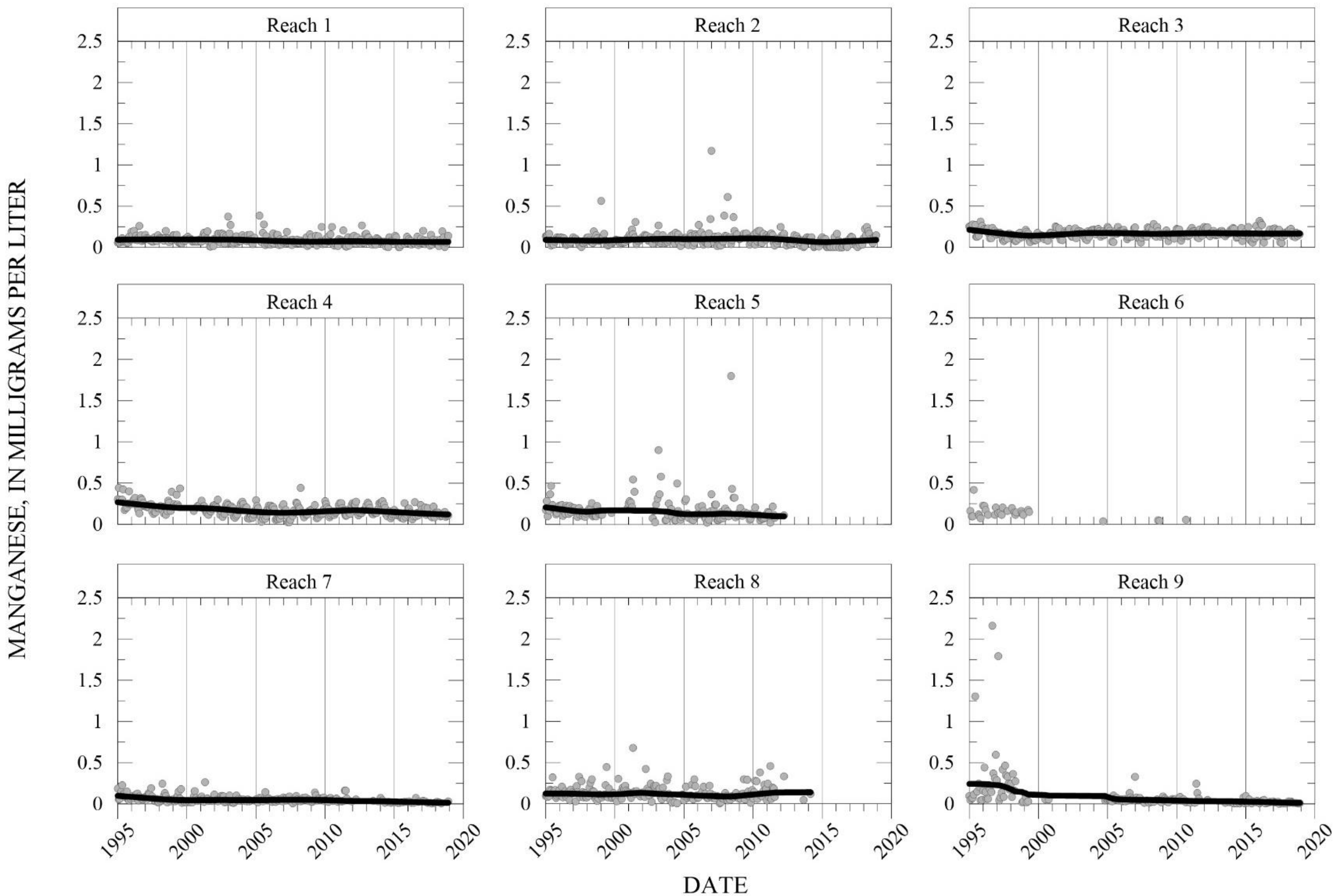

Figure 10-16. South Platte River average monthly manganese concentrations with LOWESS trend line

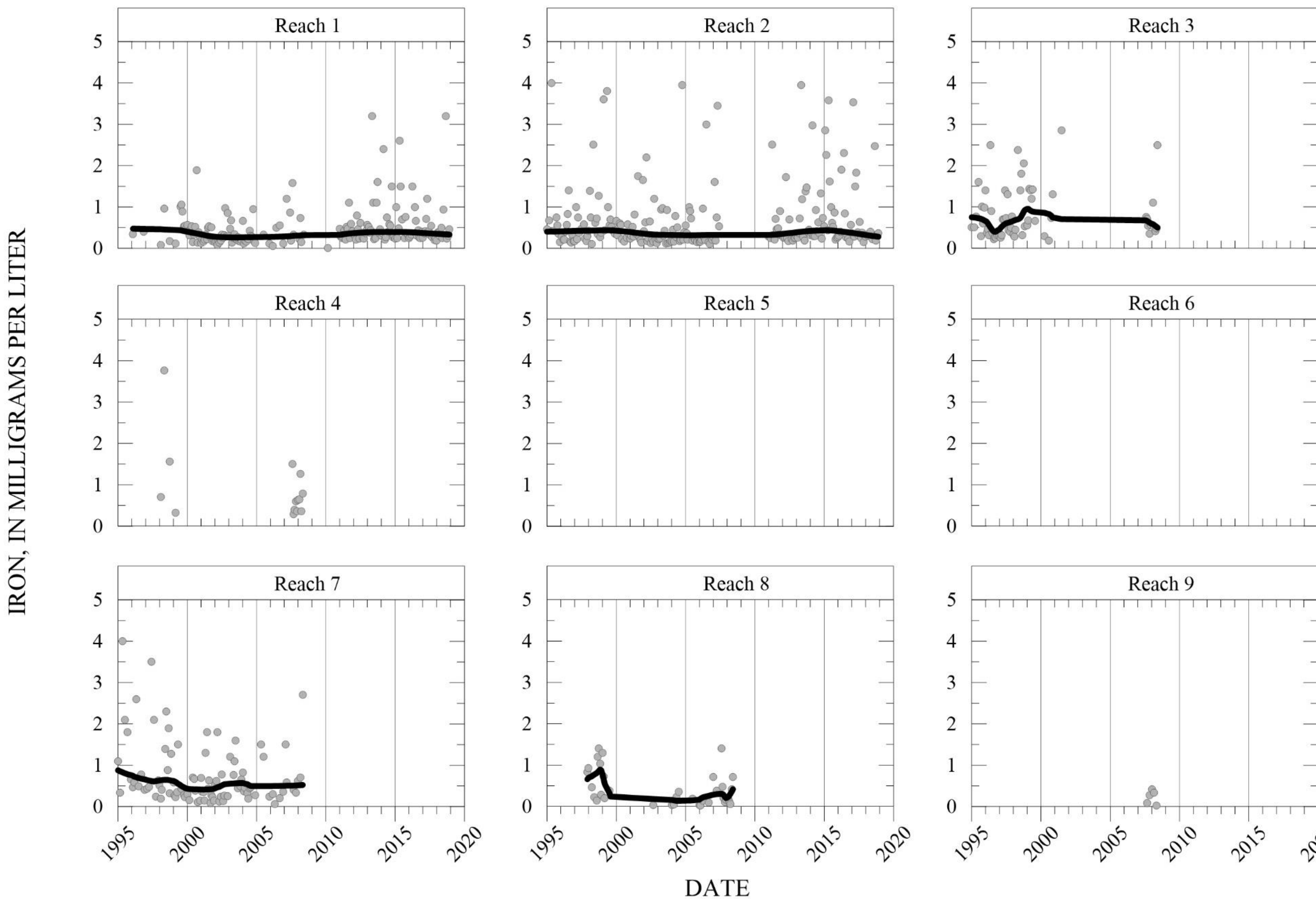

Figure 10-17. South Platte River average monthly iron concentrations with LOWESS trend line

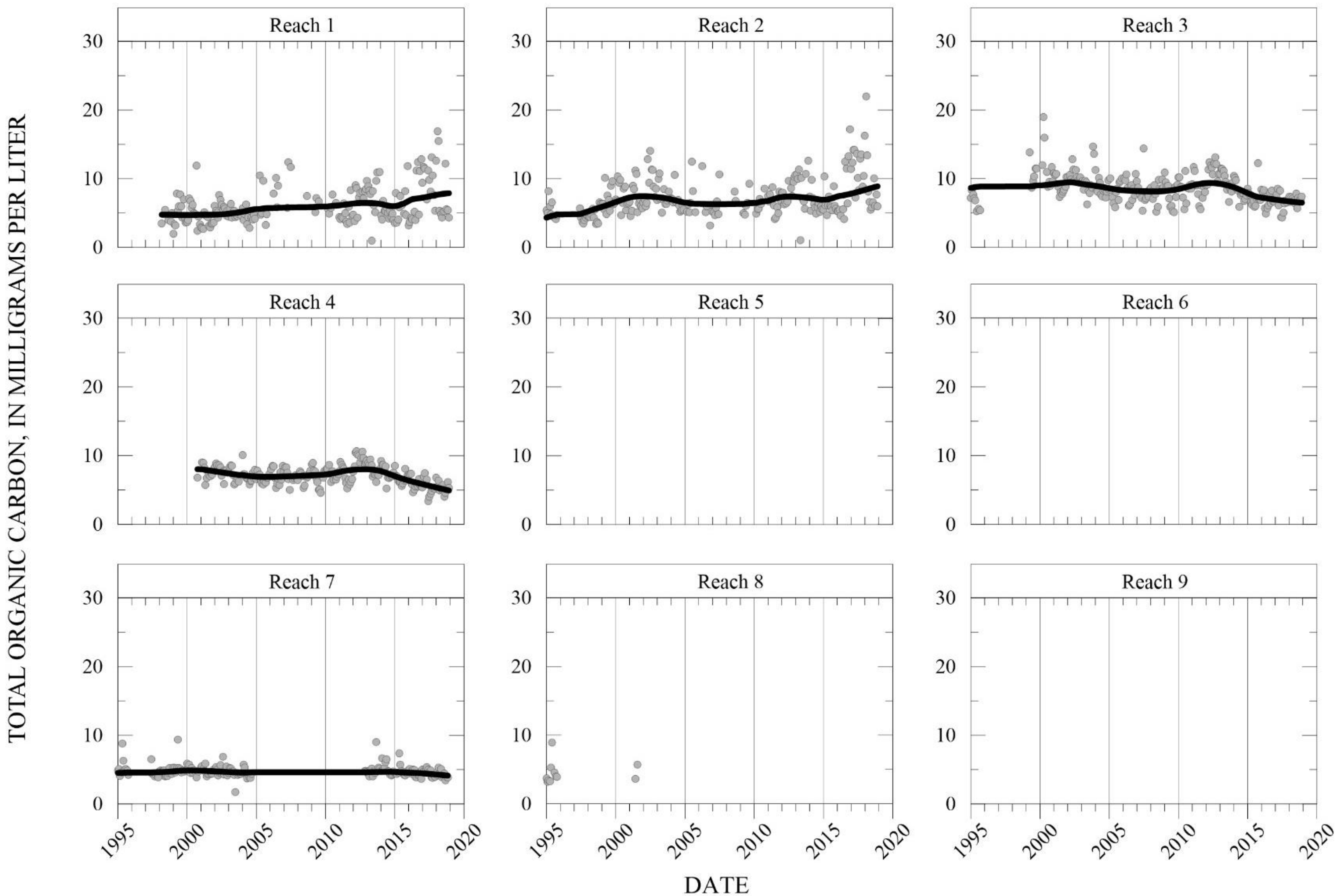

Figure 10-18. South Platte River average monthly total organic carbon concentrations with LOWESS trend line

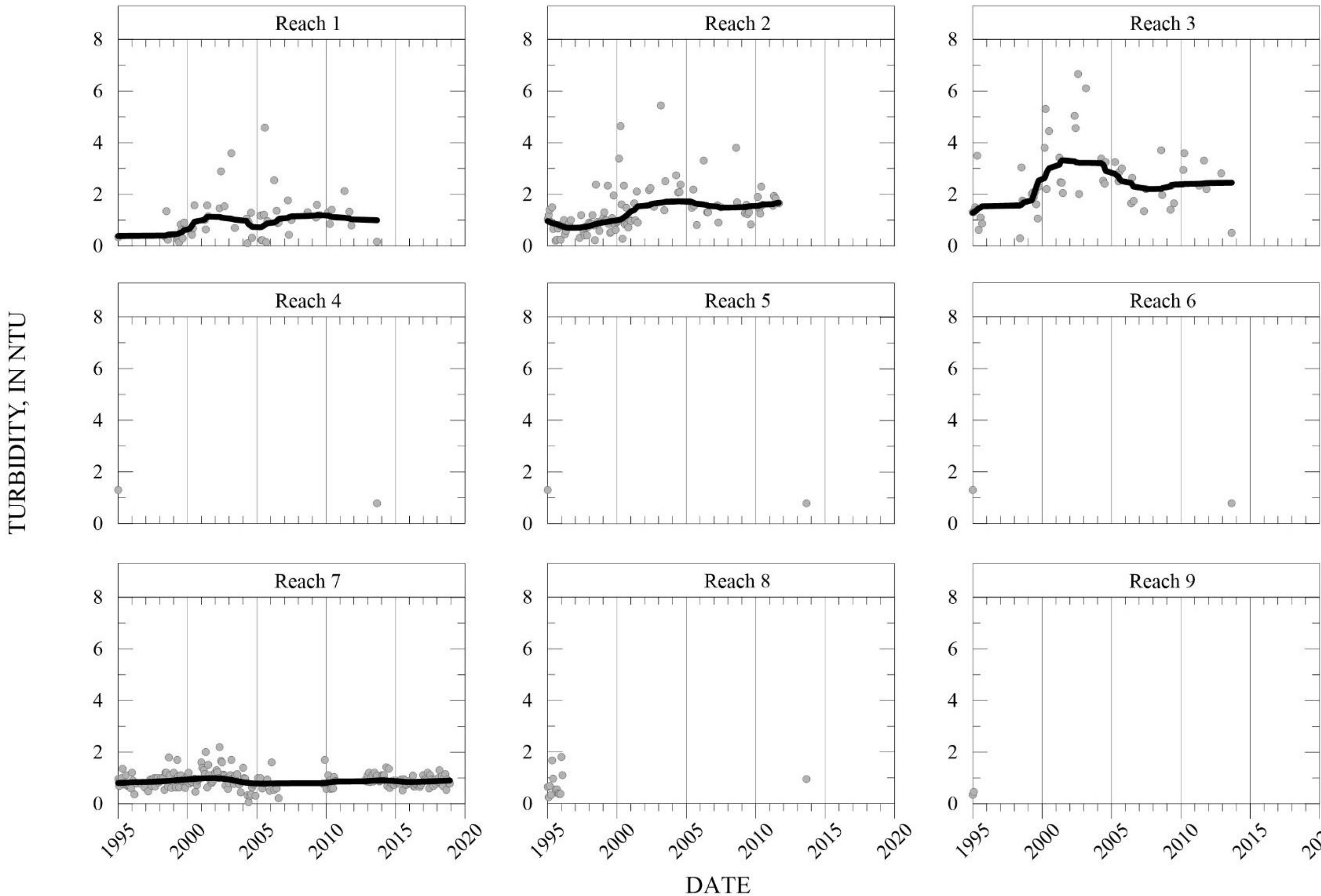

Figure 10-19. South Platte River average monthly turbidity with LOWESS trend line

