# WATER QUALITY AND BIOLOGICAL MONITORING TREND ANALYSIS

## *Missouri-Madison Water Monitoring Program*

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# PPL-MT Missouri-Madison 2188 Water Quality Analysis of 10 Year Trends

## Executive Summary

Water quality was monitored at 10 locations in the Missouri-Madison River Basin from 1997-2006 according to the water quality monitoring program established under FERC license 2188. Water quality data included field parameters such as specific conductivity, pH, temperature, dissolved oxygen, and turbidity. Lab analytes included suspended sediment, total dissolved solids, major anions/cations (calcium, magnesium, sodium, chloride, potassium, sulfate, alkalinity), and nutrient analytes (phosphorus and nitrogen components). Data were generally gathered on a monthly basis from 1997-1999, quarterly basis from 2000-2003, and monthly basis from 2004-2006.

In addition to water chemistry, periphyton, macroinvertebrate, and fish tissue samples were collected annually at a subset of 5 to 8 monitoring locations. Periphyton measures included chlorophyll a and ash free dry weight in addition to enumeration of species. Macroinvertebrate samples included qualitative and quantitative enumeration of taxon as well as composite metrics reflecting community structure. Fish tissue analyses focused on metals and organic compounds including a suite of herbicide, pesticide, and PCB congeners.

The following summary and recommendations are based on analyses of monitoring data from 1997-2006.

**Spatial Analysis of Water Quality**

Concentrations of numerous water quality constituents tended to show statistically significant differences between adjacent monitoring sites in the network. A tendency for either increasing or decreasing constituent concentrations in the downstream direction was observed throughout the monitoring period. These observations of spatial differences were consistent with previous studies (Land & Water 1999).

Statistically significant changes in concentrations of water chemistry constituents between monitoring stations was most common between upstream stations 1-5. This includes the Madison River (site 1) located near Yellowstone National Park/Highway 287 downstream to the Toston site on the Missouri mainstem (site 5) . This headwater reach of the Madison River downstream to the first station on the Missouri river includes a relatively small reservoir at Hebgen (Site 2) and the shallow Madison reservoir near Ennis (site 3). Otherwise, the area is rural and largely unregulated by hydro facilities. Statistically significant shifts in water quality observed between headwater stations were largely a function of changing geology and corresponding sources or dilution of constituents rather than hydro facilities.

The change in water quality in the downstream direction and between headwater stations can be largely attributed to geologic factors and contributing watersheds/source areas. For example, elevated concentrations of arsenic, sodium, and chloride originated largely within Yellowstone National Park were related to volcanic geology in the headwaters. These declined in the downstream direction. Increasing magnesium, calcium and other parameters in downstream direction were a function of shifts in geology from the headwaters to geology of lower elevation source areas. With few exceptions, parameters such as temperature, pH, and dissolved oxygen were typically stationary in the downstream direction. Hydro facility effects in the Madison appeared to be limited to reduced turbidity and TSS below Hebgen, and potentially increased turbidity below Madison/Ennis.

Stations lower on the Missouri mainstem (sites 6-10) tended to show increased stability in constituent concentrations and less change between stations when compared to headwater sites on the Madison

system. Few shifts in water quality appeared to be directly related to hydro facility operations. Notably Canyon Ferry (site 6) showed an apparent sag in average dissolved oxygen concentration relative to the upstream station Toston. Nutrient parameters dissolved ortho-P and nitrate-nitrite (dissolved and total) appeared to increase below Canyon Ferry. TSS, turbidity, and arsenic constituents declined. These effects are likely related to the deep water release from the hypolimnion, and potential influences from reservoir nutrient cycling, and point/non-point sources. Water quality was relatively stable at the Hauser and Holter facilities. A tendency for reduced levels of nitrate-nitrite was apparent at both sites. The Central Avenue site showed a notable shift in water chemistry due to the influence of the Sun River. In particular, suspended sediment and turbidity increased relative to the upstream Holter site. Major anions/cations and total dissolved solids generally showed to increases. The most pronounced effect at lowermost facility (Morony, site 10) was a statistically significant increase in total persulfate nitrogen.

Overall, changes in water chemistry were strongly related changes in watershed scale, contributing source area, and associated geology. Reservoir influence was commonly limited to storage-related effects (e.g. reduced TSS/turbidity). Canyon Ferry was the principal exception with additional statistically significant changes in arsenic, nitrate-nitrite, and dissolved oxygen relative to the upstream station. It is worth noting that upstream/downstream comparisons reflected the central tendency for all data during the monitoring period. Individual seasonal or flow-related differences in water chemistry may also be present.

**Trend Analysis**

Concentrations of water quality constituents were closely correlated with one another. These correlations included geology-related factors (e.g. a strong association of sodium, chloride, and arsenic). Strong correlations also included related constituents such as total phosphorus/dissolved phosphorus, total N/dissolved N fractions, and total metals/dissolved metals. In addition, many constituent concentrations were strongly related to flow, responding with either dilution or release effects. Because underlying trends in flow can drive trends in water quality an effort was made to account for flow effects.

Trends in both field and analytical constituents were analyzed for raw data. A select group of constituents were adjusted for the effects of flow. Depending on monitoring location, concentration of numerous constituents showed statistically significant trends over 1997-2010. Discharge over the same period also showed statistically significant trends. Changes in annual discharge accounted for many of the observed trends in raw data for analyte concentrations. Adjusted for the effects of flow, trends in analyte concentration were commonly explained by runoff. Changes in underlying watershed processes or potential hydro facility effects did not explain trends for in-stream concentrations.

Based on raw data, increased alkalinity, total dissolved solids, chloride, potassium, sodium, and to a lesser extent, increased sulfate and calcium were characteristic of most stations over the 10-yr period. These trends represented relatively uniform tendencies throughout the monitoring network. Raw data for arsenic also showed increasing trends throughout the network. It is worth noting that discharge tended to decrease from 1997-2006. Higher runoff was characteristic of years prior to 2000, with a series of relatively drier years following through 2007.

Trends in nutrient raw data tended to be specific to location in the watershed. Total nitrate/nitrite showed decreasing trends at Missouri sites Canyon Ferry, Holter, and Morony. Dissolved nitrate/nitrite showed an increasing trend at at the uppermost station (Madison/Hwy 287). Remaining downstream stations showed no trends in dissolved nitrate/nitrate. Total persulfate nitrogen showed an increased trend at the stations Madison/Ennis, Central Avenue and Morony with no statistically significant trends at remaining sites.

Total phosphorus showed increasing trends at the 4 upstream-most stations (1-4) and a decrease at station Central Avenue. This was the most prevalent and consistent spatial trend for nutrient parameters within the monitoring network. Total ortho-phosphorus showed an increasing trend at the Central Avenue site, and dissolved ortho-phosphorus showed statistically significant increases at Madison/Hwy 287 (site 1), Toston (site 5) and Central Ave (site 9). Total suspended sediment showed statistically significant decreases at Madison/Ennis, Toston, Central Ave, and Morony.

Overall, the consistent nutrient trends observed within the monitoring network from 1997-2006 were increased total phosphorous at the upper 4 stations (1-4) plus station 9, a tendency for increased total ortho-phosphorus (station 9), and dissolved ortho-phosphorus at stations 1, 5 and 9. Total suspended sediment also increased at the lower stations (5, 6, 9, and 10).

**Flow-Adjusted Trend Analysis**

As discussed previously, runoff showed a decreasing trend at all sites with wetter years present earlier in the monitoring period and drier years beginning in 2000. Because many concentrations of many parameters are strongly or partly related to flow, trends in raw data may express flow effects. Trends in parameters may diminish (or reverse direction) when flow is taken into account.

Conductivity, turbidity, alkalinity as bicarbonate, total arsenic, chloride, sodium, sulfate, and total suspended sediment were generally correlated to flow. Turbidity and TSS tend to increase with discharge (i.e. release), and conductivity, alkalinity as bicarbonate, total arsenic, chloride, sodium, and sulfate tend to decrease with discharge (i.e. dilution).

Results of the flow adjusted analysis showed that conductivity had an increasing trend at stations 2, 6, 8, 9, and 10. The raw data showed increasing trends for conductivity at all stations in the network. Trends in flow appeared to explain corresponding trends in conductivity at half of the monitoring stations.

Flow-adjusted turbidity decreased at station 8, and increased at station 3. Stations that had statistically significant decreasing trends in raw turbidity data included stations 2, 4, 5, 6, 7, 8, 9 and 10. Decreasing trends in raw turbidity data appear to be related to changing flow conditions, and after accounting for flow effects, turbidity generally appeared to either decreasing or unchanged. Station 3 was the exception and showed an increasing trend with flow adjusted turbidity. Based on flow adjusted data, total suspended sediment increased at stations 3 and 5. Raw total suspended sediment decreased at stations 4, 5, 9, and 10.

Alkalinity as bicarbonate decreased at station 1, but increased at station 2 using flow adjusted data. No other stations showed trends in alkalinity as bicarbonate. Using raw data, alkalinity as bicarbonate showed a statistically significant increase at all ten stations with the exception of stations 5 and 6. Decreasing trends in flow thus appeared to explain increasing trends in raw alkalinity for most monitoring stations.

Flow adjusted datasets showed total arsenic and chloride increased at stations 2, 5, 6, 7, 8, 9, and 10. Raw data showed statistically increasing concentrations at all stations in the network for total arsenic and chloride. With the exception of stations 1, 3, and 4 accounting for the effects of flow did not explain the increasing trends in sodium and total arsenic. Adjusted for the influence of discharge, parameters that generally showed a persistent tendency for increasing concentration included arsenic and chloride.

**Periphyton**

Periphyton metrics included ash free dry weight and Chlorophyll *a*. These metrics showed year to year variability, but no persistent trends with the exception of a decrease in Chlorophyll *a* and the lowermost station (Morony).

Montana guidelines for periphyton standing crop are defined as follows: "*problematic levels of AFDM (50,000 mg/m2) and a threshold of severe impairment with problematic levels of Chl-a (100 mg/m2).*"

Median chlorophyll a was below the impairment threshold in all years from 1997-2006. Median ash free dry weight (or mass) indicated that with the exception of 2002 and 2003, these metrics were below levels indicating impairment for all stations. The change in methodology from the "scrape" method to the "whole rock" method improved consistency of data collection.

**Macroinvertebrates**

Macroinvertebrate metrics included bioassessment index, taxa richness, EPT richness, Shannon diversity, biotic index, %EPT, and % Chironomidae. Macroinvertebrates showed a limited number of trends in metrics. Several sites showed a decrease in %EPT and increase in biotic index. The Madison/Hebgen station showed an increase in biotic index, and decreases in bioassessment index, EPT richness and % EPT. The Madison/Ennis station did not show any trends in macroinvertebrate metrics. The Madison powerhouse showed an increase in biotic index, and decrease in %EPT. No statistically significant trends were observed at the Toston station. The Hauser and Holter sites showed a decrease in %EPT, but no statistically significant trends otherwise. The Morony site showed an increase in the biotic index but no statistically significant trends otherwise. These shifts may be largely related to a tendency for decreasing discharge during the 1997-2006 monitoring period.

**Fish Tissue**

Fish were sampled from the Hebgen, Madison, Hauser, Holter, Cochrane, Rainbow, and Morony sites. Magnesium, strontium, iron, and zinc were commonly detected in fish species throughout the monitoring network. Aluminum and manganese were less frequently detected. The only organic constituent detected in 2009 sampling was the PCB congener Aroclor 1254 in trace amounts at the Rainbow, Cochrane, and Holter sites. The Hauser site showed Aroclor 1254 at levels above detection limits in both rainbow trout and white suckers. No other organics in the analysis suite were detected.

The Montana Department of Public Health and Human Services published sport fish consumption guidelines in 2005 for mercury and PCBs (MDPHHS 2005). This bulletin included fish sample results from 29 Montana waterbodies, including Canyon Ferry, Hauser, Holter and Hebgen. Consumption guidelines for mercury and PCB were presented. The bulletin advised an unlimited consumption of fish below 0.025 PCB, a weekly portion of 8 oz for fish containing from 0.025 to 0.10 mg/kg of PCB, and a monthly portion for 0.11 to 0.47 mg/kg PCB.

Values of Arochlor 1254 observed in rainbow trout at the Hauser site were near detection limits, but higher than the results reported for Hauser in the 2005 MDPHHS bulletin. Rainbow trout from Hauser fell into the weekly consumption category (0.025-0.10 mg/kg PCB). Holter rainbows were between unlimited consumption (<0.025 mg/kg PCB) and weekly consumption PCB levels. No mercury was detected in any fish samples in the Missouri Madison system. The detection limit was 1 mg/kg.

**Recommendations**

1) Data collection included monthly and quarterly monitoring from 1997-2006. Analysis of monthly and quarterly data provided comparable statistical results for trend analyses from 1997-2006. These results suggest that a quarterly monitoring schedule would be sufficient for discerning significant annual or long-term trends in water quality. Flow effects and seasonal variation is well-documented at each site with the existing 6 years of monthly data. For purposes of trend detection, quarterly data is expected to provide a robust means of monitoring long-term tendencies.

2) Both metal and nutrient parameters had total and dissolved analyses. Total and dissolved analytes were very closely related. This redundancy is largely unnecessary from the standpoint of documenting underlying trends in water quality. Each provide comparable results in terms of both status and trends in water quality, and either total or dissolved metals analyses should be sufficient to document water quality.

   For nitrogen parameters, total persulfate nitrogen and either total or dissolved nitrate/nitrate is recommended. Detectable levels of ammonia are not characteristic of the Missouri-Madison system and are could be discontinued. Like nitrogen, total phosphorus along with either dissolved or total ortho-phosphate should be sufficient. Monitoring both dissolved and total fraction of phosphorus does not provide significant additional information.

# 1.0 INTRODUCTION

This report presents data analysis for long-term monitoring of water quality and biological parameters for the Madison and upper Missouri rivers. This analysis follows recommendations developed with pilot studies and the water quality monitoring plan for monitoring stations along the Madison and upper Missouri rivers. The overall objectives of the monitoring plan included:

1. Identify long-term trends and spatial variation of water quality and biological parameters in the study area; and
2. Evaluate the effects of the operation and maintenance of hydroelectric facilities along the Madison and upper Missouri rivers.

The area covered by the monitoring plan extends from the headwaters of the Madison River in Yellowstone National Park through the upper reaches of the Missouri River to below Great Falls (**Figure 1-1**). Included in this area are nine hydroelectric facilities formerly operated by the Montana Power Company (MPC), now PPL Montana (PPLM), plus one dam operated by the Bureau of Reclamation. These dams include Hebgen and Madison dams on the Madison River, and Canyon Ferry, Hauser, Holter, and the five Great Falls dams (Black Eagle, Rainbow, Cochrane, Ryan, and Morony) on the upper Missouri River.

## 1.1 Purpose

This report provides analysis of the comprehensive monitoring program and incorporated the findings and recommendations of several years of water quality and biological pilot phase data collection. The monitoring plan was intended to provide statistically rigorous approach to characterize and identify trends in water quality and biological parameters. Data collected from 1997-2006 were analyzed to assess trends in water quality, and the potential influence of hydroelectric facilities on the Madison and upper Missouri rivers.

Monitoring objectives for the study area were previously identified by the Montana Department of Environmental Quality (MDHES, 1993), the 2188 Water Quality Technical Committee, and by the terms of the license issued by the Federal Energy Regulatory Commission (FERC). These objectives have been combined into the following:

1. Provide a statistical analysis of long-term trends in water quality and biological data.
2. Evaluate the potential influence of dam facilities on water quality and biological parameters with above/below comparisons.
3. Monitor the effects of operation and maintenance of dam facilities on water quality and biological parameters.
4. Evaluate the behavior of the entire system with respect to water quality and biological parameters.
5. Determine whether trends suggest an improvement or deterioration of water quality, biological integrity, and ecological health of the Madison and Missouri river system.

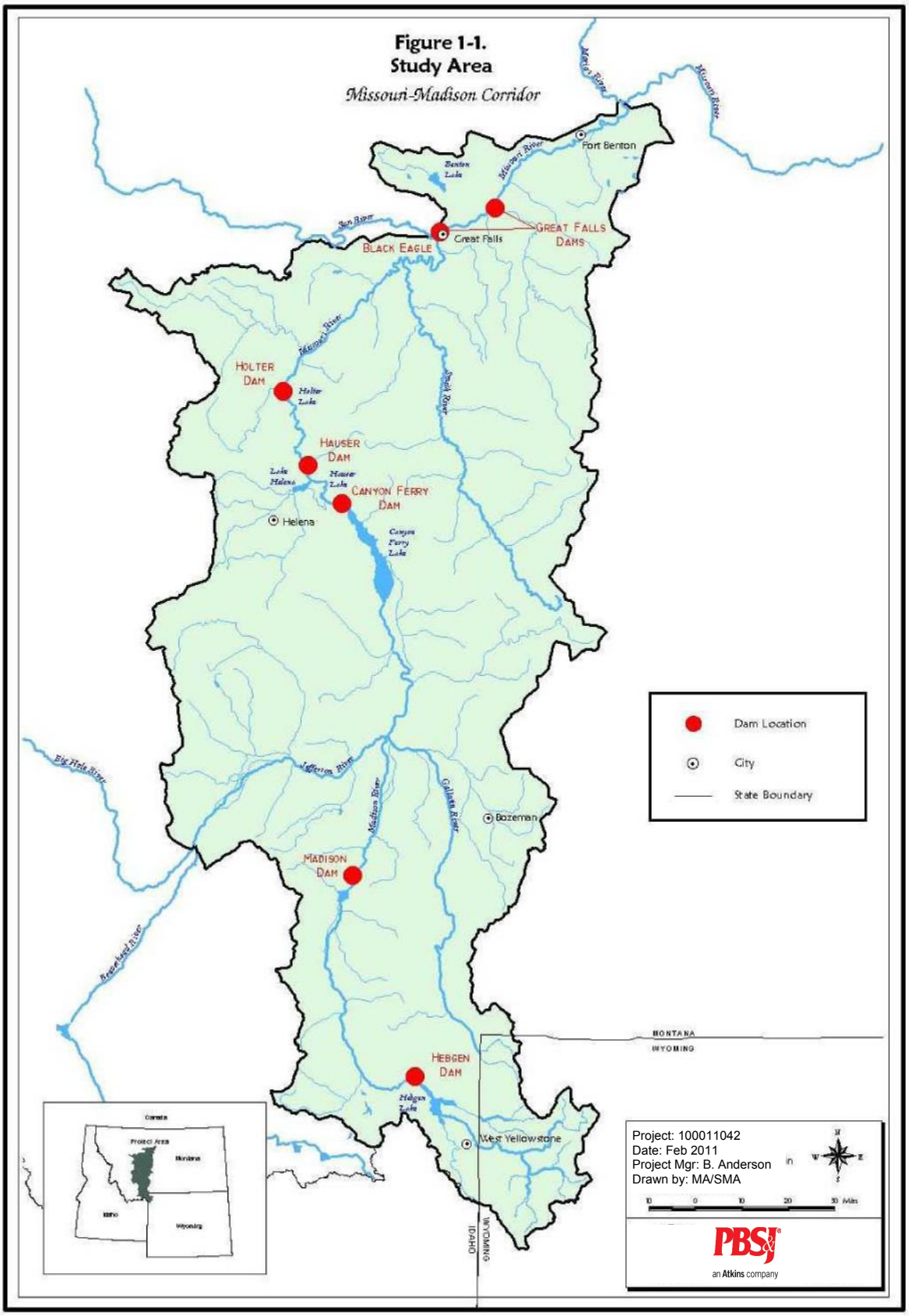



**Figure 1-1. Study Area**

**Monitoring Locations**

The monitoring locations were selected to provide data sufficient to evaluate trends, and the potential impacts of dams on the Madison and Missouri rivers. Monitoring locations used for the pilot programs, summarized in **Section 2**, were considered adequate for meeting the objectives of this plan. Sampling locations differ slightly for the water quality and biological monitoring in some instances due to physical requirements for collecting representative samples.

The monitoring locations comprise 10 water quality and biological monitoring stations (**Figure 1-2)**. The water quality and biological monitoring locations include:

HEBGEN DAM (MADISON RIVER):

- **YNP**: above Hebgen Lake, in Yellowstone National Park (biological site prior to 1995).
- **HWY 287**: above Hebgen Lake, Highway 287 (water quality only).
- **Hebgen**: below dam (water quality and biological).

MADISON DAM (MADISON RIVER):

- **Varney**: above Ennis Lake, at Varney Bridge (water quality only).
- **Ennis**: above Ennis Lake, at Ennis Campground (biological only).
- **Madison**: below dam (water quality and biological).

CANYON FERRY DAM (MISSOURI RIVER):

- **Toston**: above Canyon Ferry Lake, at Toston Bridge (water quality and biological).
- **Canyon Ferry**: below dam, above Hauser Lake (water quality).

HAUSER DAM (MISSOURI RIVER):

- **Hauser**: below dam, above Holter Lake (water quality and biological).

HOLTER DAM (MISSOURI RIVER):

- **Holter**: below dam (water quality and biological).

GREAT FALLS DAMS (MISSOURI RIVER):

- **Black Eagle**: above Black Eagle reservoir (water quality), previously known as Central Ave/G. Falls.
- **Morony**: below Morony Dam (water quality and biological).

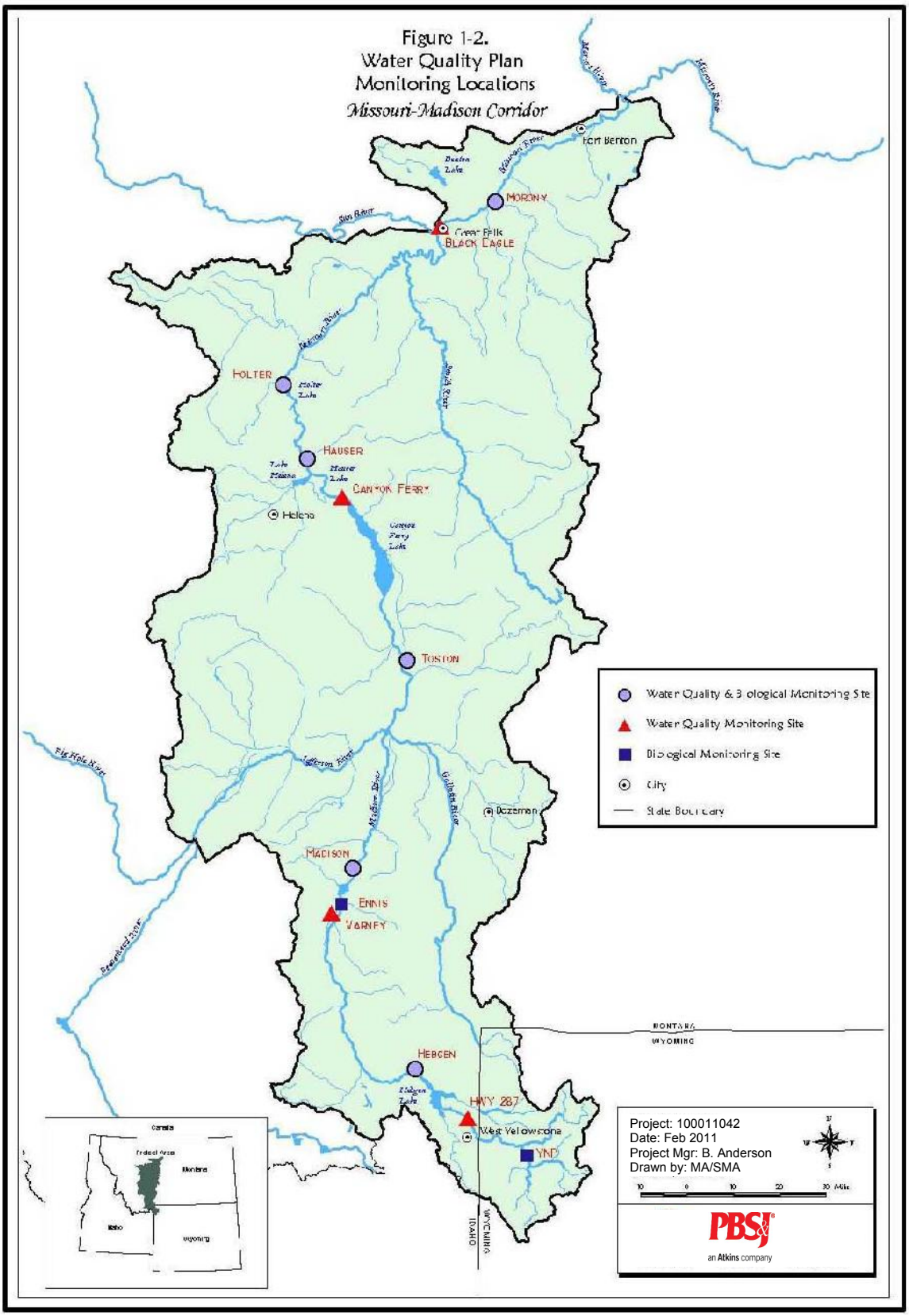



**Figure 1-2. Water Quality Plan Monitoring Locations**

Three of these locations, including sites above Hebgen Lake (YNP and HWY 287), above Ennis Lake (Ennis and Varney), and Toston are located on relatively "unregulated" reaches of the Madison and upper Missouri rivers. These sites are intended to establish natural background variability in water quality where little or no effect from reservoir discharges upstream would be expected.

A description of each of these monitoring locations is provided below, and is summarized in **Table 1-1**, **Appendix A**. Monitoring locations may be modified during the course of this monitoring program if data evaluation suggests that monitoring objectives would still be met.

### *1.1.1 Hebgen Dam*

Hebgen Reservoir, formed by the completion of Hebgen Dam in 1915, is located about 22 miles northwest of West Yellowstone, Montana. The reservoir intercepts a drainage area of about 905 square miles. The earth filled dam is 85 feet high and 721 feet long, with a broad crested weir spillway on the right bank that is 47 feet wide. The dam impounds 386,184 acre-ft of storage in the reservoir, with 378,845 acre-ft of useable storage between elevations 6,473 and 6,535 feet. Releases from the dam are made through a 12-foot diameter discharge pipe located 37 feet below full pool.

Maximum depth of the reservoir is 75 feet near the dam, with a mean depth of 27 feet. At full pool, the reservoir surface area is 19.8 square miles. The mean water retention time in the reservoir is 172 days.

The monitoring locations above Hebgen Lake are different for the water quality and biological monitoring. The biological monitoring point (YNP) is located within the boundary of Yellowstone National Park, near USGS gaging station #6037500 on the left bank (**Figure 1-3**). The water quality monitoring point (HWY 287) is located at the Highway 287 bridge and is a depth integrated, equal width increment composite (**Figure 1-4**). The water quality monitoring location below Hebgen Dam (Hebgen) is roughly 0.3 miles below the dam, at the USGS gaging station #6038500 on the right bank (**Figure 1-5**). Sampling is a depth integrated point sample. The biological monitoring station is about 1.25 miles downstream of the facility on the right bank.

### *1.1.2 Madison Dam*

Madison Reservoir is located roughly 5 miles northeast of Ennis, Montana. Madison dam is located 68.8 miles downstream of Hebgen Dam, and 40.2 miles upstream of the Missouri River headwaters at Three Forks, Montana. The reservoir intercepts a drainage area of about 2,181 square miles. The dam is a 38.5-foot high rock-filled crib structure that is operated primarily as a run-of-the river facility. The dam impounds 39,115 acre-ft of useable storage between elevations 4,826 and 4,841 feet.

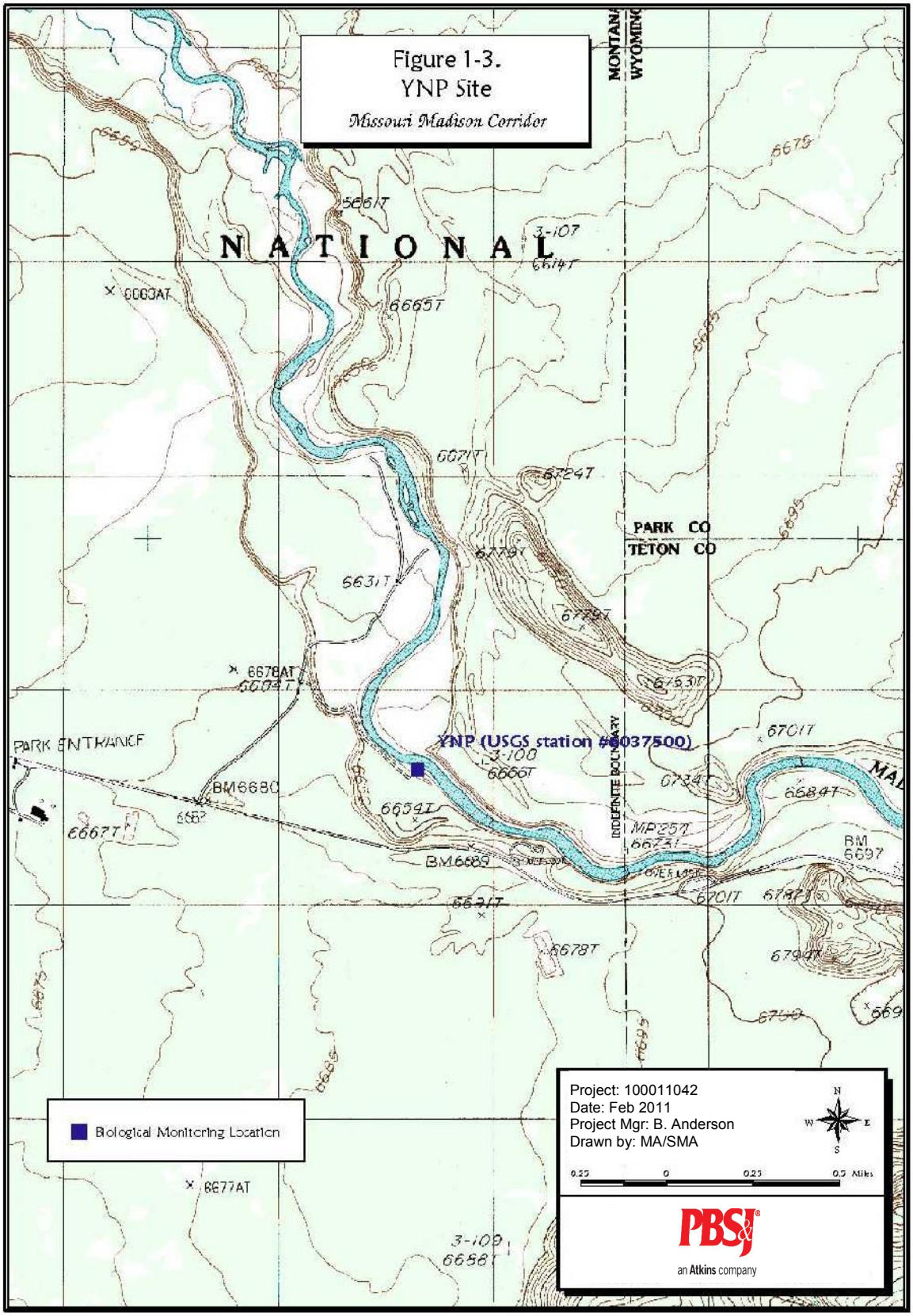



**Figure 1-3. YNP Site**

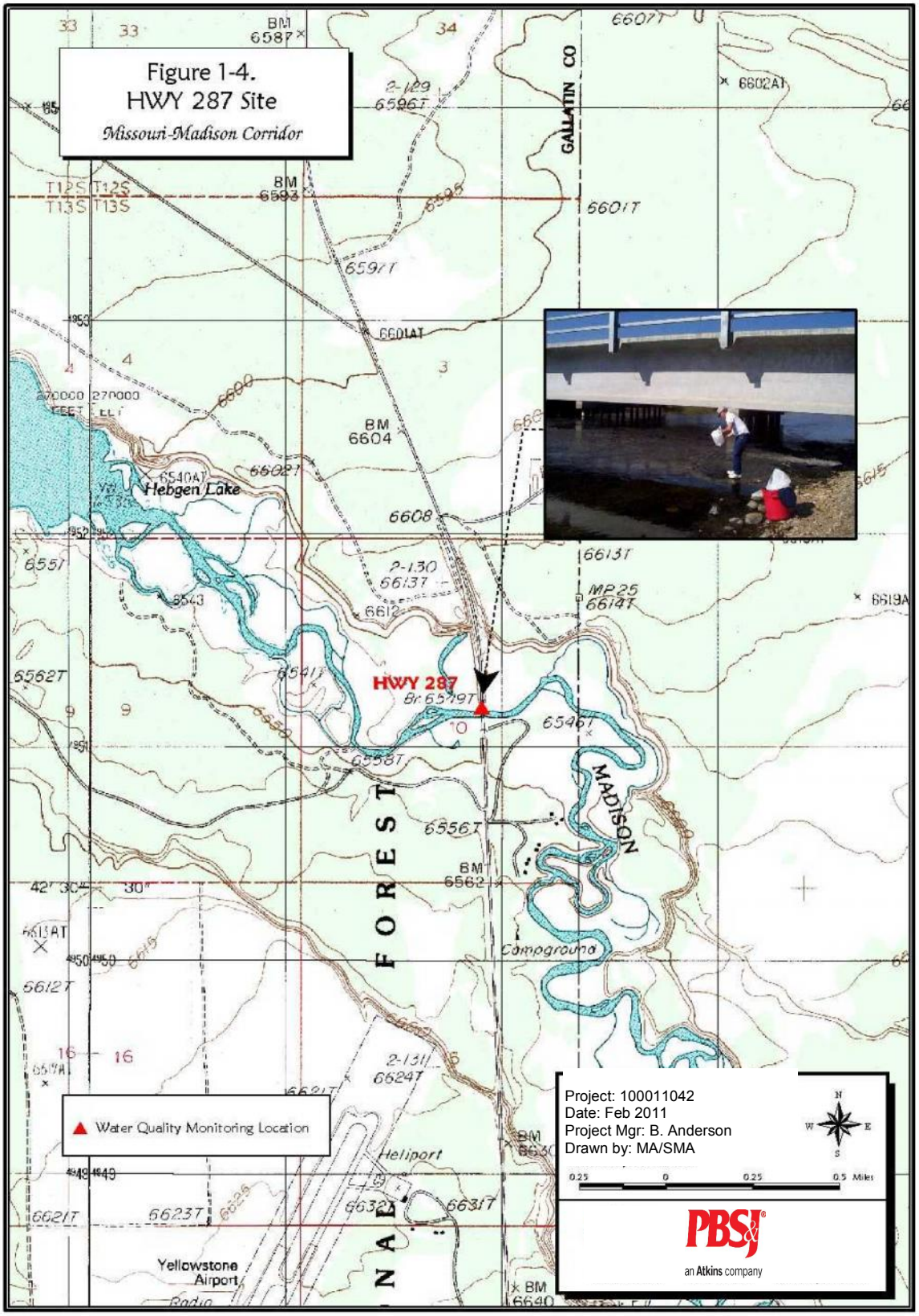



**Figure 1-4. HWY 287 Site**

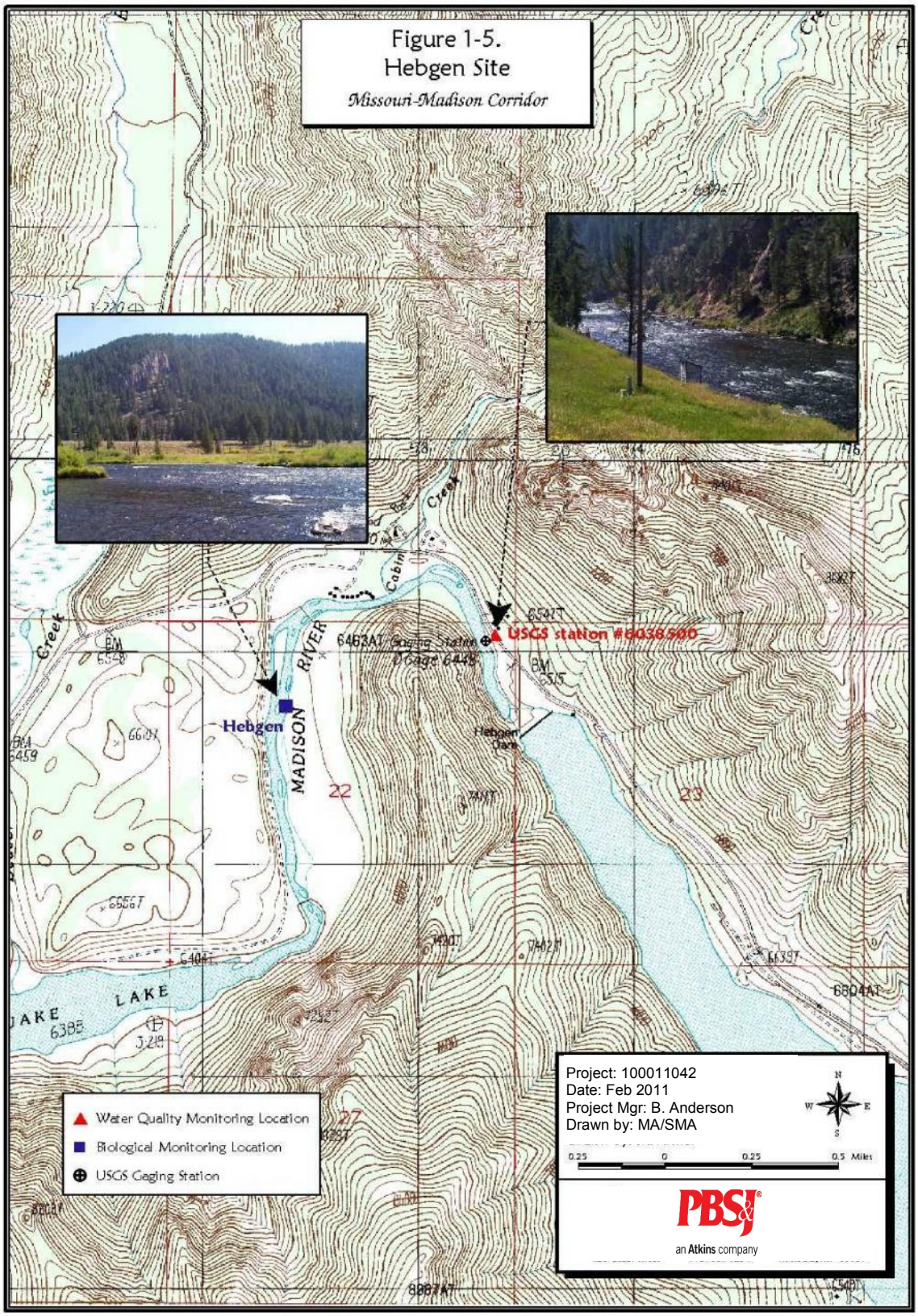



**Figure 1-5. Hebgen Site**

A concrete intake structure, 26 feet deep in front of the dam, provides water to a 13-foot diameter flow line. The flow line extends 7,500 feet down the canyon to the powerhouse, which has a hydraulic capacity of 1,650 cfs. Maximum depth of the reservoir is 32 feet near the dam, with a mean depth of 12 feet. Mean water residence time in the reservoir is 15 days.