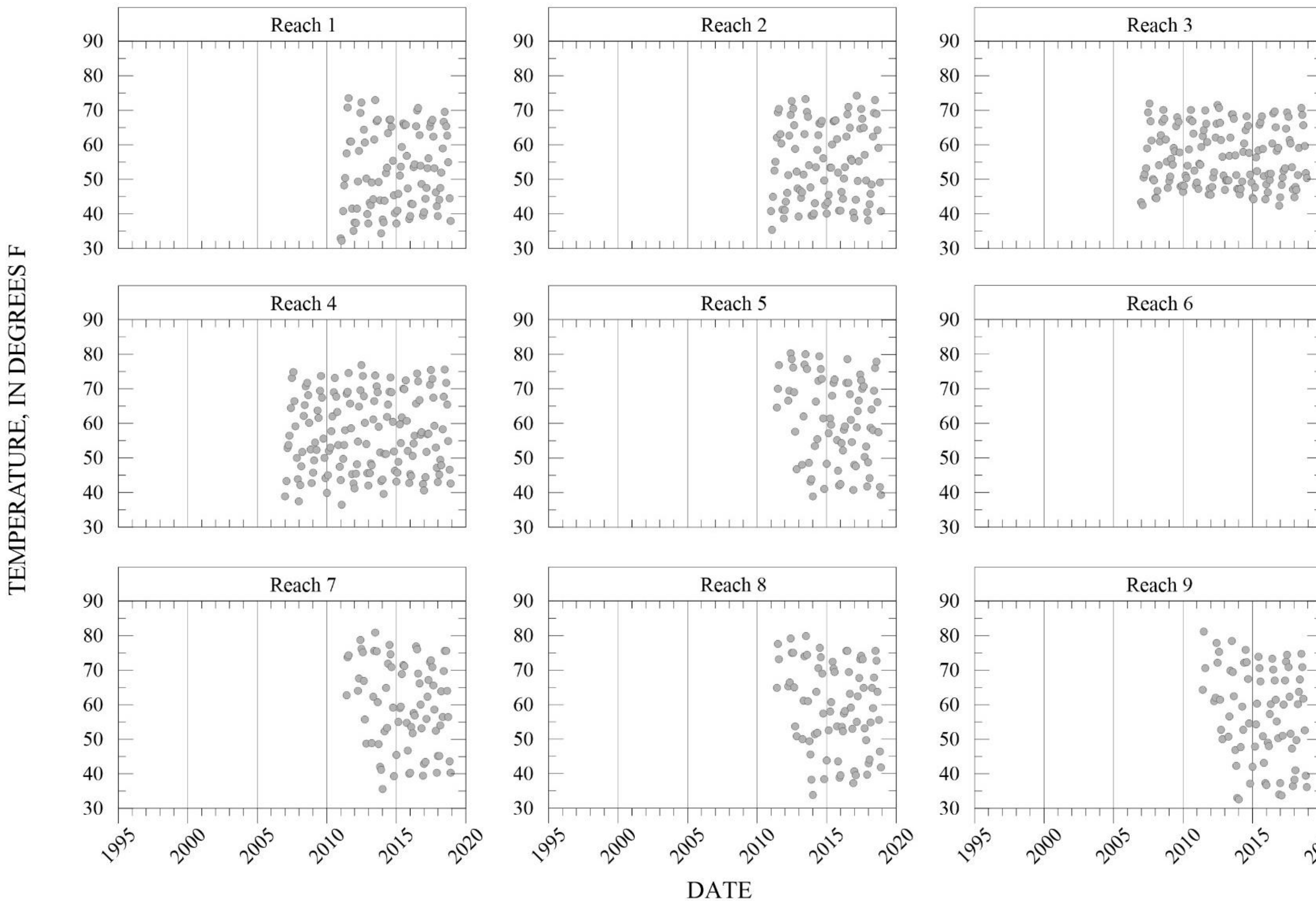

Figure 10-20. South Platte River average monthly temperature

11. SUMMARY

Salinity is a water-quality concern for irrigated agriculture because it can reduce crop yields, reduce crop choices, and destroy soil structure. Municipal, domestic, and industrial water supplies require water treatment prior to using high salinity water due to poor taste, scaling, and hardness. Ecosystems and aquatic species can also be negatively impacted by salinity. This study shows that salinity has been steadily increasing in the upper basin and is at unacceptable levels for many uses in the lower basin. As population growth, development, and water reuse continue to increase, salinity increases are likely to continue.

Field salinity measurements in September 2018 showed that salinity was less than 200 mg/l at Waterton Canyon on the upstream end of the basin. Salinity rapidly increased to 700 mg/l as the river flowed through the Denver Metro area. Concentrations gradually increased downstream of Kersey, exceeding 1,200 mg/l at Sterling and 1,275 mg/l at Julesburg. These sampling results are consistent with the average 2018 concentrations obtained in the analysis presented herein.

The South Platte River can accumulate salts from many sources as it flows through the Basin, including: 1) municipal and industrial wastewater; 2) geologic formations; 3) irrigated agriculture; 4) livestock; 5) oil and gas operations; 6) stormwater runoff; and 7) highway deicing agents. These salt sources occur throughout the basin, some occur continuously, some are sporadic, and the comingling results in constantly changing water quality. Municipal and industrial wastewater are the major contributors in the upper basin and agricultural return flows dominate the lower basin.

Salinity in the upper basin has been increasing since the start of the 1995-2018 study period. The uppermost reaches, 1 and 2, had dramatic rate increases starting in 2005-06. Reaches 3 and 4 had more consistently rising salinity trends. In the upper basin, salinity has increased from less than 400 mg/l in 1995 to about 700 mg/l in 2018. These current salinity levels raise the baseline salinity for water being diverted for agricultural use.

Salinity increases with downstream distance and it is most severe in the lower basin. Although salinity has generally been decreasing since 1995 in the lower basin, which was unexpected given the rising salinity in the upper basin, these trends are somewhat uncertain due to the lack of data.

The lower basin trends appear to be correlated to salinity trends in the Saint Vrain, Big Thompson, and Cache la Poudre tributaries. These tributaries had high salinity concentrations in the 1990's that have generally been decreasing since 1995. However, the 2018 salinity levels in these tributaries were in the 700 to 1,000 mg/l range, which are comparable to or higher than the Denver Metro area concentrations. These tributaries have a large influence on the lower basin because their combined flows are typically higher than the South Platte River flow, which is mostly diverted upstream of these tributary confluences.

In addition to wastewater effluent contributions from front range cities like Boulder, Longmont, Loveland, Fort Collins, and Greeley the tributary watersheds may have geologic salinity sources. Geologic units that formed in marine environments, like the Pierre Shale, outcrop and underlay alluvial deposits from the Denver area to north of Fort Collins. Although the direct exposure of the tributaries to these shale units is limited, groundwater that flows slowly over and through shale units eventually discharges to the alluvial channels and flows downstream to the South Platte River.

Salinity concentrations vary depending on the amount of freshwater in the hydrologic system. Salinity decreases during snowmelt runoff in the spring and during summer storms that generate runoff. This freshwater inflow dilutes the baseline salinity conditions. Salinity rises during summer, fall, and winter months when this freshwater inflow decreases.

Salinity on a given day can greatly exceed monthly averages that mask extreme salinity conditions. These salinity spikes, that can exceed 1,800 mg/l, can occur even during months with runoff and high average flow. The impact of these salinity spikes on irrigated agriculture depends on many factors, including the crop type and growth stage at the time high salinity water is applied.

The South Platte River transports hundreds of thousands of tons of salt each year. In Reach 9, which includes Julesburg, the long-term annual average salt load was estimated to be over 650,000 tons of salt per year. Farmland that is irrigated with 24 inches of 1,000 mg/l water over a season will have 5,520 pounds of salt deposited per acre every year.

Drought conditions exacerbate salinity problems for irrigated agriculture. Irrigation water salinity rises due to the lack of freshwater and there is less water available at a time when crop demand is the highest. Hot and dry conditions increase crop transpiration and evaporation, which eliminates or reduces salt flushing through the root zone. These compounding conditions can lead to reduced crop yields. Multi-year droughts that limit salt leaching can lead to salinity build-up in soils. Areas with unfavorable water and soil chemistry can be susceptible to permanent soil damage if these conditions persist.

Water demands are increasing due to population growth and development. These demands are necessitating that South Platte River water is used multiple times and each use can increase salinity. Water reuse, water efficiency, augmentation plans, exchanges, water-storage projects, and recharge projects are also being used to reduce the water-supply gap. High salinity reduces the suitability of water for most uses and exacerbates the water-supply gap.

This study also included compilation of several water-quality constituents to support evaluation of water-treatment methods for the South Platte Regional Opportunities Water Group (SPROWG) Feasibility Study. Long-term trends for many constituents indicated increasing concentrations over time and with downstream distance. Some constituents lacks sufficient data to effectively evaluate trends and concentrations.

12. DISCUSSION

The South Platte River is heavily used and highly managed. Under normal conditions, mountain streamflow no longer exits the basin. Water is diverted and replaced by wastewater effluent and return flows. Reuse occurs many times as the river flows through the basin. Each use can add chemical constituents, including salts. Although high snowmelt runoff and stormwater runoff may exit the basin, this is largely due to a lack of diversion and storage capacity. Projects in the planning and construction phase intend to increase conveyance and storage capacity to fully utilize these unmanaged flows.

Municipal and industrial water users prefer to obtain low salinity, high-quality river flow as it exits the mountains or water delivered by transbasin diversions. These water supplies can be used with minimal or no treatment. Irrigated agriculture uses wastewater effluent and whatever freshwater flow that can be diverted or stored. Ecological systems and aquatic species depend on the prevailing water-quality and quantity.

Salinity concentrations have historically increased as the river flows through the Denver Metro area. However, in recent years, salinity concentrations are very similar through the heavily populated and industrialized upper basin. This may reflect the effect of using transbasin water diversions to extinction and complete diversion and reuse of the South Platte River and its tributaries. Streamflow is diverted, used, and the unconsumed, higher salinity water is returned. Since wastewater treatment processes are similar, they would be expected to produce similar effluent salinity concentrations. This results in consistent downstream salinity concentrations when wastewater effluent is the dominate water source.

Irrigated agriculture is the dominate water user in the lower basin. River water is diverted and conveyed by the complex network of head gates and canals to farmland across the basin. Since crops consume a portion of the water and leave behind the salts these return flows have higher salinity than the originally diverted water. These return flows can be used over and over, picking up additional salts as it flows back to the river. This process leads to gradually increasing salinity as the river flows through the lower basin.

Wastewater effluent and irrigated agriculture appear to be the largest salinity sources based on the magnitude of these water users. However, as water flows through the basin it can also accumulate salinity from other sources. For example, there are numerous livestock operations in the basin and although they are not allowed to discharge to surface water under normal flow conditions, the land-applied waste can increase groundwater salinity. This higher salinity groundwater can flow into the South Platte River and its tributaries.

Road deicing agents applied in the mountains and throughout the basin contribute salts during the winter months. Although these affected flows may not be used immediately for agricultural use, they may be diverted and stored for future agricultural or municipal use.

Oil and gas operations are not allowed to discharge produced water to surface drainages. Spills should be rare, but if they do occur, they could contribute a pulse of high salinity water to the South Platte River, tributaries, and groundwater.

Salinity can vary greatly even though municipal wastewater, industrial wastewater, geologic, and livestock salinity contributions can be considered continuous and consistent sources. Operational problems in engineered processes can lead to short-term release of higher salinity discharge. A wastewater treatment facility, for example, may occasionally have conditions that result in discharge of higher than normal salinity. Likewise, highway deicing solutions and produced water releases can be short-term, periodic salinity contributors. Salinity spikes and variability reflect the mix of sources in the basin. As population growth and development continue to increase, average salinity and high-salinity pulses are likely to increase.

Water law and water-management practices have been consistently evolving over time. Laws are enacted and their implementation can be sudden or increase over time. Just as the salinity sources mix, evolving water-management practices are constantly mixing and changing as water development continues to expand. For example, using transbasin water diversions to extinction was enacted in 1972 and its implementation increased over time. On January 1, 2006, wells without augmentation plans were prohibited from pumping. This has triggered activity for exchanges, augmentation plans, substitute water supplies, and water-management replacement. The complex administration of water rights can result in river calls for South Platte River water on nearly every day of the year. Implementation of water law and water decrees has fundamentally changed the hydrologic system. Streamflow patterns have changed, groundwater levels have risen, groundwater flow paths have been altered, and the magnitude and distribution of salt loads has changed.