The monitoring locations above Ennis Lake are different for the water quality and biological monitoring. The water quality monitoring point (Varney) is located at the Varney Bridge and is a depth integrated, equal width interval composite (**Figure 1-6**). The biological monitoring point (Ennis) is in Ennis Campground (**Figure 1-7**). The monitoring location below the Madison Reservoir (Madison) is a depth integrated, single point sample composite of the turbine and surface water discharge at the footbridge (**Figure 1-8**). The biological monitoring site below Madison Reservoir is located approximately 200 yards downstream from the Madison powerhouse.

### *1.1.3 Canyon Ferry Dam*

Canyon Ferry Dam is owned and operated by the Bureau of Reclamation and was built between 1949 and 1954. The facility is used for power supply, flood control, irrigation, and recreation. The dam is constructed of concrete and is roughly 1,000 feet long and 225 feet high. The reservoir storage capacity is 2,050,900 acre-ft (at an elevation of 3800 ft) with a mean residence time of 135 days.

The monitoring location above Canyon Ferry Lake (Toston) is at the bridge in Toston (**Figure 1-9**), and is a depth integrated, equal width interval composite. This location is considered an unregulated site reflecting little or no influence of upstream reservoir discharge. Biological monitoring at Toston is located approximately 3 miles upstream of the bridge on the left bank (**Figure 1-9**). The monitoring point below the dam (Canyon Ferry) is located at the penstock discharge, and is sampled as a single point, depth integrated sample (**Figure 1-10**). Only water quality parameters were monitored below the dam during the pilot study. An effort was made to sample proportionally with spill/turbines, however, this was difficult to accomplish at high flow, and high flow samples are limited to turbine discharge only.

### *1.1.4 Hauser Dam*

Hauser Reservoir is located about 14 miles northeast of Helena, Montana and 14 miles downstream of Canyon Ferry Dam. The reservoir intercepts a drainage area of about 16,876 square miles. The dam is a concrete gravity structure with a 445-foot long overflow spillway and non-overflow sections at each abutment.

The reservoir is comprised of two connected bodies of water. The main water body, Hauser Reservoir, has a useable storage of 52,893 acre-ft. A smaller water body, Lake Helena, has 11,360 acre-ft of useable storage. Mean depth of the reservoir is 25.8 feet at full pool with a mean water residence time of about 9 days.

The monitoring point below Canyon Ferry Dam (Canyon Ferry) will be used to define water quality parameters above Hauser Lake. The monitoring point below Hauser Dam (Hauser) is roughly 0.2 miles below the power plant on the left bank (**Figure 1-11**), and is a single point, depth integrated sample.

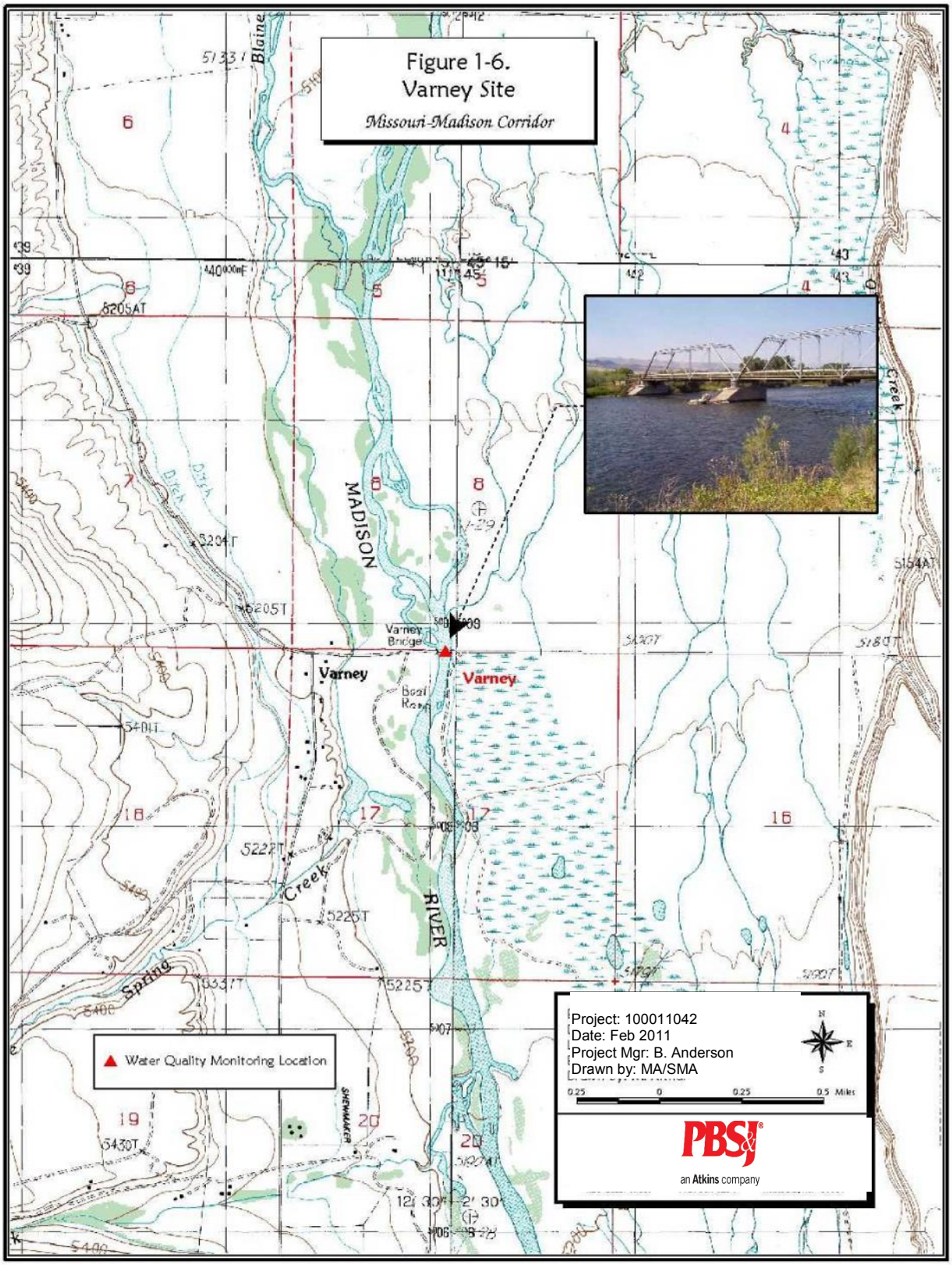



**Figure 1-6. Varney Site**

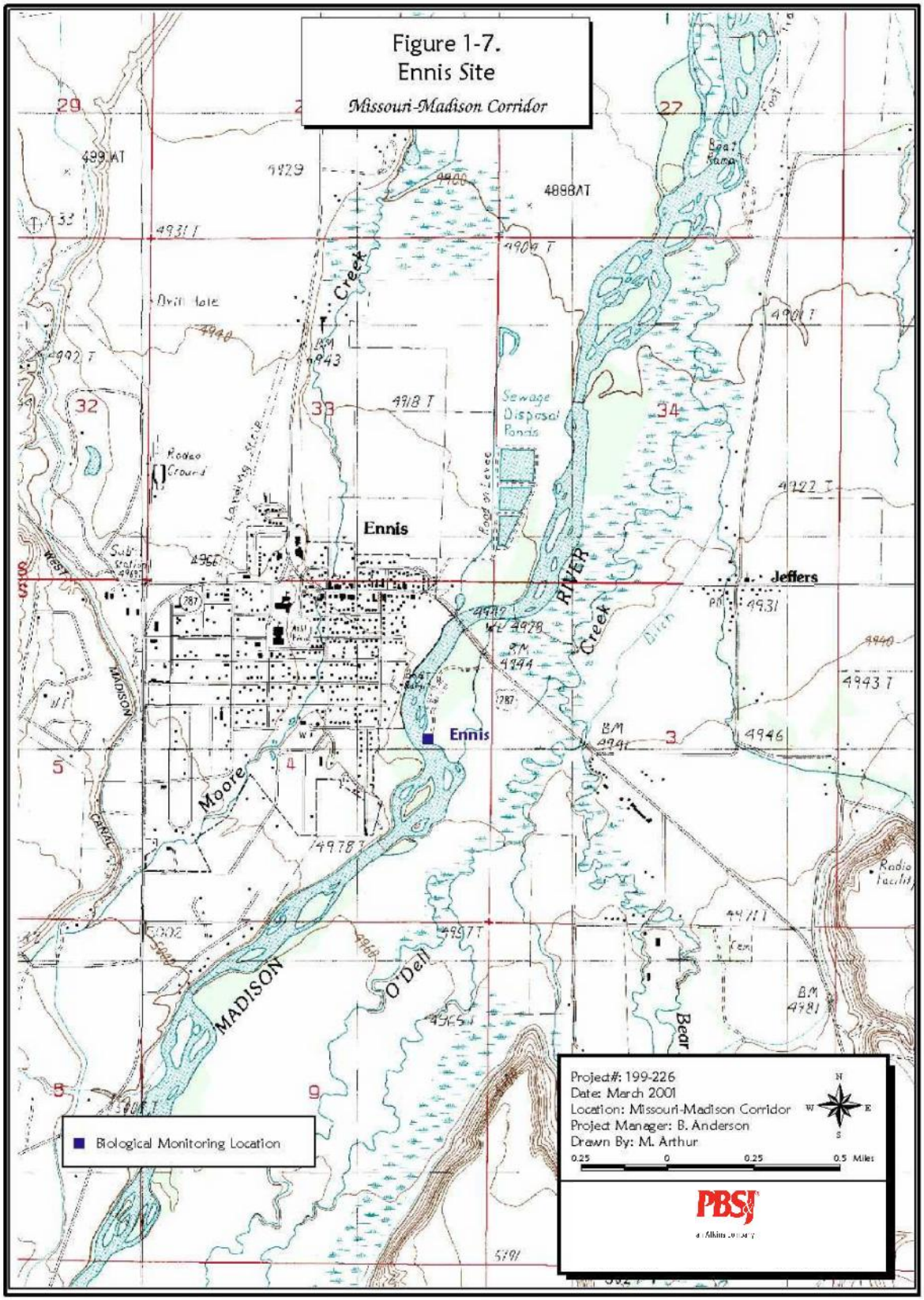



**Figure 1-7. Ennis Site**

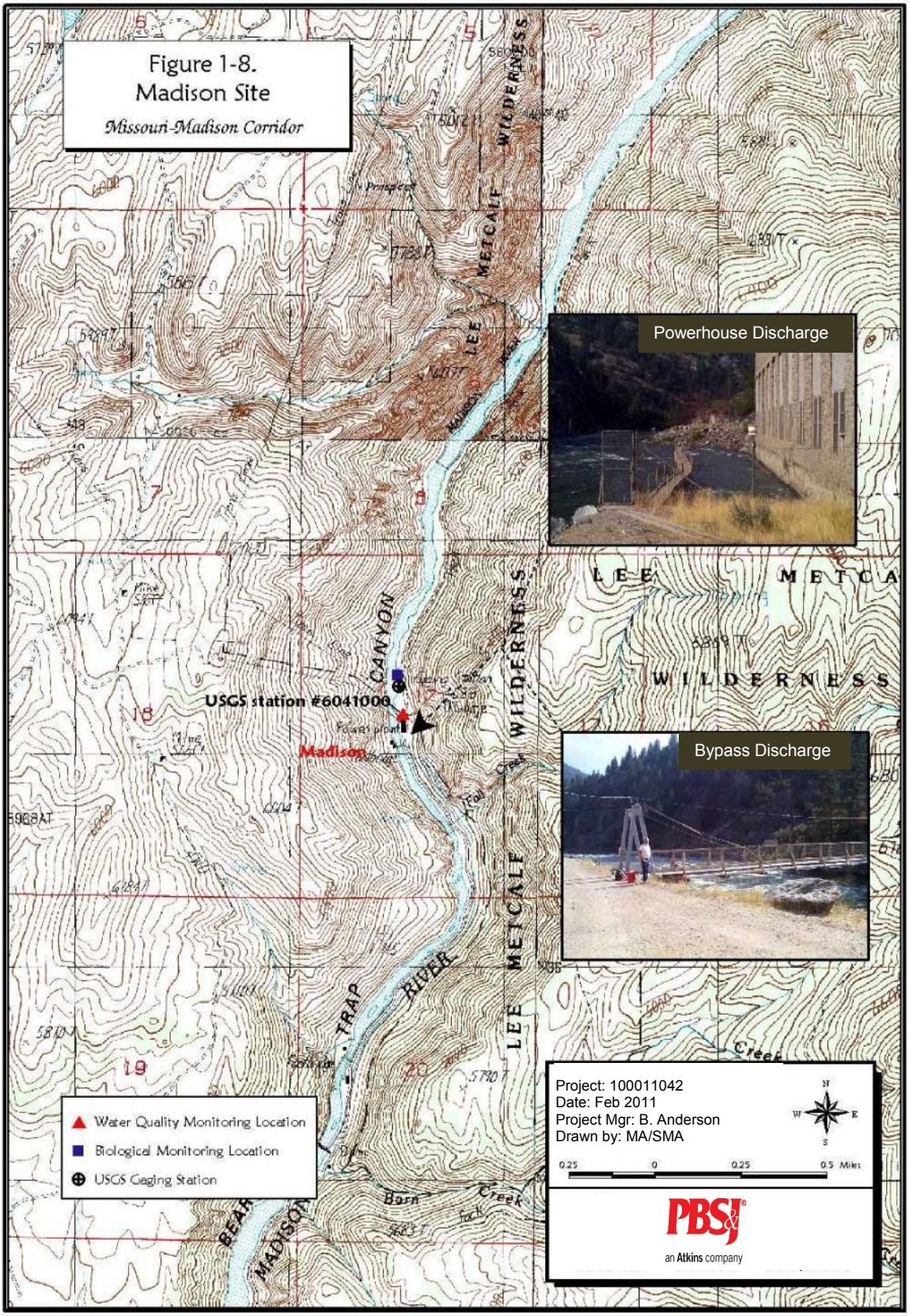



**Figure 1-8. Madison Site**

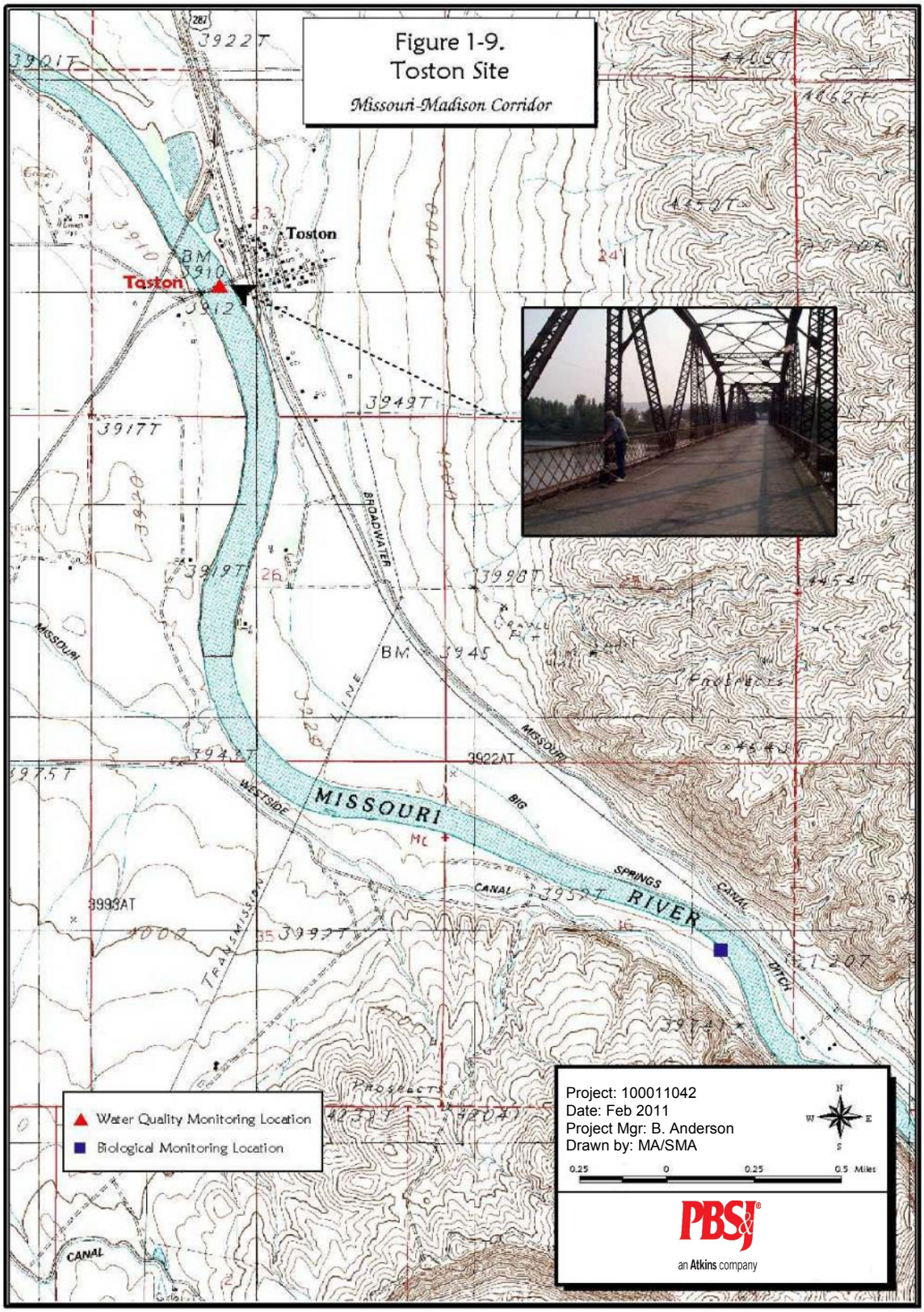



**Figure 1-9. Toston Site**


**Figure 1-10. Canyon Ferry Site**

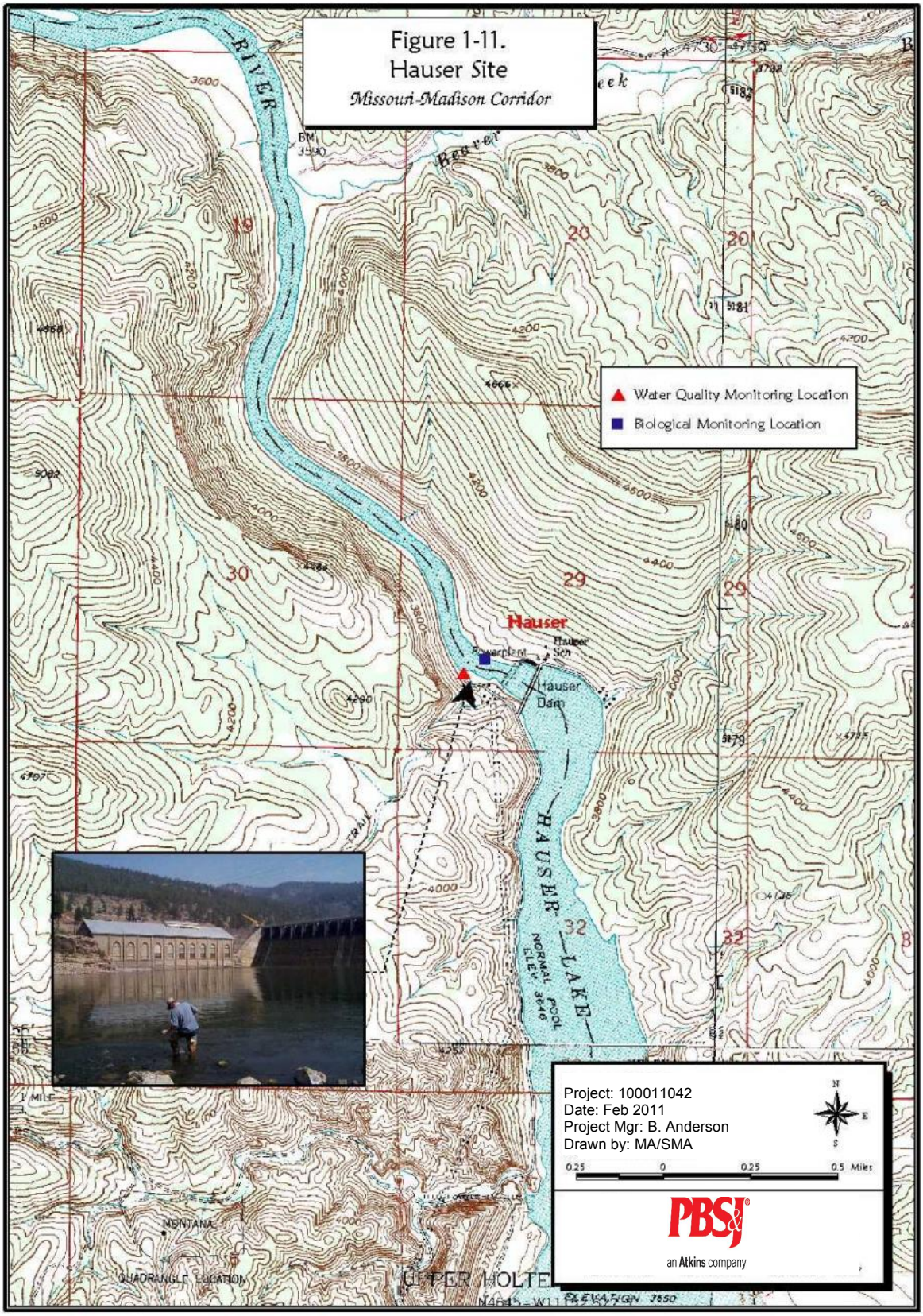



**Figure 1-11. Hauser Site**

### *1.1.5 Holter Dam*

Holter Reservoir is located about 27.7 miles downstream of Hauser Dam, and 43 miles northeast of Helena, Montana. The reservoir intercepts a drainage area of about 17,150 square miles. The dam is a 124-foot high, straight concrete gravity structure with an ogee spillway section that is 682 feet long. The dam impounds 81,920 acre-ft of useable storage with a surface area of 4,550 acres and is operated primarily as a run-of-the river facility. Mean water residence time in the reservoir is 22 days. The Holter Reservoir biological monitoring site is located approximately 0.3 miles downstream from the USGS gage on the left bank.

The monitoring point below Hauser Dam (Hauser) will be used to define water quality and biological parameters above Holter Lake. The monitoring points below Holter Dam (Holter) are below the power plant on the left bank (**Figure 1-12**), and taken as a single point, depth integrated sample.

### *1.1.6 Great Falls Dams*

The Great Falls dams consist of a series of five hydroelectric developments within a 12.1-mile section of the Missouri River. The cumulative effects of the five Great falls dams (Black Eagle, Rainbow, Cochrane, Ryan, and Morony) will be evaluated using monitoring points above Black Eagle and below the Morony dams. Brief descriptions of each of the dams are presented below, along with a description of the monitoring points for this study.

Black Eagle Dam is located in Great Falls, 93 miles downstream from Holter Dam. The Sun River empties into Black Eagle Reservoir 3.8 miles upstream from Black Eagle Dam. The reservoir intercepts a drainage area of about 22,100 square miles. The dam is operated as a run-of-the river facility. The dam impounds 1,710 acre-ft of useable storage between elevations 3,279 and 3,290 feet, with a surface area of 402 acres.

The Rainbow Development is located 6 miles northeast of Great Falls, 3.2 miles downstream from Black Eagle Dam. The reservoir intercepts a drainage area of about 22,920 square miles. The dam is operated as a run-of-the river facility. The dam impounds 1,170 acre-ft of useable storage, with a surface area of 126 acres.

The Cochrane Development is located northeast of Great Falls, 3.2 miles downstream from Rainbow Dam. The reservoir intercepts a drainage area of about 23,270 square miles. The dam is operated as a run-of-the river facility. The dam impounds 4,503 acre-ft of useable storage, with a surface area of 249 acres.

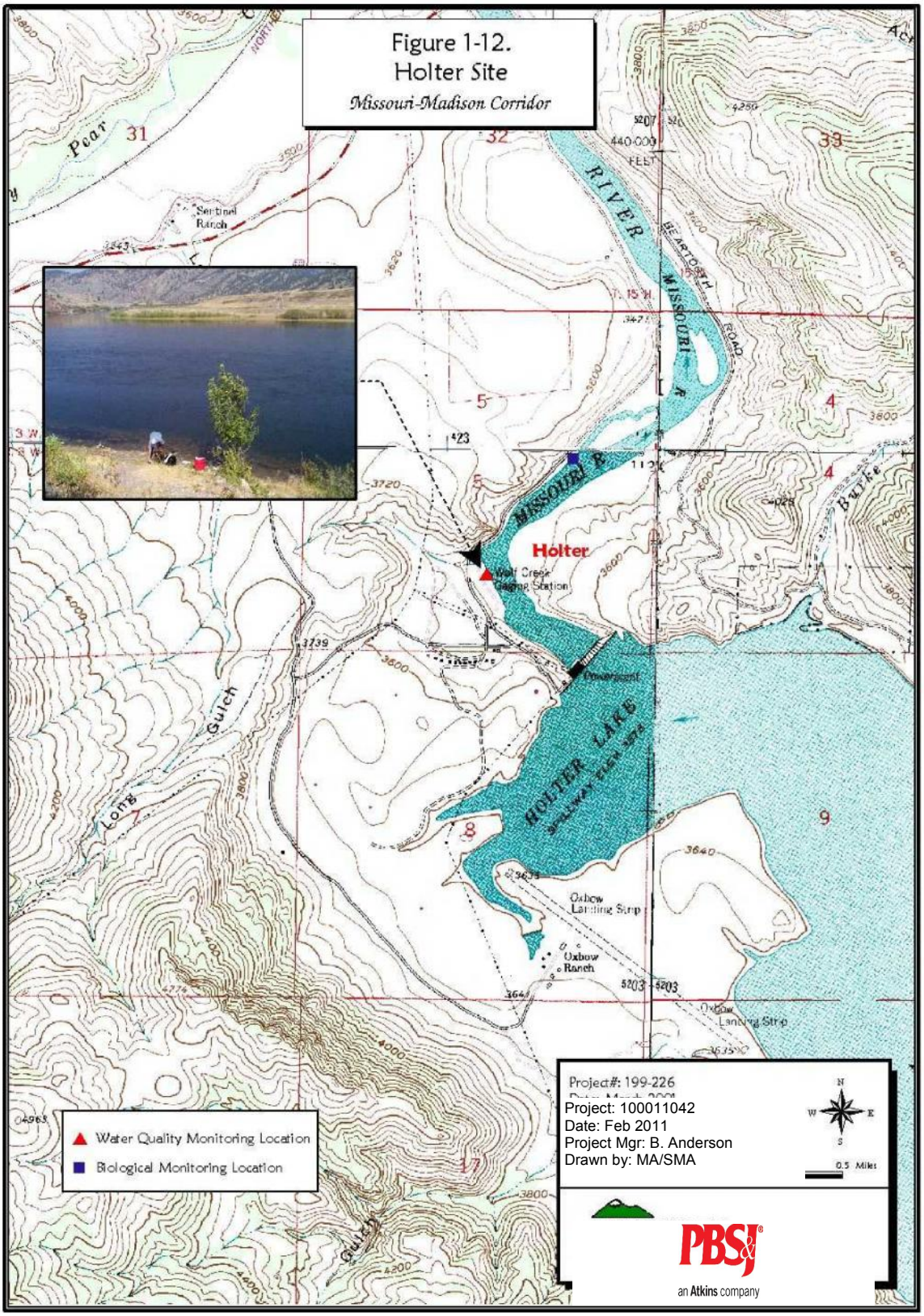



**Figure 1-12. Holter Site**

The Ryan Development is located northeast of Great Falls, 1.9 miles downstream from Cochrane Dam. The reservoir intercepts a drainage area of about 23,080 square miles. The dam is operated as a run-of-the river facility. The dam impounds 3,653 acre-ft, of which 2,440 acre-ft is useable storage, with a surface area of 168 acres.

The last of the five dams, Morony Dam, is located northeast of Great Falls, 3.9 miles downstream from Ryan Dam. The reservoir intercepts a drainage area of about 23,292 square miles. The dam is operated as a run-of-the river facility. The dam impounds 7,595 acre-ft of useable storage, with a surface area of 304 acres.

Only water quality parameters have been monitored above the dams in the Great Falls area. The location (Black Eagle) is above the Black Eagle reservoir on the Central Avenue Bridge in Great Falls (**Figure 1-13**) and sampling is comprised of 12 equal width, depth integrated samples. Both water quality and biological parameters are monitored downstream of the Great Falls dams. The water quality monitoring point (Morony) is located off the discharge structure of the Morony Dam (**Figure 1-14**). Sampling of the penstock discharge is a single point depth integrated sample. The biological location is 0.2 miles below the dam on the left bank.

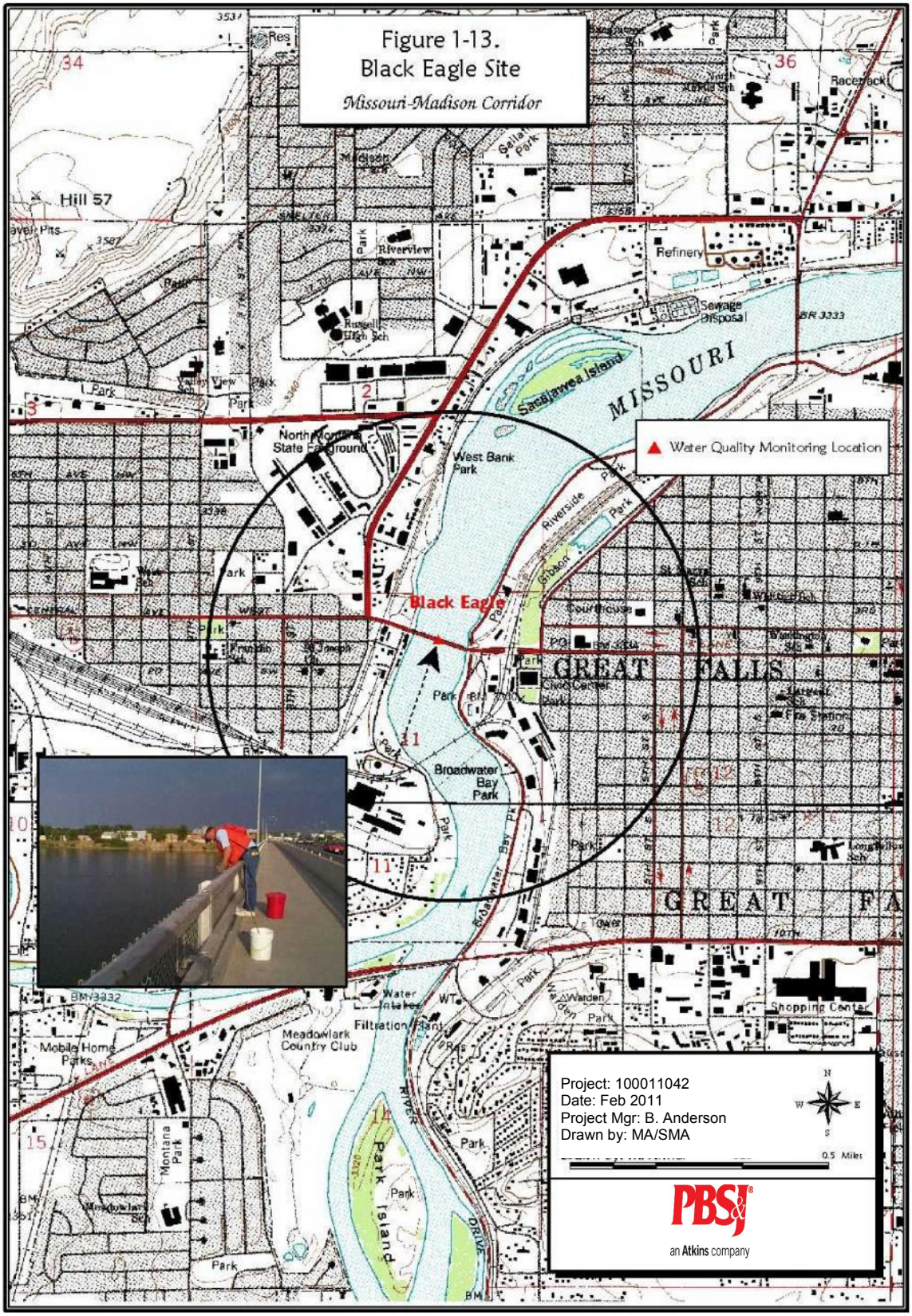



**Figure 1-13. Black Eagle Site**

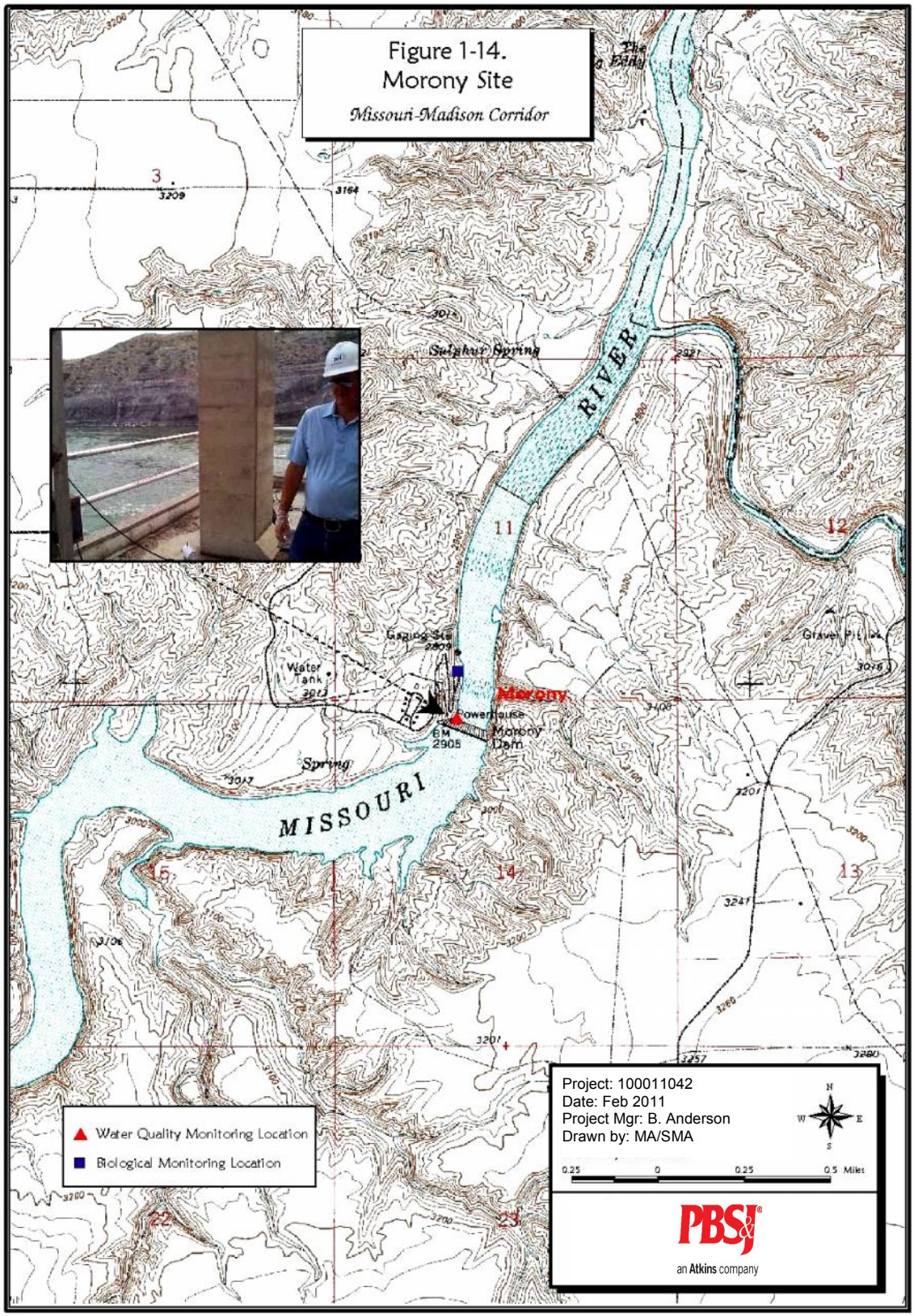



**Figure 1-14. Morony Site**

## 2.0 PREVIOUS INVESTIGATIONS AND PILOT PROGRAM RESULTS

Pilot programs for biological and water quality monitoring of the Madison and upper Missouri rivers began in earnest in 1994 and 1996, respectively. Pilot phase monitoring programs were initiated to evaluate water quality and refine long term monitoring network requirements. A small amount of data was collected prior to these pilot studies.

Previous water quality and biological monitoring evaluations are summarized below, with the monitoring locations for these studies shown on **Figure 1-2** through **Figure 1-14**. Greater detail can be found in the references provided.

### 2.1 Water Quality

Four locations in the study area have been monitored by the United States Geological Survey (USGS). The USGS data was summarized and evaluated by Land & Water (1998). The data collected by the USGS included flow and various water quality parameters. Sample frequency and continuity were variable; the most useable data covering the period of 1978 to 1995. The stations evaluated include:

1. USGS #6037500, above Hebgen, 4/89-9/95
2. USGS #6038500, below Hebgen, 10/89-8/95
3. USGS #6041000, below Madison Dam, 10/89-8/95
4. USGS # 6054500, Toston Bridge, 12/78-8/95

Water quality data was collected by the Montana Power Company at ten monitoring stations (**Figure 1-2**) on the Madison and upper Missouri rivers between 1996 and 1999 as part of the pilot phase monitoring program. The USGS data and the MPC data from 1996-1997 was used to develop a plan for continued monitoring (Land & Water 1998).

Pilot program sampling was performed on roughly a monthly basis, with the exception of low flow winter months. These data were evaluated to determine the statistical power of the network to detect trends in water quality (Land & Water 1998 and 2000). Important findings of the water quality evaluation include:

- Many parameters showed strong correlation of concentration to flow (35% of parameters) and season (52% of parameters).
- Autocorrelation effects resulted in smaller effective sample populations, and reduced the power to detect trends in the raw datasets.
- Approximately 27% of the parameters had normal data distributions for raw data. Parametric statistics such as confidence intervals around the mean become increasingly unreliable as distributions depart from normal. Use of parametric measures with non-normal data must be recognized as approximate. Flow and seasonal adjustments improve the normal distribution of many parameters.
- Data variability, expressed as coefficient of variation (CV) varied considerably with parameter and location. Major ions, TDS, and arsenic had the lowest variability (10% to 25%), while trace metals and turbidity/TSS had the variability (60% to over 100%).
- Statistical adjustments for flow and seasonal effects were completed for selected parameters. The resulting datasets suggested that trend detection capabilities could be improved by accounting for flow and seasonal factors. Adjusted parameters had absolute CV reductions of 12% to 75%.
- An alternative sampling strategy of alternating monthly and quarterly sampling was evaluated. Although this strategy provides fewer data points, trend detection capabilities comparable to continuous monthly sampling are possible using a step test methodology.

- The use of turbidity as a surrogate appeared to be viable for certain parameters/ locations (e.g. TSS at Madison Reservoir, Toston, Great Falls and Morony).
- Monitoring for water quality parameters has been on-going through 2010 following the monitoring plan established in 2000 (Land & Water 2000).

## 2.2 Biological Monitoring

Periphyton pilot phase sampling was conducted from 1994 through 1998 on the Madison and upper Missouri rivers by the Montana Power Company. This sampling was performed to support relicensing of the hydro facilities on these rivers by FERC. Samples were collected annually and analyzed for biomass, Chlorophyll *a*, species composition, and community structure. Data from 1997 and 1998 were evaluated by Bahls (1999b). Additional periphyton data was also presented by Bahls (1997, 1998, and 1999a). Prior to the pilot phase sampling program, periphyton samples were collected by the Montana Department of Health and Environmental Sciences in 1993 (Bahls, 1996).

Macroinvertebrate pilot phase monitoring was also conducted between 1994 and 1998. The 1994 through 1996 data were presented and evaluated by McGuire (1996 and 1997). An evaluation of the 1997 and 1998 data was provided by McGuire (1999), along with a summary of the earlier data.

### *2.1.1 Periphyton*

Results of the periphyton pilot data evaluation (Bahls, 1999b) were presented in terms of biomass (ash-free dry mass or AFDM, Chlorophyll *a*, and autotrophic index or AI) and assorted metrics. Coefficients of variation (CV) of replicate values ranged from less than 50% (Toston) to 285% (Ennis), with the rest falling between 60% and 180%.

An AFDM guideline of 50,000 mg/m$^2$ was used because extensive smothering of bed sediments may be expected above this level (Bahls 1999b). Mean values of AFDM replicates indicated problematic levels of periphyton biomass at all sites except YNP. Periphyton standing crops tended to increase in a downstream direction, with the threshold being exceeded most frequently below Hauser Dam.

Chlorophyll *a* levels above 100 mg/m$^2$ are considered to represent severe impairment and non-support of fish and aquatic life uses. Based on this guideline, problematic standing crops of benthic algae were identified at all sites except Ennis. Mean Chlorophyll *a* levels exceeded the threshold level every year from 1995 to 1998 below Hauser, Holter, and Morony dams, often by a factor of three or four. Unregulated sites generally had significantly lower Chlorophyll *a* levels than the regulated sites. It should be noted that AFDM/Chlorophyll *a* guidelines developed for smaller wadeable rivers may not be strictly applicable to the Missouri-Madison system, and are provided for comparative purposes.

Mean AI values tended to decline in the downstream direction. Mean AI values were also higher at unregulated sites, indicating that periphyton communities at these sites contained larger proportions of non-algal biomass (bacteria, rotifers, fungi, protozoa, nematodes, detritus, etc.).

Other key data summary items include:

- Sites that had problematic levels of AFDM and Chlorophyll *a* were dominated by conspicuous filamentous green macroalgae.
- Diatom species diversity values exceeded the threshold of low diversity indicating non-impairment at all stations on all dates. Diatom diversity values and number of species counted were all within the range measured for least-impaired reference streams in western Montana.

- Pollution index values also exceeded the threshold of moderate impairment indicating non-impairment at all stations on all dates except YNP in 1994.
- Siltation index values exceeded the threshold for moderate impairment indicating non-impairment at least once at all sites except YNP.
- Only the siltation index at Ennis in 1993 resulted in a "poor" rating, all other limiting diatom metrics indicated "fair" biological integrity and partial support of aquatic life uses.

The evaluation also provided six recommendations for the periphyton monitoring program. These recommendations are summarized as follows:

1. Suggest limits for mean periphyton biomass values and ratings of biological integrity. Proposed criteria would serve as action levels for additional study or review and include:
   - Biomass: Upper limit of one standard deviation above the highest recorded mean at each site. Lower limit of one standard deviation, or one order of magnitude below the lowest recorded mean (if one S.D. is a negative value).
   - Composition and Structure: Lower limits defined by the ratings of biological integrity for the baseline data. Worse ratings than baseline values would be considered an adverse change in biological integrity.

2. Resume monitoring of periphyton at the YNP site, and continue monitoring at the Ennis site, or at another nearby.

3. Optical densities of chlorophyll samples should be measured both before and after acidification in order to adjust calculated Chlorophyll *a* concentrations. This would avoid potentially overestimating Chlorophyll *a* due to degradation compounds (e.g. pheophytin).

4. Use a spatially representative biomass sampling approach, as opposed to selecting heaviest growth areas for future sampling. This will avoid biased results and excessively high CV's.

5. Sample periphyton during or as close as possible to the August 8-14 "window". This period approximates the time of peak algal growth, and corresponds to the summer period for which diatom biocriteria have been developed.

### *2.1.2 Macroinvertebrates*

The macroinvertebrate data were analyzed using a composite (multimetric) assessment, as well as an evaluation of the individual metrics. Detailed descriptions of the metrics used are presented in **Section 5.3.2** of this plan. Results of the metric analysis of the pilot data are summarized as follows:

- Percent Community Similarity Index (PCS): A comparison of community similarities showed that the Madison River stations had unique benthic communities, and the Missouri River stations were split into two groups with similar characteristics (Holter/Hauser, and Toston/Morony).
- Macroinvertebrate Density: Macroinvertebrates were most abundant below Holter and Hauser dams (2,900 and 2,000 organisms per sample), potentially indicating organic enrichment from upstream reservoirs. Densities were lowest at Hebgen and Ennis (average of 500 to 550 organisms per sample).
- Taxa Richness: Samples from Hebgen and Ennis had the highest number of taxa, interpreted as a measure of good health of the ecosystem. Toston and Morony had the highest taxa richness of the Missouri River sites. Four-year mean values ranged from 18 at Hauser to 31 at Hebgen.
- Shannon Diversity: The highest diversities (greater than 3.0) were at Hebgen, Ennis, Toston, and Morony. Diversities for the four-year period ranged from 2.5 at YNP to 3.8 at Hebgen. Low

diversities below Ennis, Hauser, and Holter reservoirs reflect thermal modifications and organic enrichment from upstream impoundments.

- Biotic Index: This index is on a scale of 0 to 10, with higher values indicating more eutrophic conditions. Mean values ranged from 3.8 to 6.2. Ennis had the lowest (best) index value. More eutrophic conditions were indicated below Ennis, Hauser, and Holter reservoirs.
- EPT Richness: This is a measure of mayflies, stoneflies, and caddisflies, and increases with improving water quality. Mean values ranged from 17 to 5 taxa per sample. Values exceeded 15 at Hebgen, Ennis, and Toston, but averaged less than 8 below Ennis, Hauser, and Holter reservoirs.
- Percent EPT Relative Abundance: Lower values suggest increased environmental stress. Mean values ranged from 78% at Toston to 34% at YNP. Values exceeded 60% at Hebgen, Ennis, Toston, and Morony. Mean values were below 40% at YNP, Madison, and Hauser.
- Percent Chironomidae Relative Abundance: Higher values of this measure are indicative of declining water quality. Mean values ranged from 6 to 30%. Values exceeded 20% below Hebgen, Hauser, and Morony dams.
- Amphipoda to Isopoda Ratio: This measure ranges from 0 to 1, with lower values indicating dissolved oxygen limiting conditions. Four-year average values were 0.01 at Madison, 0.14 at Hauser, and 0.30 at Holter. Values were higher during 1994 at Hauser (0.75) and Holter (0.54).
- Multimetric Assessment: This approach combines seven metrics into a composite score. Scores ranged from 27 to 97% for the four-year period. Scores were higher at Ennis and Toston than at sites below the dams. In the Madison River, Ennis (94%) had only slightly higher scores than Hebgen (81%), with Madison having a much lower score (44%). Mean scores for the Missouri River sites were 83% at Toston, 71% at Morony, 57% at Holter, and 39% at Hauser.

McGuire (1999) concluded that the monitoring locations are adequate to evaluate long-term trends in ecological effects and dam effects. The multimetric assessment was considered tentative, and may require refinement as the monitoring proceeds. Two recommendations were provided in the evaluation:

1. Relocate the Ennis site from the current depositional site. This site was moved upstream to a site with cleaner substrate in 1999.
2. Additional sampling sites could be included below the Madison Powerhouse to document the downstream extent of low dissolved oxygen impacts. Review of this data may be helpful to identify a site that better reflects more typical conditions.

McGuire has continued macroinvertebrate sampling as described in the hydro facility monitoring plan (Land & Water 2000).

### *2.1.3 Fish Tissue Biocontaminants*

MPC and Montana Fish, Wildlife and Parks personnel collected six fish samples from each of four reservoir sites (Hebgen, Madison, Hauser, Holter) in 1994. Additional sampling was conducted in 1995. Three individuals of a predatory species and three individuals of a bottom-feeding species were collected at each fish sampling site. The following discussion is derived from Palawski, Pickett, and Olsen (1995).

Trace element samples were analyzed for the following elements: aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium, strontium, vanadium, and zinc. Organochlorine samples were analyzed for aldrin, alpha-BHC, beta-BHC, delta-BHC, gamma-BHC, p,p'-DDD, p,p'-DDE, p,p'-DDT, dieldrin, alpha-endosulfan, beta-endosulfan, endosulfan sulfate, endrin, endrin aldehyde, heptachlor, heptachlor epoxide, p,p'-methoxychlor, technical chlordane, toxaphene, PCB. Fish were analyzed as individual whole-body samples and were reported on a wet weight basis.

Predatory fish collected included mountain whitefish (Prosopium williamsoni), brown trout (Salmo trutta), and rainbow trout (Onchorhynchus mykiss). Bottom feeding fish sampled were longnose suckers (Catostomus catostomus) and white suckers (Catostomus commersoni).

Among brown and rainbow trout, concentrations of all elements appeared generally higher at the upstream sites and lower in downstream reaches of the Missouri-Madison system. The higher trace element concentrations observed in brown and rainbow trout collected from upstream sites likely reflected the higher background concentrations of trace elements observed in sediments collected from the upper Missouri and Madison Rivers. No spatial difference was observed in longnose suckers. Mountain whitefish and white suckers were sampled from only one site each, and no spatial inferences could be made. Coefficients of variation for trace metals (estimated from ranges) were similar for rainbow trout and longnose suckers, and averaged 16% and 15% overall in 1994-1995.

Compared to trace element concentrations in fish of the same or similar taxa collected from National Wildlife Refuges and Waterfowl Production Areas in Montana (Palawski et al. 1991), arsenic, selenium, and strontium in fish collected during this study appeared elevated. Many of the fish collected by Palawski et al. (1991) came from west of the continental divide, where trace element concentrations in general and strontium concentrations in particular are lower in sediments and biota than they are east of the divide. Arsenic, copper, and selenium in some rainbow and brown trout and in longnose suckers and mountain whitefish exceeded the geometric mean concentrations of those elements reported by Lowe et al. (1985) in a nationwide survey of freshwater fish.

Seven organochlorine compounds were detected in fish tissue in 1994. Those were beta-BHC, p,p'-DDD, p,p'-DDE, p,p'-DDT, dieldrin, endrin, and heptachlor. Residues of at least one compound were detected in all species except white suckers. The most frequently occurring compound among those detected was p,p'-DDE. The other compounds were detected most frequently in rainbow trout and longnose suckers. No geographical pattern in organochlorine residue occurrence was apparent. Sample sizes were small (n=1 to 3), and based on reported ranges, coefficients of variation for detected organic compounds ranged from an estimated 22% to 46%.

DDE was the most commonly detected organochlorine compound in fish collected elsewhere in Montana and the north-central United States (Martin and Hartman 1985, Schmitt et al. 1985, Schmitt et al. 1990). Concentrations of organochlorine compounds detected in this study were similar to the concentrations reported by Martin and Hartman (1985) and considered by them to be relatively low. Schmitt et al. (1985, 1990) reported organochlorine concentrations from brown trout and white suckers collected from the Missouri River at Great Falls that were very similar to the concentrations reported for those species in the 1994 sample event. Phillips and Bahls (1994) reported no detectable PCBs in fish from Hebgen and Hauser Reservoirs, but did find low PCB concentrations in walleye from Holter Reservoir.

With the exceptions of some trace elements in sediment from upstream reservoirs, trace element and organochlorine concentrations in sediment and fish collected from reservoirs on the Missouri and Madison Rivers were typical of concentrations reported from elsewhere in the Missouri River drainage and the western United States. The study concluded that observed concentrations represented a baseline contaminant level in fish associated with the Madison-Missouri River Hydro-Projects (Palawski, Pickett, and Olsen 1995).

## 3.0 MONITORING OBJECTIVES

The overall objectives of the Missouri-Madison water monitoring program (**Section 1.1**) included the following:

1. Provide a statistical analysis of long-term trends in water quality and biological data;
2. Evaluate the potential influence of dam facilities on water quality and biological parameters with above/below comparisons;
3. Monitor the effects of operation and maintenance of dam facilities on water quality and biological parameters;
4. Evaluate the behavior of the entire system with respect to water quality and biological parameters; and
5. Determine whether trends suggest an improvement or deterioration of water quality, biological integrity, and ecological health of the Madison and Missouri river system.

The present report includes 1) trends analysis, 2) assessment of upstream/downstream water quality from hydro facilities, and 3) conclusions regarding trends in the overall health of the Madison and Missouri river system for the ten year period 1997-2006. Specialized studies documenting operational effects such as pulse flow to moderate temperature are covered by other investigators.

### 3.1 Water Quality Monitoring

Monitoring objectives and analyses are outlined in the following table and are summarized in **Table 3-1, Appendix A**. Referenced statistical methodologies are outlined in **Section 5**. All Missouri-Madison water monitoring program objectives were met.

#### *3.1.1 Long-term Trend Identification*

| | |
|---|---|
| MANAGEMENT GOAL: | Maintain or improve water quality. |
| MONITORING GOAL: | Detect significant temporal (5 to 10 year) trends in water quality parameters. |
| DEFINITION OF WATER QUALITY: | Analysis of nutrient, metals, and other parameters defined in **Table 4-1, Appendix A.** |
| DEFINITION OF TREND: | Correlation between concentration and time at the 0.05 significance level. |
| STATISTICAL METHODOLOGY: | Kendall non-parametric test applied to flow and seasonally adjusted data as appropriate. |
| STATISTICAL HYPOTHESIS: | No trend exists. |
| DATA ANALYSIS RESULT: | Conclusions regarding presence and nature of trends (statistical significance of +- correlation); provide estimate of trend magnitude (Sen slope estimate). |
| INFORMATION PRODUCT: | Management goal met when no trend exists, or indicates improvement in water quality (e.g. decreasing trend for nutrient concentration) |

### *3.1.2 Dam Baseline Evaluation, Routine Operations*

| | |
|---|---|
| MANAGEMENT GOAL: | Maintain or improve water quality downstream of dam facilities. |
| MONITORING GOAL: | Detect and quantify significant differences in parameters above and below each dam. Determine if differences suggest dam-related improvement or impact on water quality. |
| DEFINITION OF WATER QUALITY: | Analysis parameters defined below in **Table 4-1, Appendix A.** |
| DEFINITION OF EFFECT: | Differences in median response, 0.05 significance level. |
| STATISTICAL METHODOLOGY: | Kruskall Wallace non-parametric test applied to paired parameter data, seasonally stratified as appropriate. |
| STATISTICAL HYPOTHESIS: | No differences in median values exist. |
| DATA ANALYSIS RESULT: | Conclusions regarding presence and nature of facility effects. |
| INFORMATION PRODUCT: | Management goal met when no upstream/downstream differences exist, or results indicate stability or improvement in water quality over time. |

## 3.2 Biological Monitoring

The objectives of the biological monitoring portion of this plan are presented below and follow the format presented in **Table 3-1, Appendix A**.

### *3.2.1 Periphyton Long-term Trend Identification*

| | |
|---|---|
| MANAGEMENT GOAL: | Maintain or improve periphyton integrity. |
| MONITORING GOAL: | Detect significant trends in periphyton standing crop.<br>Determine if trends suggest dam related improvement or deterioration of water quality. |
| DEFINITION OF WATER QUALITY: | AFDM, Chlorophyll *a*, various metrics. |
| DEFINITION OF TREND: | Correlation between parameter and time to the 0.10 significance level. |
| STATISTICAL METHODOLOGY: | Kendall non-parametric test applied to seasonal or covariate-adjusted data as necessary. |
| STATISTICAL HYPOTHESIS: | No trend exists. |
| DATA ANALYSIS RESULT: | Conclusions regarding presence and nature of trends in periphyton biomass or metrics, and provide estimate of trend magnitude(s). |
| INFORMATION PRODUCT: | Management goal met when no trend exists, or indicates improvement (i.e. a reduction in biomass for most sites). |

### *3.2.2 Macroinvertebrate Long-term Trend Identification*

| | |
|---|---|
| MANAGEMENT GOAL: | Maintain Or Improve Macroinvertebrate Integrity. |
| MONITORING GOAL: | Detect significant trends in composite ("multimetric") measures of macroinvertebrates. Determine if trends suggest an improvement or deterioration of water quality. |
| DEFINITION OF WATER QUALITY: | Multimetric scores. |
| DEFINITION OF TREND: | Correlation between parameter and time to the 0.10 significance level. |
| STATISTICAL METHODOLOGY: | Kendall non-parametric test applied to seasonal or covariate-adjusted data (as necessary). |
| STATISTICAL HYPOTHESIS: | No trend exists. |
| DATA ANALYSIS RESULT: | Conclusions regarding presence and nature of trends.<br>Provide estimate of trend magnitude. |
| INFORMATION PRODUCT: | Management goal met when no trend exists, or indicates improvement in benthic community integrity. |

### *3.2.3 Fish Tissue Biocontaminants*

| | |
|---|---|
| MANAGEMENT GOAL: | Maintain or improve (i.e. reduce) biocontaminant levels in fish tissue. |
| MONITORING GOAL: | Detect significant differences in biocontaminant levels over 4 year period[11]. |
| DEFINITION OF WATER QUALITY: | Analysis of metal and organochlorine parameters defined in **Section 4.1, Appendix A.** |
| DEFINITION OF TREND: | Detect a 40% difference in mean or median concentrations at 80% power, 90% confidence. |
| STATISTICAL METHODOLOGY: | Wilcoxon rank sum test (or Kruskall-Wallace), confidence level set at 0.10. |
| STATISTICAL HYPOTHESIS: | No statistical difference exists between mean or median values. |
| DATA ANALYSIS RESULT: | Conclusions regarding potential changes in biocontaminant levels in fish tissue. |
| INFORMATION PRODUCT: | Management goal met when no statistically significant increases occur in biocontaminant levels. |

[1] *Trace metals will be sampled every three years; organochlorine compounds every 9 years*

# 4.0 DATA COLLECTION AND SAMPLE ANALYSIS

This section outlines the methodology for the collection of water quality and biological samples, sample analysis, and the measurement of dam operation parameters.

## 4.1 Sample Collection

Sample collection methodology for water quality and biological sampling was refined during the pilot monitoring studies and is summarized below. The sampling and analysis methodology is also summarized in **Table 4-1**.

### *4.1.1 Water Quality*

The water quality sampling consisted of collection of either single point depth integrated samples, or depth integrated, equal width increment composites at each monitoring location. Grab samples were collected from the bank in a well-mixed portion of the river. Sample bottles were rinsed three times with native water (or filtered native water) prior to sampling. Samples were taken in the upstream direction to avoid entrainment of sediment disturbed by wading.

Samples were transferred to a decontaminated teflon churn splitter, stored with blue ice, and sealed in a secure container (wrapped in plastic in a soft cooler) until processing. Processing and splitting of sample aliquots occurred at the end of each day in a clean indoor location. Filtration with a 0.45um filter for dissolved parameters was done as a batch process within 8 hours of sampling. All sample bottles were virgin polyethylene bottles supplied by Energy Labs in Billings, Montana.

Quality control samples were analyzed for water quality parameters. These samples generally consisted of one replicate for every ten samples, and one equipment blank for each sampling event. The replicate was a sequential sample taken at one of the locations as a control measure of both field variability, sample processing procedures, and laboratory methodology. The equipment blank was a deionized water sample run through the sampling apparatus after standard decontamination procedures and analyzed for the full suite of water quality parameters. The blank primarily represented a quality control measure of lab methodology, but also integrated procedural aspects such as decontamination and sample handling.

The sampling methodology described above conformed to the standard operating procedures described in the document "*Monitoring and Data Management Standard Operating Procedures Manual.*" This document is found at the Montana Department of Environmental Quality web site.

### *4.1.2 Biological Monitoring*

Periphyton biomass and Chlorophyll *a* sampling methodology (Bahls, 1999) consisted of collecting replicate samples that represent the range of crops that are present at each site. The pilot study recommended the use of spatially representative biomass sampling instead of selecting heaviest growth areas. A square area of 6.45 $cm^2$ (2.54 cm on a side) was scraped from each of ten rocks selected in this manner. Replicate samples are placed in opaque, 250 ml wide-mouth poly bottles. Samples were preserved by freezing on dry ice. The samples are then transported in a cooler with dry ice, and stored in a freezer until analyzed. Whole rock samples and extraction was performed as an alternative to rock template scraping if biomass accumulation was low enough to preclude use of scraping methods (Randy Apfelbeck, MDEQ, pers. comm.). A composite sample from all microhabitats was collected and preserved with Lugol's to provide a representative sample for periphyton species composition analysis.

Macroinvertebrate sampling methods were initially identified in the Biological Monitoring Plan (MDHES, 1993). These methods were modified after field testing (McGuire 1997). The modified sampling consisted of collecting five replicate samples enclosing 0.25 $m^2$ at each site. The samples were collected using a fine 560 micron mesh kicknet, and the entire sample (macroinvertebrates, vegetation, sediment, and debris) were preserved in 90% ETOH.

Fish tissue biocontaminants were evaluated for both predator species (rainbow trout or walleye), and bottom dwellers (longnose sucker or white sucker). Samples of individuals of similar size class were collected (length within 25%) for analysis as filets (predators) or whole body samples (bottom dwellers). Approximately 560 grams of tissue were required for each analysis; required a composite of multiple fish if size classes did not allow provide enough tissue from individuals. Fish were captured with electrofishing equipment, weighed, measured, wrapped in aluminum foil, and placed in double plastic bags. Fish were placed on ice in the field and then frozen until chemical analyses were performed by the laboratory. Sampling procedure conformed to recommended U.S. EPA sampling methods (Land & Water, 2000). This level of sampling intensity (4 individuals per species) was intended to allow detection of 40% differences in mean concentration at the 80% power, 90% confidence level based on an average coefficient of variation of less than 15% for trace metals. This sampling intensity conforms to the statistical performance criteria suggested by the USFWS in 1998 (Land & Water, 2000).

## 4.2 Sample Analyses

Sample analysis methodologies for the water quality and biological samples are summarized below. The sampling and analysis methodology is also summarized in **Table 4-1, Appendix A**. The methodologies presented were refined during the pilot monitoring studies.

### *4.2.1 Water Quality*

Water quality samples were analyzed for various parameters both in the field and laboratory. The parameters, analysis methods, holding times, and detection limits (**Table 4-1, Appendix A)** corresponded to the pilot study analyses. Lab analyses focused on anion/cation species, nutrient components and metals.

### *4.2.2 Biological Monitoring*

Periphyton sample analysis consisted of measurement of Ash Free Dry Mass (AFDM), Chlorophyll *a*, diatom species count, and identification of other orders/families. The methodology for these followed EPA guidance (Barbour et. al.1999). The analysis of AFDM consists of a measurement of the difference in mass between a sample after drying and after incinerating organic matter in the sample. Chlorophyll *a* was measured using a spectrophotometer or fluorometer on a sample extracted in acetone. The pilot study recommended measuring the chlorophyll optical density both before and after acidification to correct for the error associated with degraded Chlorophyll *a*. In addition, the sample analysis consisted of a diatom species count that was used to develop the metrics described in **Section 5.3.2**.

The sample processing for macroinvertebrates was described by McGuire (1999) and followed EPA guidance (Plafkin et. al.1989). This process consisted of obtaining a subsample consisting of approximately 300 organisms using RBP III techniques (Plafkin et al., 1989). The sample was placed in a US Standard #30 sieve and rinsed with water, and the entire sample was evenly distributed in a gridded enamel pan (9" x 12" or 14" x 20"). All macroinvertebrates in a randomly selected grid square were removed. This process was repeated until 270 to 330 had been picked. The total number of macroinvertebrates in the sample was estimated from the percentage of sample used to obtain 300 organisms. Rare taxa, which might be missed by subsampling, were removed from the remainder of the

sample to determine taxa richness and EPT richness for the entire sample. Macroinvertebrates in the subsample were then identified to taxonomic levels specified in the MDEQ Standard Operating Procedures manual (Section 12) and enumerated.

Fish tissue samples were analyzed for a suite of trace elements, organochlorine compounds, and PCB's as detailed in Land & Water (2000) This list of analytes conformed to reporting requirements of the USFWS. Laboratory analysis was conducted by an approved USFWS contractor. Fish were analyzed as individual whole-body samples (composited from multiple fish, if required to meet 560 gram tissue requirement), and reported on a wet weight basis.

### 4.3 Sampling and Data Collection Schedule

The schedule for collecting water quality and biological samples is presented in **Table 4-3, Appendix A**. The schedule consisted of the following:

1. Routine water quality sampling conducted on an alternating monthly or quarterly schedule;
2. Routine biological sampling conducted annually;
3. Special studies or site specific water quality sampling conducted as needed;
4. Dam non-routine operations data collected over the course of a non-routine operational event, as needed; and
5. Potential extreme event sampling if unusual runoff or other conditions dictate.

The routine sampling for water quality parameters was conducted on an alternating schedule of monthly and quarterly sampling. Monthly water quality sampling was conducted for a period of three years, followed by four years of quarterly monitoring.

Biological macroinvertebrate and periphyton sampling was conducted annually from 1997-2006. The timing of periphyton sampling generally fell within the early August "window" as defined by pilot studies. Fish tissue biocontaminant sampling occurred once every three years at each reservoir, and rotated throughout the basin so that a complete sampling cycle was obtained over 4 years.

## 5.0 DATA MANAGEMENT AND ANALYSIS METHODOLOGY

Data quality control, management, and analysis methods are summarized below.

### 5.1 Data QA/QC

Data quality assurance and quality control (QA/QC) employed procedures described in the MDEQ Standard Operating Procedures Manual (Section 11.11). These procedures included:

- Validation: review of analytical laboratory techniques including lab duplicate, matrix spikes, blanks, and surrogate recoveries to determine if the methods are within acceptable limits.
- Replicates: collection of one replicate per ten samples for water quality, and the collection of replicate samples for the biological monitoring. Replicate variability was analyzed using standard methods with objective of obtaining Relative Percent Differences (RPD's) within 10% for values greater than 5 times the method detection limit.
- Splits: splits were collected using a churn splitter to achieve equal aliquots, and samples were analyzed for the full suite of parameters.

- Field methodology: field blanks were collected for each water quality event to monitor field methodology. Methods and field sampling forms will be reviewed to assure consistency.
- Individual data which fails to achieve QA/QC objectives were flagged with appropriate qualifiers in the database.

Quality control measures were employed for the statistical analyses. These measures include testing the data for normality and adjusting for seasonal and flow effects as needed. For water quality, assigning one-half the detection limit to non-detect values and evaluating the methodology/detection limits to assure the analyses are valid. Addressing missing values and trend analyses in a consistent manner that avoids biasing the results.

## 5.2 Database Management

Baseline water quality data was housed in a Microsoft Access database at PPLM facilities. Water quality data was merged into the database through the electronic transmittal of data from the analytical laboratory. PPLM staff was responsible for managing and verifying QA/QC data entry procedures.

## 5.3 Data Analysis and Statistical Methodology

The statistical approach used for data analysis varied for water quality and biological parameters. These methods were designed to meet the objectives noted above, and have been presented in previous data evaluations (Land & Water 2000; Bahls, 1999b, McGuire 1999).

Statistical analyses evaluated whether changes in parameters or metrics indicated improving or deteriorating water quality. Analyses evaluated changes in water quality and biological conditions at each site, between upstream and downstream pairs at each dam, and for the study area as a whole.

The methods employed identify statistically significant differences temporal and spatial variability. Observed differences may be related to dam operations if the change is not accompanied by an equivalent response above the dam. Similar change identified concurrently at multiple sites may be considered as indicators of systemic or basin-wide effects.

Inter-correlations of parameters and metrics identified factors that behave in a similar fashion (i.e. co-variates) were evaluated. This information was used to interpret water quality response, and also to develop recommendations for streamlining the program through optimizing the sample collection with key indicator parameters or metrics.

### *5.3.1 Water Quality*

The water quality statistical analysis methodology is summarized in **Table 5-1, Appendix A**. The magnitude of a trend that can be detected is a function of inherent data variability and sample size. As sample size increases with continued monitoring, the power to detect trends will improve. A summary of the trends that can be detected for various sample populations is documented in the Land & Water (1999).

Data had non-detect values set to one-half the detection limit for purposes of statistical analysis. Tests for normality were conducted using the Kolmogorov-Smirnov (K-S) or Shapiro-Wilkins test to the 0.05 significance level to determine the suitability of parametric or non-parametric statistical techniques. Non-normal datasets and data with high levels of left censored data (i.e. below detection limit) will generally be analyzed using non-parametric approaches.

Previous evaluations documented a relationship of certain parameters to discharge and season. Normalizing these data to flow or season helped account for the effects of variable discharge and allow trend evaluation of residuals. Raw data were tested for correlation to discharge using Spearman's non-parametric analysis. Those parameters showing significant positive correlations were adjusted using power functions for flow (or seasonal means). Those with significant negative correlations were adjusted using inverse functions for flow or alternatively, seasonal means. Trend analysis included both raw and adjusted data series.

The datasets that resulted from this processing include:

1. Raw data sets

2. Datasets with seasonality or flow effects removed

Once the data was processed, trends in water quality were evaluated. This was accomplished as follows:

1. Long-Term Trend Identification:
   - Statistical trend analysis of concentration over time at each location using Kendall or seasonal Kendall non-parametric method and linear function for trend magnitude.
   - Correlation analysis between parameters at each location using Spearman's non-parametric method.

2. Dam Effect Evaluation:
   - Statistical comparison of parameter data for paired upstream-downstream locations using Mann Kendall non-parametric method.

Statistical methodology for time series analysis employed the non-parametric Kendall-Thiel method (USGS 1993) which is computationally similar the Sen slope/Mann-Kendall statistic.

### *5.3.2 Biological Data*

Data analysis methods for evaluating the periphyton and macroinvertebrate data are summarized below. Separate sections are provided for detailing the preparation of the periphyton and macroinvertebrate data for analysis. Both periphyton and macroinvertebrate data were analyzed using a common approach summarized in **Table 5-2, Appendix A**.

Due to the inherent challenge of identifying appropriate reference conditions for the Missouri Madison system, the evaluation of biological data will be based on data trends relative to the baseline data. Multimetric assessments will use the range of data collected during the pilot phase (baseline) to assign scores for the various metrics and allow comparison between monitored locations. The development of the scoring strategy is based on procedures outlined by the EPA (EPA, 1998), with the exception that the baseline data serves as the functional basis for the reference site.

**Periphyton Data Preparation**

Periphyton data was processed according to procedures developed during the pilot study. The data was organized into the following categories:

1. Biomass or standing crop:
   - Ash Free Dry Mass (AFDM in $mg/m^2$). A measure of periphyton biomass, preferred over dry mass because silt can account for a substantial proportion of dry mass in samples. Extensive smothering of bed sediments may be expected when AFDM exceeds 50,000 $mg/m^2$.
   - Chlorophyll *a* ($mg/m^2$). Chlorophyll *a* ranges from 0.5-2% of total algal biomass, depending on taxonomy, light, and nutrients (Barbour et al., 1999). Generally, Chlorophyll *a* levels less than 100 $mg/m^2$ will protect fish and aquatic life.
   - Autotrophic index or AI (ratio of AFDM to Chlorophyll *a*). Algae in pure culture typically contain 0.5-2.0% Chlorophyll *a*, yielding AI values between 50 and 200.

2. Diatom metrics
   - Shannon Diversity (Weber, 1973). Based on taxa richness and distribution of individuals among taxa (evenness).
   - Pollution Tolerance Index or PTI. Resembles Hilsenhoff Biotic Index (described below for macroinvertebrates). PTI is a sum of values assigned to three categories of diatoms based on their pollution tolerance. Values range from 1 (most polluted) to 3 (least polluted);
   - Siltation Index. Based on the difference between dry mass and AFDM.
   - Percent Community Similarity, or PCS (Whittaker, 1958). Referred to as the Floristic Similarity Index in the pilot study. This metric measures the similarity of community composition between two sites, and is calculated for all possible station pairings. PCS is 100% when all taxa are present in exactly the same proportion at each site.
   - Disturbance Index.
   - Number of Species Counted (Species Richness). Number of species per sample is indicative of water quality. Loss of most sensitive species to any stress will affect index.
   - Percent Abundance of the Dominant Species. A measure similar to species richness. The greater the stress the higher the percentage of the dominant (tolerant) species.
   - Percentage of Abnormal Cells. Percent of diatoms that have anomalies in striate patterns or frustules shape. This metric has been positively correlated with heavy metals contamination (Barbour et al., 1999).

The biomass or standing crop data consisted of the laboratory measured median values for AFDM and Chlorophyll *a*, along with a ratio of these two parameters. The metrics listed generally follow recommended metrics (EPA, 1998 and Barbour et al., 1999).

**Macroinvertebrate Data Preparation**

The macroinvertebrate taxa and species count data, expressed in terms of median values of the replicate samples, were used to develop various metrics in accordance with the pilot study. A total of 10 metrics were deemed appropriate in the pilot study for evaluating changes in macroinvertebrate assemblages associated with water quality and flow regimes below the dams (McGuire, 1999). These metrics generally follow EPA guidance (Plafkin et al., 1989), and included:

- Taxa Richness. Number of taxa per sample is indicative of water quality. Loss of most sensitive species to any stress will affect index.

- Shannon Diversity (Weber, 1973). Based on taxa richness and distribution of individuals among taxa (evenness).
- Biotic Index (Hilsenhoff, 1988; tolerance values from Bukantis, 1996). Also known as the Modified Family Biotic Index. Based on indicator organism approach. Index on a scale of 0-10, with higher values indicating more eutrophic conditions.
- EPT Richness. Also known as EPT Index. Total number of distinct taxa in EPT Groups (Ephemeroptera, Plecoptera, and Trichoptera or mayfly, stonefly, and caddisfly taxa). Groups are primarily intolerant species. Index increases with improving water quality.
- Percent Relative Abundance of EPT. EPT commonly the most abundant species in streams with good quality. Lower abundances are indicative of stress.
- Percent Relative Abundance of Chironomidae. These are common and tolerant species. Increased abundance is indicative of stress.
- Ratio of Amphipoda to Isopoda (Hawkes and Davies, 1971). Amphipods need high oxygen concentrations, Isopods are tolerant of low oxygen levels. Ranges from 0 to 1, with lower values indicating more eutrophic/reduced oxygen conditions.
- Community Density. Number of organisms per 0.25 $m^2$ sample. Density increases in response to organic and/or nutrient enrichment and can be used as measure of trophic status;
- Ordinal Relative Abundance.
- Percent Community Similarity, or PCS (Whittaker, 1958). This metric measures the similarity of community composition between two sites, and is calculated for all possible station pairings. PCS is 100% when all taxa are present in exactly the same proportion at each site.

The first seven metrics were used in a composite (multimetric) assessment to document trends in benthic macroinvertebrate assemblage composition and structure over time. This was accomplished by assigning a score according to the criteria shown in **Table 5-2, Appendix A**. The scoring was developed during the pilot study and reflects the range of values at study sites for the period 1995-1998.

Community density, ordinal relative abundances, and percent community similarity were also used to characterize and compare study area sites, but are not incorporated into the multimetric assessment.

**Biological Data Statistical Analysis Methodology**

Statistical analysis of periphyton, macroinvertebrate, and fish tissue data included the following, as applicable:

1. Long-Term Trend Identification:
   - Statistical trend analysis of metric data over time at each location using non-parametric Kendall method.
   - Correlation analysis between metrics at each location using Kendall.

## 6.0 ANALYSES

Spatial and temporal analyses of water quality, periphyton and macroinvertebrates are found in the following sections. For purposes of simplifying labeling in graphs and tables, monitoring stations were numbered as followed:

**Table 6-1. Station Identification and Numbering**

| Station ID | Numbering |
|---|---|
| Madison at Highway 287 | 1 |
| Madison below Hebgen Dam | 2 |
| Madison at Varney | 3 |
| Madison downstream of Ennis Powerhouse | 4 |
| Missouri at Toston | 5 |
| Missouri at Canyon Ferry | 6 |
| Missouri below Hauser | 7 |
| Missouri below Holter | 8 |
| Missouri at Central Avenue | 9 |
| Missouri below Morony | 10 |

This labeling convention was adopted for analyses in the following water quality results.