Due to constantly changing water law and water management, attributing salinity trends to individual laws or practices is likely not possible. Rather, salinity conditions in the South Platte Basin are due to a complicated mix of many natural and man-made factors.

13. RECOMMENDATIONS

This high-level analysis provides an overall understanding of salinity within the South Platte Basin's hydrologic system. Hopefully, this leads to greater awareness of salinity and its importance for irrigated agriculture and our water resources. Unknowns remain and additional monitoring and analysis will clarify the path forward. Ultimately, the goal is to identify water-management practices that will protect all water users from salinity's detrimental effects. The many salinity sources and diverse water users will necessitate contributions and collaboration from many government agencies, conservation districts, water suppliers, and water users. The following recommendations for monitoring and analyses will provide the information needed to guide development of appropriate management strategies.

1) **Monitoring**
   a) Daily salinity and flow monitoring for discharging facilities. Monthly or bi-weekly monitoring is insufficient for characterizing salt loading and identifying approaches for reducing salt loading.
   b) Daily salinity monitoring of rivers, streams, irrigation canals, and groundwater to characterize seasonal and streamflow changes throughout the basin. Consistent basin-wide monitoring will assist in identifying high salinity source areas, defining salt loading, and characterizing variability that can lead to improved management practices.

c) Real-time salinity monitoring for individual irrigators. Electrical conductivity is a cheap and easy measurement that can be obtained continuously or on-demand. Since salinity can vary greatly from day to day, this monitoring would inform irrigators about the salt loads applied to their crops and soils.

d) Soil salinity monitoring will provide current conditions and repeat measurements will indicate how much salt is being stored and released from agricultural soils.

2) Analyses

a) Characterize salinity in municipal and industrial wastewater effluent to assess its role in salinity loading. Daily electrical-conductivity monitoring and weekly basic water-quality analyses to determine salt compounds.

b) Characterize salinity concentrations and loading for groundwater and return flows. This will improve the understanding of the salinity hazard for groundwater users and the role of return flow in the lower basin's salinity.

c) Identify specific salts and water-quality constituents that can damage soils and reduce crop yields. These analyses would identify specific hazards to soils, crops, and water supplies. This would support and inform water treatment needs and water management practices

d) Develop a basin-wide "salt balance" that describes and quantifies how salts are moving into and out of the South Platte Basin.

3) Water management

It is recommended that salinity be considered explicitly in South Platte Basin water-management policies and projects. Improved practices can be further developed based on the information gained from the recommended monitoring and analysis. The following are examples of decision-making processes that can lead to improved salinity management.

a) Evaluate the need for salinity discharge limits for municipal and industrial wastewater effluent.

b) Evaluate water-treatment strategies and water management approaches that reduce salinity in water deliveries to end-users.

c) Evaluate management and mitigation controls for the largest salinity contributors.

Salinity can have many negative effects on our water supply including exacerbating the water-supply gap. The foundation for understanding and managing salinity is data and analysis. These recommendations focus on this fundamental need. As more data are collected and analyzed the problems will become more defined and solutions will be developed.

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APPENDIX A
STREAMFLOW STATISTICS

A-1 Daily and Monthly Flow Graphs

A-2 Boxplots

A-3 Summary Statistic Tables

Table A-1. Stream Gages Used in Analyses

USGS Identification number	Colorado Department of Water Resources Identifier	Site Name	Short Name	River Reach In This Study	Latitude	Longitude
6711565	PLAENGCO	South Platte River at Englewood, CO	SPR at Englewood	1	39.6650	-105.00
6714000	PLADENCO	South Platte River at Denver, CO	SPR at Denver	2	39.7597	-105.00
6720500	PLAHENCO	South Platte River at Henderson, CO	SPR at Henderson	3	39.9219	-104.87
6721000	PLALUPCO	South Platte River at Fort Lupton, CO	SPR at Fort Lupton	4	40.1161	-104.82
6731000	SVCPLACO	St. Vrain Creek at Mouth, Near Platteville, CO	SVR nr Platteville	Saint Vrain Creek*	40.2580	-104.88
--	BIGLASCO	Big Thompson River Near La Salle, CO	BTR at La Salle	Big Thompson River*	40.3500	-104.78
6752500	CLAGRECO	Cache La Poudre River Near Greeley, CO	CLPR nr Greeley	Cache La Poudre River	40.4178	-104.64
6754000	PLAKERCO	South Platte River Near Kersey, CO	SPR nr Kersey	7	40.4122	-104.56
6759910	PLABALCO	South Platte River at Cooper Bridge Near Balzac	SPR at Balzac	8	40.4066	-103.47
6764000	PLAJURCO	South Platte River at Julesburg, CO	SPR at Julesburg	9	40.9750	-102.25

* No South Platte River stream gages in reaches 5 and 6

APPENDIX A-1
DAILY AND MONTHLY STREAMFLOW

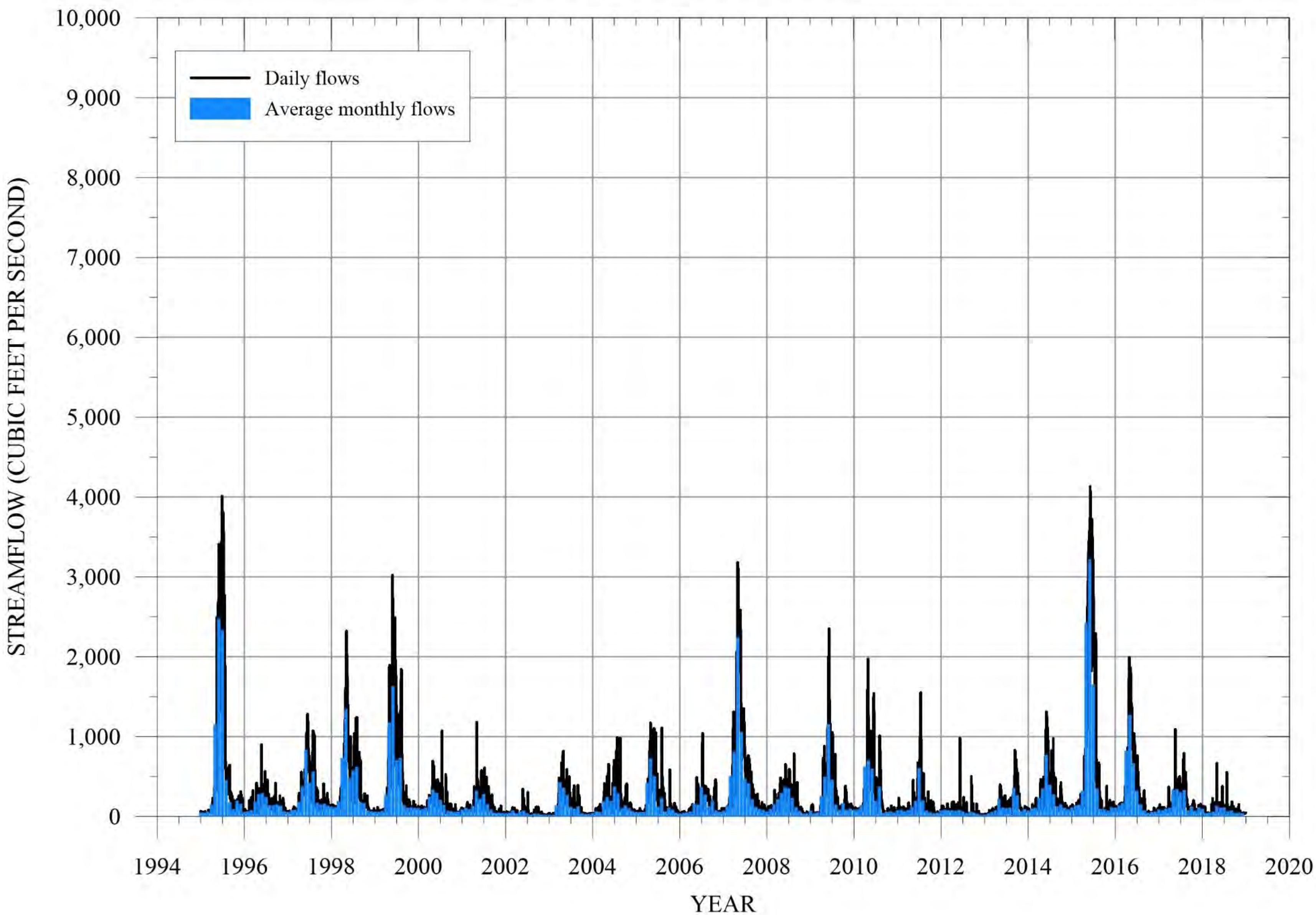


Figure A-1. Streamflow at USGS 06711565, South Platte River at Englewood, Reach 1