## 6.1 Water Quality Analyses

### *6.1.1 Spatial Water Quality*

A summary of water quality results are presented below in **Table 6-2**. These data represent mean values by station for parameters over the ten year monitoring period from 1997-2006. Complete descriptive statistics can be found in **Appendix B,** including summary annual statistics by station and parameter.

Concentrations of many parameters such as total/dissolved metals (e.g. cadmium, copper, lead, zinc) were either at or below detection limits throughout the monitoring network. With rare exceptions, ammonia was also below detection limits.

**Table 6-2. Water Quality Descriptive Statistics**

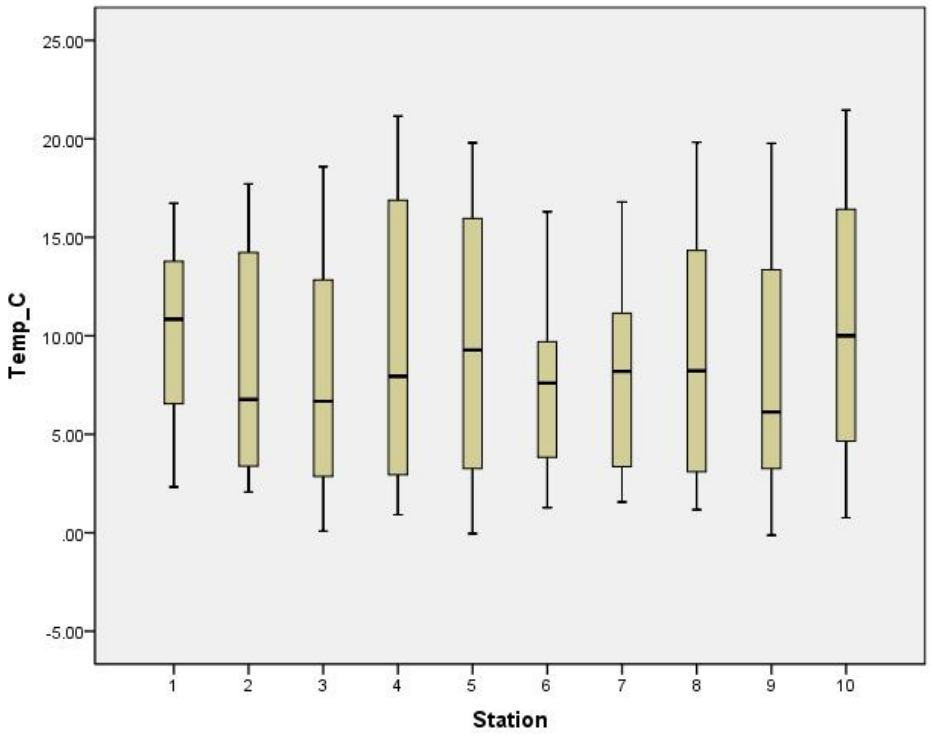
| DESCRIPTIVE STATISTICS MEAN VALUES (1997-2006) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Station 1** | **Station 2** | **Station 3** | **Station 4** | **Station 5** | **Station 6** | **Station 7** | **Station 8** | **Station 9** | **Station 10** |
| Temp_C | 9.84 | 8.18 | 7.89 | 9.65 | 9.56 | 8.21 | 9.34 | 9.78 | 9.74 | 10.17 |
| ph_field | 7.78 | 7.84 | 8.23 | 8.22 | 8.22 | 7.95 | 8.11 | 8.20 | 8.27 | 8.16 |
| uS_cm | 387.6 | 263.6 | 2523.0 | 270.4 | 333.0 | 337.3 | 340.6 | 345.0 | 365.6 | 386.8 |
| DO_Sat | 99.6 | 103.1 | 107.5 | 102.0 | 98.4 | 79.9 | 94.2 | 95.8 | 96.6 | 96.0 |
| DO_mgl | 9.05 | 9.89 | 10.77 | 10.03 | 9.99 | 8.53 | 9.67 | 9.80 | 9.99 | 9.85 |
| Turbidity (NTU) | 2.67 | 1.29 | 6.52 | 5.43 | 12.32 | 2.69 | 2.67 | 1.86 | 10.51 | 10.61 |
| Flow (CFS) | 548.6 | 1119.0 | 1644.3 | 1865.3 | 4483.7 | 5076.7 | 4969.5 | 4384.8 | 6352.8 | 5926.2 |
| PH_AV | 7.87 | 7.816 | 8.064 | 8.077 | 8.159 | 8.031 | 8.115 | 8.175 | 8.251 | 8.212 |
| Alkalinity as CaCO3 (mg/l) | 100.66 | 81.780 | 89.373 | 101.256 | 134.506 | 134.187 | 137.400 | 137.506 | 146.037 | 148.458 |
| Bicarbonate (mg/l) | 121.8 | 99.827 | 108.793 | 123.259 | 163.756 | 163.700 | 167.215 | 167.187 | 177.111 | 180.500 |
| Calcium (mg/l) | 6.26 | 10.544 | 15.853 | 20.588 | 36.386 | 37.088 | 37.667 | 38.246 | 40.325 | 43.571 |
| Chloride (mg/l) | 49.02 | 27.171 | 20.301 | 17.976 | 11.590 | 10.840 | 10.901 | 10.802 | 9.561 | 9.542 |
| Potassium (mg/l) | 7.50 | 4.647 | 3.838 | 3.721 | 3.586 | 3.515 | 3.536 | 3.551 | 3.301 | 3.190 |
| Sodium (mg/l) | 70.93 | 39.868 | 30.618 | 28.015 | 19.957 | 19.074 | 19.232 | 19.420 | 19.554 | 18.929 |
| Sulfate (mg/l) | 12.44 | 9.159 | 10.463 | 13.634 | 31.819 | 31.988 | 32.679 | 33.457 | 40.793 | 48.747 |
| Total Dissolved Solids (mg/l) | 288.7 | 187.0 | 171.7 | 179.7 | 214.8 | 213.519 | 216.099 | 217.654 | 229.902 | 242.133 |
| Arsenic Total (mg/l) | .2191 | .1202 | .0852 | .0722 | .0322 | .0268 | .0259 | .0257 | .0208 | .0194 |
| Arsenic Dissolved (mg/l) | .2192 | .1177 | .0853 | .0717 | .0318 | .0275 | .0259 | .0259 | .0214 | .0199 |
| Cadmium Total (mg/l) | .00005 | .00005 | .00005 | .00005 | .00005 | .000125 | .00005 | .00005 | .0000927 | .0001024 |
| Copper Total (mg/l) | .0005 | .0005 | .0005 | .0005 | .0005 | .0005 | .0005 | .0005 | .0034 | .0037 |
| Copper Dissolved (mg/l) | | | | | | | | | .002204 | .001929 |
| Iron Total (mg/l) | .20000 | .10000 | .09000 | .08000 | .22000 | .01500 | .01500 | .01500 | .38902 | .31788 |
| Iron Dissolved (mg/l) | .080000 | .070000 | .040000 | .015000 | .015000 | .015000 | .015000 | .015000 | .014939 | .016488 |
| Magnesium (mg/l) | .647 | 2.118 | 3.926 | 5.603 | 11.043 | 11.015 | 11.232 | 11.449 | 13.614 | 14.595 |
| Lead Total (mg/l) | .001000 | .001000 | .001000 | .001000 | .001000 | .001000 | .001000 | .001000 | .003171 | .002298 |

**Table 6-2. Water Quality Descriptive Statistics**

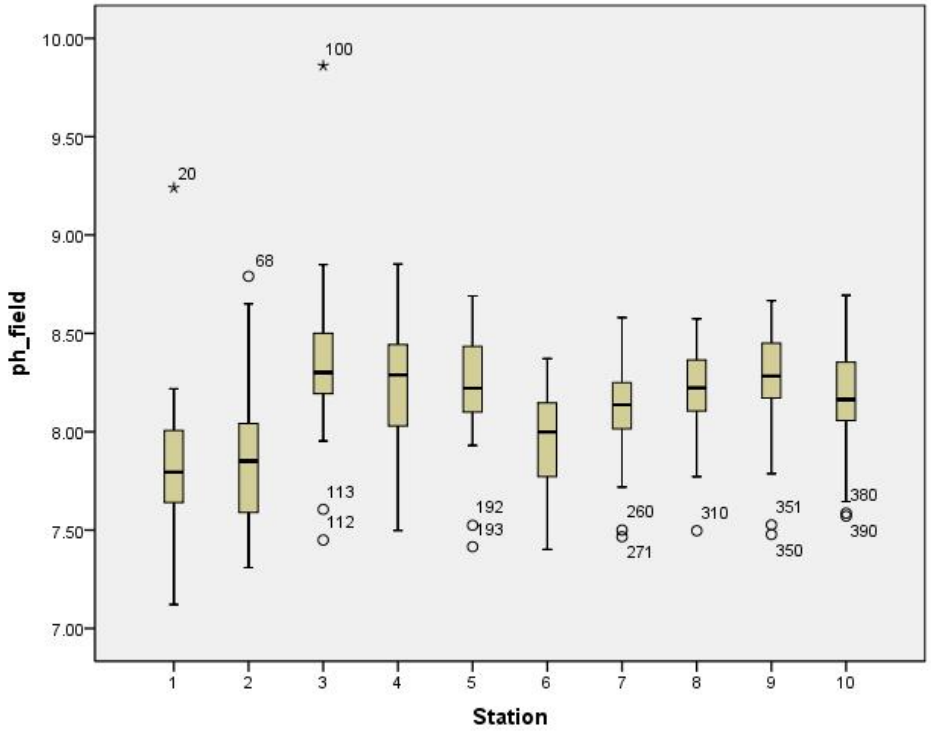
| DESCRIPTIVE STATISTICS MEAN VALUES (1997-2006) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Station 1** | **Station 2** | **Station 3** | **Station 4** | **Station 5** | **Station 6** | **Station 7** | **Station 8** | **Station 9** | **Station 10** |
| Lead Dissolved (mg/l) | .001000 | .001000 | .001000 | .001000 | .001000 | .001000 | .001000 | .001000 | .001817 | .001595 |
| Zinc Total (mg/l) | .005000 | .005000 | .005000 | .005000 | .005000 | .005000 | .005000 | .005000 | .007317 | .007059 |
| Zinc Dissolved (mg/l) | .005000 | .005000 | .005000 | .005000 | .005000 | .005000 | .005000 | .005000 | .007805 | .007917 |
| Manganese Total (mg/l) | | | | | | | | | .015435 | .014082 |
| Manganese Dissolved (mg/l) | | | | | | | | | .039574 | .016771 |
| Nitrate Nitrate Total (mg/l) | .03027 | .03480 | .04635 | .03365 | .10620 | .16824 | .13361 | .11350 | .10356 | .11978 |
| Nitrate Nitrite Dissolved (mg/l) | .03157 | .03176 | .04370 | .03922 | .10647 | .16320 | .12620 | .09400 | .10330 | .11920 |
| Nitrogen Persulfate Total (mg/l) | .106290 | .140645 | .132813 | .151349 | .257891 | .296129 | .300161 | .273710 | .225079 | .274219 |
| Ammonia Total (mg/l) | .032840 | .034329 | .032744 | .032840 | .033171 | .035127 | .036500 | .035500 | .032840 | .038293 |
| Ammonia Dissolved (mg/l) | .03333 | .03333 | .03333 | .03333 | .03333 | .03333 | .03333 | .04833 | .03333 | .05500 |
| Phosphorus Total (mg/l) | .035000 | .031396 | .031875 | .031761 | .045845 | .037786 | .038429 | .039357 | .044753 | .041829 |
| Phosphorus Ortho Total (mg/l) | .036778 | .030556 | .025222 | .021136 | .025000 | .026932 | .025233 | .025349 | .024318 | .027614 |
| Phosphorus Ortho Dissolved (mg/l) | .028375 | .025750 | .019188 | .016000 | .015187 | .028101 | .024810 | .026456 | .019178 | .021164 |
| Total Suspended Sediment (mg/l) | 8.695 | 5.878 | 10.878 | 8.707 | 25.036 | 6.198 | 6.074 | 6.469 | 21.012 | 16.048 |

Box plots showing median concentrations for each parameter (center bar) and data distribution (25% and 75% percentiles, and 1.5 interquartile range) are found in the following figures. These illustrate the overall spatial distribution of data within the monitoring network from 1997-2006.

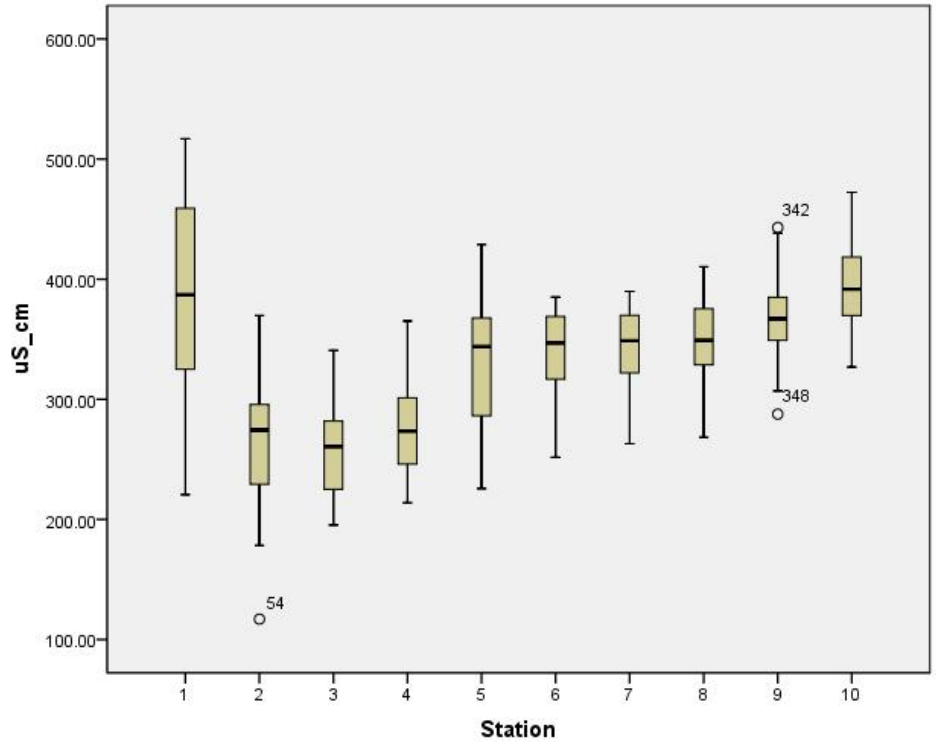
**Average temperature ranged from about 8 to 10C, and was relatively consistent throughout the monitoring network.**



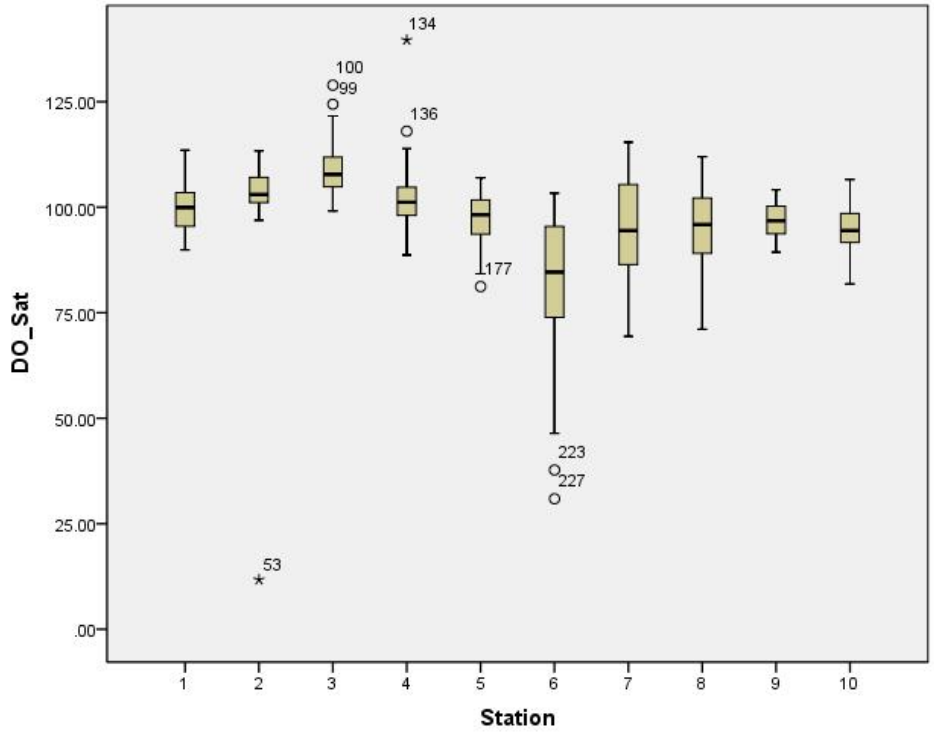

**Average field pH tended to increase slightly in the downstream direction.**



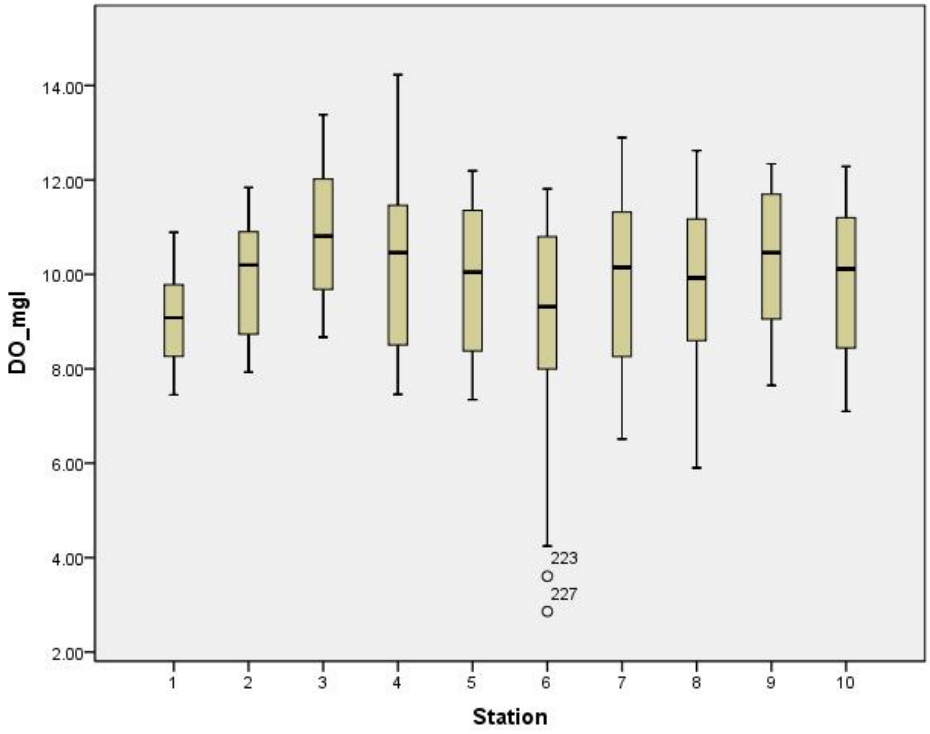
**Average specific conductivity was elevated at the uppermost station, decreased sharply at the next station downstream, and steadily climbed back to levels at the Morony site.**



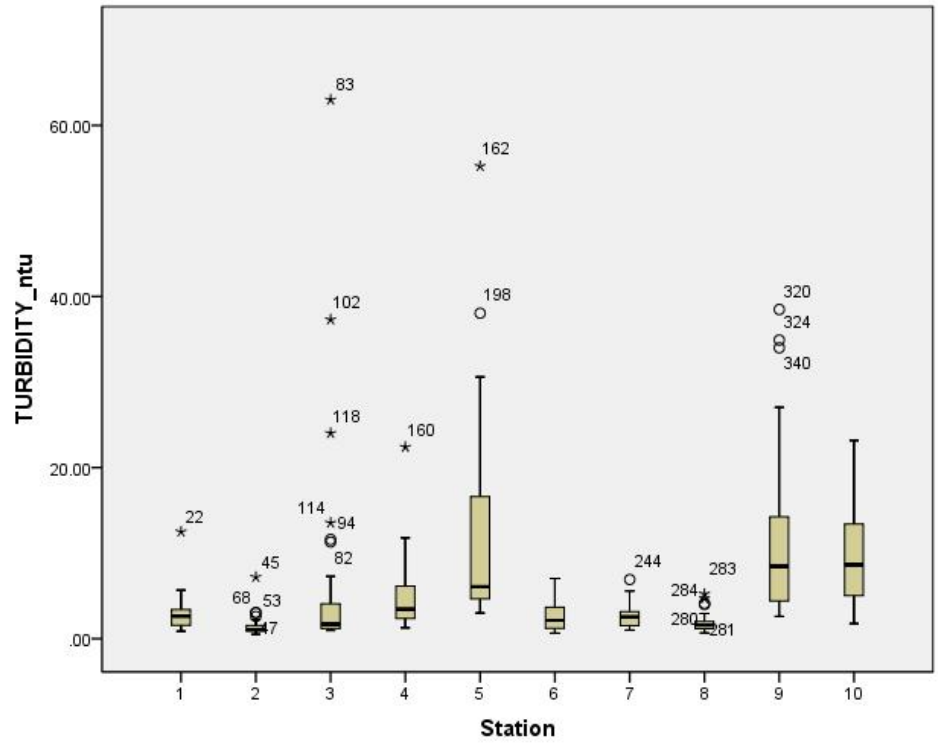

**Dissolved oxygen saturation showed a tendency to decrease in the downstream direction, with an apparent relative sag at station 6 (Canyon Ferry).**



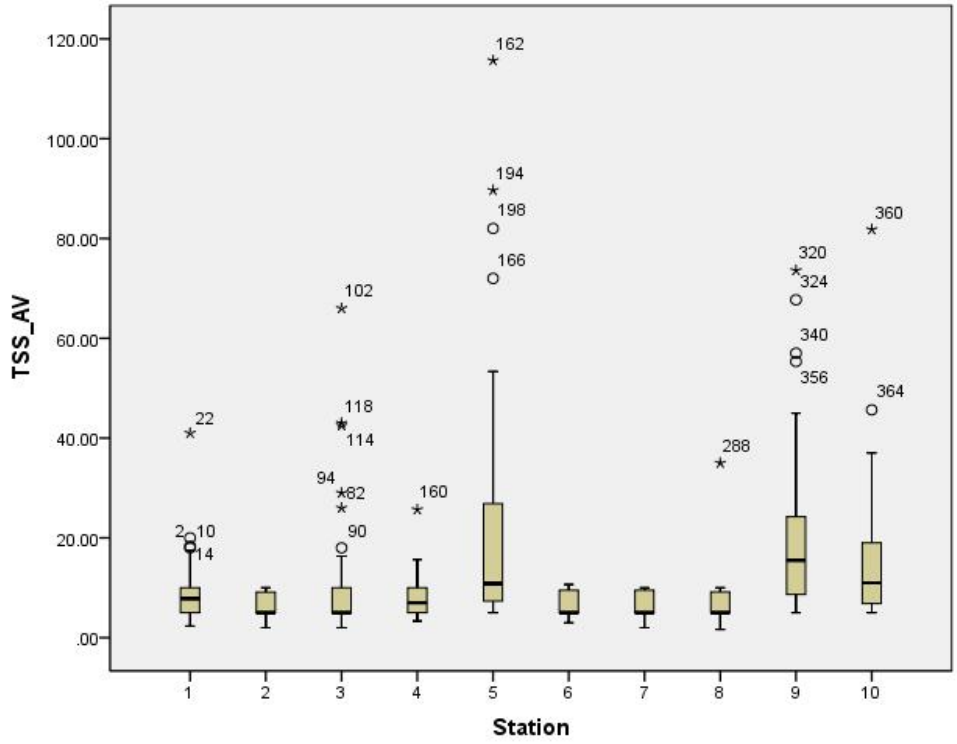
**Dissolved oxygen concentration was variable and did not show a clear a tendency to shift in the downstream direction, though a slight drop at station 6 (Canyon Ferry) appeared to be present relative to upstream/downstream stations.**



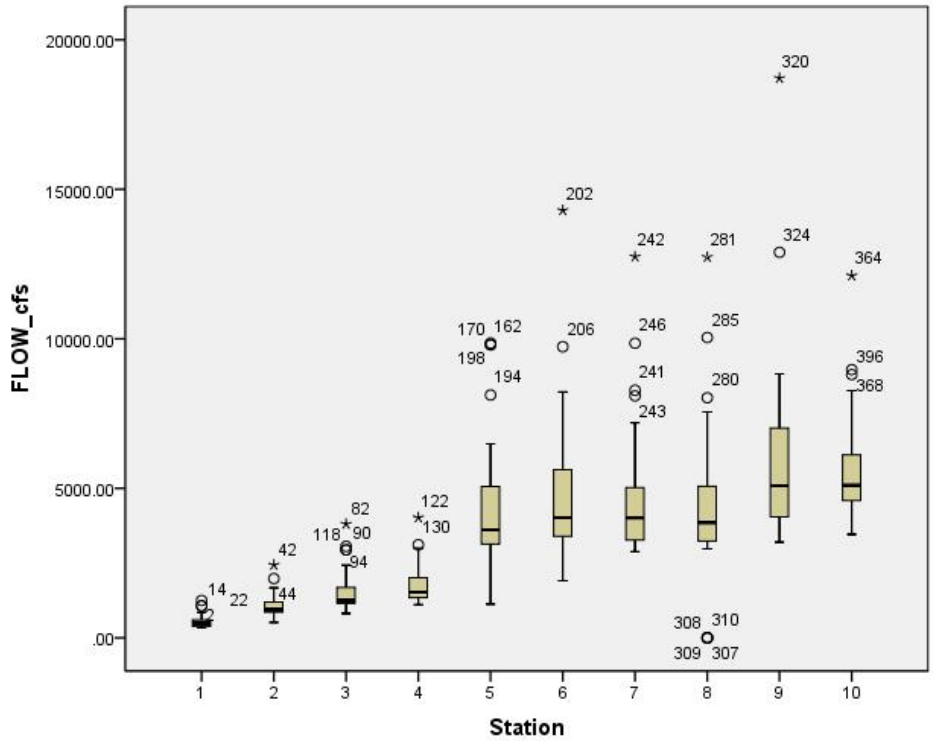

**Turbidity showed elevated levels at stations 5, 9, and 10 but was otherwise low throughout the monitoring network.**



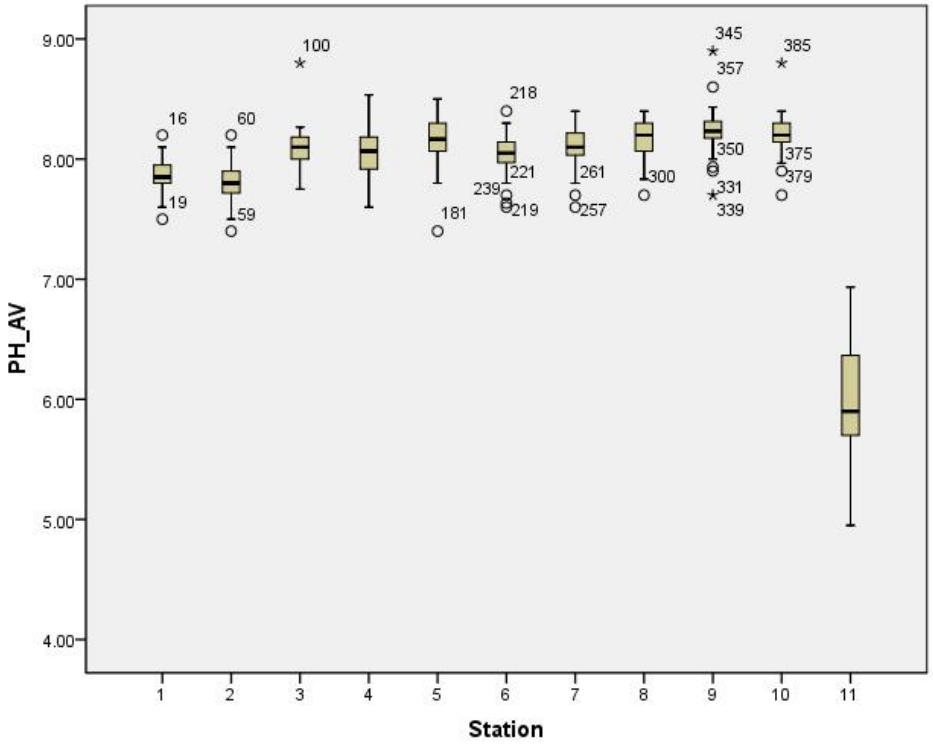
**Like turbidity, total suspended sediment showed elevated levels at stations 5, 9, and 10 but was otherwise low throughout the monitoring network.**



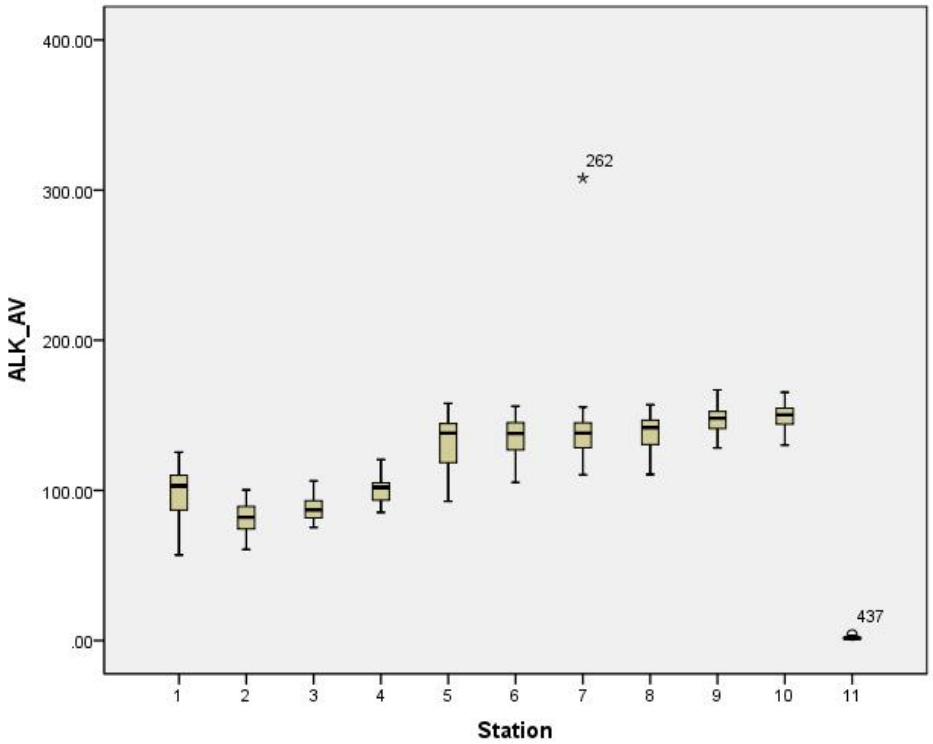

**Flow increased steadily in the downstream direction, most notably increased at Toston.**



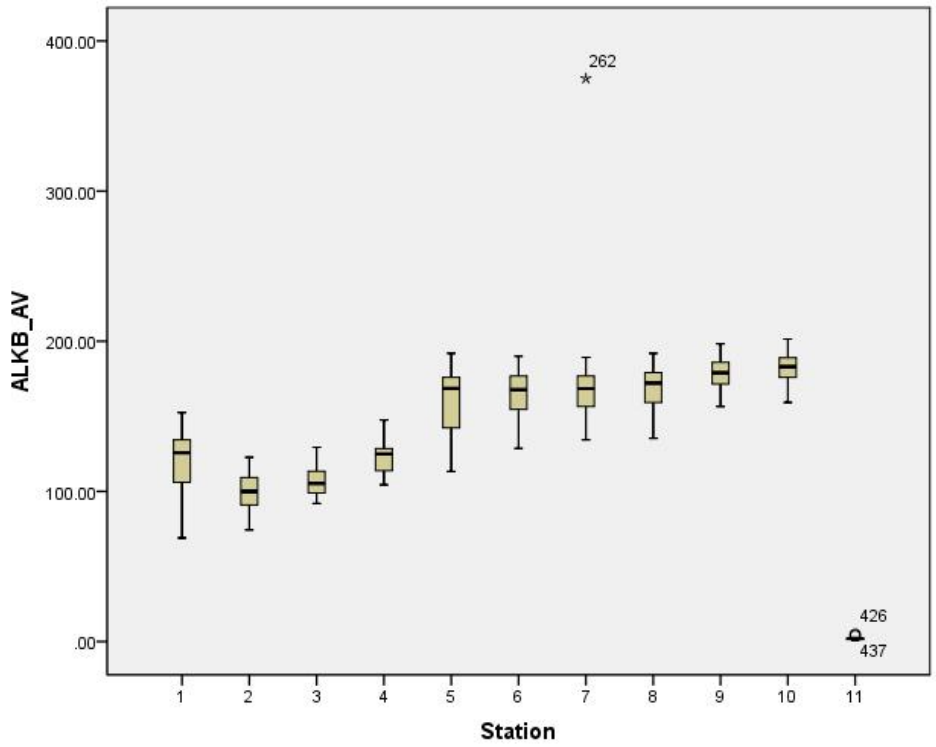
**pH increased steadily in the downstream direction. Note that station 11 is the equipment blank in the following figures (not generally shown for improved clarity in the graphs).**



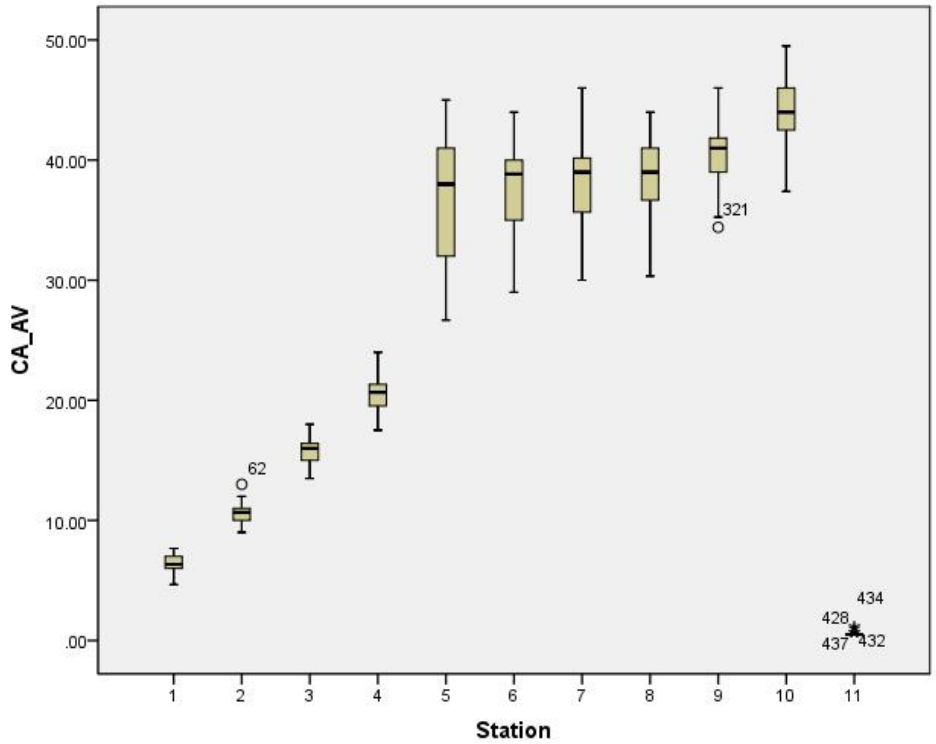

**Alkalinity as CaCO3 generally increased in the downstream direction.**



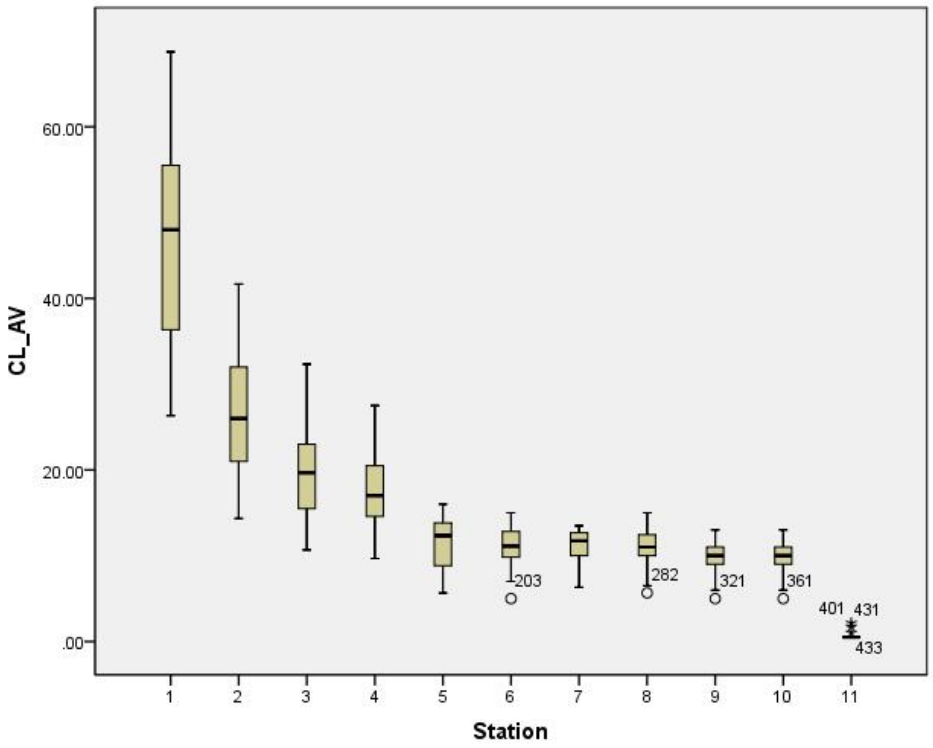
**Alkalinity as HCO2 also generally increased in the downstream direction.**



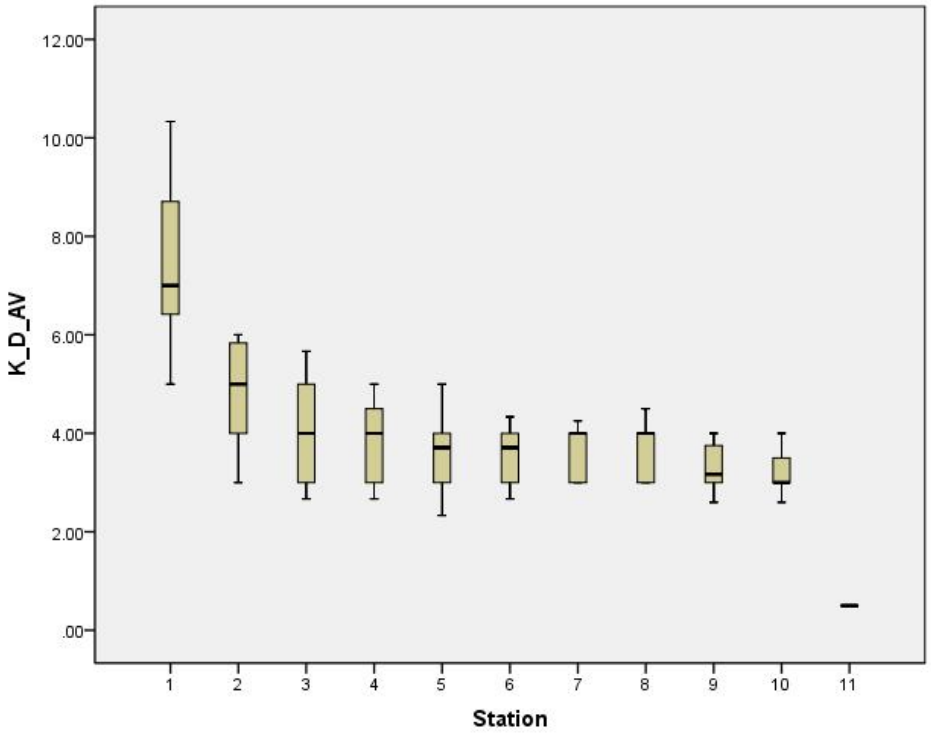

**Calcium increased steadily in the downstream direction and increased notably at Toston (Station 5).**



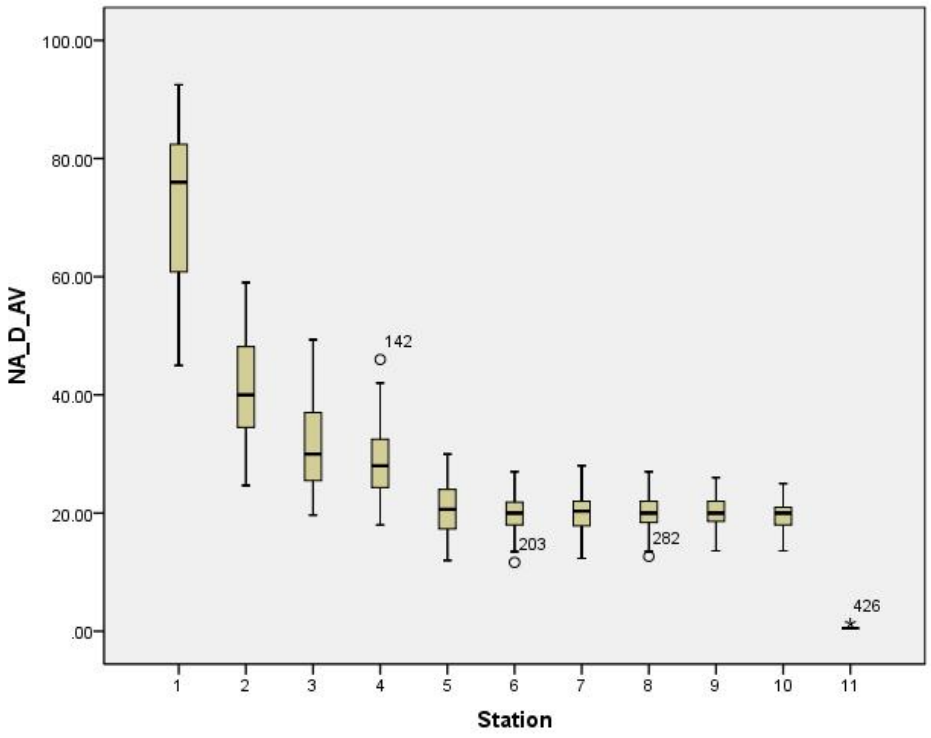
**Chloride decreased steadily in the downstream direction and began to stabilize at Toston (Station 5).**



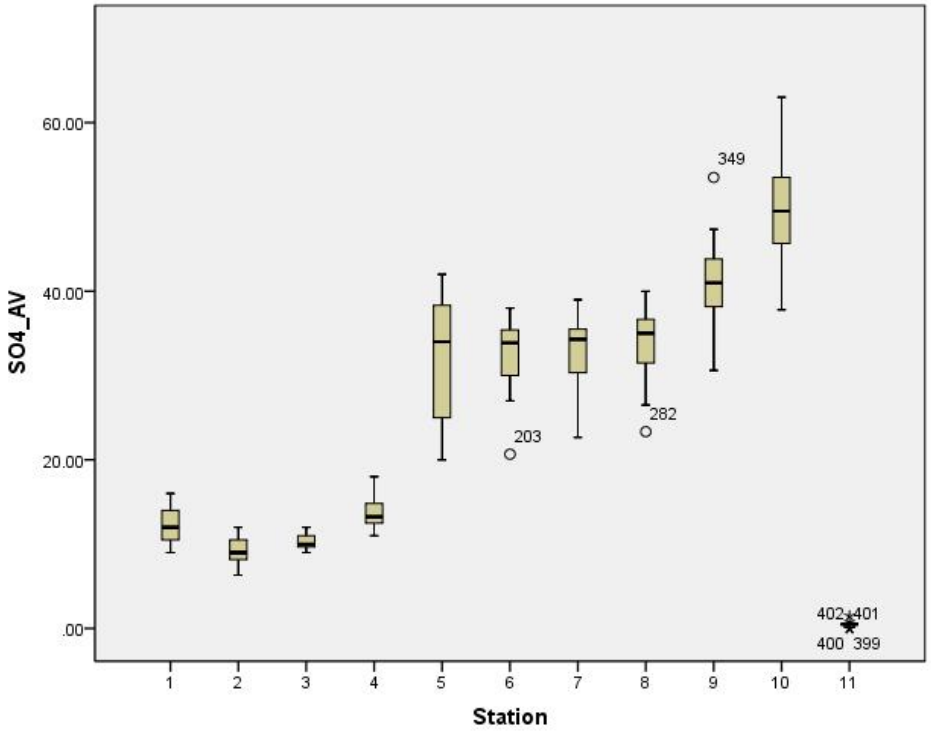

**Potassium decreased in the downstream direction stabilized at Toston (Station 5).**



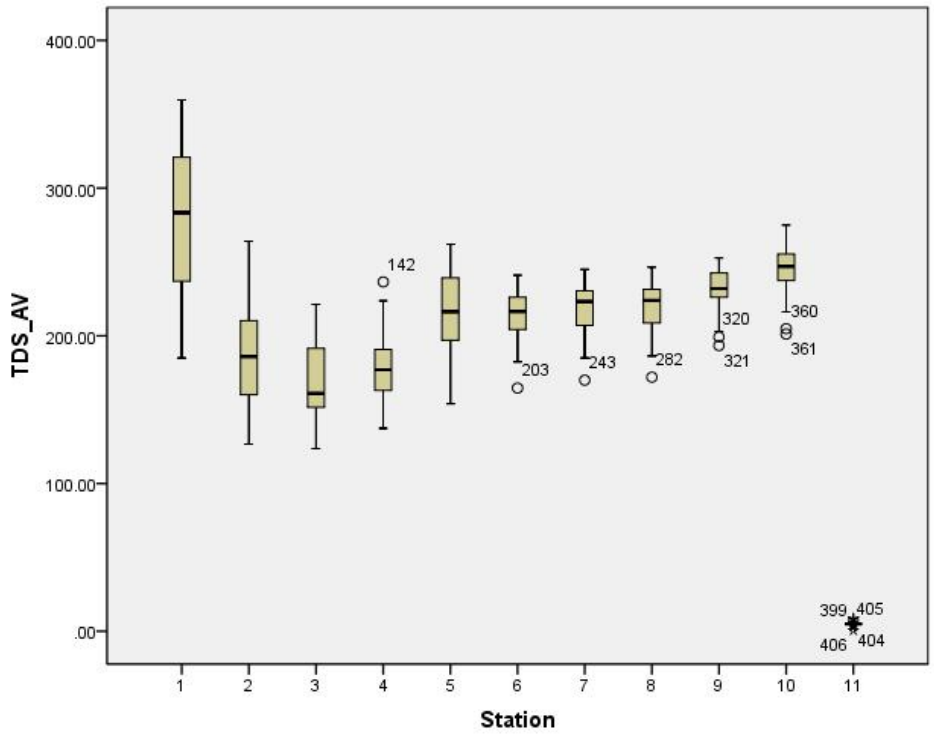
**Sodium decreased steadily downstream and began to stabilize at Toston (station 5).**



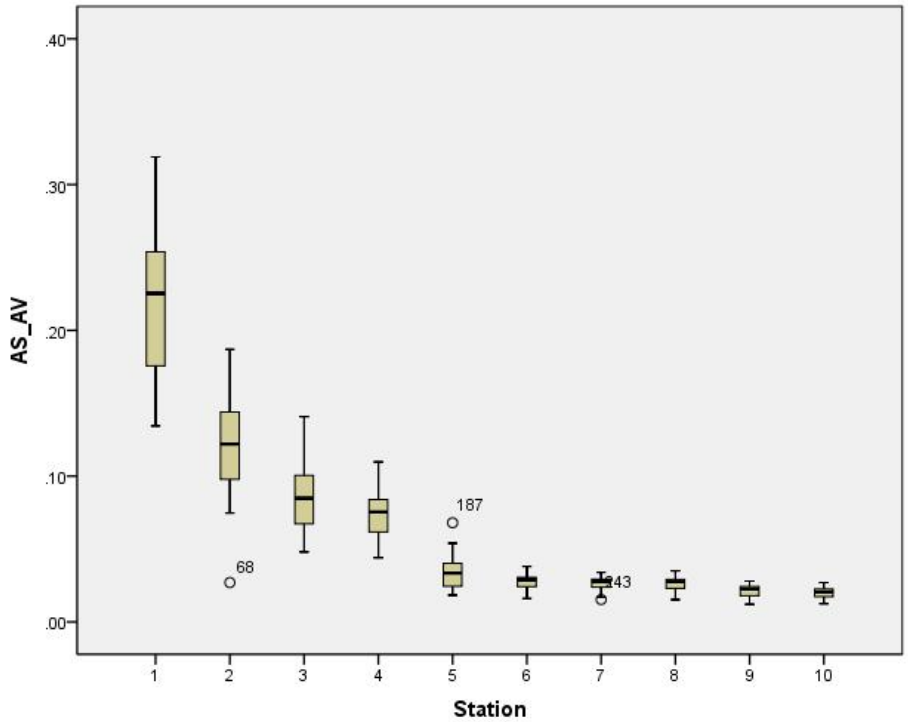

**Sulfate notably increased at Toston (Station 5), and increased at the lowermost stations.**



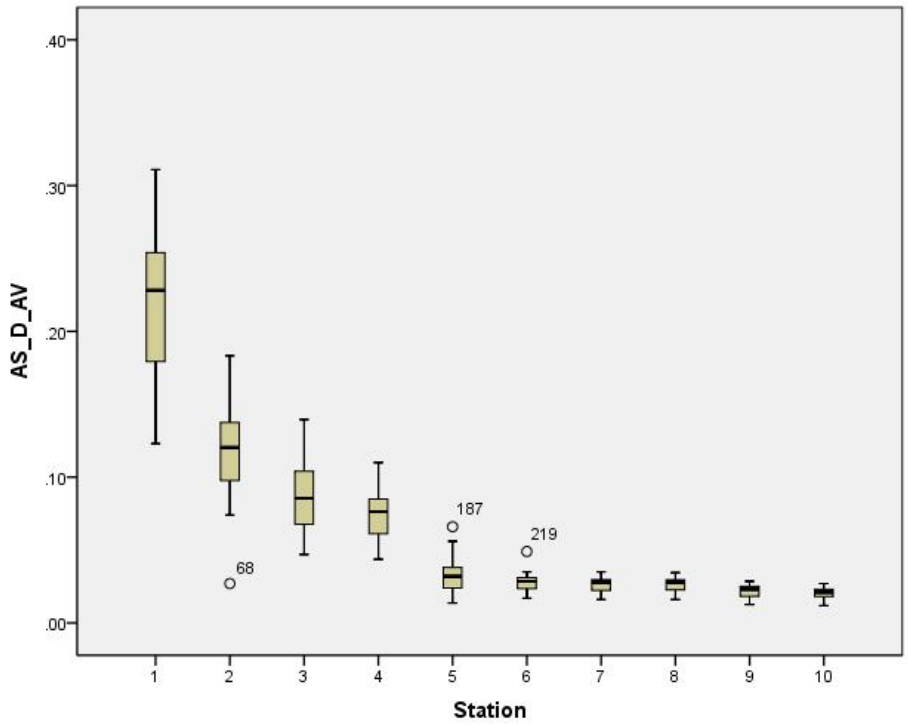
**Total dissolved solids decreased at the uppermost stations, and slowly increased in the downstream direction. An increase at Toston (Station 5) was apparent.**



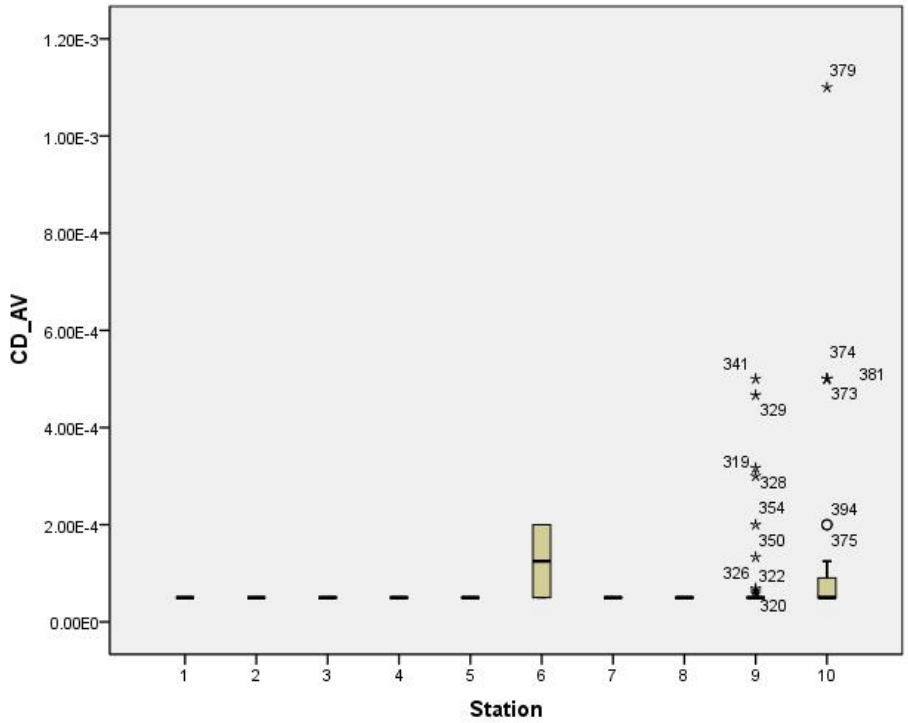

**Total arsenic decreased steadily in the downstream direction and began to stabilize at Toston (Station 5).**



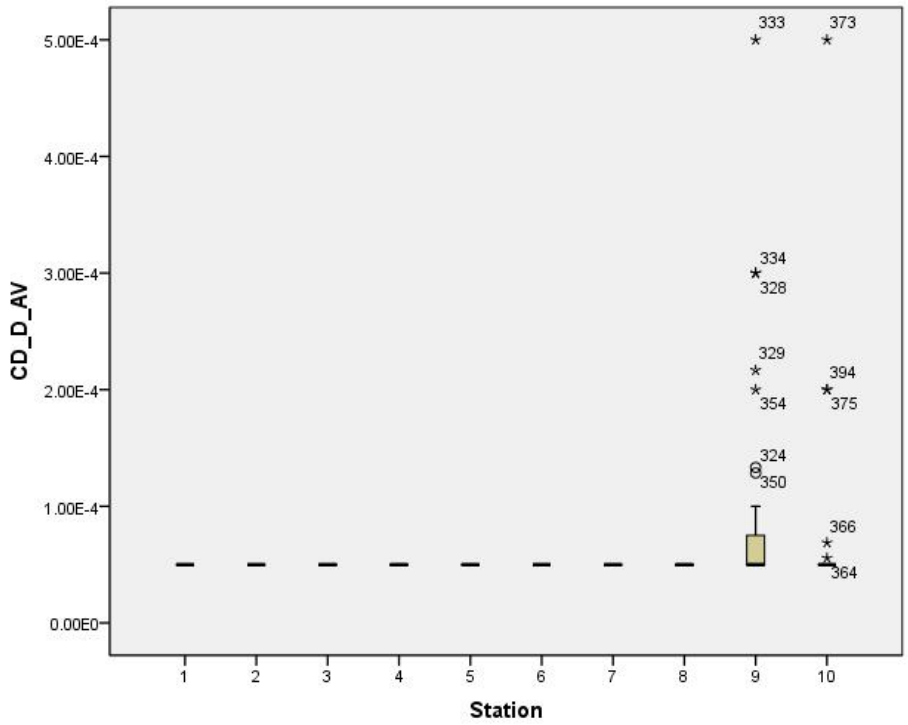
**Dissolved arsenic showed an identical pattern to total arsenic and decreased steadily in the downstream direction and began to stabilize at Tolston (Station 5).**



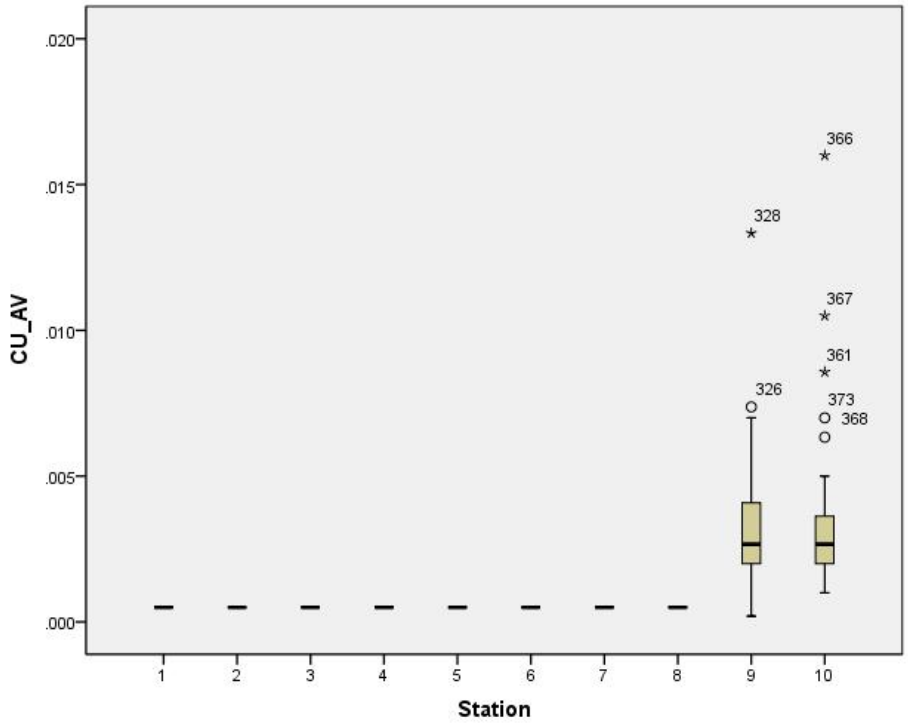

**Total cadmium monitored at downstream stations was generally near detection limits.**



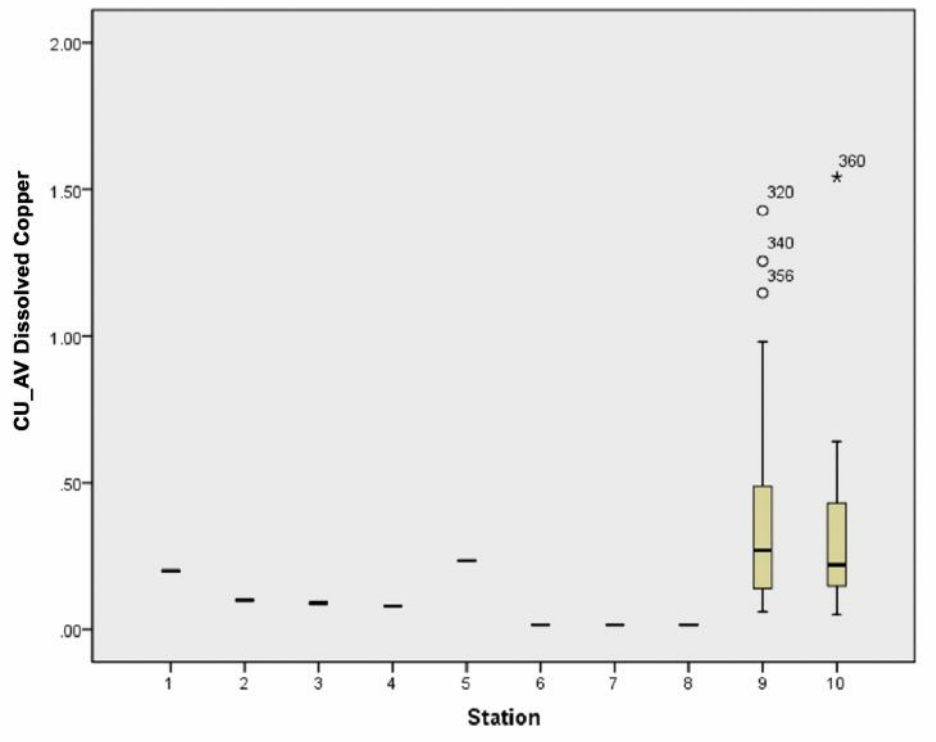
**Dissolved cadmium monitored at downstream stations was generally near detection limits.**



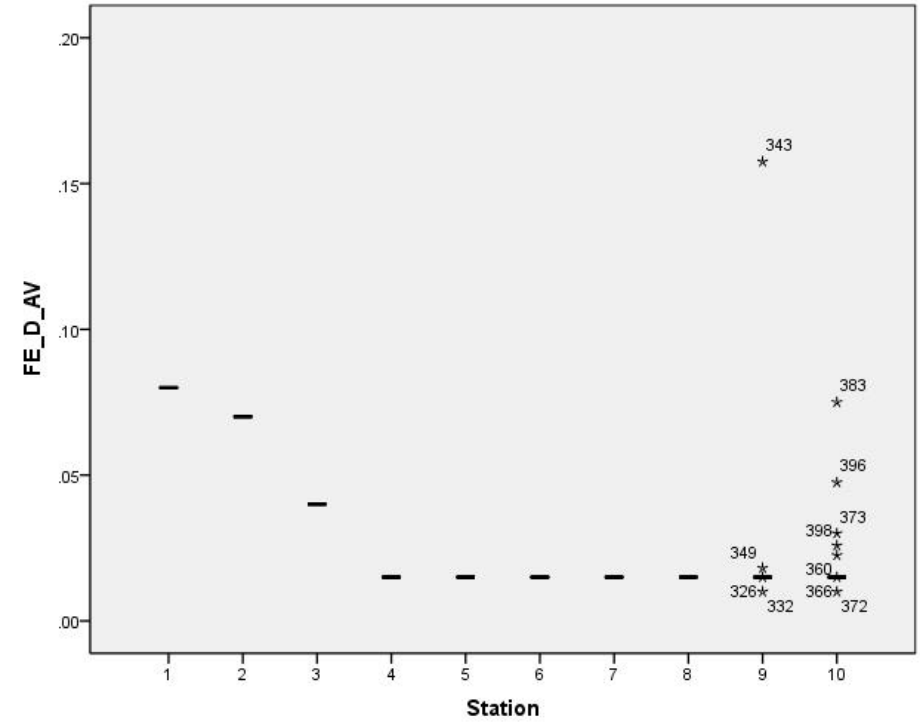

**Total copper monitored at downstream stations 9 and 10 was generally near detection limits with infrequent outliers.**



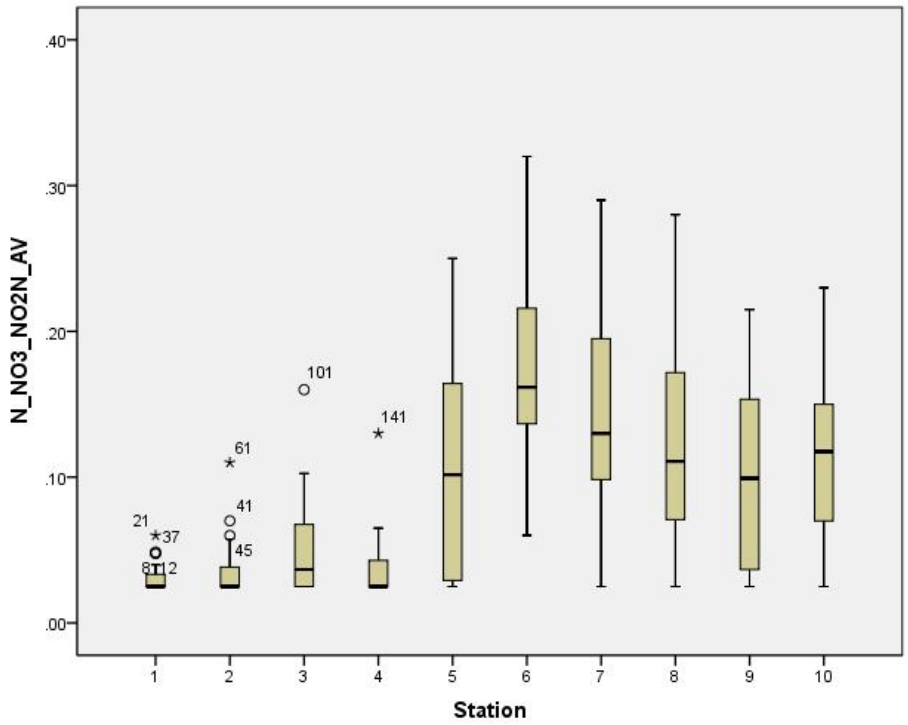
**Similar to total copper, dissolved copper monitored at downstream stations was generally near detection limits.**



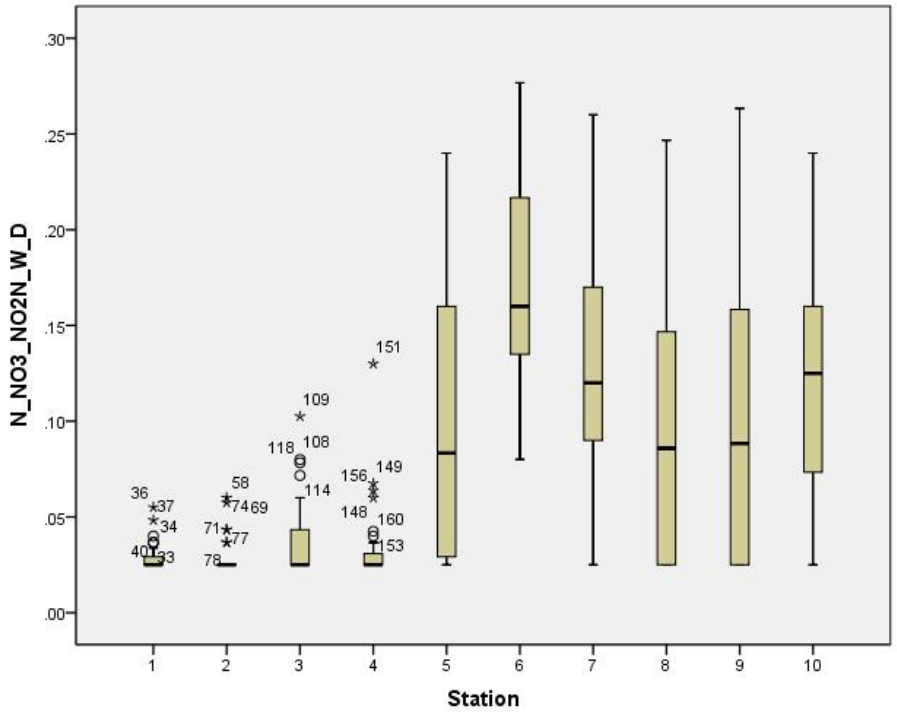

**Dissolved iron monitored at downstream stations 9 and 10 was rarely above detection limits.**



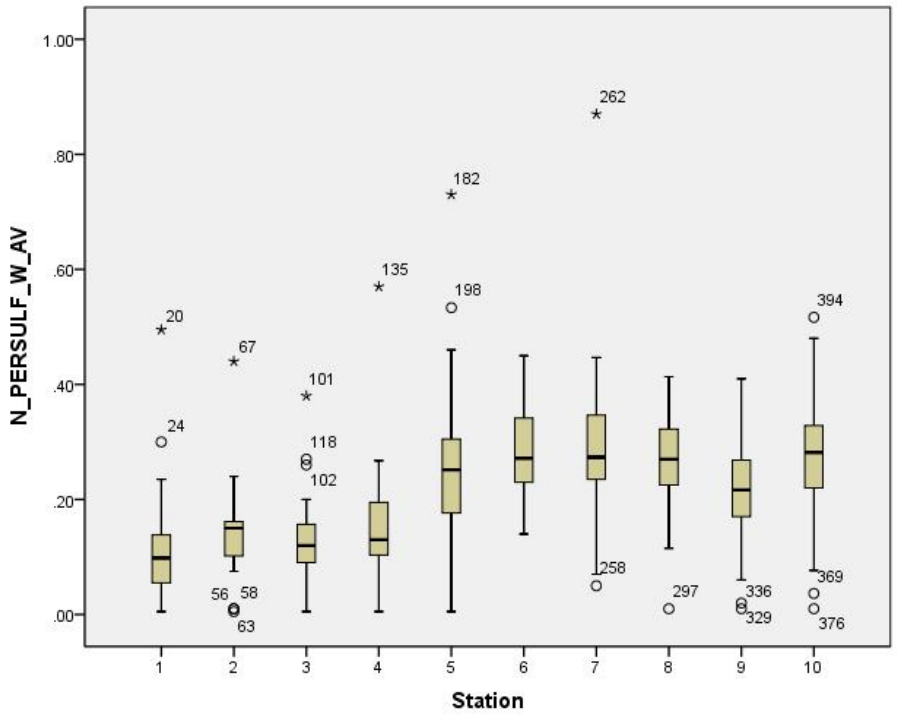
**Total nitrate-nitrate increased at Toston (Station 5).**



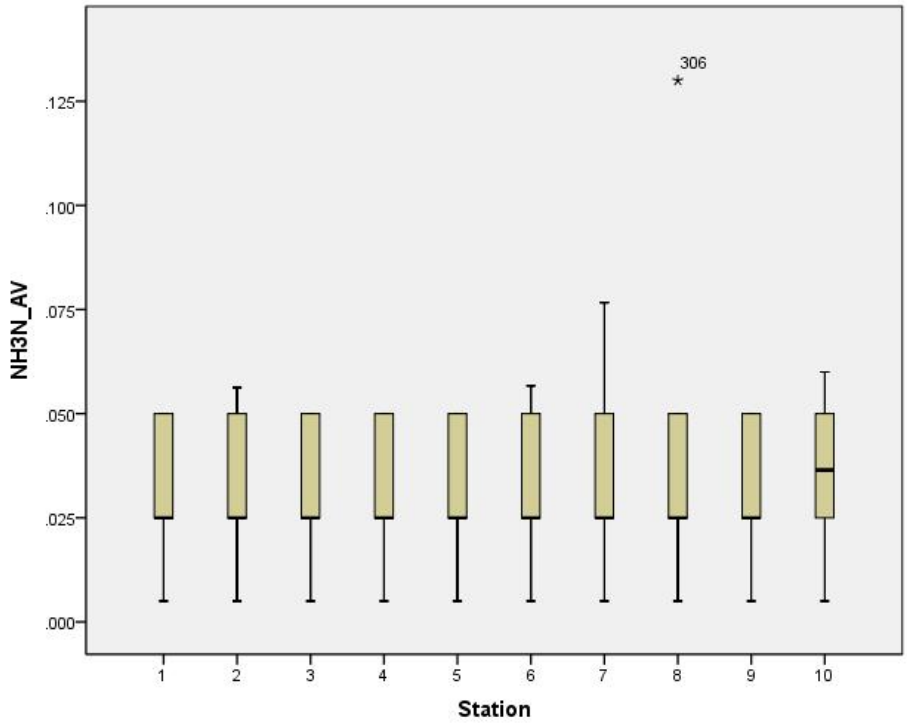

**Similar to total nitrate-nitrate, dissolved nitrate-nitrate increased at Toston (Station 5).**



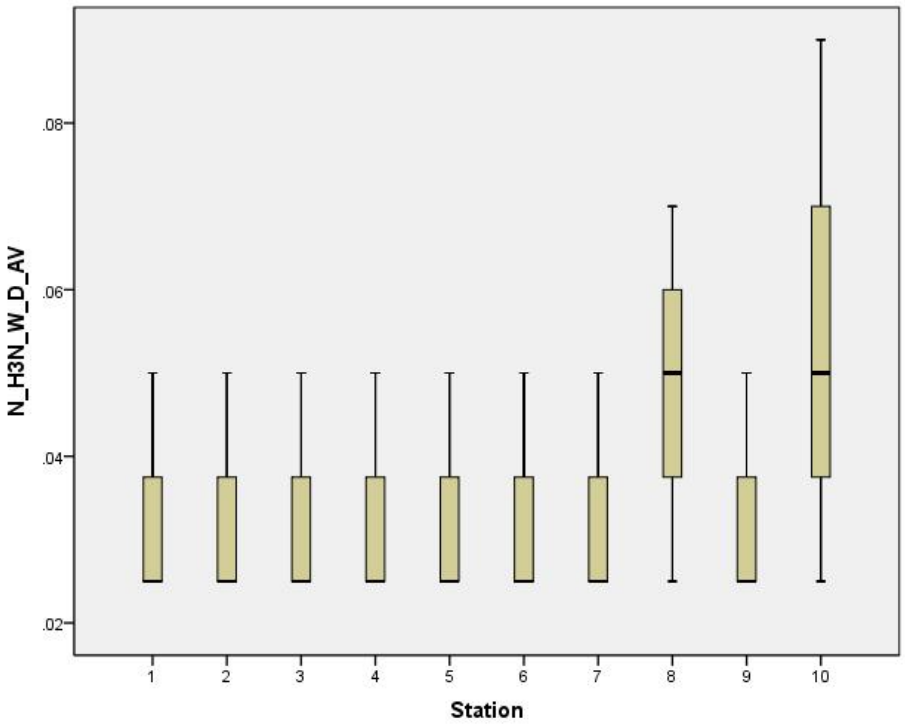
**Total persulfate nitrogen increased in the downstream direction with a distinct difference occurring at Toston (Station 5).**



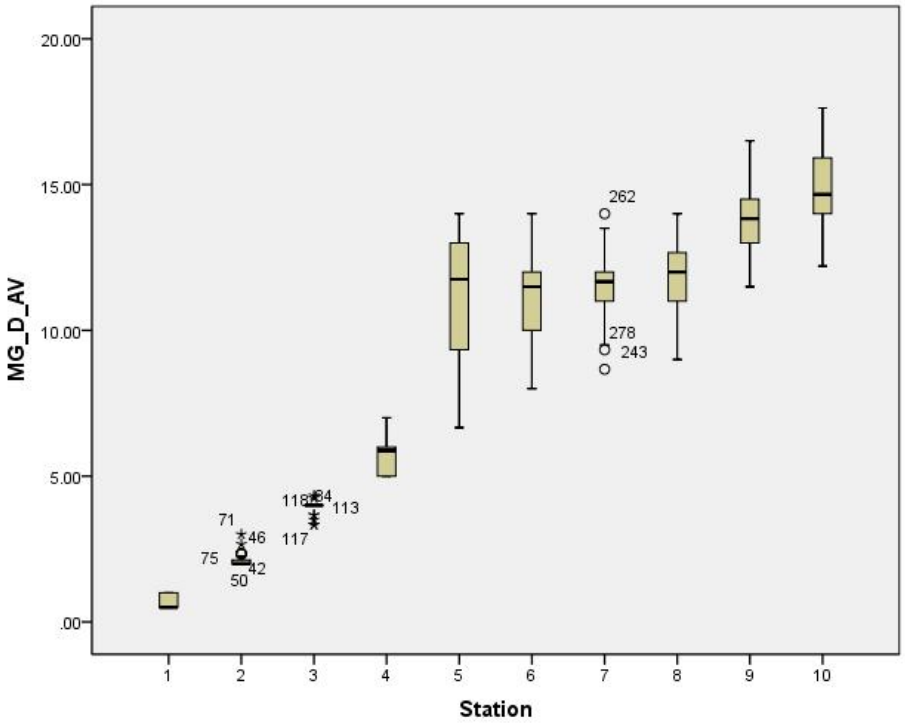

**Total ammonia was below detection limits at all stations with very few values above detection limits.**



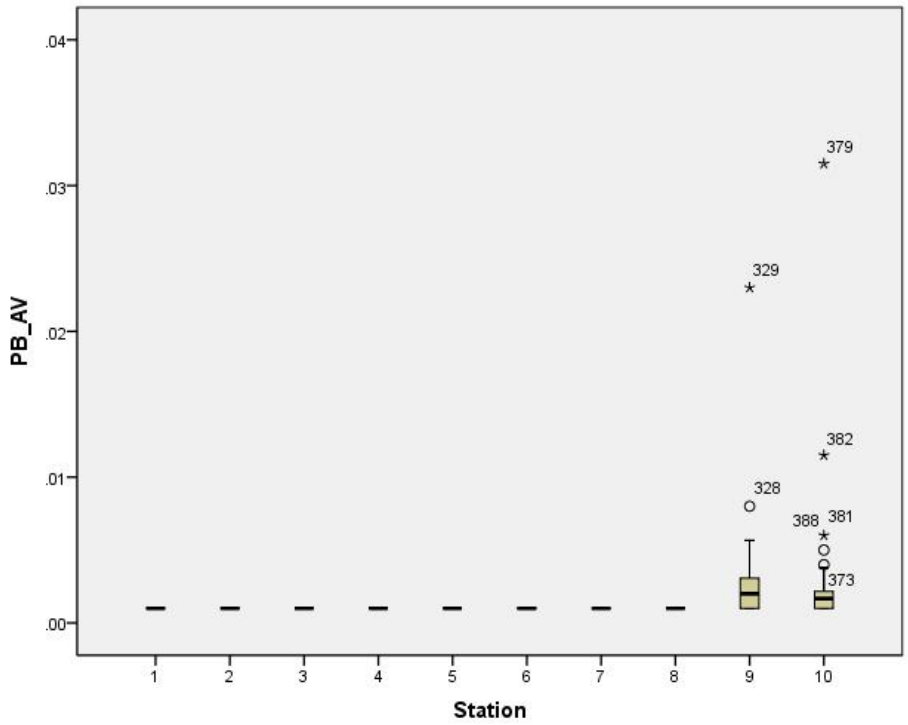
**Like total ammonia, dissolved ammonia was below detection limits at all stations with few detections.**