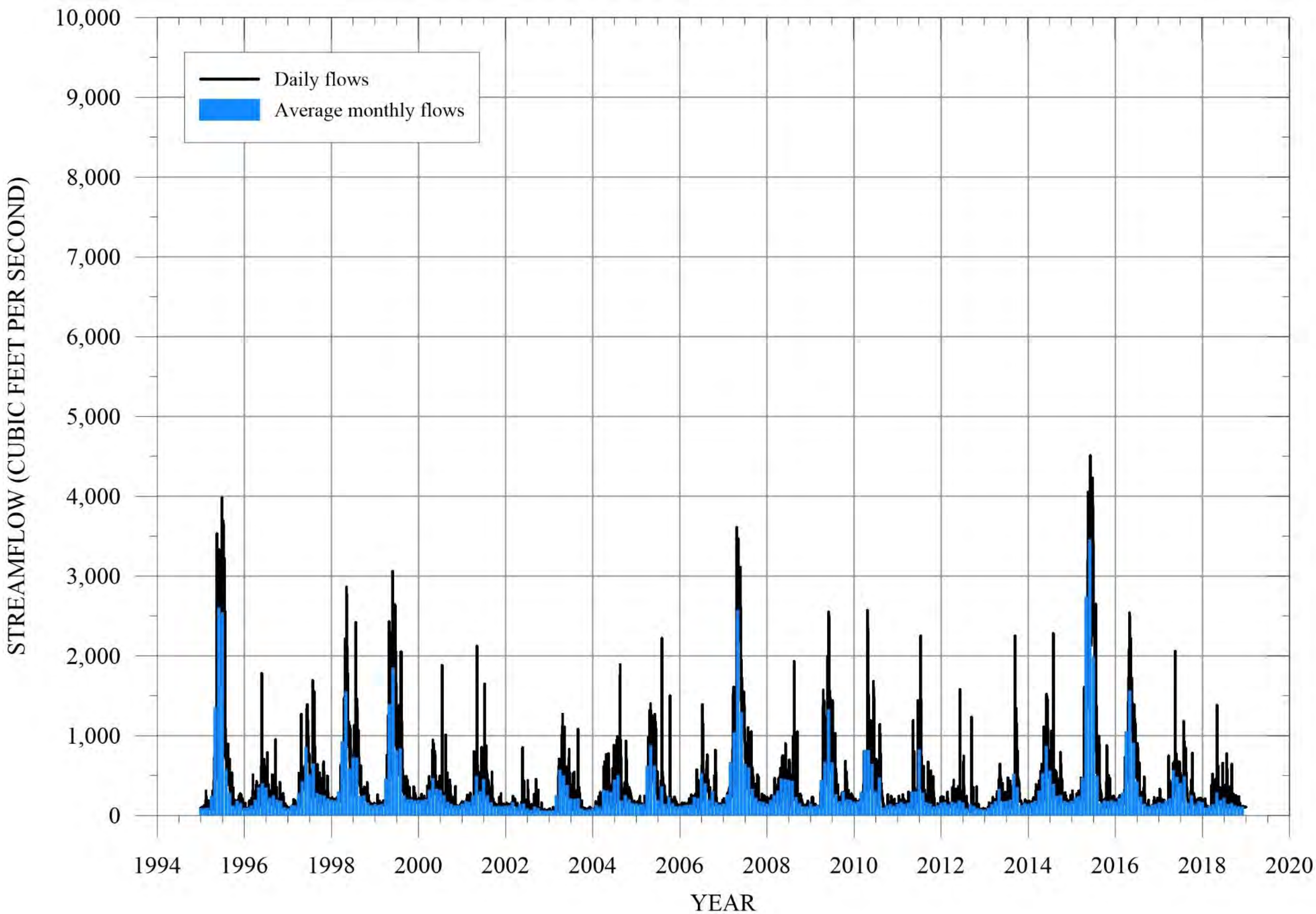


Figure A-2. Streamflow at USGS 06714000, South Platte River at Denver, Reach 2

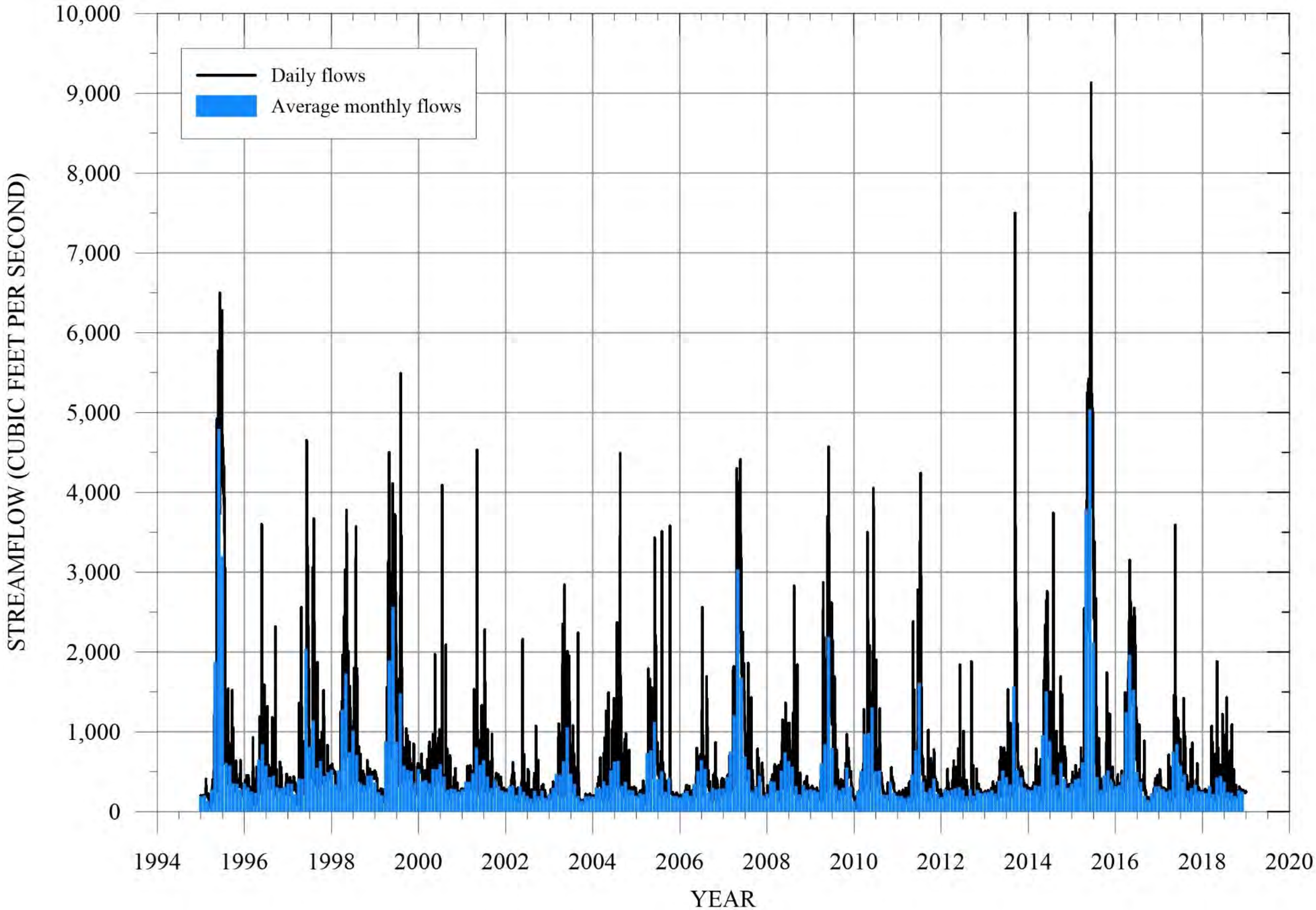


Figure A-3. Streamflow at USGS 06720500, South Platte River at Henderson, Reach 3

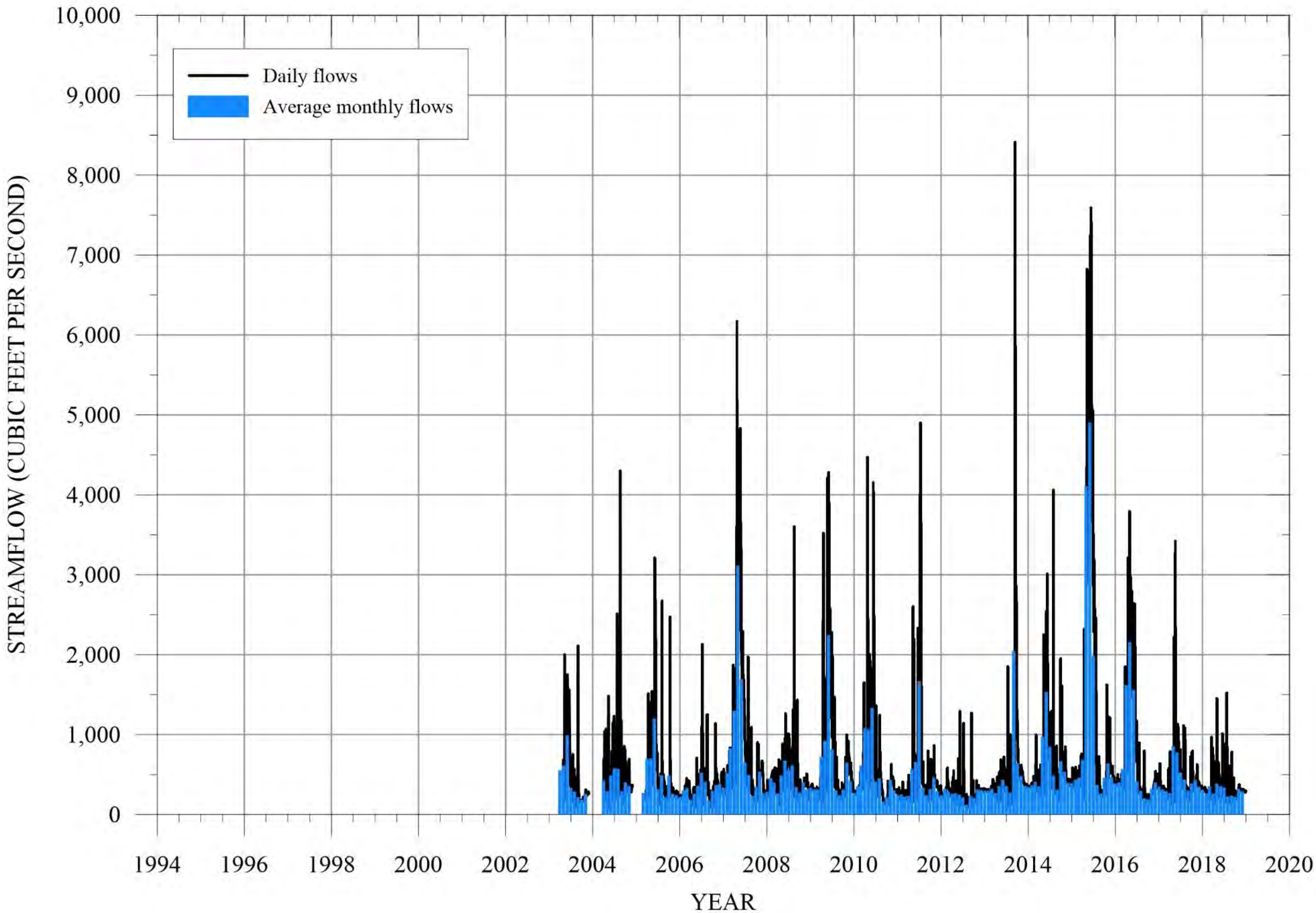


Figure A-4. Streamflow at USGS 06721000, South Platte River at Fort Lupton, Reach 4

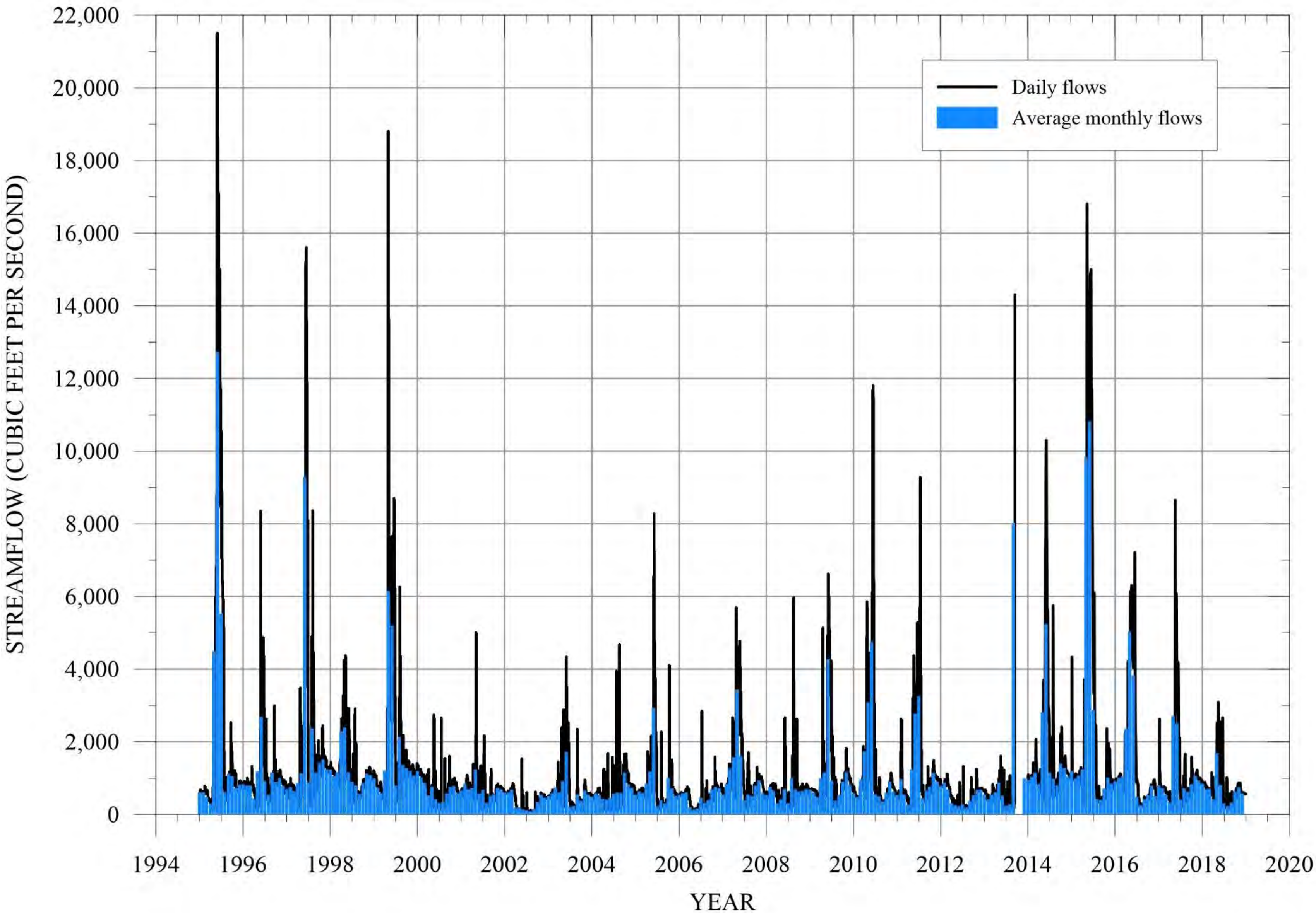


Figure A-5. Streamflow at USGS 06754000, South Platte River at Kersey, Reach 7

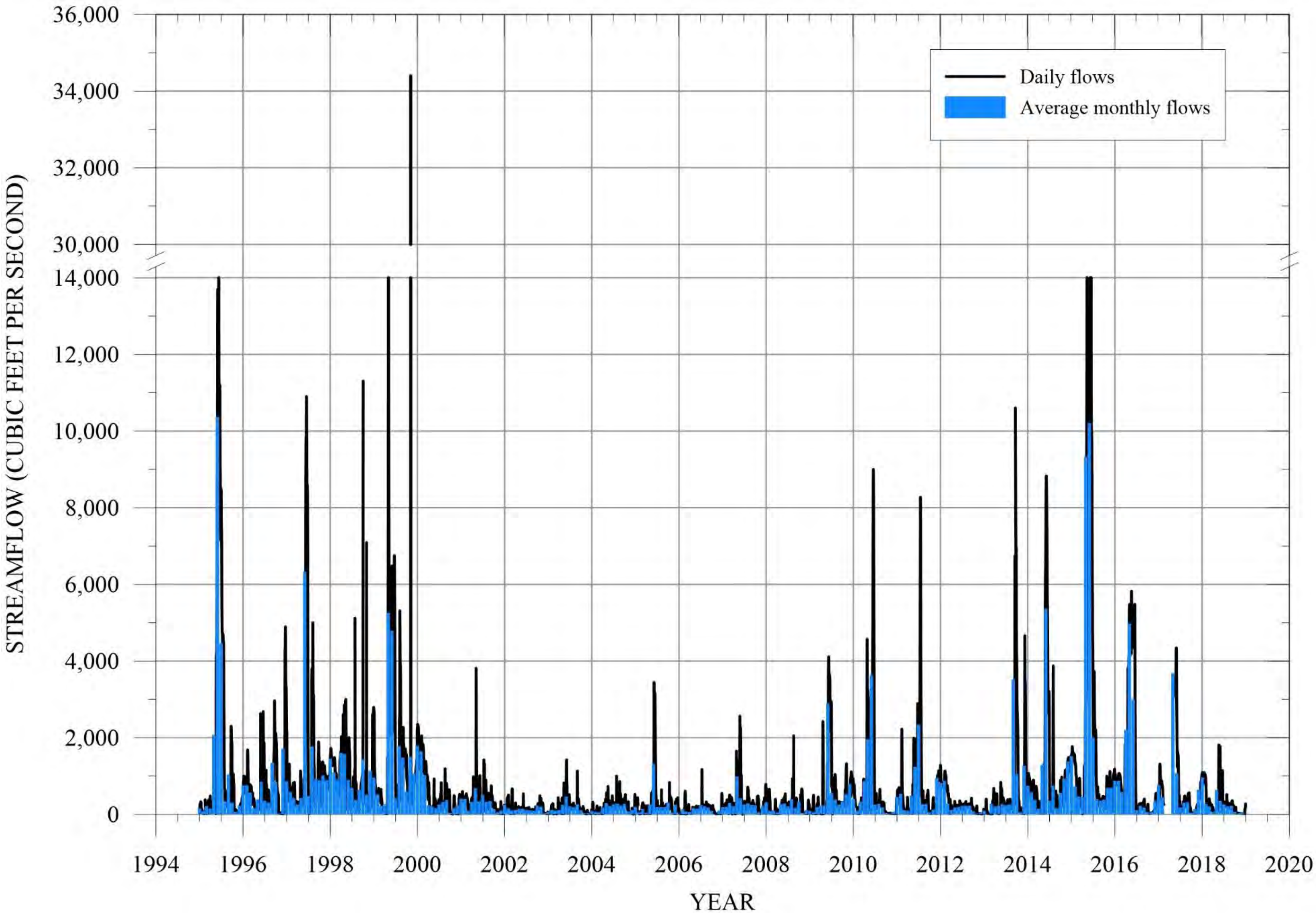


Figure A-6. Streamflow at USGS 06759910, South Platte River at Balzac, Reach 8

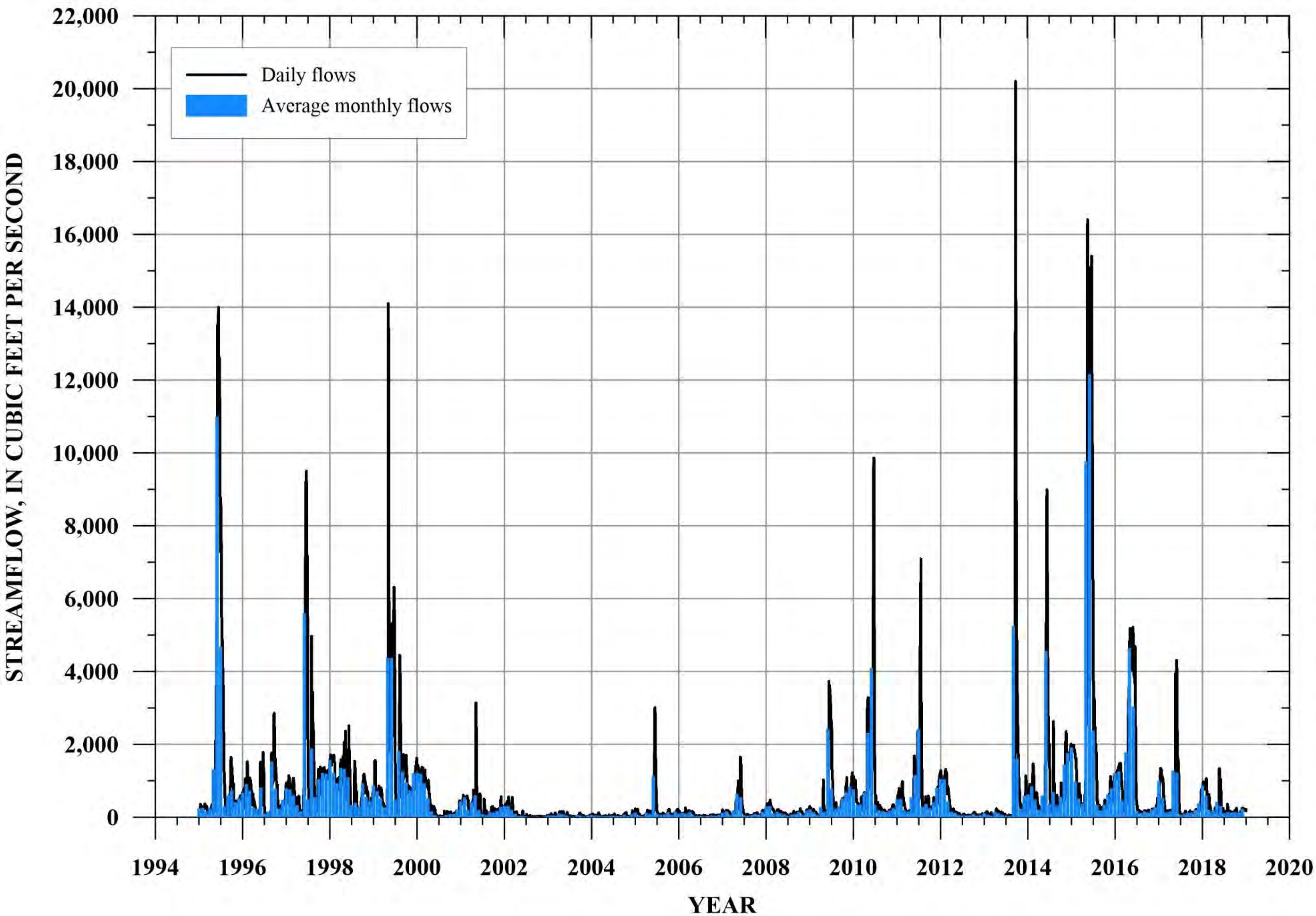


Figure A-8. Streamflow at USGS 06764000, South Platte River at Julesburg, Reach 9