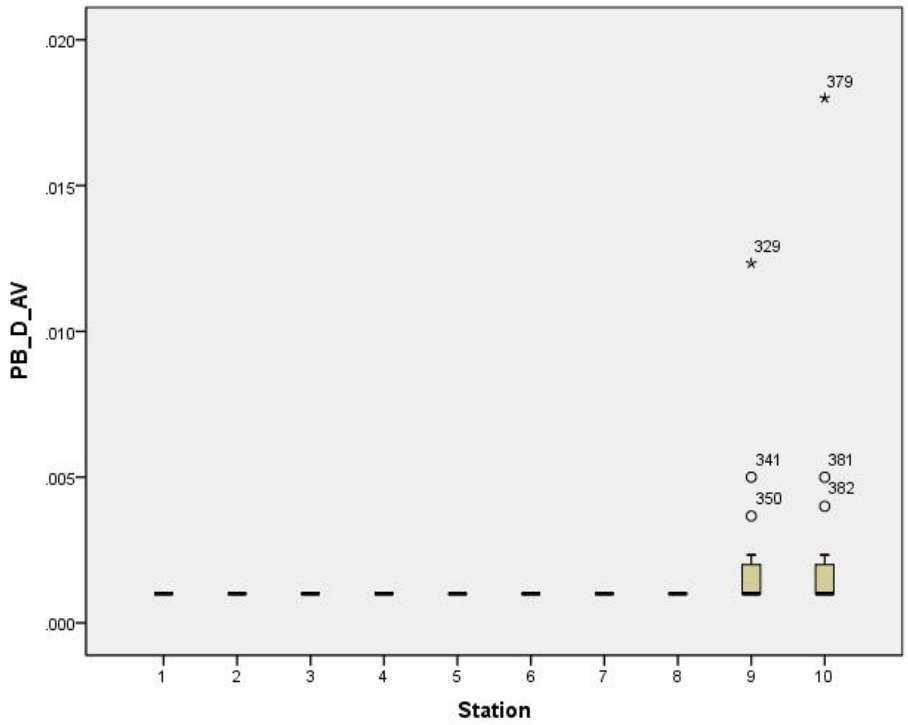

**Magnesium increased consistently in the downstream direction, with a distinct change at Toston (station** 5).



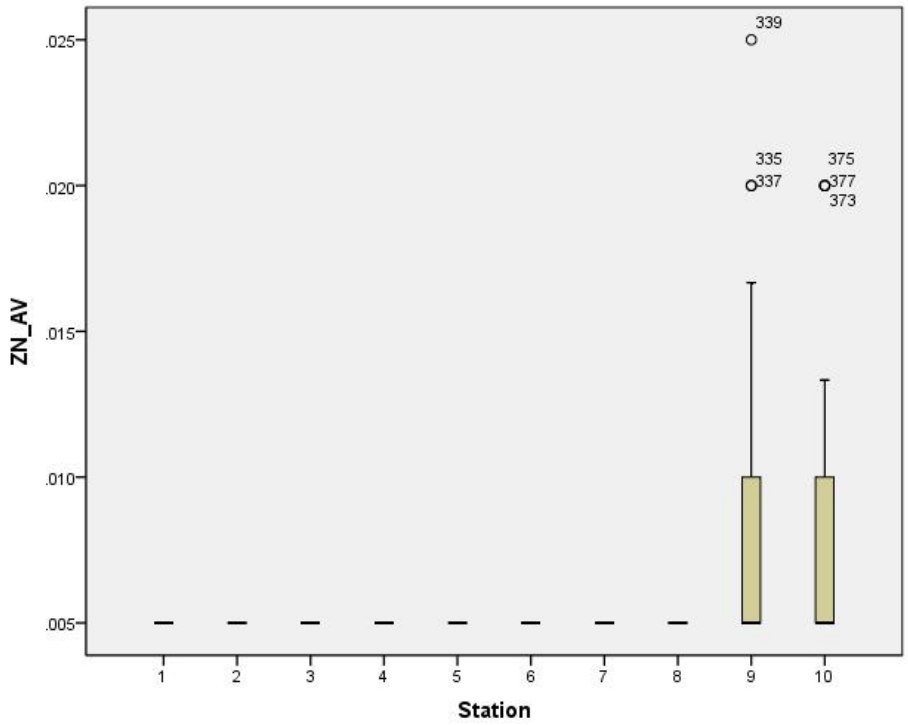
**Total lead was monitored at stations 9 and 10, and showed infrequent values above detection limits.**



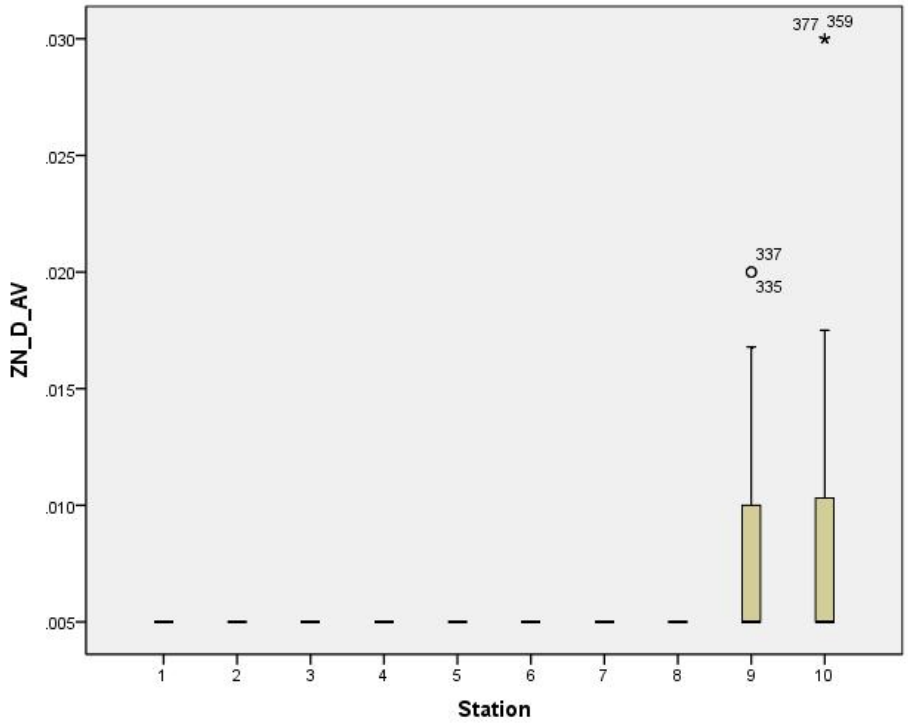

**Like total lead, dissolved lead was monitored at stations 9 and 10, and showed infrequent values above detection limits.**



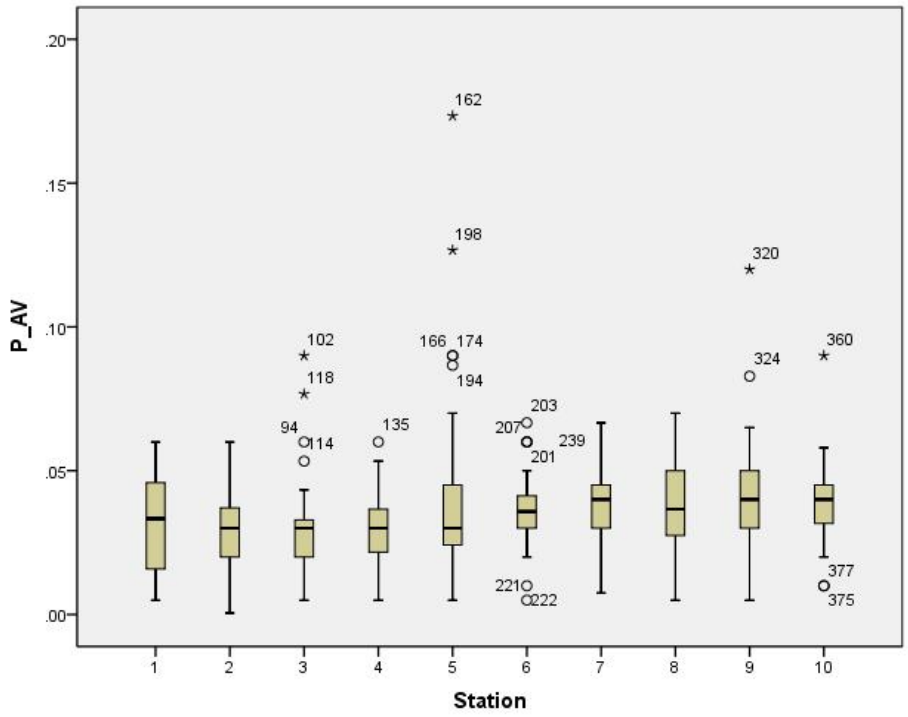
**Total zinc was monitored at stations 9 and 10, and showed infrequent values above detection limits.**



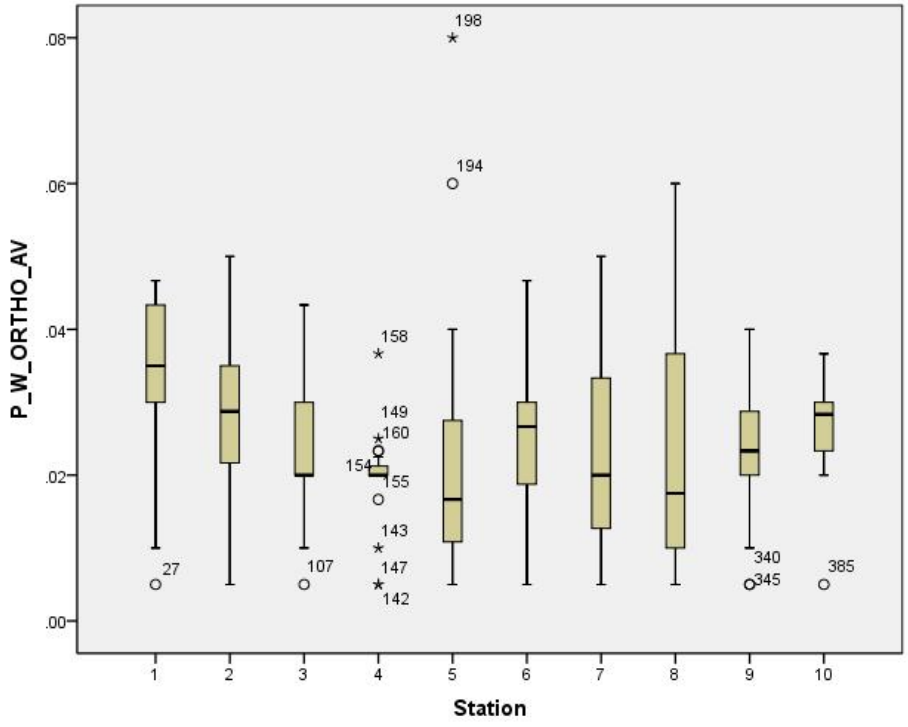

**Dissolved zinc was monitored at stations 9 and 10, and showed few values above detection limits.**



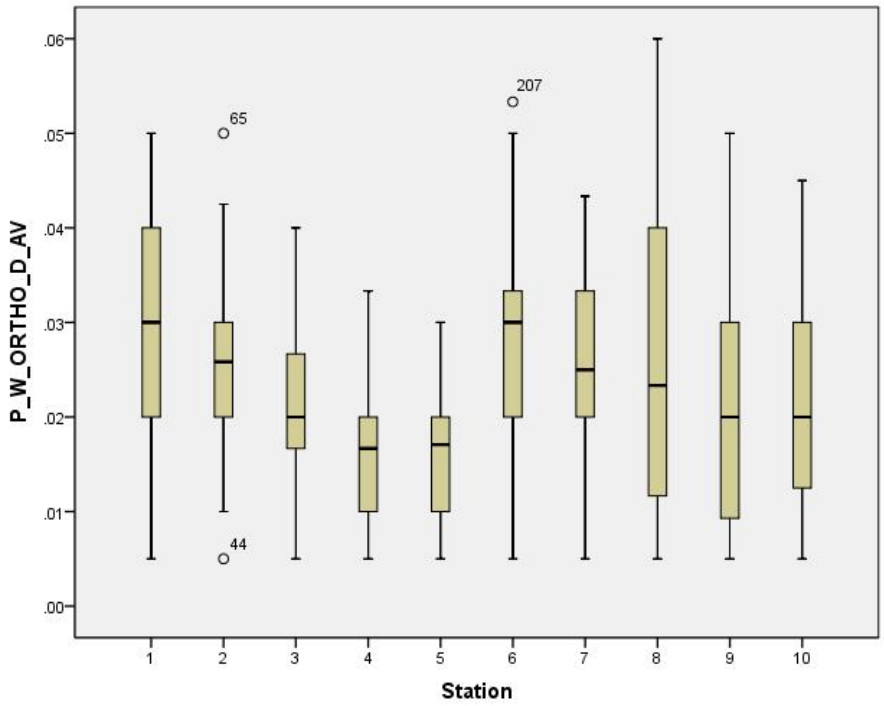
**Total phosphorus tended to increase slightly in the downstream direction.**




**Total phosphorus as ortho-phosphate showed a slight tendency to decrease in the downstream direction.**



**Dissolved phosphorus as ortho-phosphate showed a slight tendency to decrease in the downstream direction.**




### *6.1.2 Upstream/Downstream Comparisons*

Comparisons of adjacent station pairs were made using the non-parametric Mann-Whitney test for each parameter to identify persistent statistical differences during the monitoring period. The percent change for each parameter between station pairs is found below in **Table 6-3.** Percent change was calculated by subtracting the median value of the downstream station from the upstream station, divided by the upstream value. Those values highlighted in the table indicate statistically significant differences between stations for a given analyte. Complete test statistics can be found in **Appendix C.** A visual representation of the station comparisons discussed below is shown on box plots found in **Section 6.1.1.**

Average temperature showed statistically significant differences only between stations 1 and 2 (+28%). Remaining station pairs showed no statistical differences in temperature. Dissolved oxygen saturation was statistically different between all station pairs with the exception of the lowermost pairs 7/8, 8/9, and 9/10. Dissolved oxygen concentration showed a similar pattern of differences at the lower station pairs, and pairs 4/5 showed no difference in dissolved oxygen concentration. The principal change was at stations 5/6, where D.O. saturation and concentration decreased -16 and -11% respectively. This appeared to reflect the influence of Canyon Ferry. Oxygen metrics rebounded downstream at Hauser (+12%).

Field pH showed statistical differences between station pairs 2/3, 5/6, 6/7, 7/8, and 9/10. These pH differences were generally small, ranging from +5.7 to -2.7%. Lab pH showed (-1.5% to +3.8%) changes at station pairs 2/3, 4/5, 5/6, 6/7, and 8/9. Flow was statistically different between all station pairs with the exception of 6/7, 7/8 and 9/10. This generally reflected increasing watershed area. The increase in flow was especially notable at Toston, (station pair 4/5; +137%) which is below the confluence of the Madison with other major tributaries. It is worthwhile to note that the change in flow, watershed area,

and corresponding geology at Toston corresponded closely to change significant change the majority of other monitoring parameters.

Conductivity showed differences between station pairs 1/2, 3/4, 4/5, 8/9, and 9/10. Conductivity decreased 32% between stations 1/2 and reflected the diminishing influence of YNP hydrothermal sources. Conductivity increased 26% between stations 4/5 and reflected change in contributing source area (i.e. Madison river confluence with other major tributaries).

Turbidity was statistically different between all station pairs with the exception of 6/7 and 9/10. The percent change in median values between stations ranged from -59% to + 408%. Turbidity (along with TSS) was the most variable analyte between stations. Turbidity decreased 55% below Hebgen, and increased 56 and 104% at Varney and the Madison Ennis stations. Turbidity increased 66% at Toston, and decreased 59% below Canyon Ferry. A decrease was also noted below Holter (-37%). The largest increase (408%) was noted at the Central Avenue site 9. This reflected the strong influence of the Sun River and Muddy Creek.

**Table 6-3. Change in Median Values Between Station Pairs**

| Test Statistics, Mann Whitney | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **1 / 2** | **2 / 3** | **3 / 4** | **4 / 5** | **5 / 6** | **6 / 7** | **7 / 8** | **8 / 9** | **9 / 10** |
| Temp_C | -28.2% | -1.5% | 19.0% | 16.9% | -18.1% | 7.7% | 0.4% | -11.6% | 37.5% |
| ph_field | 0.5% | 5.7% | -0.1% | -0.8% | -2.7% | 1.5% | 1.3% | 1.0% | -1.4% |
| uS_cm | -31.9% | -5.0% | 4.9% | 26.4% | -0.1% | 1.0% | 0.1% | 6.2% | 4.3% |
| DO_Sat | 3.0% | 4.6% | -6.1% | -2.7% | -15.5% | 12.3% | 2.7% | 0.5% | -1.3% |
| DO_mgl | 11.3% | 6.0% | -3.2% | -3.9% | -10.7% | 12.2% | -1.4% | 3.0% | -0.2% |
| Turbidity (NTU) | -55.2% | 55.9% | 104.3% | 65.9% | -59.1% | 8.4% | -37.4% | 408.3% | 14.5% |
| Flow (CFS) | 93.7% | 32.1% | 22.4% | 136.7% | 11.4% | -0.2% | -4.0% | 32.0% | 1.2% |
| PH_AV | -0.7% | 3.8% | -0.5% | 1.2% | -1.5% | 0.8% | 1.2% | 0.4% | -0.4% |
| Alkalinity as CaCO3 (mg/l) | -21.0% | 8.0% | 14.5% | 33.1% | 0.6% | 0.7% | 2.2% | 4.2% | 1.6% |
| Alk_Bicarbonate (mg/l) | -20.5% | 8.2% | 14.5% | 33.7% | -0.5% | 0.8% | 2.1% | 3.8% | 2.2% |
| Calcium (mg/l) | 66.2% | 50.0% | 29.2% | 83.9% | 1.8% | 0.9% | 0.0% | 5.1% | 7.3% |
| Chloride (mg/l) | -44.4% | -29.2% | -5.0% | -33.1% | -8.2% | 2.9% | -8.3% | -9.1% | 0.0% |
| Potassium (mg/l) | -30.2% | -20.0% | 0.0% | -6.3% | -2.2% | 9.1% | 0.0% | -22.9% | -2.7% |
| Sodium (mg/l) | -47.7% | -23.8% | -8.2% | -25.0% | -4.8% | 3.3% | -3.2% | 0.8% | -0.8% |
| Sulfate (mg/l) | -26.8% | 11.1% | 35.0% | 150.6% | -0.4% | 0.9% | 2.9% | 17.1% | 21.3% |
| Total Dissolved Solids (mg/l) | -38.5% | -6.0% | 3.4% | 18.3% | 1.3% | 1.8% | 0.7% | 3.3% | 6.2% |
| Arsenic Total (mg/l) | -45.9% | -30.5% | -11.0% | -55.6% | -13.4% | -3.4% | -1.2% | -18.7% | -8.9% |
| Arsenic Dissolved (mg/l) | -47.3% | -28.9% | -10.7% | -58.1% | -10.9% | -1.8% | 0.0% | -17.9% | -8.7% |
| Iron Total (mg/l) | | | | | | | | | -18.5% |
| Iron Dissolved (mg/l) | | | | | | | | | 0.0% |
| Magnesium (mg/l) | 300% | 100.0% | 46.9% | 100.0% | -2.1% | 1.4% | 2.9% | 15.3% | 6.0% |
| Nitrate Nitrate Total (mg/l) | 0.0% | 46.7% | -31.8% | 306.7% | 59.0% | -19.6% | -14.7% | -10.5% | 18.4% |
| Nitrate Nitrite Diss. (mg/l) | 0.0% | 0.0% | 0.0% | 233.3% | 92.0% | -25.0% | -28.5% | 2.9% | 41.5% |
| Nitrogen Persulfate Total (mg/l) | 52.5% | -20.0% | 8.3% | 93.6% | 7.9% | 0.6% | -1.2% | -19.8% | 30.0% |
| Phosphorus Total (mg/l) | -10.0% | 0.0% | 0.0% | 0.0% | 19.4% | 11.6% | -8.3% | 9.1% | 0.0% |
| Phosphorus Ortho Total (mg/l) | -17.9% | -30.4% | 0.0% | -16.7% | 60.0% | -25.0% | -12.5% | 33.3% | 21.4% |
| Phosph. Ortho Dissolved (mg/l) | -13.9% | -22.6% | -16.7% | 2.5% | 75.6% | -16.7% | -6.7% | -14.3% | 0.0% |
| Total Suspended Sediment (mg/l) | -36.2% | 0.0% | 40.0% | 54.8% | -53.8% | 0.0% | 0.0% | 210.0% | -29.0% |

Note: Highlighted values (p <0.05) are considered statistically significant.

Alkalinity as CaCO3 and HCO3 were statistically different between stations 1/2, 2/3, 3/4, 4/5 and 8/9. The largest differences were at stations 1/2 (-21%) and stations 4/5 (+33%). Calcium generally showed the same pattern of statistical differences, with the addition of station pair 9/10. Calcium increased 66% between stations 1/2, 50% between stations 2/3, 29% between 3/4, and 84% between 4/5. Chloride generally showed the opposite pattern of calcium and tended to decrease between station pairs.

Remaining anions and cations including potassium, sodium, and sulfate generally followed a pattern similar to chloride, with statistical differences observed between upper station pairs, and less so at downstream pairs. Sulfate notably increased 150% at Toston and reflected the influence of watershed source area. Magnesium increased steadily at the upper four station pairs (47% to 300% increases between stations) and leveled off below Toston. Lesser magnesium increases (6-15%) were noted at Central Avenue and Morony due to the influence of the Sun River.

It is worthwhile to note that alkalinity, calcium, chloride, magnesium, potassium, sodium, and sulfate and TDS were not generally influenced by the Canyon Ferry, Hauser, Holter, or Morony hydro facilities. Shifts in these parameters were generally observed at Central Ave (8/9 pair) and were related to the influence of the Sun River.

Total and dissolved arsenic were statistically different between all station pairs except 6/7, 7/8, and 9/10. Both total and dissolved arsenic decreased steadily in the downstream direction. The largest decrease was at Toston (57% total and 58% dissolved) and was related to increased flow and dilution at the confluence of major tributaries. Further decreases of 11% to 13% were apparent below Canyon Ferry, and 18% to 19% at Central Avenue. The decrease below Canyon Ferry likely reflected some storage (along with TSS), and the Central Avenue decrease in arsenic was related to the influence of the Sun River. Remaining metals (not shown in 6.3 for brevity) showed no statistical differences between stations 9 and 10.

Total nitrate/nitrate was statistically different between pairs 4/5, 5/6, and 6/7. Dissolved nitrate/nitrate was statistically different between pairs 4/5, 5/6, 6/7 and 7/8. Most notable was an increase of total and dissolved nitrate of + 307% and +233%, respectively at Toston. This reflected the change of flow and watershed source area below the confluence of major Missouri tributaries. Total and dissolved nitrogen also increased 59 to 92% below Canyon Ferry. These increases may have reflected reservoir nutrient cycling influences, as well as watershed point and non-point sources. Total persulfate nitrogen was variable between station pairs with statistical differences between station pairs 1/2 (+53%), 4/5 (+94%), 8/9 (-20%), and 9/10 (+30%). It is worthwhile to note that unlike nitrate/nitrite, total persulfate nitrogen did not show a significant increase below Canyon Ferry. Total persulfate nitrogen decreased from Holter to Central Avenue likely as a result of the Sun River's influence. An increase of 30% was noted below Morony. The Morony site also had a tendency for higher nitrate/nitrite, but these differences were not statistically significant relative to the upstream station at Central Ave.

No statistical differences were present between station pairs for total phosphorus or total ortho phosphate. Dissolved ortho phosphate showed differences between station pairs 2/3 (-23%) and 5/6 (+76%). The increase below Canyon Ferry may have reflected a combination of reservoir nutrient cycling influences, as well as watershed point or non-point sources.

Total suspended sediment showed differences between station pairs 1/2 (-36%), 4/5 (+55%), 5/6 (-54%), and 8/9 (+210%). Sediment decreases at Hebgen and Canyon Ferry were likely related to storage effects. Increases at Toston and Central Avenue were related to large tributary sources above Toston, and the Sun River/Muddy Creek at Central Avenue.

### *6.1.3 Parameter Correlation*

Correlation between individual parameters by station was evaluated using Kendall-tau statistic. This provided an assessment establishing which parameters were statistically associated. Close association of concentration and flow provided the rationale for "flow adjustment" of selected trend analyses. The test method also provided trend analysis when correlating parameter concentration to over time (i.e. date).

The matrices of cross-correlations are extensive and are not detailed in narrative form. Complete results of cross-correlations for individual stations and parameters are found in **Appendix D**.

Parameter inter-correlations showed that numerous constituents were closely related to one another. In addition, many parameters were closely related to flow. Total and dissolved correlations for arsenic and other trace metals showed close relationships. This was also characteristic of dissolved and total nutrient parameters for nitrogen. A variety of parameters were closely related to discharge. Among others, specific conductivity, turbidity, total suspended sediment, alkalinity (bicarbonate), sodium, chloride, sulfate and total arsenic had a strong correlation with discharge. This suite of parameters was analyzed for trends in both raw data (**Section 6.1.4**), and also trends in concentration adjusted for the effects of flow (**Section 6.1.5**).

### *6.1.4 Trend Analysis*

Trend testing for the Missouri-Madison monitoring stations 1-10 was conducted using the Kendall non-parametric test of correlation between date and analyte result. Results below ½ of the detection limit were replaced by the detection limit for purposes of analysis.

The results for trend tests not adjusted for flow including pooled monthly and quarterly raw data are summarized in **Tables 6-4 to 6-7**.

In addition, quarterly raw data were analyzed for trends to assess the ability of quarterly sampling frequency to detect trends (**Appendix E**). A select suite of constituents was adjusted for the effects of flow on concentration. Trend analysis of these flow-adjusted parameters is presented in **Section 6.1.5**.

No adjustments were made for potential influence of autocorrelation. Autocorrelation is the tendency for sequential data points to be related and not fully independent. e.g. high values tend to follow highs. Autocorrelation can lead to a tendency to identify trends more frequently, and some of these apparent trends may be an artifact of autocorrelation. Seasonal adjustment is a common approach to address this issue. Quarterly data cannot be seasonally adjusted, however, so flow adjustment was employed to help address the issue of autocorrelation.

#### Field Parameters

Several stations indicated isolated trends in field parameters, and trends in several parameters were widespread within the monitoring network (**Tables 6-4 to 6-7**). Field temperature tended to decrease at all stations from 1997-2006. The stations showing statistically significant decreases in temperature were station 1 and station 3. Field pH tended to remain stable over this same time period and no statistically significant trends were discernable with the exception of station 9. Station 9 showed an increase in pH. Field conductivity showed a statistically significant increase at all stations in the monitoring network.

Dissolved oxygen (% saturation) did not show any statistically significant trends with the exception of station 7. DO saturation showed a decreasing trend at stations 7 and 10, although dissolved oxygen

concentration (mg/l) was statistically unchanged at both stations. The sole station showing a statistical trend in dissolved oxygen was station 3, and the trend was increasing.

Field turbidity generally showed a decreasing trend for most stations from 1997 to 2006. Those stations with statistically significant trends in turbidity included stations 2, 4, 5, 6, 7, 8, 9 and 10. Flow showed a decreasing trend over the period of analysis at all stations in the network.

Overall, the consistent trends observed within the monitoring network from 1997-2006 were increased field conductivity, decreased turbidity and decreased flow values. These represented relatively uniform tendencies throughout the monitoring network.

**Table 6-4. Kendall Trend Test (Field Parameters Set 1)**

| Correlations | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Temp_C | Cor. Coeff. | -.190* | -.095 | -.205** | -.062 | -.095 | -.084 | -.103 | -.075 | -.076 | -.076 |
| | Sig. (2-tail) | .011 | .205 | .006 | .409 | .205 | .267 | .173 | .322 | .305 | .305 |
| | N | 82 | 83 | 83 | 82 | 83 | 81 | 81 | 81 | 85 | 85 |
| ph_field | Cor. Coeff. | .017 | .114 | -.036 | .105 | .029 | .095 | .118 | .250** | .177* | .089 |
| | Sig. (2-tail) | .826 | .126 | .634 | .162 | .700 | .212 | .119 | .001 | .016 | .230 |
| | N | 82 | 83 | 83 | 82 | 83 | 81 | 81 | 81 | 85 | 85 |
| uS_cm | Cor. Coeff. | .355** | .293** | .225** | .273** | .190* | .261** | .283** | .332** | .356** | .338** |
| | Sig. (2-tail) | .000 | .000 | .003 | .000 | .011 | .001 | .000 | .000 | .000 | .000 |
| | N | 82 | 83 | 83 | 81 | 83 | 81 | 81 | 81 | 84 | 85 |
| DO_Sat | Cor. Coeff. | -.085 | .023 | .048 | .097 | -.074 | .052 | -.161* | -.094 | -.045 | -.345** |
| | Sig. (2-tail) | .259 | .759 | .519 | .199 | .325 | .488 | .034 | .217 | .544 | .000 |
| | N | 82 | 83 | 83 | 82 | 83 | 81 | 81 | 81 | 85 | 85 |
| DO_mgl | Cor. Coeff. | .116 | .048 | .210** | .096 | .070 | .065 | -.052 | .008 | .074 | -.006 |
| | Sig. (2-tail) | .122 | .524 | .005 | .203 | .351 | .392 | .493 | .919 | .316 | .933 |
| | N | 82 | 83 | 83 | 82 | 83 | 81 | 81 | 81 | 85 | 85 |
| Turbidity (NTU) | Cor. Coeff. | -.147 | -.251** | -.129 | -.169* | -.188* | -.263** | -.264** | -.329** | -.167* | -.147* |
| | Sig. (2-tail) | .050 | .001 | .084 | .025 | .013 | .001 | .000 | .000 | .023 | .046 |
| | N | 82 | 83 | 83 | 82 | 82 | 76 | 81 | 81 | 85 | 85 |
| Flow (CFS) | Cor. Coeff. | -.390** | -.327** | -.322** | -.324** | -.270** | -.387** | -.346** | -.364** | -.300** | -.154* |
| | Sig. (2-tail) | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .044 |
| | N | 78 | 82 | 81 | 81 | 78 | 73 | 78 | 80 | 73 | 80 |

*. Correlation is significant at the 0.05 level (2-tail).
**. Correlation is significant at the 0.01 level (2-tail).

**Lab Analytes**

Trend analyses of lab results indicated several major trends that were widespread within the monitoring network from 1997-2006 (Tables 6-2 and 6-3). Lab pH was generally stable at all stations, showing a statistically significant increase solely at station 2. Alkalinity (as CaCO3) showed a statistically significant increase at all ten stations with the exception of stations 5 and 6. Alkalinity expressed as bicarbonate showed the same results for increasing trends as alkalinity/CaCO3. Calcium increased at upstream monitoring sites 1-4, and also stations 9 and 10. Chloride, potassium, sodium, and total dissolved solids showed a statistically significant increasing trend at all 10 stations within the network. Sulfate showed statistically significant increasing trends for 7 of ten stations, with the exception of stations 3, 5 and 6.

Overall, the consistent trends observed within the monitoring network from 1997-2006 were increased alkalinity metrics, total dissolved solids, chloride, potassium, sodium, and to a lesser extent, sulfate. These trends represented uniform tendencies throughout the monitoring network. The stations that exhibited more stability in lab analytes were stations 5 and 6.

**Table 6-5. Kendall Trend Test (Lab Analytes Set 2)**

| Correlations | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| PH_AV | Cor. Coeff. | .091 | .169* | -.040 | .098 | .007 | -.097 | .055 | .112 | .044 | -.050 |
| | Sig. (2-tail) | .259 | .035 | .610 | .220 | .930 | .231 | .499 | .164 | .580 | .537 |
| | N | 82 | 82 | 83 | 81 | 83 | 80 | 81 | 81 | 84 | 83 |
| Alkalinity as CaCO3 (mg/l) | Cor. Coeff. | .291** | .258** | .183* | .204** | .029 | .112 | .178* | .171* | .194* | .215** |
| | Sig. (2-tail) | .000 | .001 | .015 | .007 | .697 | .146 | .021 | .026 | .011 | .005 |
| | N | 82 | 82 | 83 | 82 | 83 | 80 | 80 | 81 | 82 | 83 |
| Bicarbonate (mg/l) | Cor. Coeff. | .289** | .254** | .191* | .205** | .031 | .120 | .174* | .155* | .181* | .204** |
| | Sig. (2-tail) | .000 | .001 | .012 | .007 | .683 | .117 | .024 | .044 | .018 | .007 |
| | N | 81 | 81 | 82 | 81 | 82 | 80 | 79 | 80 | 81 | 82 |
| Calcium (mg/l) | Cor. Coeff. | .319** | .462** | .207* | .326** | .016 | .100 | .111 | .144 | .190* | .213** |
| | Sig. (2-tail) | .001 | .000 | .022 | .000 | .851 | .242 | .193 | .090 | .015 | .006 |
| | N | 68 | 68 | 68 | 68 | 70 | 68 | 69 | 69 | 83 | 84 |
| Chloride (mg/l) | Cor. Coeff. | .386** | .297** | .235** | .217** | .256** | .345** | .362** | .347** | .402** | .382** |
| | Sig. (2-tail) | .000 | .000 | .002 | .005 | .001 | .000 | .000 | .000 | .000 | .000 |
| | N | 82 | 82 | 83 | 82 | 83 | 81 | 81 | 81 | 82 | 83 |
| Magnesium (mg/l) | Cor. Coeff. | -.234* | -.182 | -.164 | . | . | . | . | . | .192* | .198* |
| | Sig. (2-tail) | .020 | .071 | .103 | . | . | . | . | . | .018 | .015 |
| | N | 68 | 68 | 68 | 1 | 1 | 1 | 0 | 1 | 83 | 84 |
| | N | 82 | 82 | 83 | 82 | 83 | 81 | 81 | 81 | 82 | 83 |
| Potassium (mg/l) | Cor. Coeff. | .489** | .383** | .329** | .317** | .326** | .445** | .474** | .405** | .264** | .265** |
| | Sig. (2-tail) | .000 | .000 | .000 | .001 | .001 | .000 | .000 | .000 | .003 | .003 |
| | N | 68 | 68 | 68 | 68 | 70 | 68 | 69 | 69 | 83 | 84 |
| Sodium (mg/l) | Cor. Coeff. | .393** | .291** | .222** | .214* | .255** | .319** | .334** | .318** | .321** | .330** |
| | Sig. (2-tail) | .000 | .001 | .008 | .011 | .002 | .000 | .000 | .000 | .000 | .000 |
| | N | 68 | 68 | 68 | 68 | 70 | 68 | 69 | 69 | 83 | 84 |
| Sulfate (mg/l) | Cor. Coeff. | .263** | .164* | .116 | .186* | .069 | .117 | .182* | .196* | .290** | .277** |
| | Sig. (2-tail) | .001 | .041 | .156 | .019 | .364 | .133 | .020 | .013 | .000 | .000 |
| | N | 82 | 82 | 82 | 82 | 83 | 81 | 81 | 81 | 82 | 83 |
| Total Dissolved Solids (mg/l) | Cor. Coeff. | .351** | .234** | .221** | .212** | .148* | .214** | .246** | .271** | .365** | .351** |
| | Sig. (2-tail) | .000 | .002 | .003 | .005 | .049 | .005 | .001 | .000 | .000 | .000 |
| | N | 82 | 82 | 82 | 82 | 83 | 81 | 81 | 81 | 82 | 83 |

*. Correlation is significant at the 0.05 level (2-tail).
**. Correlation is significant at the 0.01 level (2-tail).

**Dissolved and Total Metal Analytes**

Dissolved and total arsenic were collected at each of 10 stations from 1997-2006. Additionally, total and dissolved cadmium, copper, iron, lead, zinc and manganese were collected at stations 9 and 10.

Trend analysis of total and dissolved arsenic showed a uniform tendency for robustly increasing trends at all stations in the monitoring network (**Table 6-6**). Arsenic increased from 1997 to 2000 at all stations, and appeared to have leveled out following 2000. Increasing trends were statistically significant at all stations. No trends were present for total and dissolved cadmium. Total copper showed decreasing trends at both stations 9 and 10. The tendency for decreasing trends in total copper was not statistically significant at stations 9 and 10. Total and dissolved iron showed a decreasing trend for total iron at station 9, but no trends otherwise. Total and dissolved lead showed a decreasing trend for total lead at station 10, but no trends otherwise. Both total and dissolved zinc and total and dissolved manganese showed decreasing trends at both stations 9 and 10.