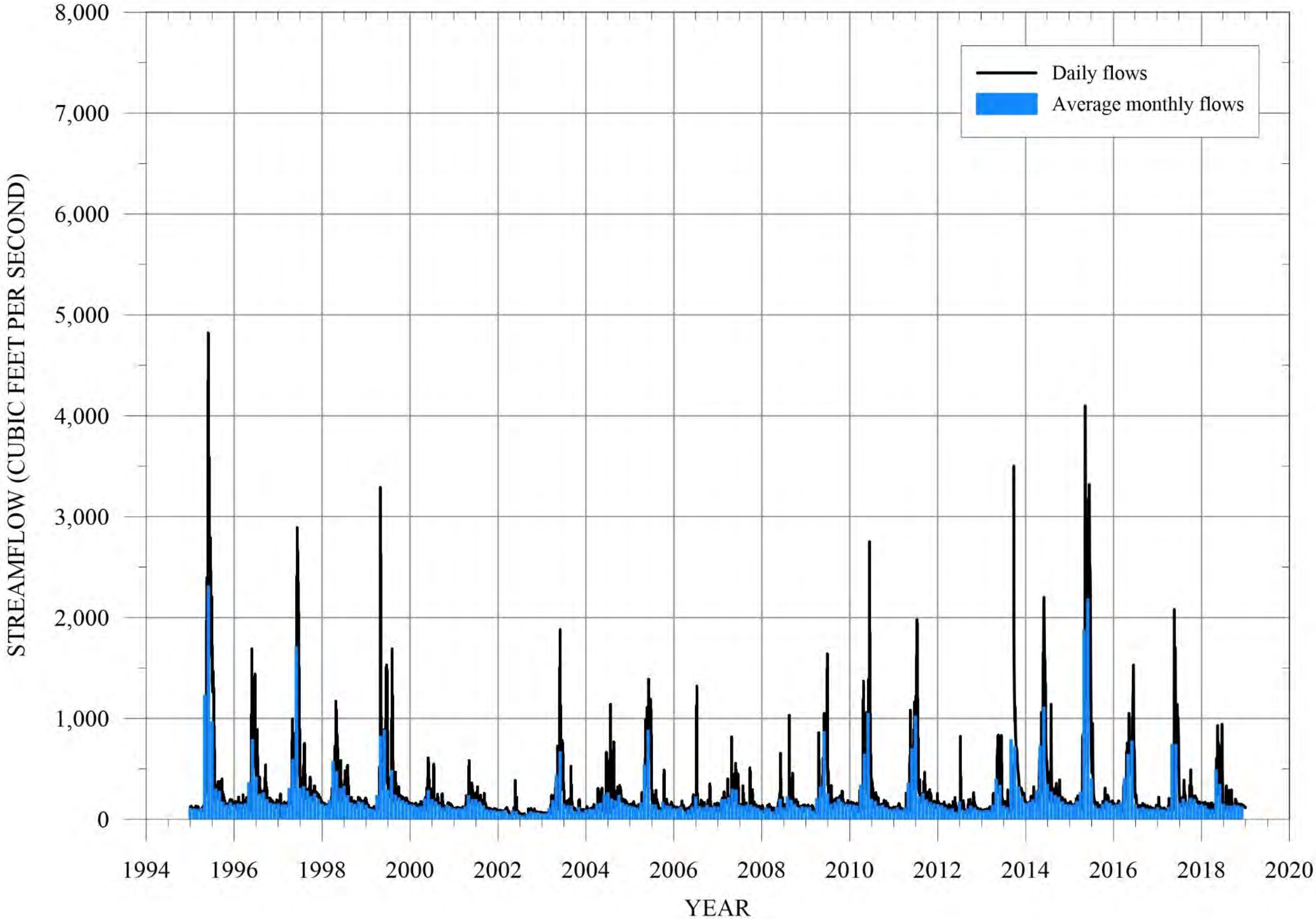


Figure A-9. Streamflow at USGS 06731000, Saint Vrain Creek near Platteville

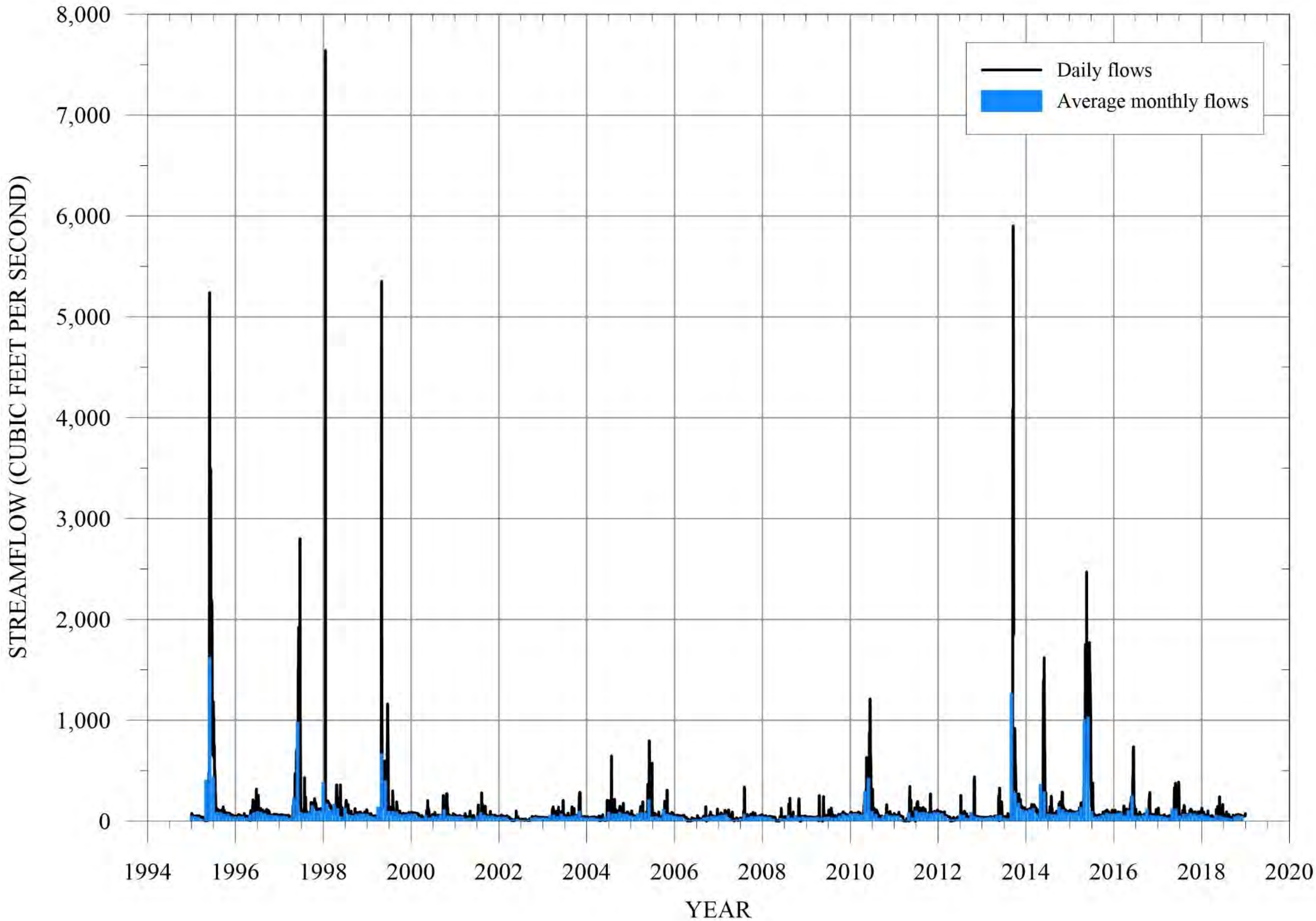


Figure A-10. Streamflow at DWR BIGLASCO, Big Thompson River near La Salle

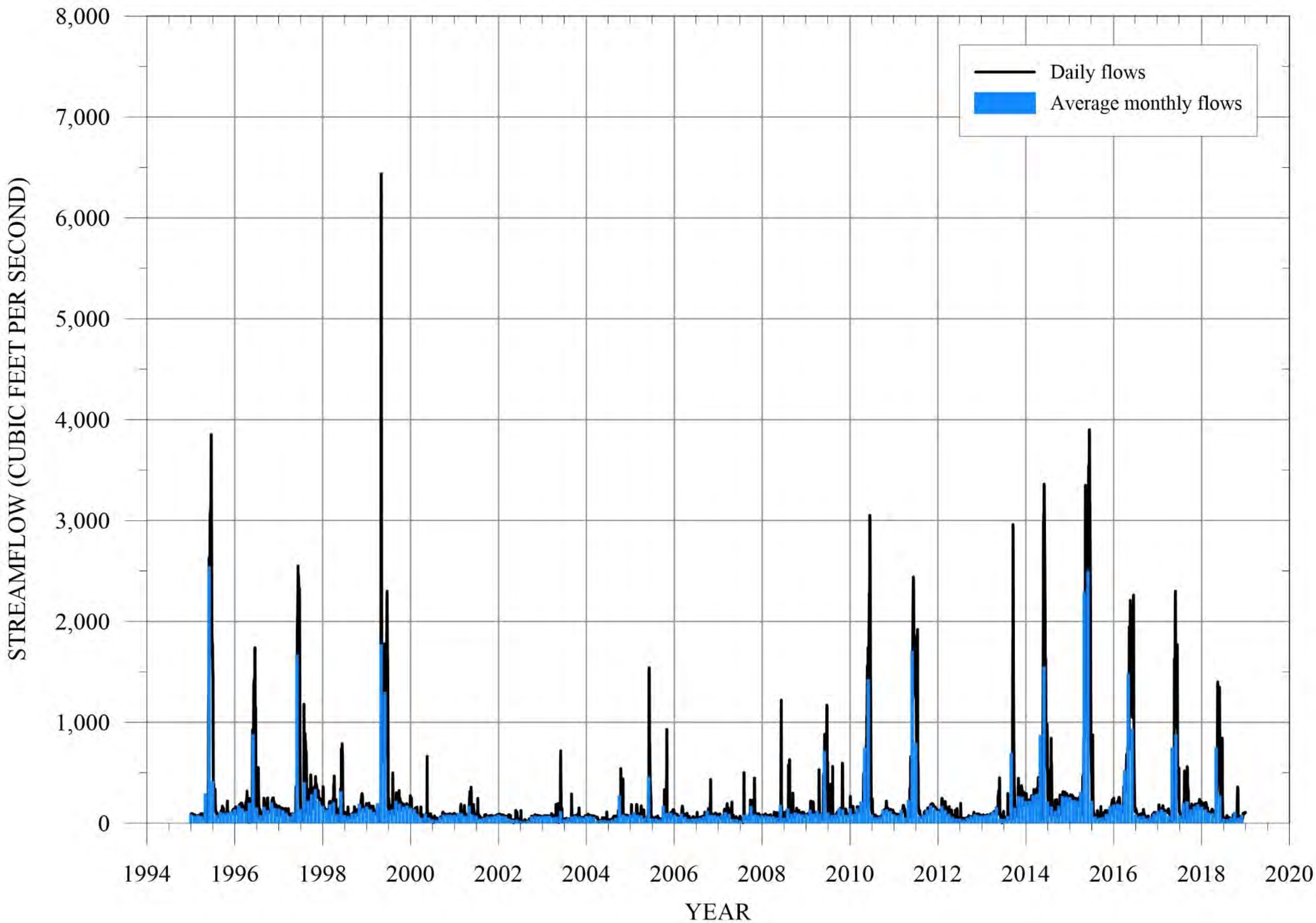
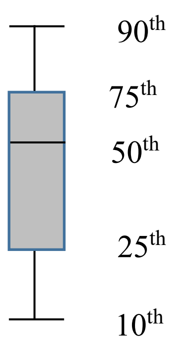


Figure A-11. Streamflow at USGS 06752500, Cache la Poudre River near Greeley

APPENDIX A-2
STREAMFLOW BOXPLOTS

Boxplot percentiles:



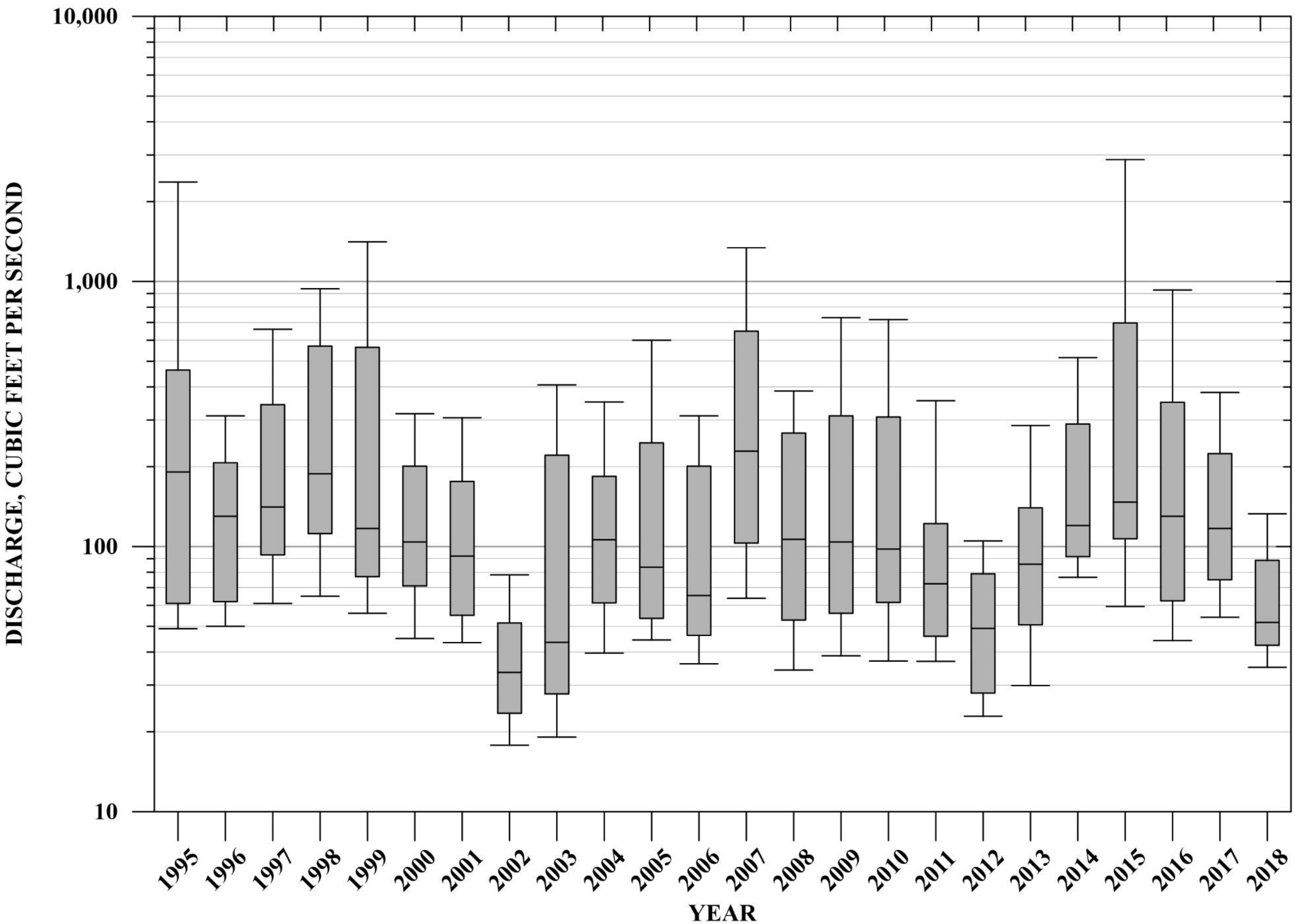


Figure A-12. Streamflow boxplot, USGS 06711565, South Platte River at Englewood, Reach 1

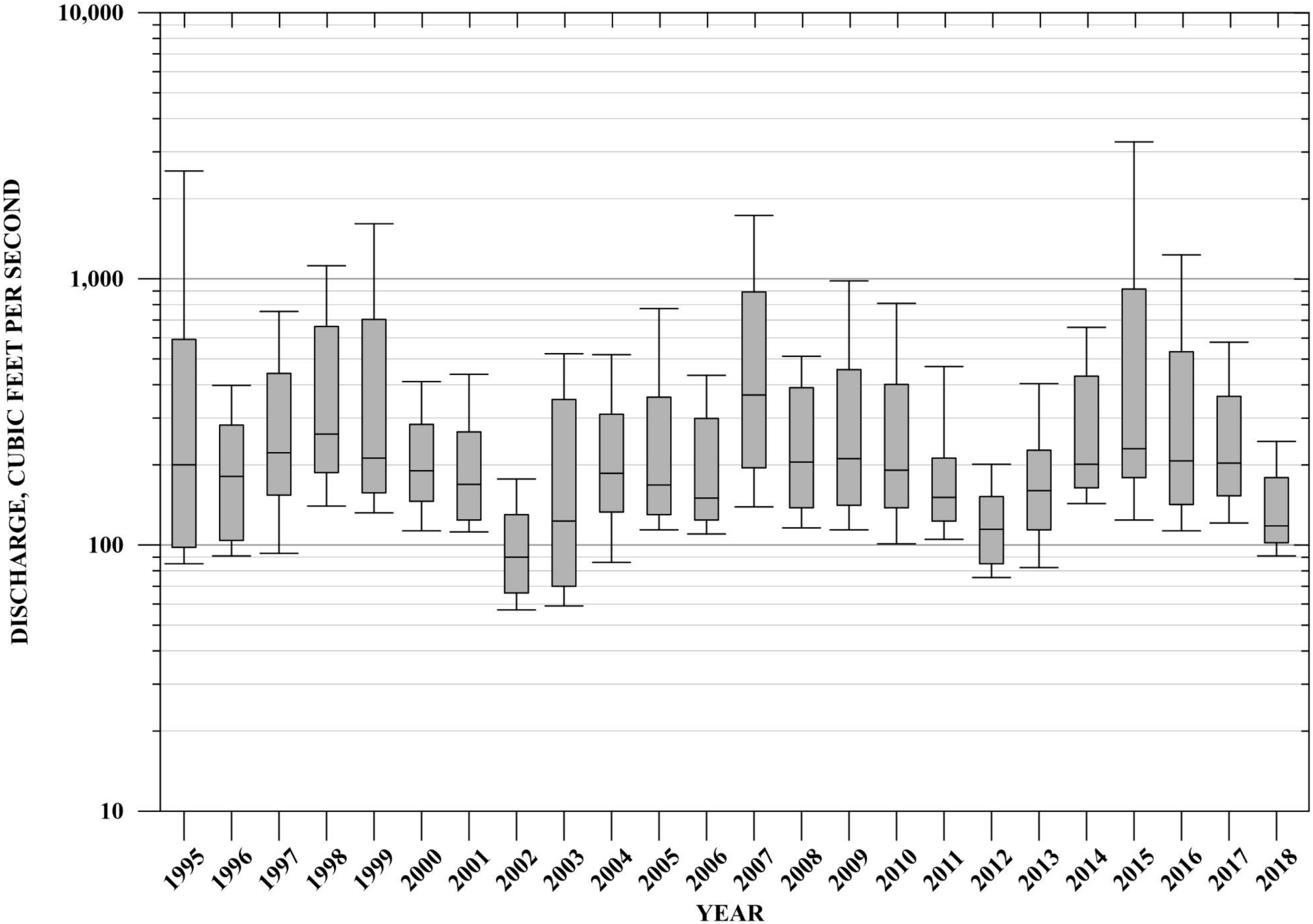


Figure A-13. Streamflow boxplot, USGS 06714000, South Platte River at Denver, Reach 2

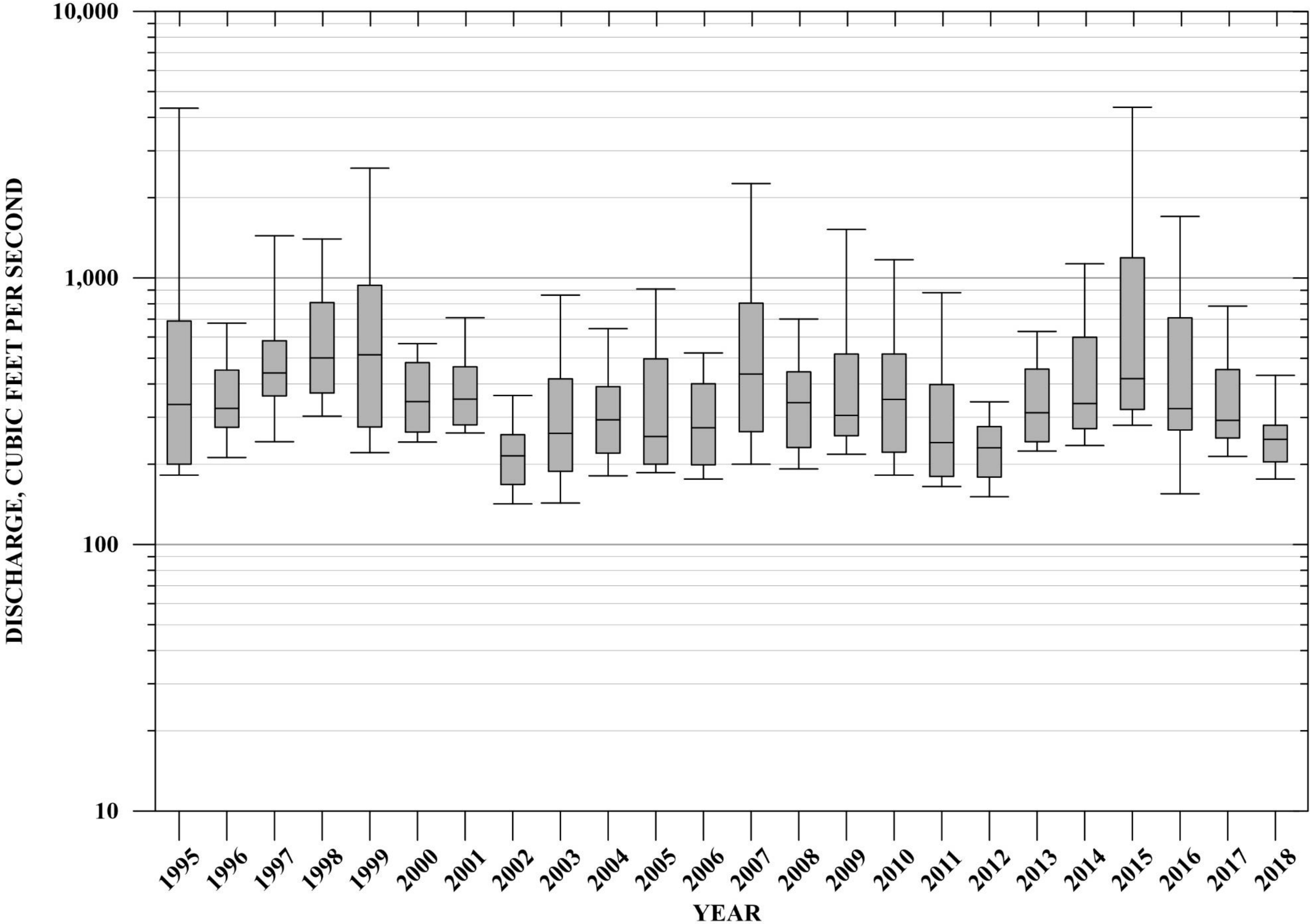


Figure A-14. Streamflow boxplot, USGS 06720500, South Platte River at Henderson, Reach 3