**Table 6-6. Kendall Trend Test (Lab Analytes Set 3)**

| Correlations | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Arsenic Total (mg/l) | Cor. Coeff. | .335** | .246** | .203** | .232** | .306** | .457** | .405** | .469** | .478** | .458** |
| | Sig. (2-tail) | .000 | .001 | .007 | .002 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 82 | 83 | 83 | 82 | 83 | 81 | 81 | 81 | 84 | 86 |
| Arsenic Dissolved (mg/l) | Cor. Coeff. | .348** | .276** | .217** | .235** | .320** | .494** | .499** | .529** | .477** | .477** |
| | Sig. (2-tail) | .000 | .000 | .004 | .002 | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 82 | 83 | 83 | 82 | 83 | 81 | 81 | 81 | 84 | 85 |
| Cadmium Total (mg/l) | Cor. Coeff. | | | | | | | | | -.120 | -.107 |
| | Sig. (2-tail) | | | | | | | | | .180 | .223 |
| | N | | | | | | | | | 82 | 84 |
| Cadmium Dissolved (mg/l) | Cor. Coeff. | | | | | | | | | -.069 | -.007 |
| | Sig. (2-tail) | | | | | | | | | .471 | .942 |
| | N | | | | | | | | | 72 | 73 |
| Copper Total (mg/l) | Cor. Coeff. | | | | | | | | | -.189* | -.283** |
| | Sig. (2-tail) | | | | | | | | | .020 | .000 |
| | N | | | | | | | | | 82 | 84 |
| Copper Dissolved (mg/l) | Cor. Coeff. | | | | | | | | | -.186 | -.205 |
| | Sig. (2-tail) | | | | | | | | | .089 | .058 |
| | N | | | | | | | | | 47 | 49 |
| Iron Total (mg/l) | Cor. Coeff. | | | | | | | | | -.151* | -.111 |
| | Sig. (2-tail) | | | | | | | | | .046 | .137 |
| | N | | | | | | | | | 82 | 85 |
| Iron Dissolved (mg/l) | Cor. Coeff. | | | | | | | | | .041 | .004 |
| | Sig. (2-tail) | | | | | | | | | .657 | .962 |
| | N | | | | | | | | | 82 | 84 |
| Lead Total (mg/l) | Cor. Coeff. | | | | | | | | | -.016 | -.226** |
| | Sig. (2-tail) | | | | | | | | | .850 | .008 |
| | N | | | | | | | | | 82 | 84 |
| Lead Dissolved (mg/l) | Cor. Coeff. | | | | | | | | | -.092 | -.141 |
| | Sig. (2-tail) | | | | | | | | | .296 | .107 |
| | N | | | | | | | | | 82 | 84 |
| Zinc Total (mg/l) | Cor. Coeff. | | | | | | | | | -.311** | -.301** |
| | Sig. (2-tail) | | | | | | | | | .000 | .001 |
| | N | | | | | | | | | 82 | 85 |

**Table 6-6. Kendall Trend Test (Lab Analytes Set 3)**

| Correlations | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Zinc Dissolved (mg/l) | Cor. Coeff. | | | | | | | | | -.470** | -.460** |
| | Sig. (2-tail) | | | | | | | | | .000 | .000 |
| | N | | | | | | | | | 82 | 84 |
| Manganese Total (mg/l) | Cor. Coeff. | | | | | | | | | .552** | .532** |
| | Sig. (2-tail) | | | | | | | | | .000 | .000 |
| | N | | | | | | | | | 46 | 49 |
| Manganese Dissolved (mg/l) | Cor. Coeff. | | | | | | | | | -.276* | -.547** |
| | Sig. (2-tail) | | | | | | | | | .013 | .000 |
| | N | | | | | | | | | 47 | 48 |

**. Correlation is significant at the 0.01 level (2-tail).
*. Correlation is significant at the 0.05 level (2-tail).

**Nutrient Analytes**

Trends in nutrient constituents were variable by location (**Table 6-7**). Total nitrate/nitrite showed decreasing trends at downstream stations 6, 8, and 10. Dissolved nitrate/nitrite showed an increasing trend at uppermost station 1. Remaining downstream stations showed no trends in dissolved nitrate/nitrate. Total nitrogen persulfate showed an increased trend at stations 4, 9 and 10, and no statistically significant trends at remaining stations. Dissolved and total ammonia was below detection limits for the vast majority of observations and did not show any statistically valid trends over the monitoring period. Trend results for ammonia components are not presented. Reduced detection limits for ammonia over the study period adversely bias the analysis, and rare detection of total and dissolved ammonia limit the applicability of trend analysis methods.

Total phosphorus showed increasing trends at stations 1, 2, 3, and 4 and a decrease at station 9. This was the most prevalent and consistent spatial trend for nutrient parameters within the monitoring network.

Dissolved and total ortho-phosphorus showed limited statistically significant trends. Total ortho-phosphorus showed an increasing trend at station 9, and dissolved ortho-phosphorus showed statistically significant increases at stations 1, 5 and 9.

Total suspended sediment showed statistically significant decreases at stations 4, 5, 9 and 10.

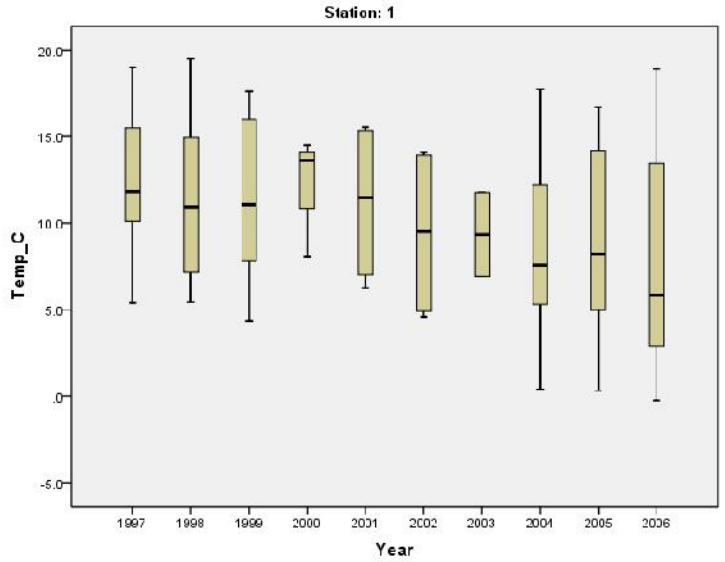
Overall, the consistent trends observed within the monitoring network from 1997-2006 were increased total phosphorous at the upper 4 stations (1-4) plus station 9, a tendency for increased total ortho-phosphorus (station 9), and dissolved ortho-phosphorus at stations 1, 5 and 9. Total suspended sediment also increased at the lower stations (5, 6, 9, and 10).

**Table 6-7. Kendall Trend Analyses for Nutrients**

| Correlations | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Nitrate Nitrate Total (mg/l) | Cor. Coeff. | .153 | -.083 | -.012 | .006 | .001 | -.207* | -.149 | -.220** | -.171 | -.168* |
| | Sig. (2-tail) | .107 | .372 | .891 | .948 | .989 | .011 | .071 | .009 | .052 | .049 |
| | N | 73 | 74 | 74 | 74 | 75 | 74 | 72 | 70 | 66 | 67 |
| Nitrate Nitrite Dissolved (mg/l) | Cor. Coeff. | .279* | -.002 | .109 | .082 | .002 | -.113 | -.036 | .022 | -.124 | -.154 |
| | Sig. (2-tail) | .014 | .989 | .325 | .469 | .987 | .260 | .718 | .830 | .216 | .122 |
| | N | 51 | 51 | 50 | 51 | 51 | 50 | 50 | 50 | 53 | 50 |
| Nitrogen Persulfate Total (mg/l) | Cor. Coeff. | .130 | .088 | .154 | .243** | .084 | .118 | .043 | -.009 | .272** | .308** |
| | Sig. (2-tail) | .142 | .325 | .080 | .006 | .333 | .183 | .622 | .918 | .002 | .000 |
| | N | 62 | 62 | 64 | 63 | 64 | 62 | 62 | 62 | 63 | 64 |
| Phosphorus Total (mg/l) | Cor. Coeff. | .474** | .350** | .313** | .338** | -.046 | .085 | .076 | .000 | -.167* | -.121 |
| | Sig. (2-tail) | .000 | .000 | .000 | .000 | .600 | .339 | .389 | .996 | .045 | .143 |
| | N | 71 | 72 | 72 | 71 | 71 | 70 | 70 | 70 | 81 | 82 |
| Phosphorus Ortho Total (mg/l) | Cor. Coeff. | .108 | -.120 | -.058 | .135 | .093 | .211 | .141 | .126 | .267* | .171 |
| | Sig. (2-tail) | .345 | .291 | .615 | .255 | .409 | .067 | .214 | .268 | .022 | .155 |
| | N | 45 | 45 | 45 | 44 | 45 | 44 | 43 | 43 | 44 | 44 |
| Phosphorus Ortho Dissolved (mg/l) | Cor. Coeff. | .323** | .151 | .092 | .107 | -.301** | -.190* | -.153 | -.073 | -.268** | -.063 |
| | Sig. (2-tail) | .000 | .075 | .278 | .218 | .000 | .027 | .066 | .372 | .002 | .474 |
| | N | 80 | 80 | 80 | 80 | 80 | 79 | 79 | 79 | 73 | 73 |
| Total Suspended Sediment (mg/l) | Cor. Coeff. | -.140 | -.014 | -.097 | -.212* | -.221** | -.126 | -.144 | -.073 | -.210* | -.256** |
| | Sig. (2-tail) | .087 | .871 | .251 | .010 | .004 | .139 | .096 | .399 | .007 | .001 |
| | N | 82 | 82 | 82 | 82 | 83 | 81 | 81 | 81 | 82 | 83 |

*. Correlation is significant at the 0.05 level (2-tail).
**. Correlation is significant at the 0.01 level (2-tail).