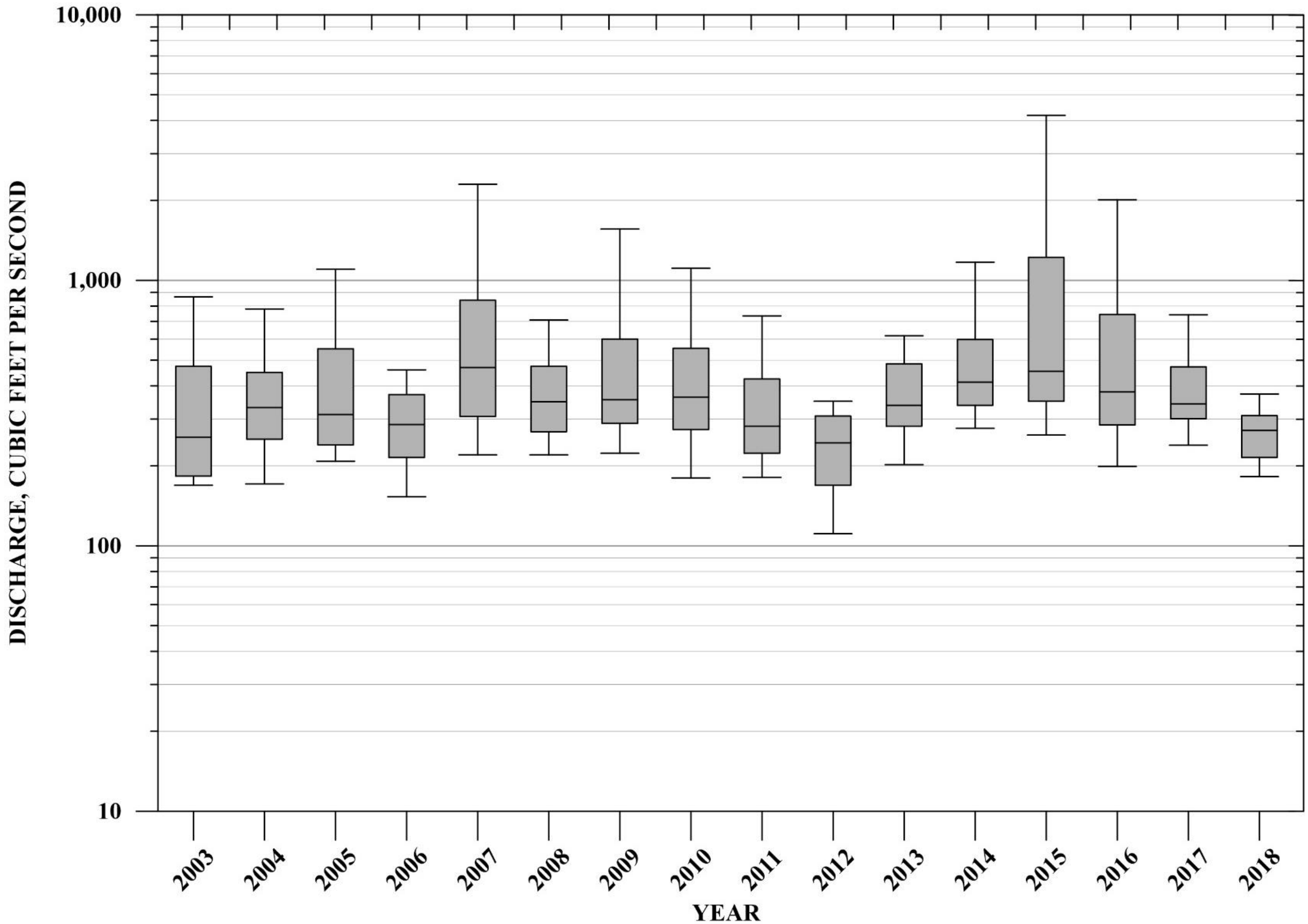


Figure A-15. Streamflow boxplot, USGS 06721000, South Platte River at Fort Lupton, Reach 4

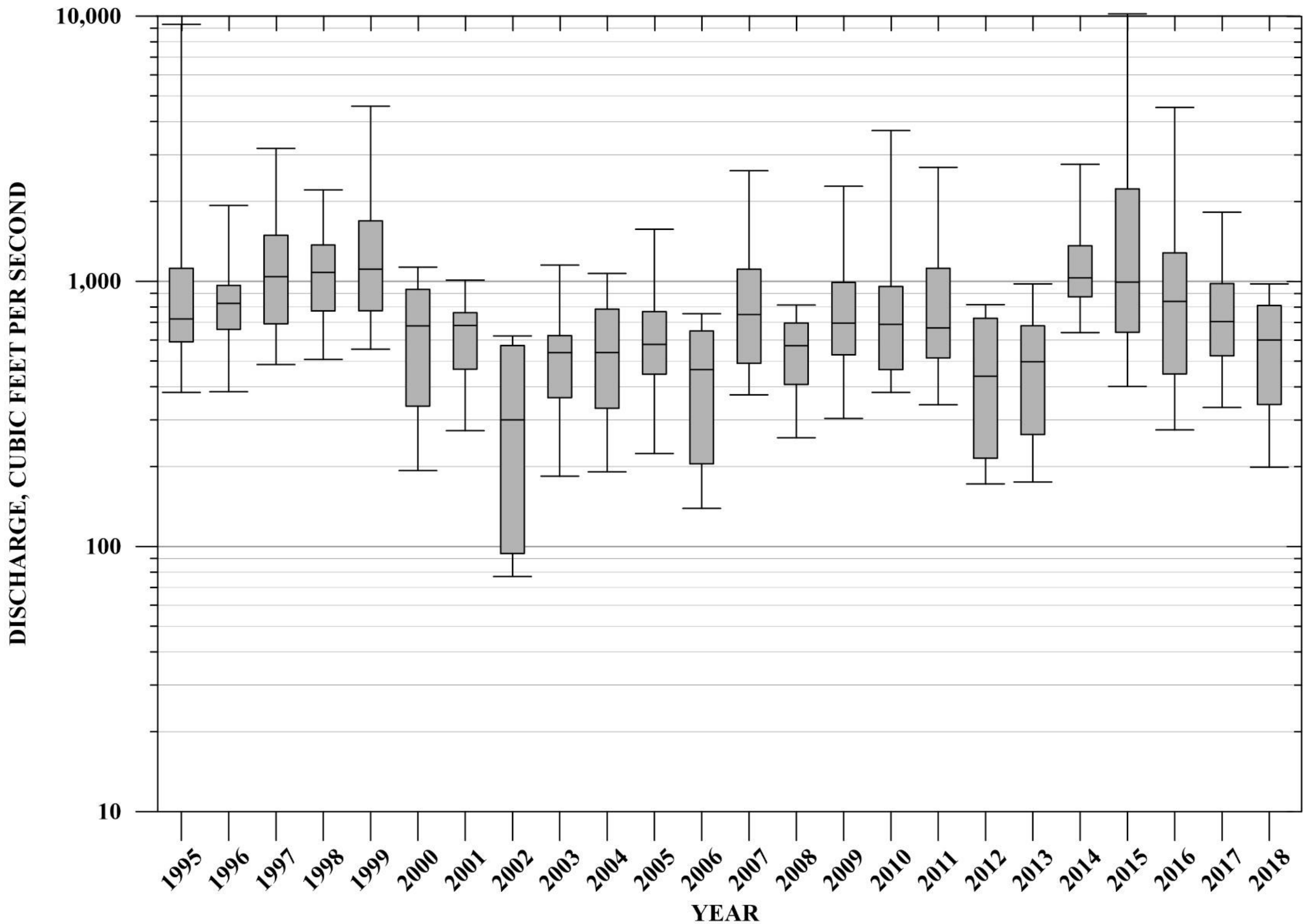


Figure A-16. Streamflow boxplot, USGS 06754000, South Platte River at Kersey, Reach 7

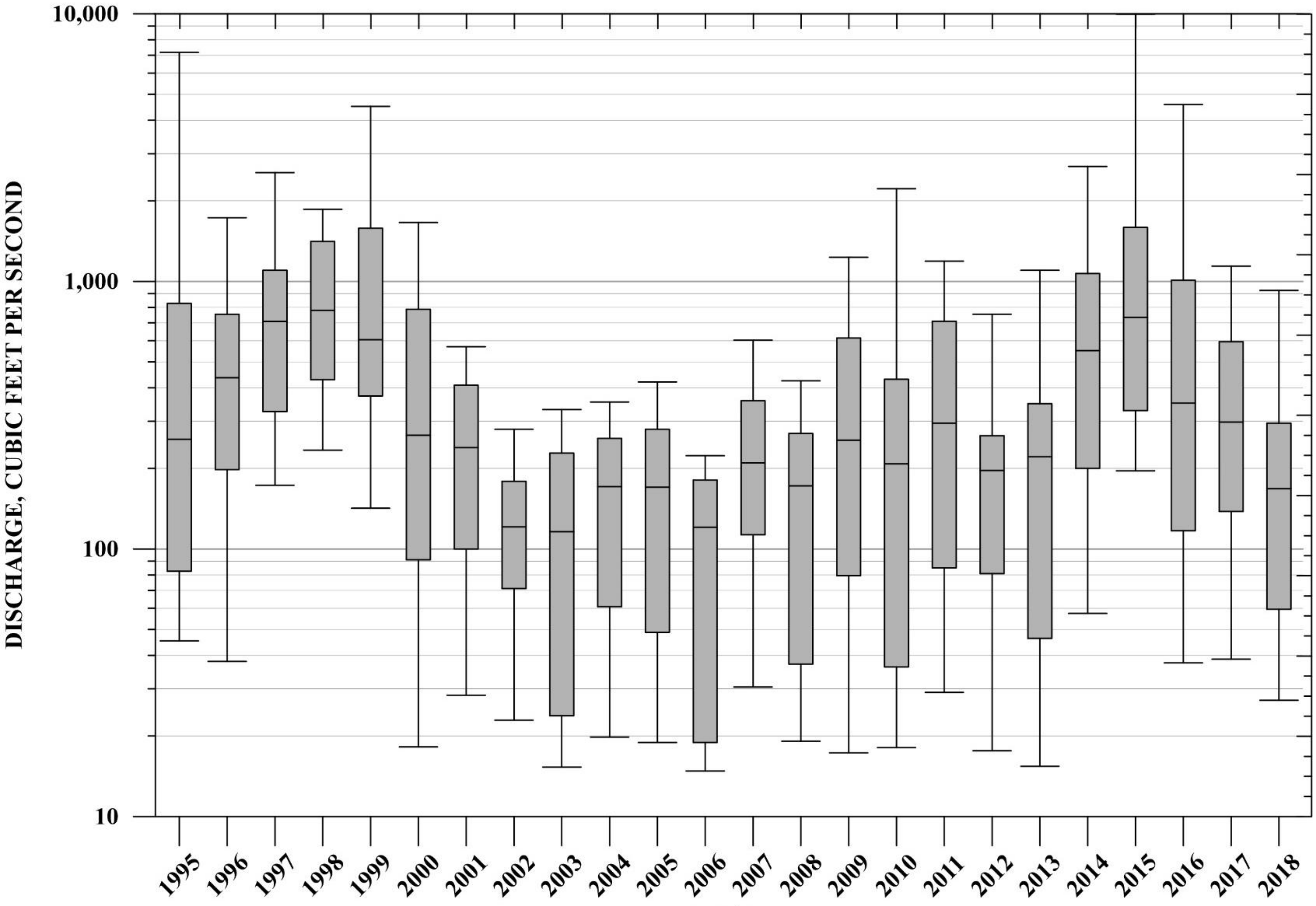


Figure A-17. Streamflow boxplot, USGS 06759910, South Platte River at Balzac, Reach 8