Box plots for parameter/station combinations over time show the trends graphically and are found in the following box plots. Note that no trend lines are included as parameters did not necessarily show uniform monotonic trends in concentration.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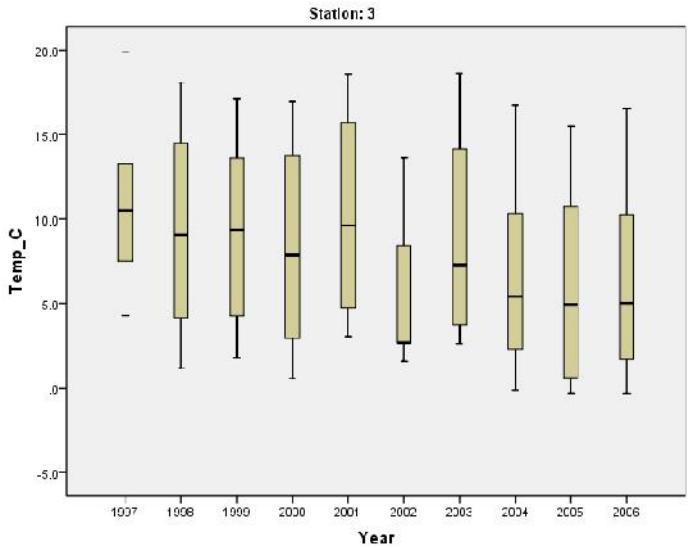
1999
2000
2001
2002
2003
2004
2005
2006
Year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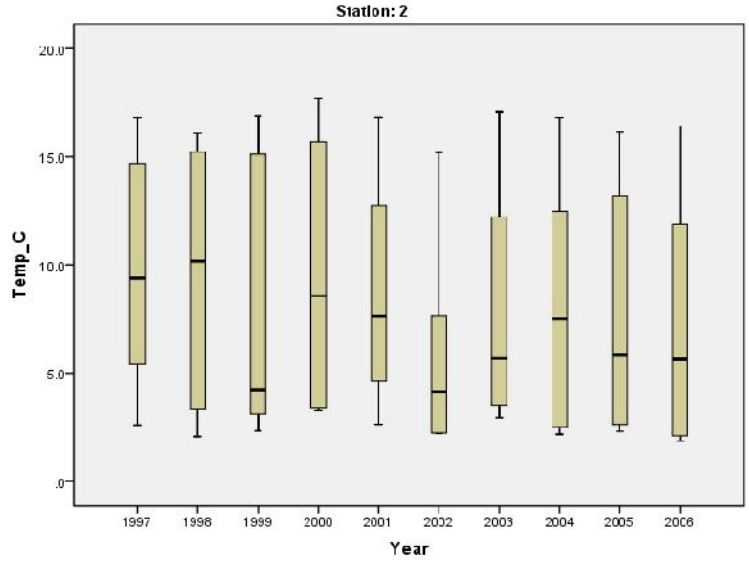
2005
2006
Year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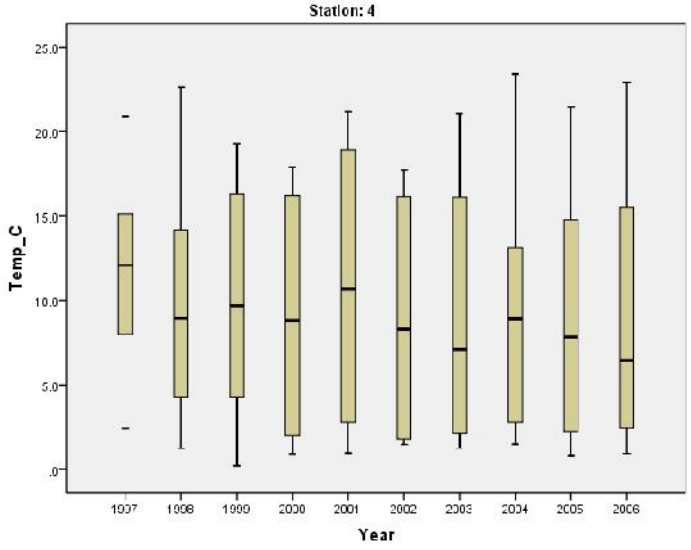
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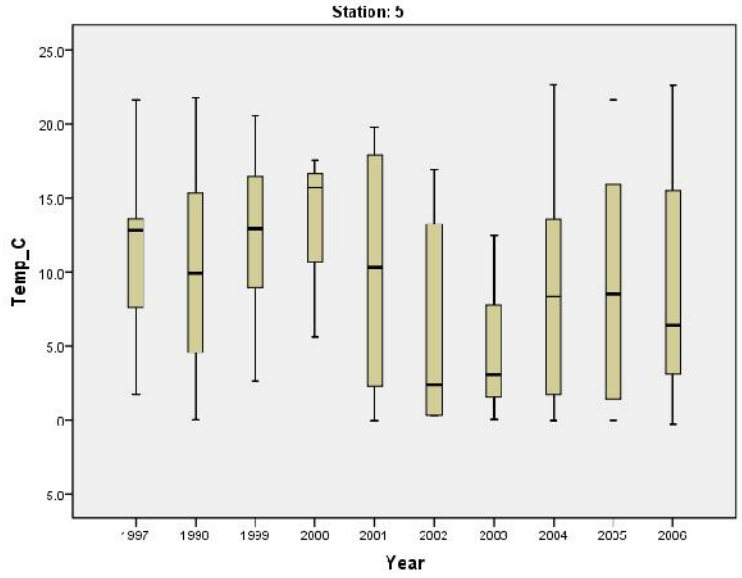
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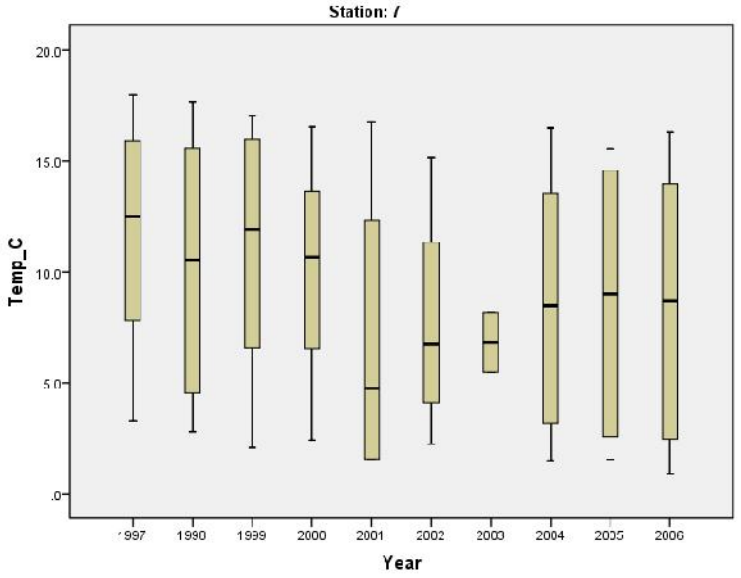
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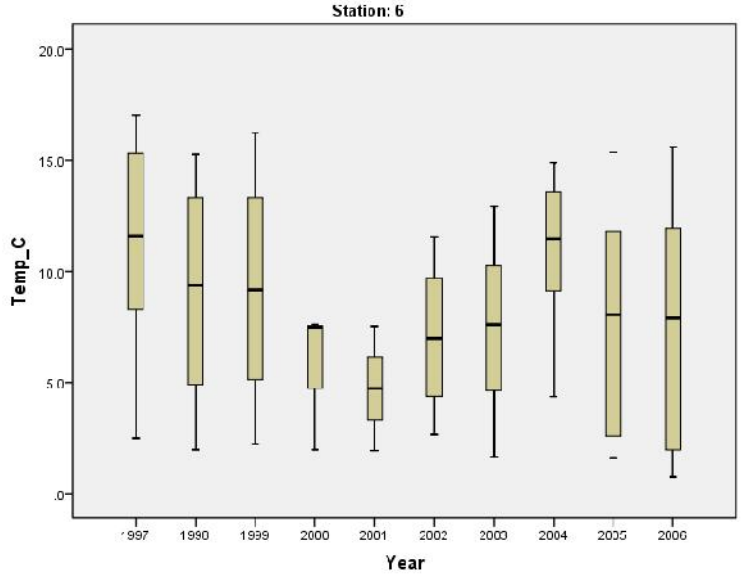
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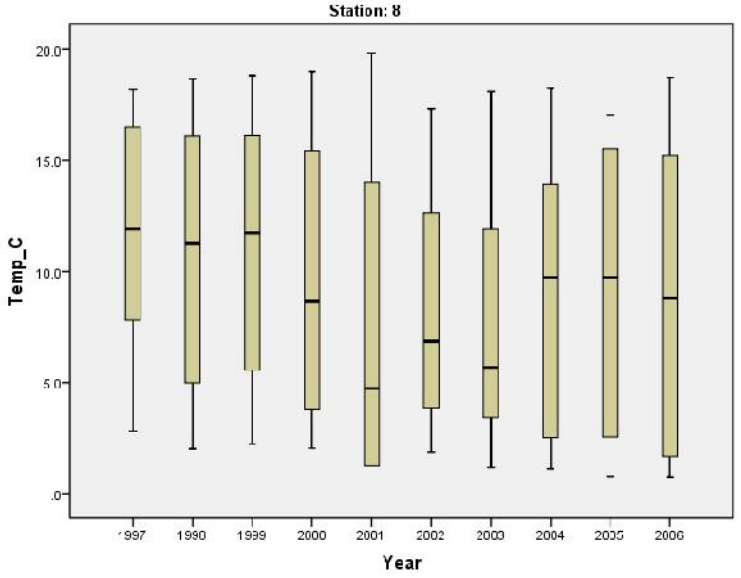
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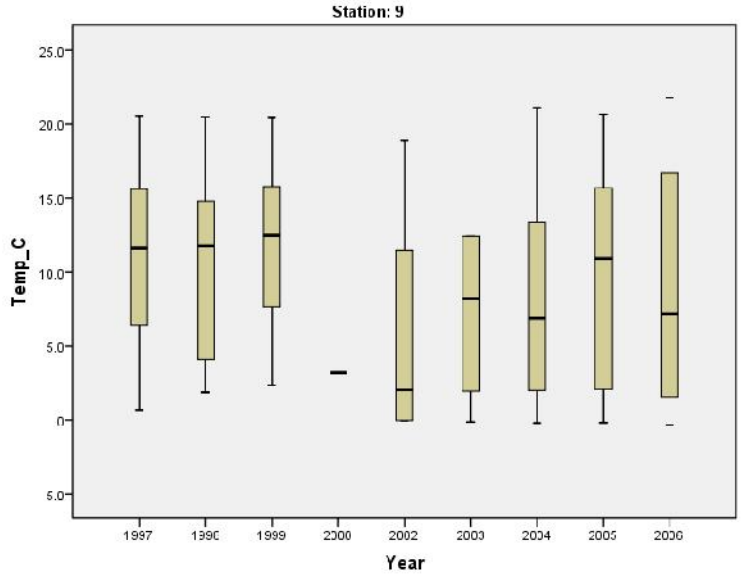
2005
2006
Year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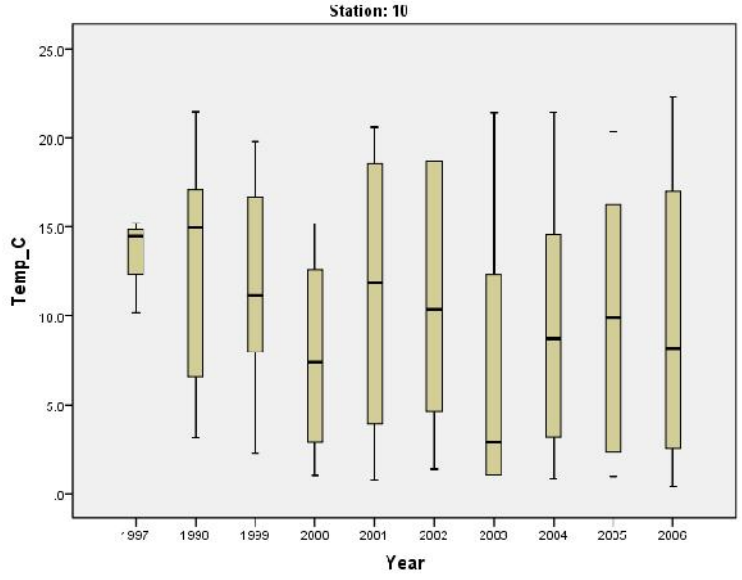
2004
2005
2006
Year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2006
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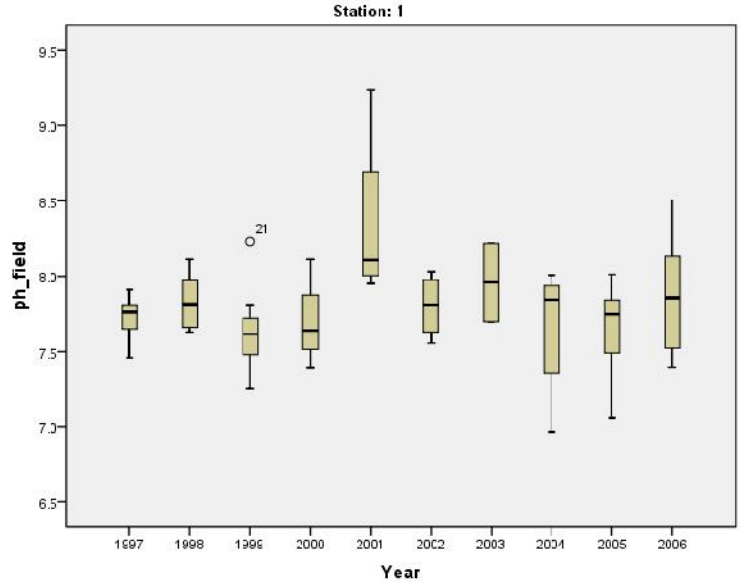
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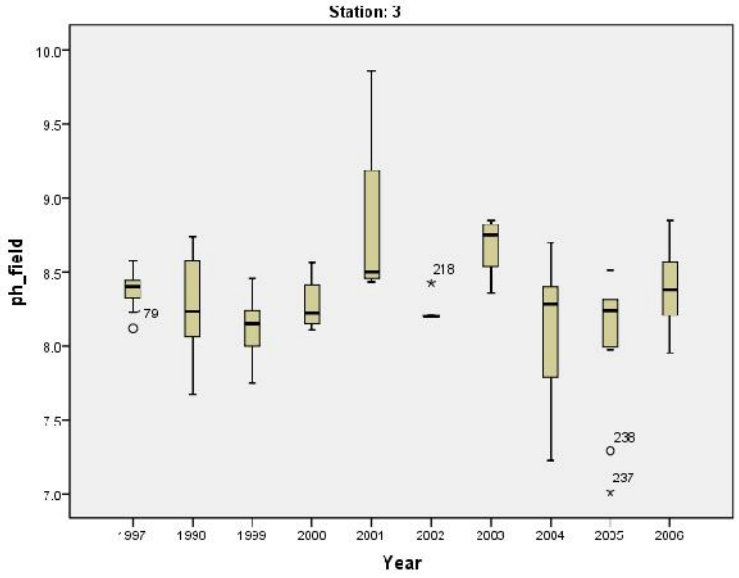
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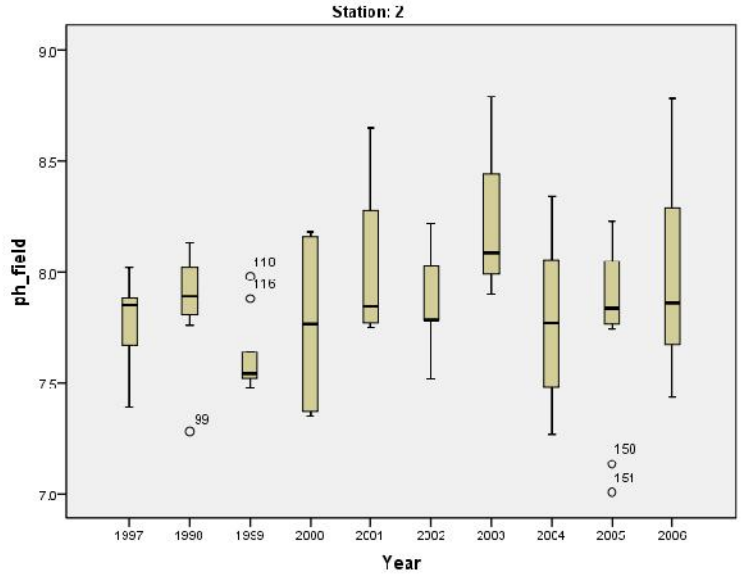
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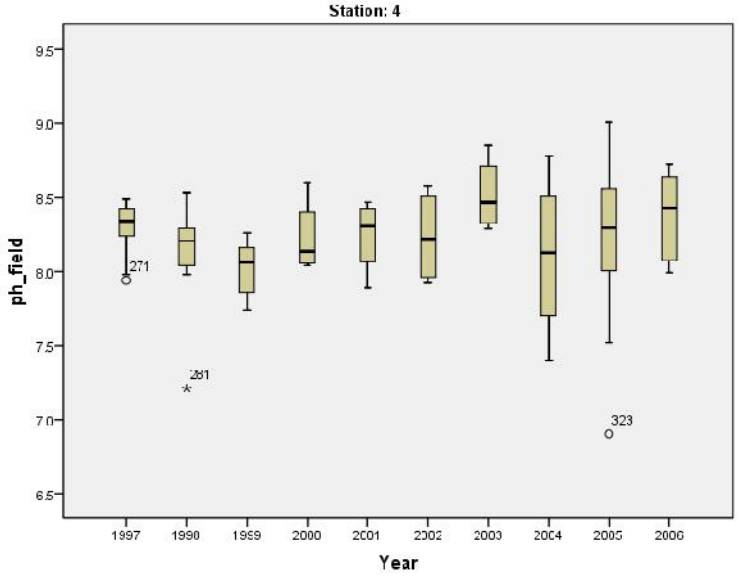
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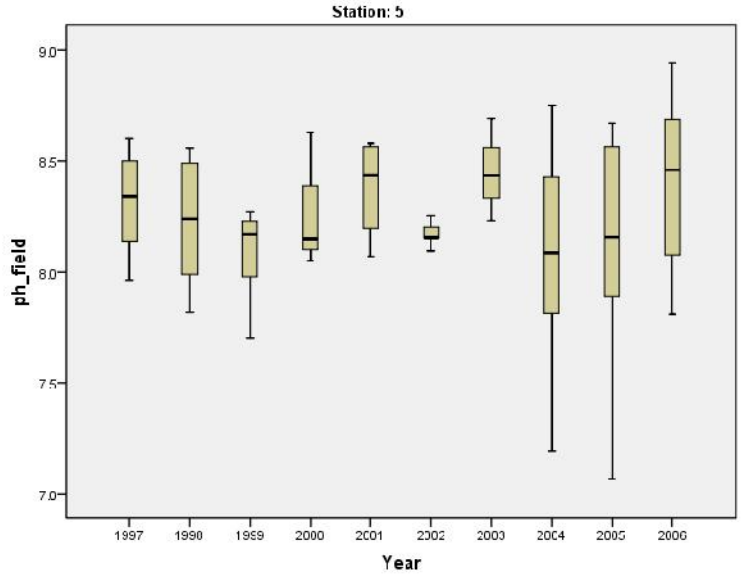
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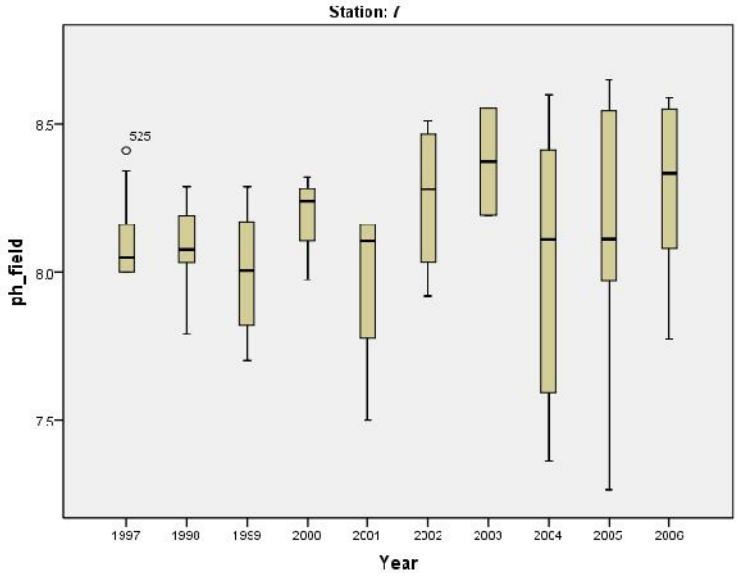
2006
Year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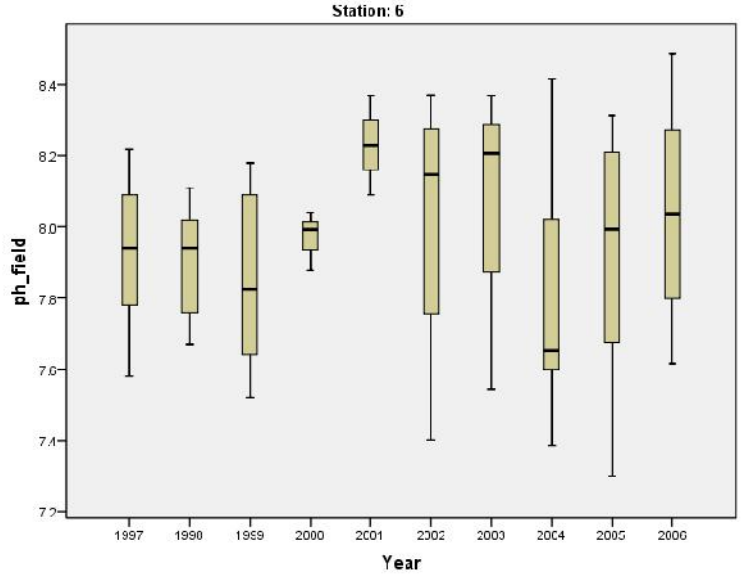
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2004
2005
2006
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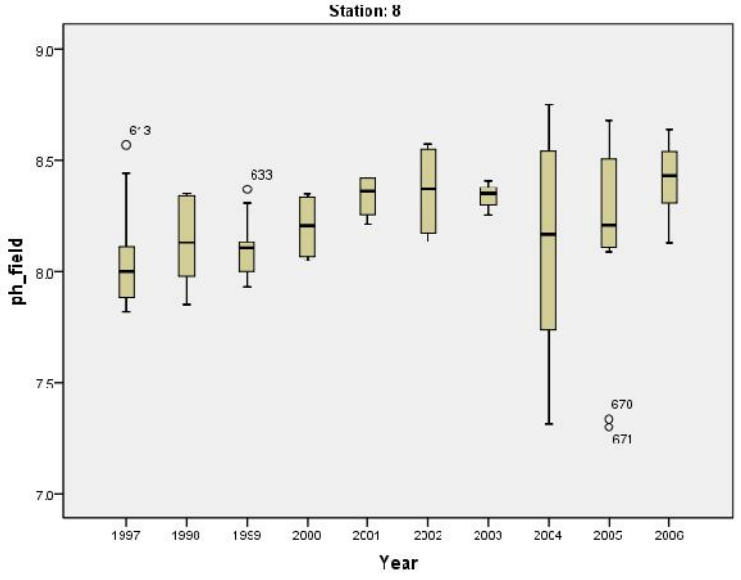
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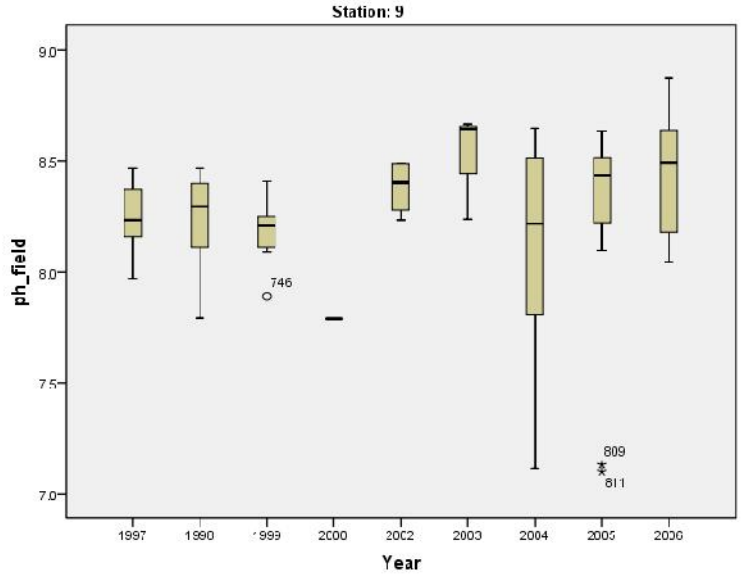
2004
2005
2006
Year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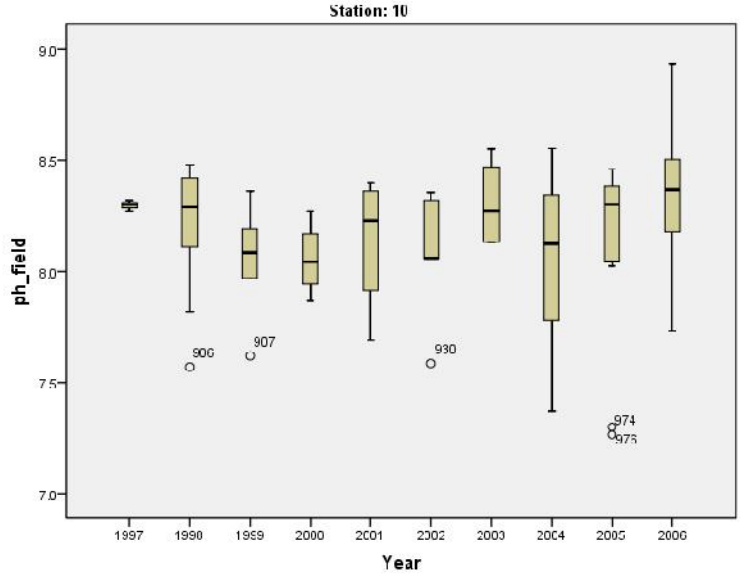
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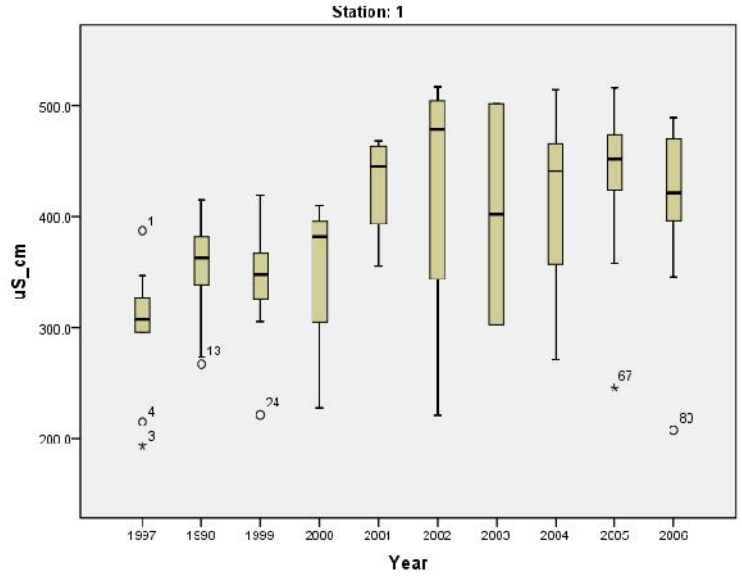
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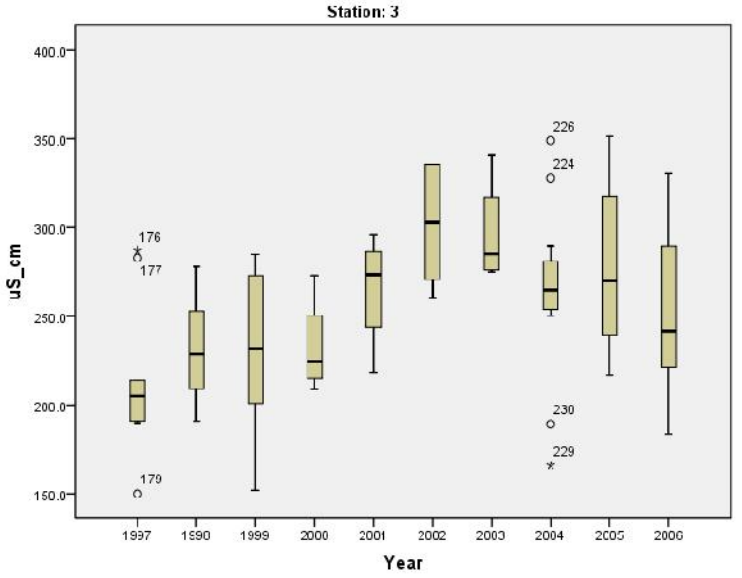
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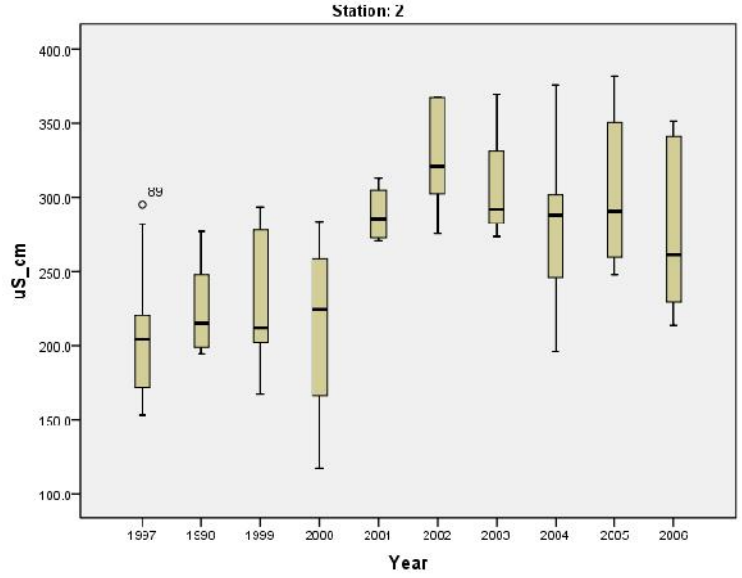
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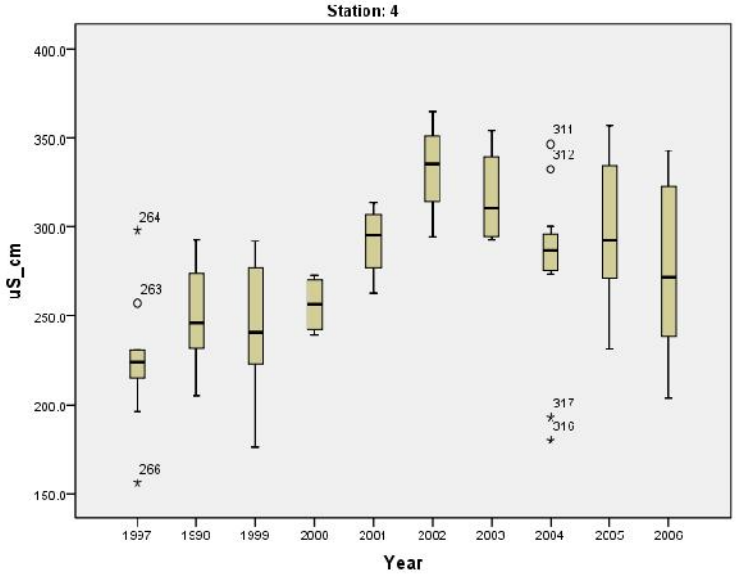
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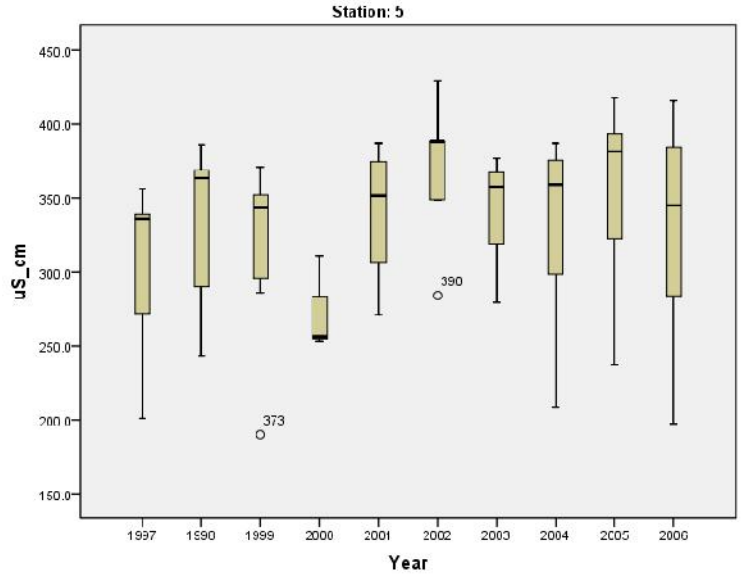
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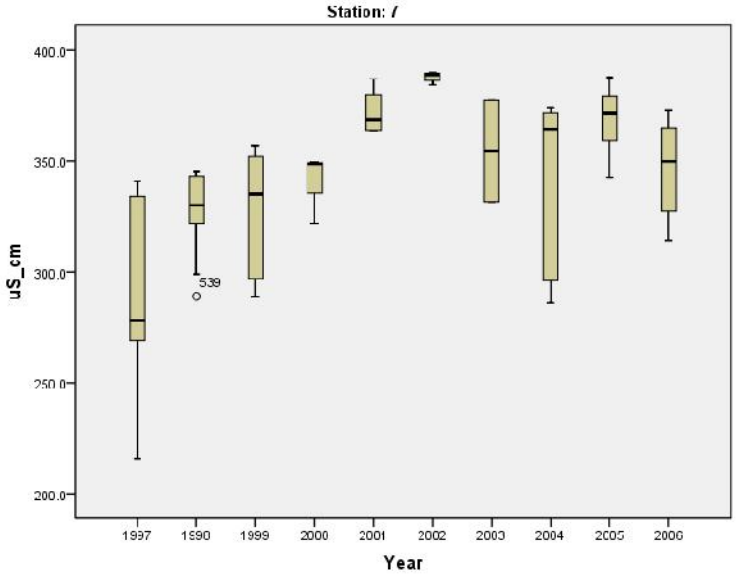
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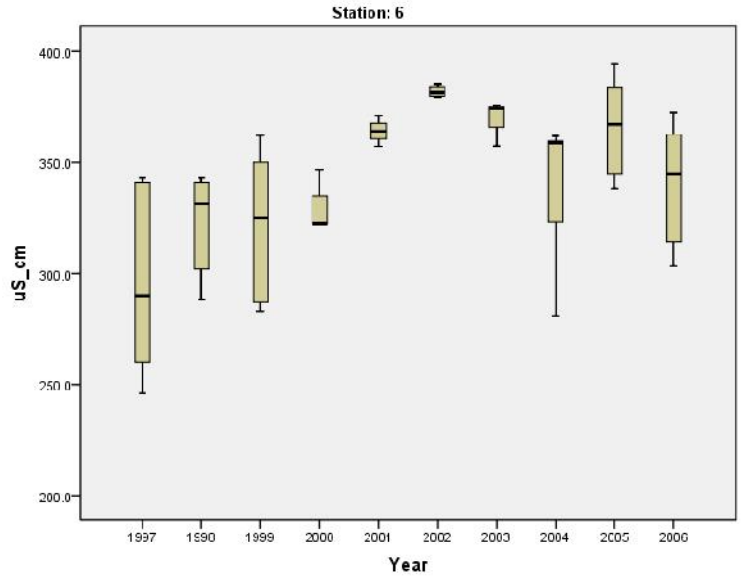
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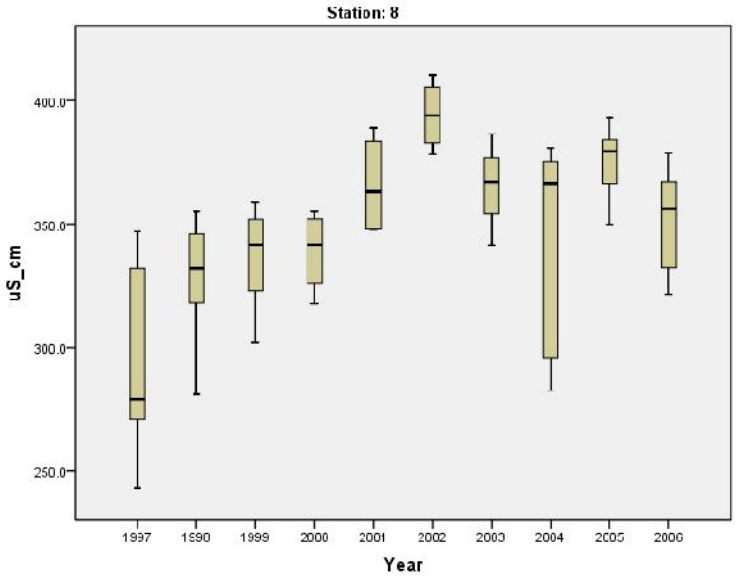
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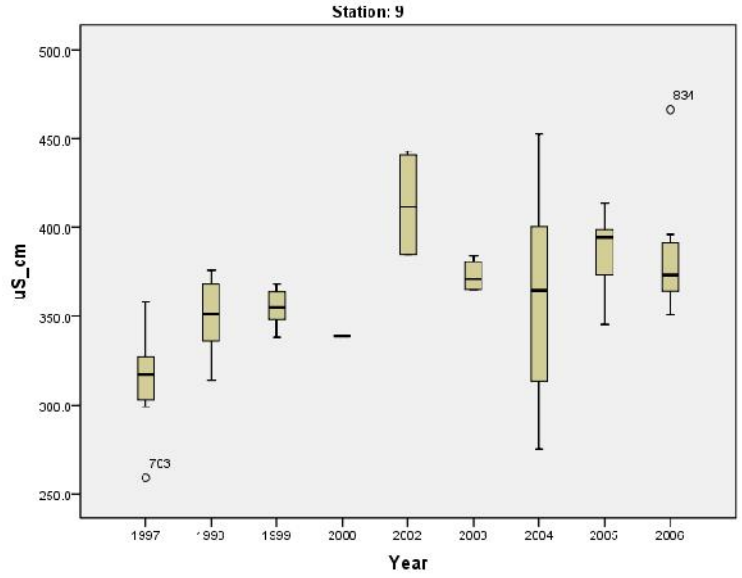
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2004
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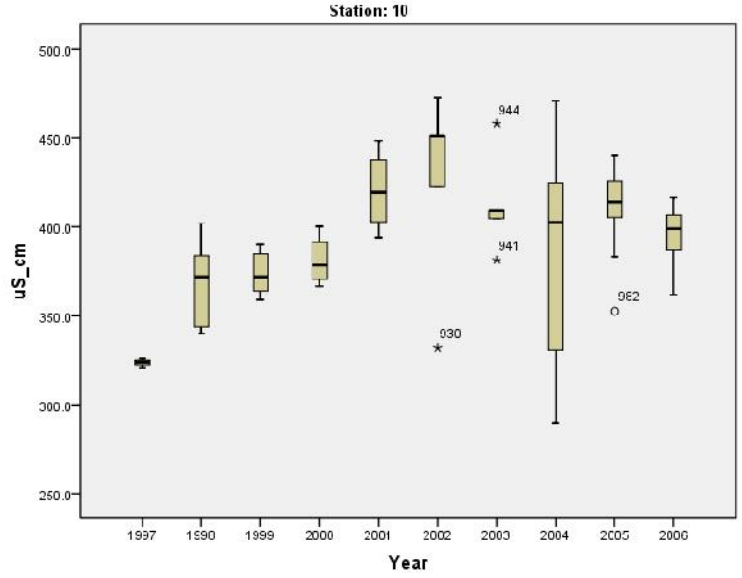
Year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2006
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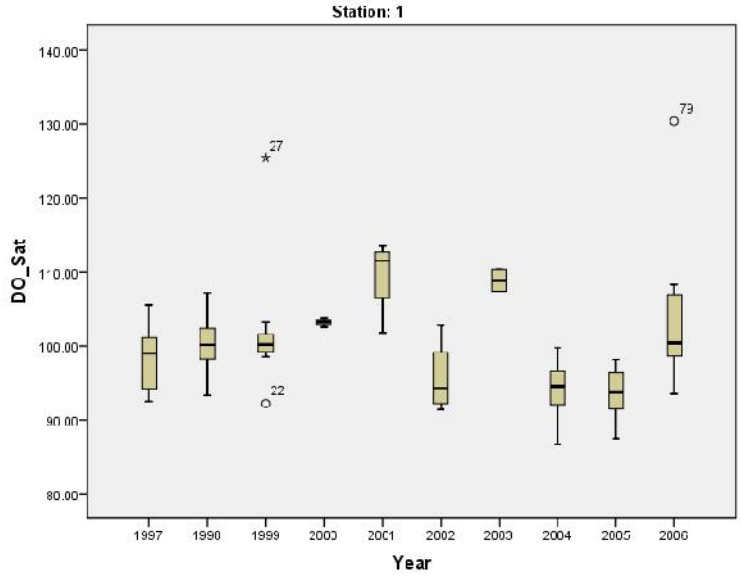
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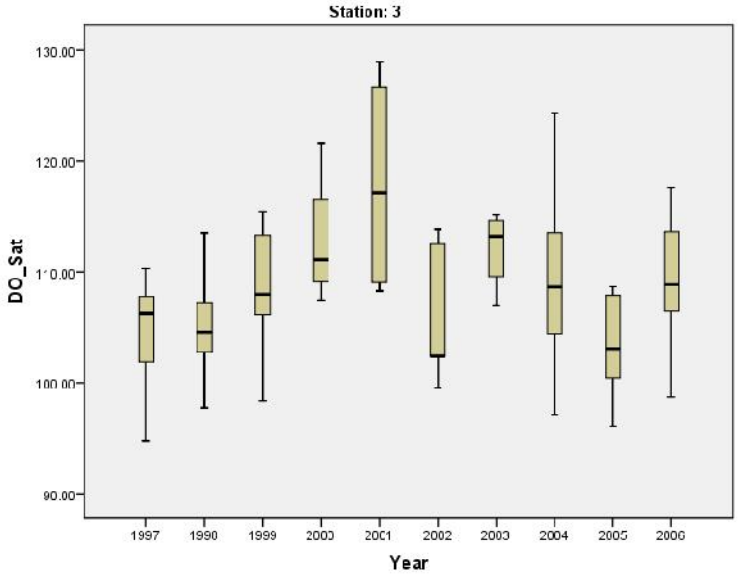
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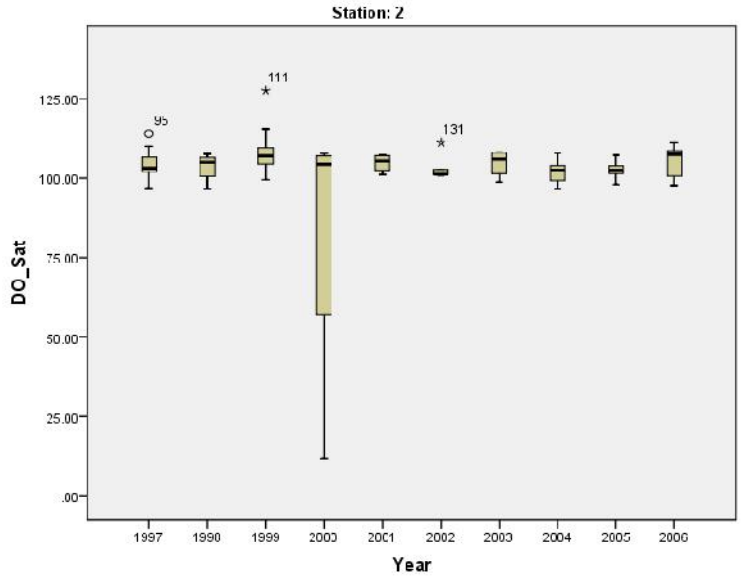
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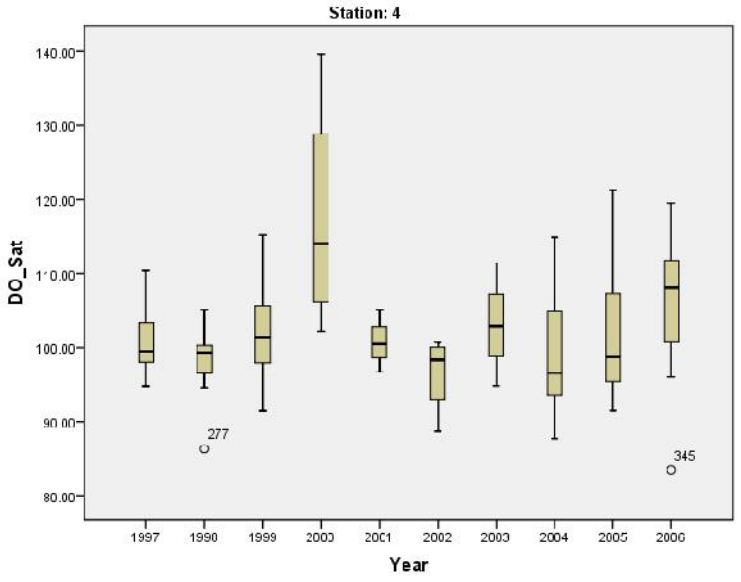
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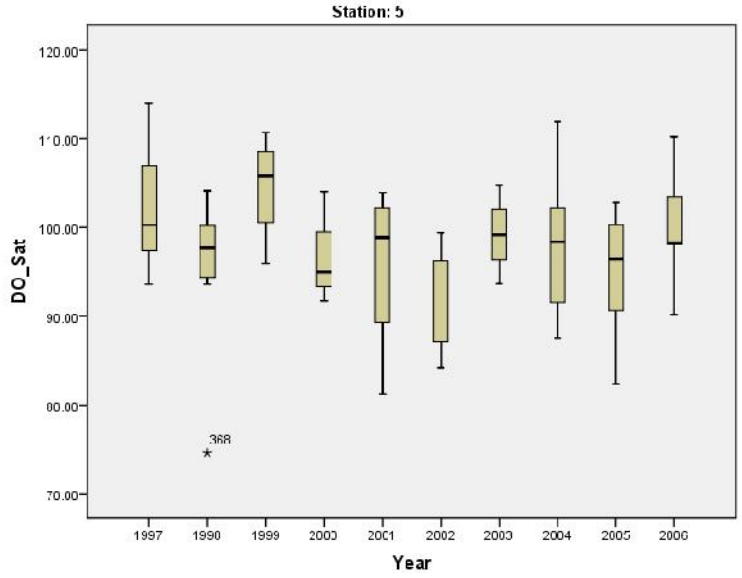
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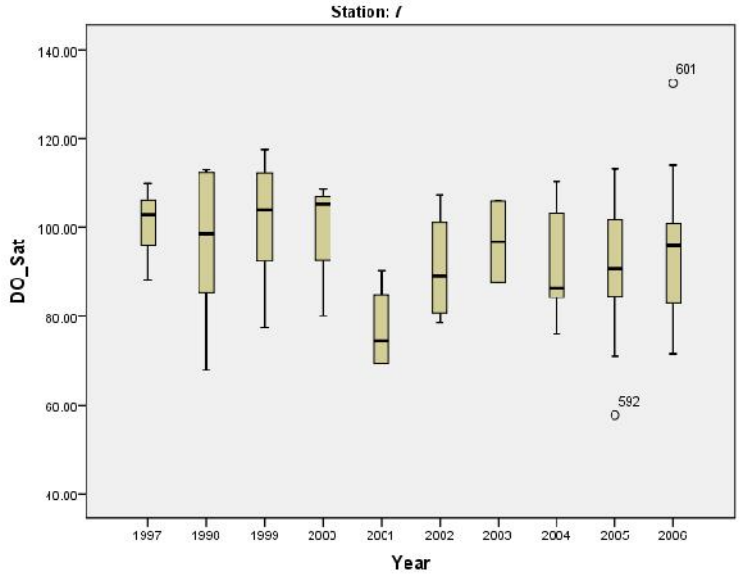
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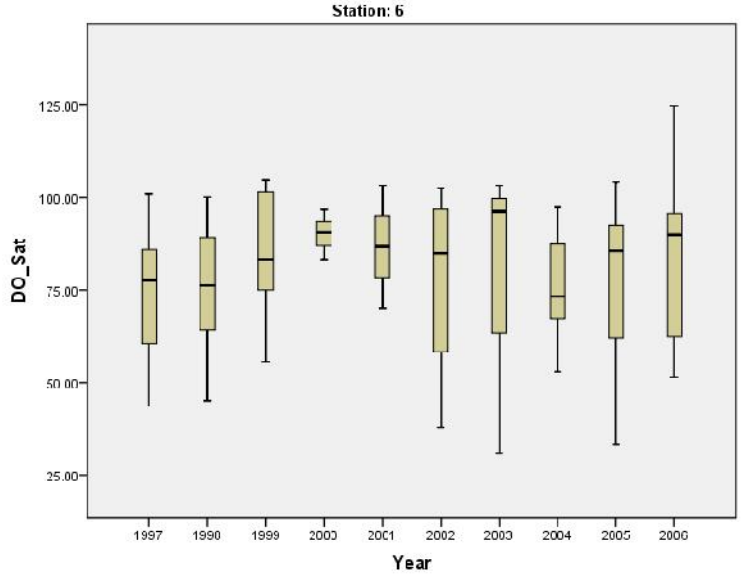
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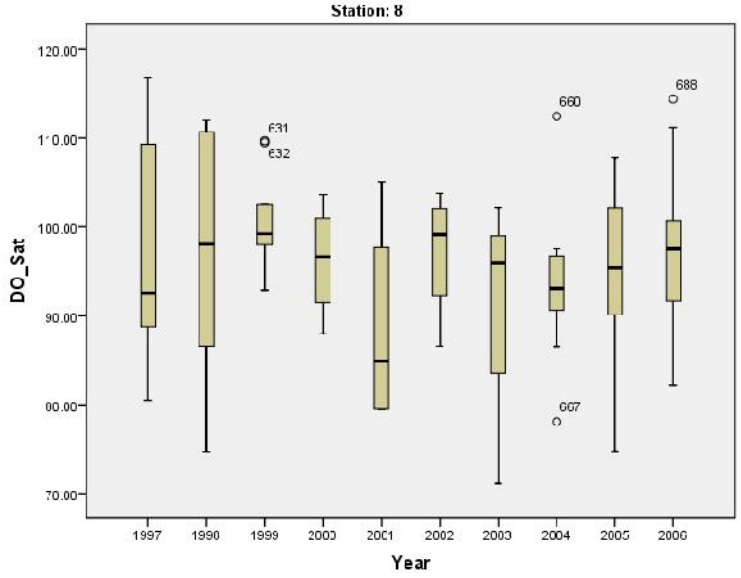
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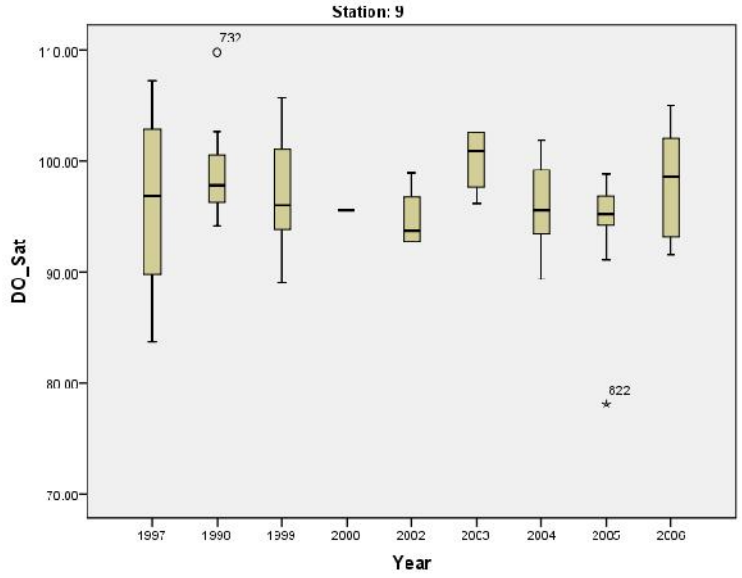
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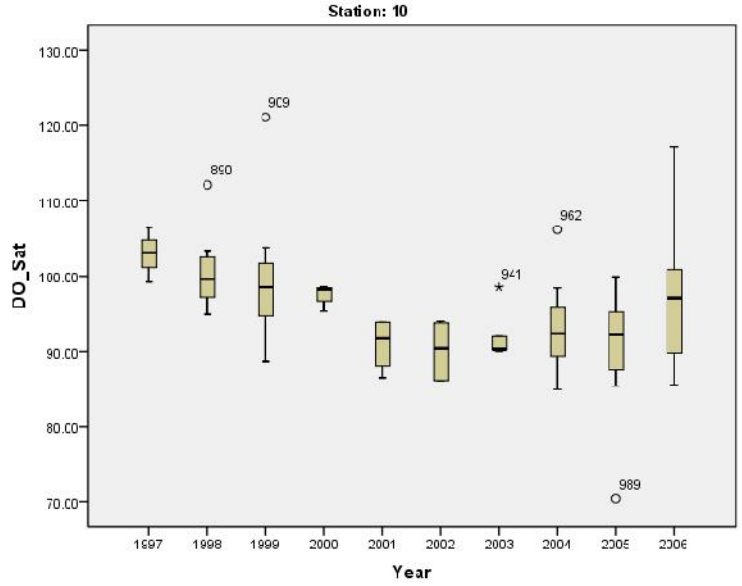
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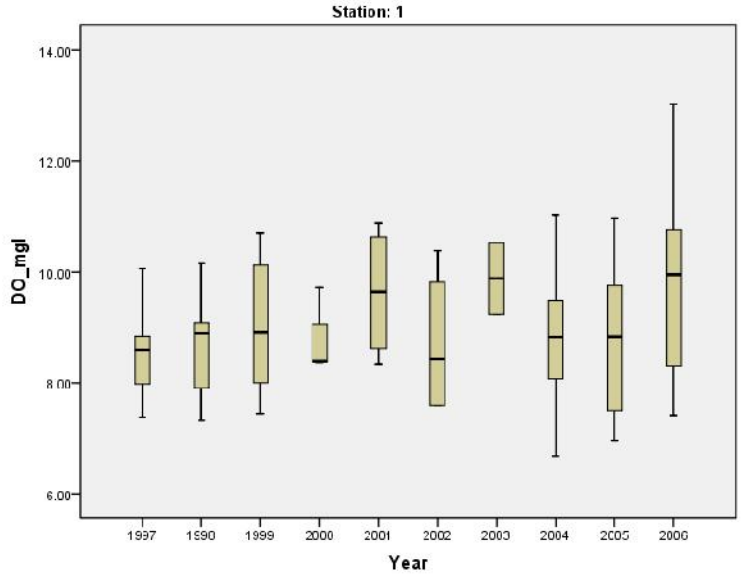
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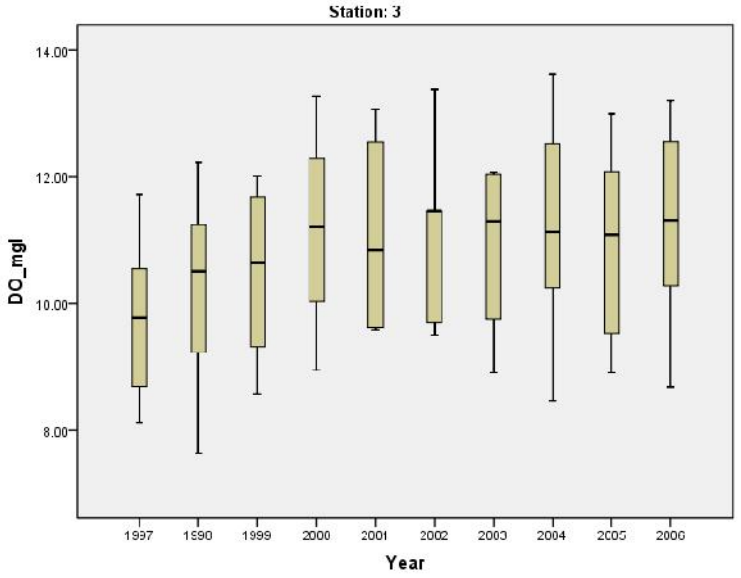
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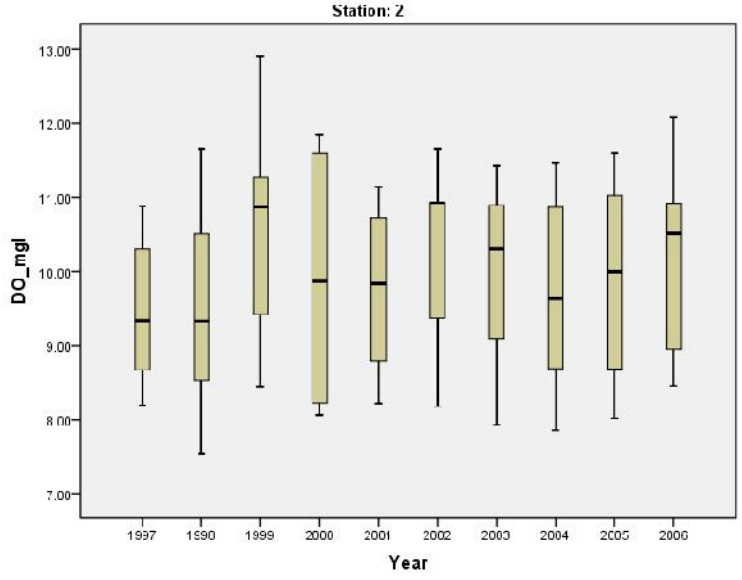
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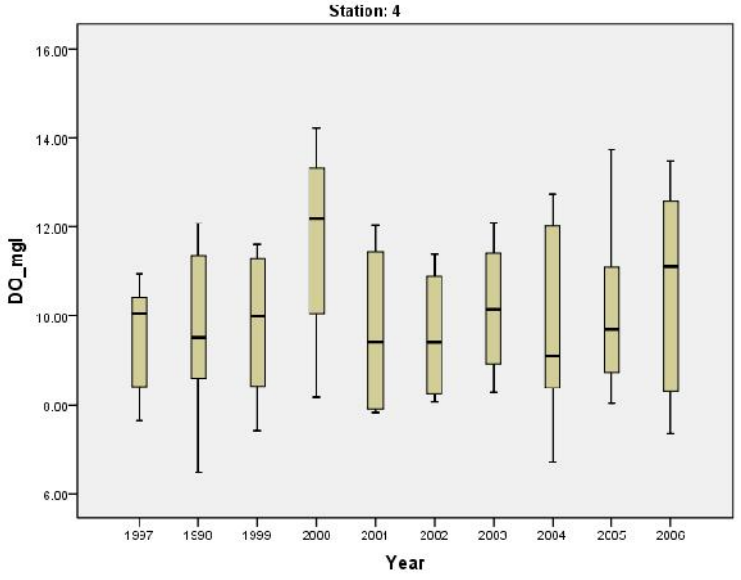
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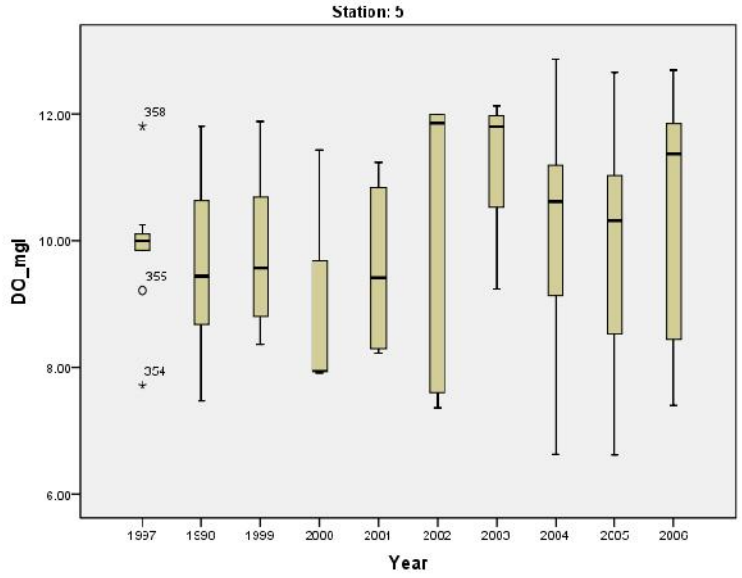
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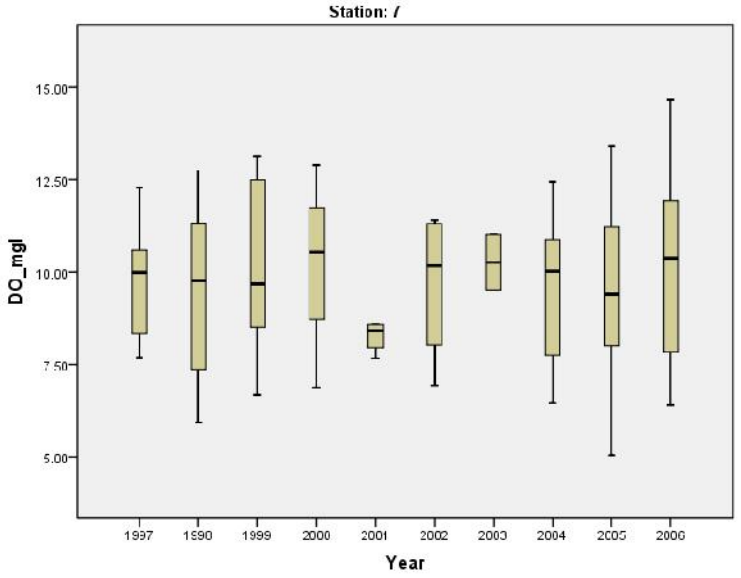
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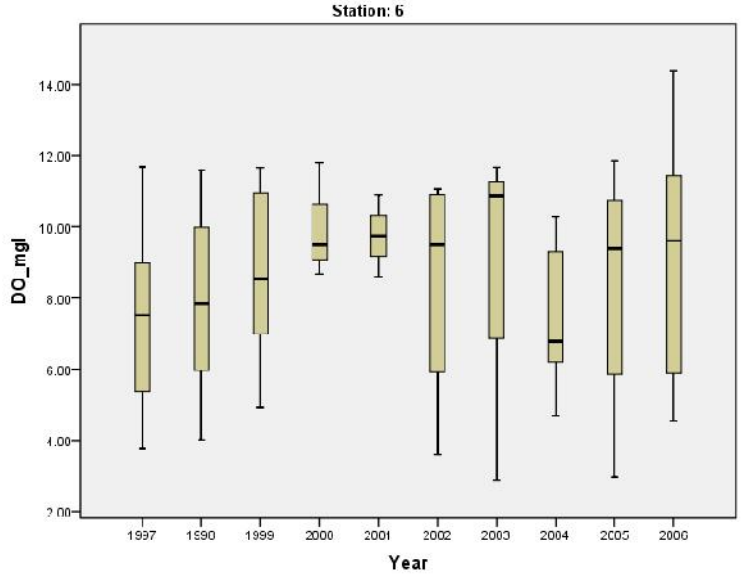
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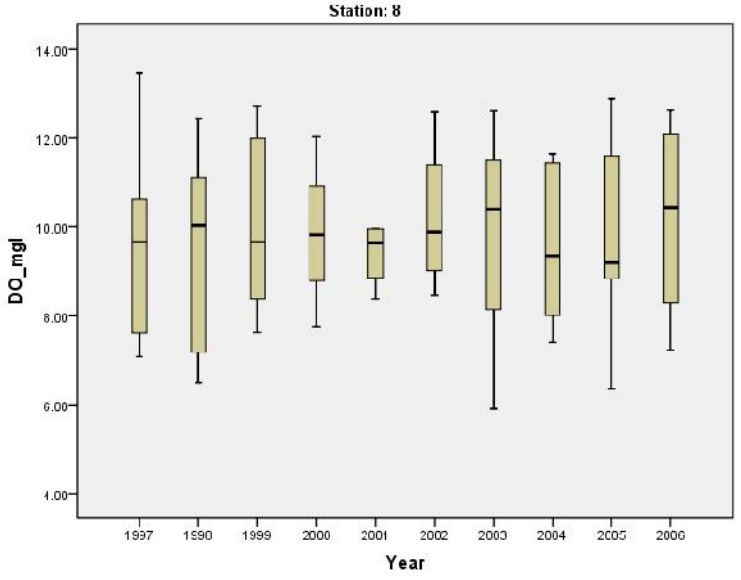
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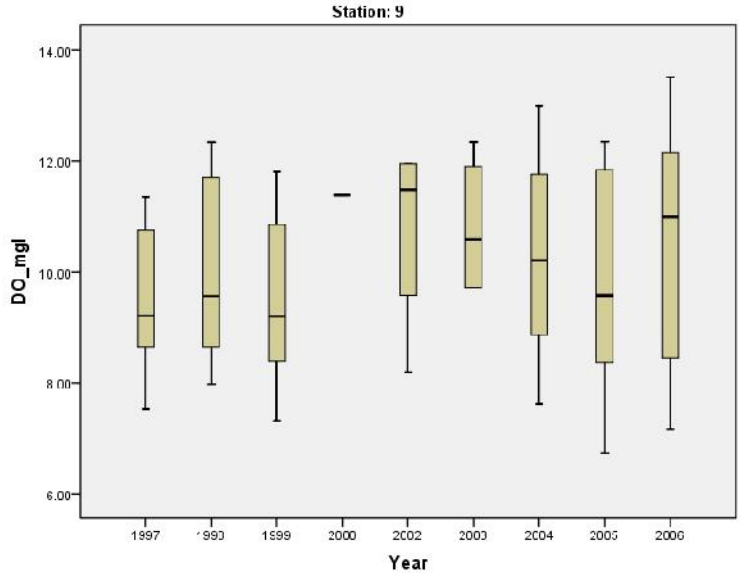
Station: 9
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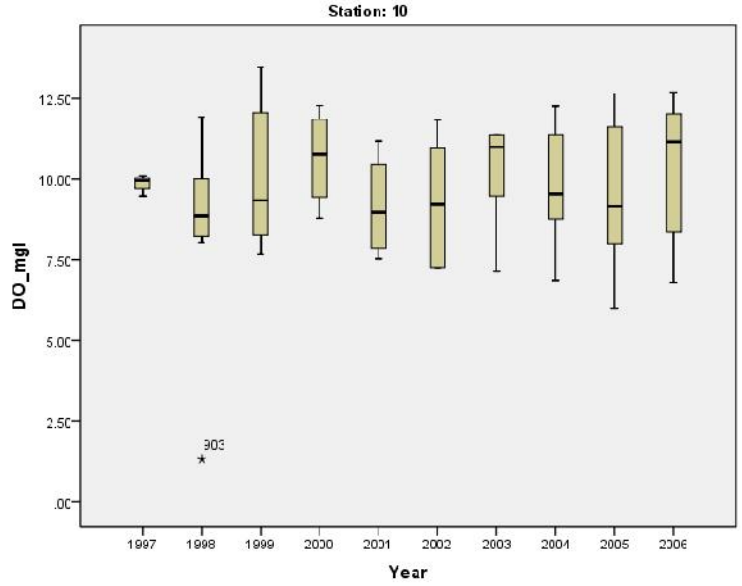
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