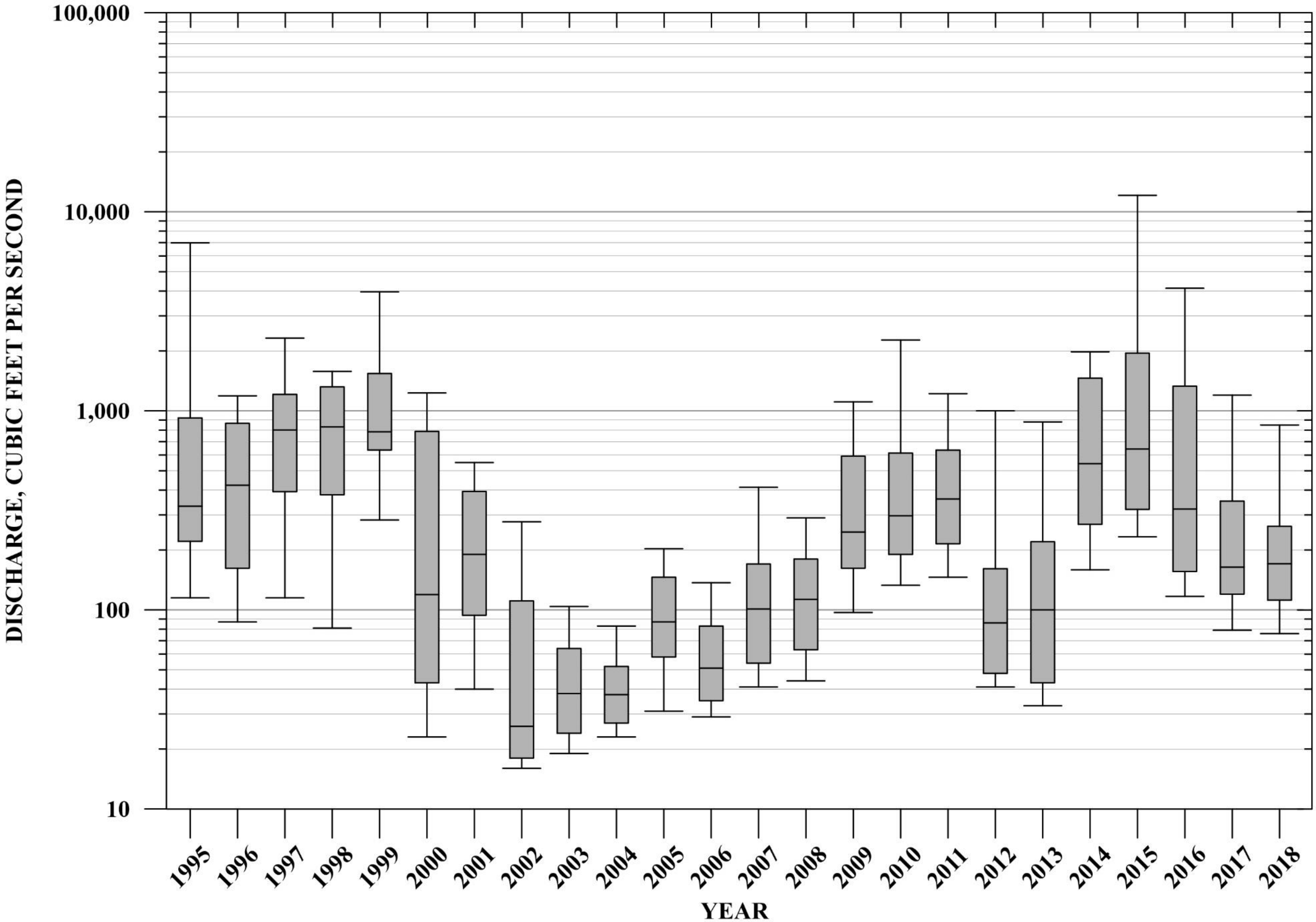


Figure A-18. Streamflow boxplot, USGS 06720500, South Platte River at Julesburg, Reach 9

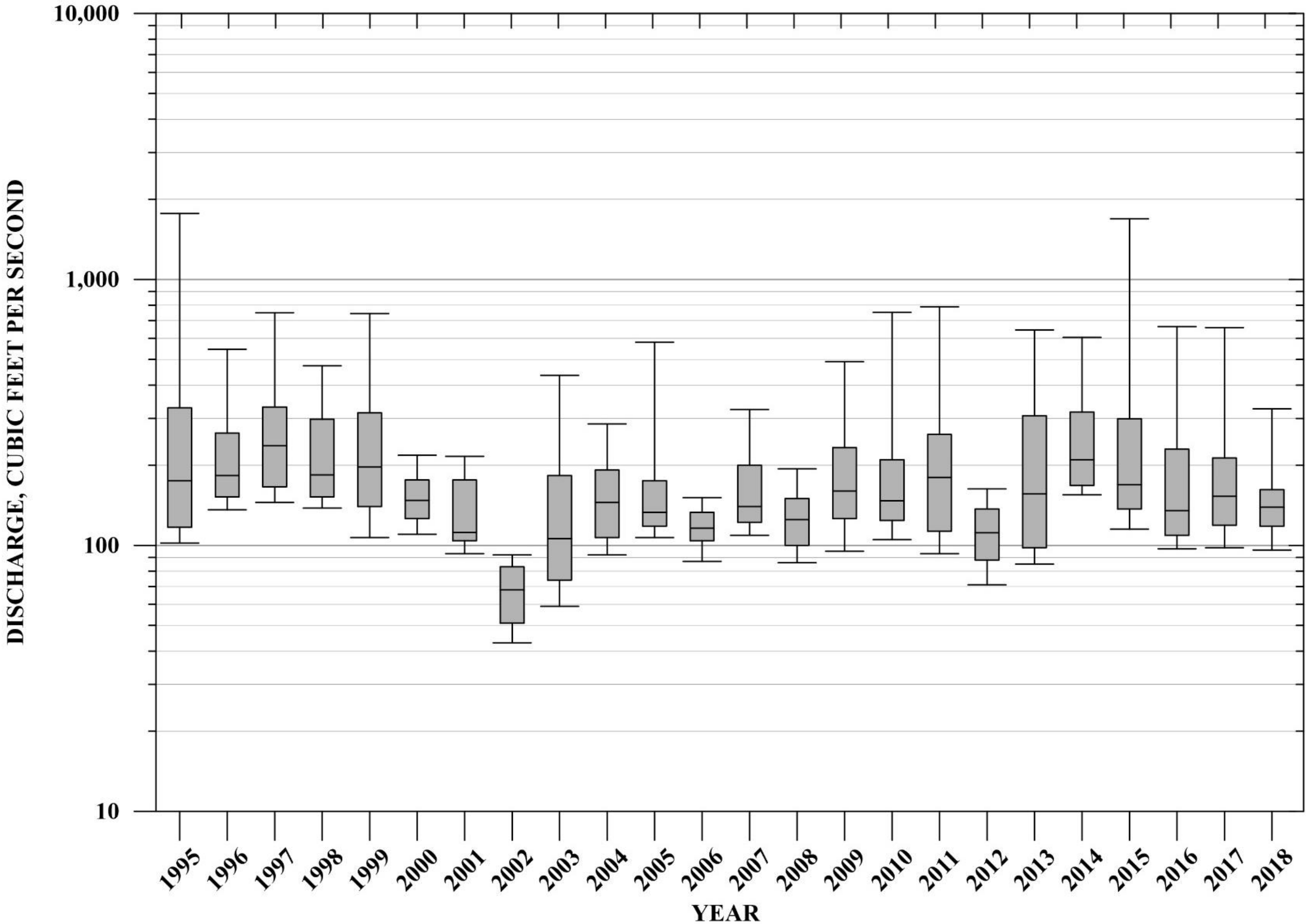


Figure A-19. Streamflow boxplot, USGS 067315000, Saint Vrain Creek near Platteville

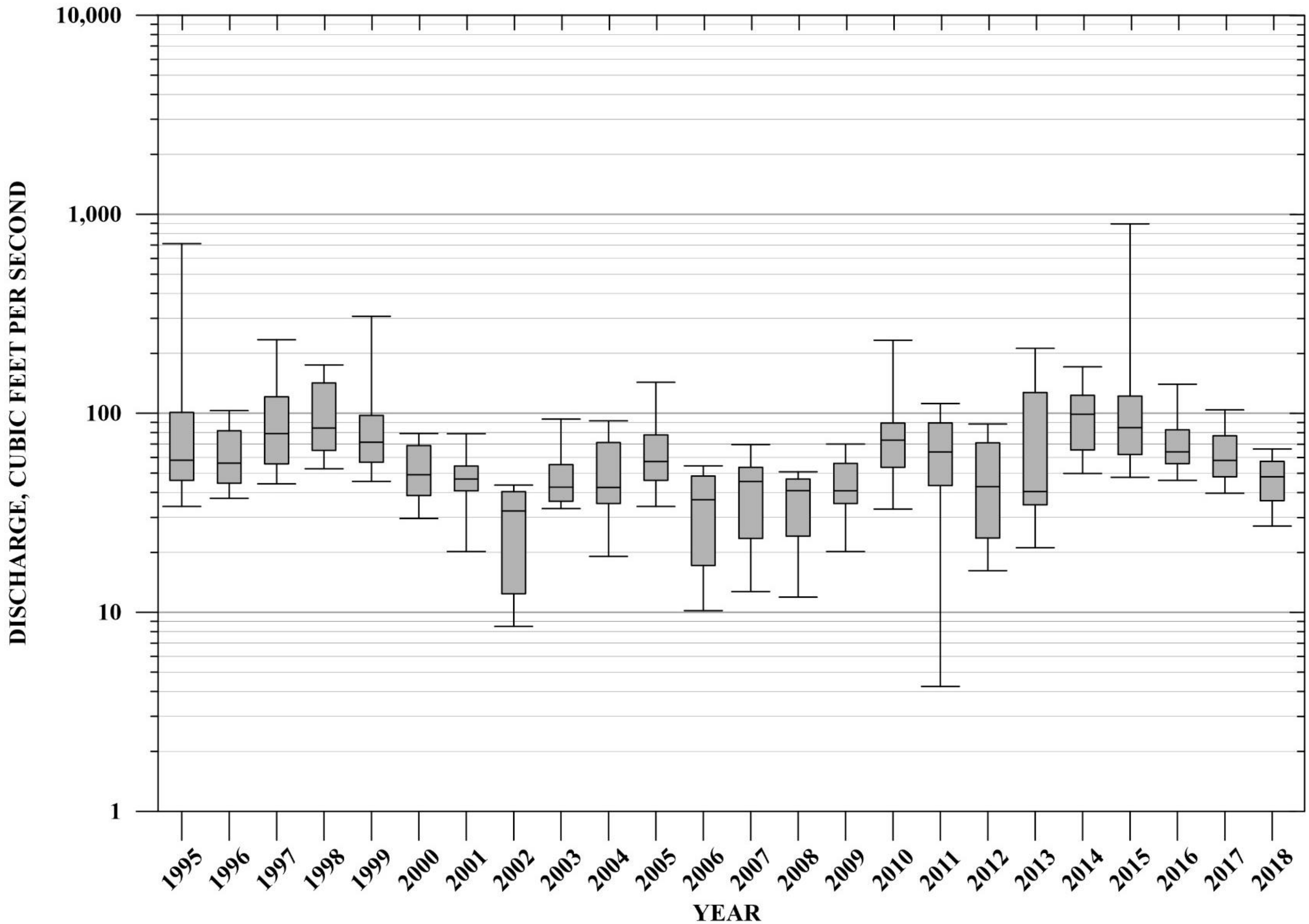


Figure A-20. Streamflow boxplot, DWR BIGLASCO, Big Thompson River near La Salle

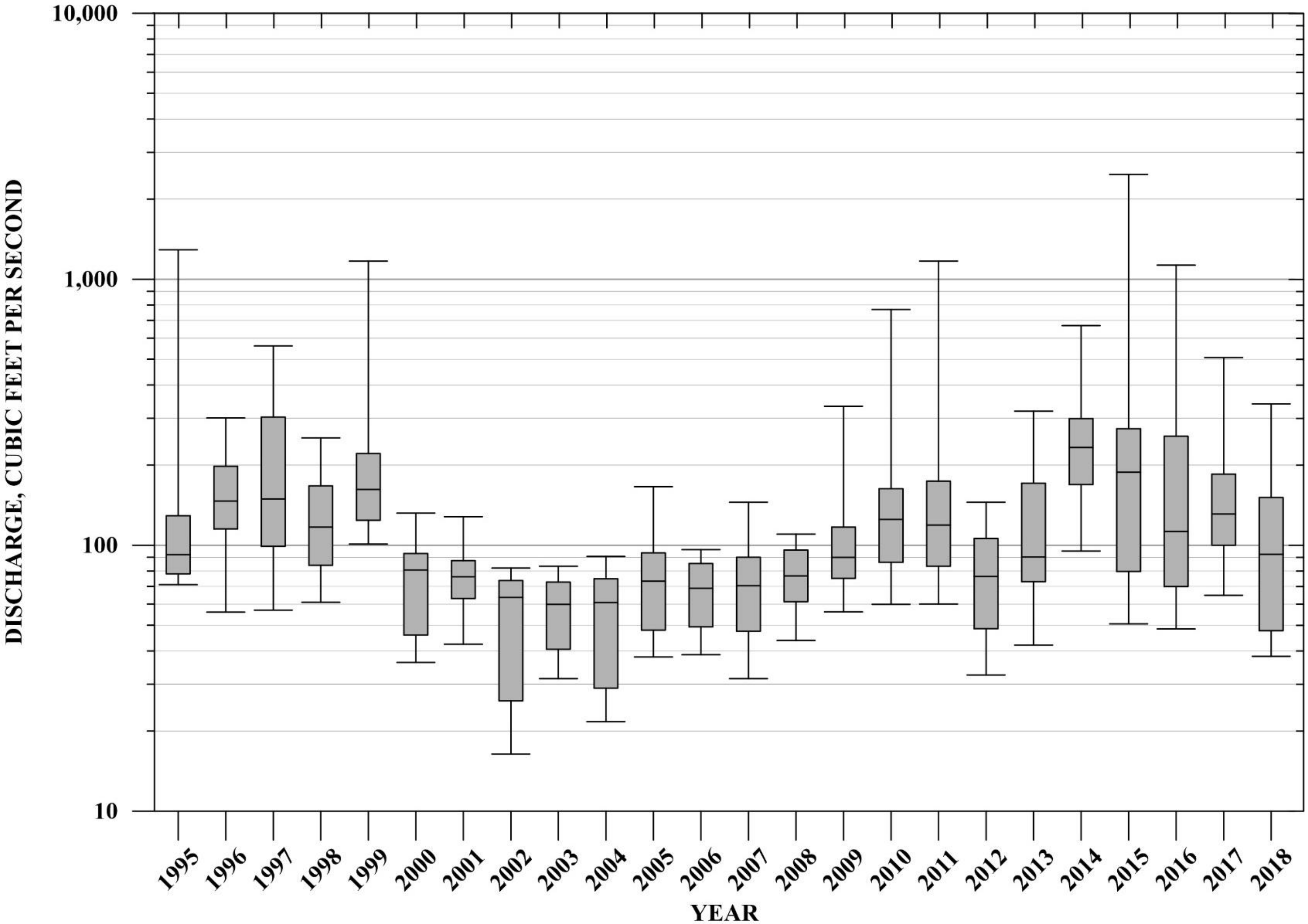


Figure A-21. Streamflow boxplot, USGS 06752500, Cache la Poudre River near Greeley

APPENDIX B
TOTAL DISSOLVED SOLIDS STATISTICS

APPENDIX B-1
TOTAL DISSOLVED SOLIDS
BOXPLOTS

Boxplot percentiles: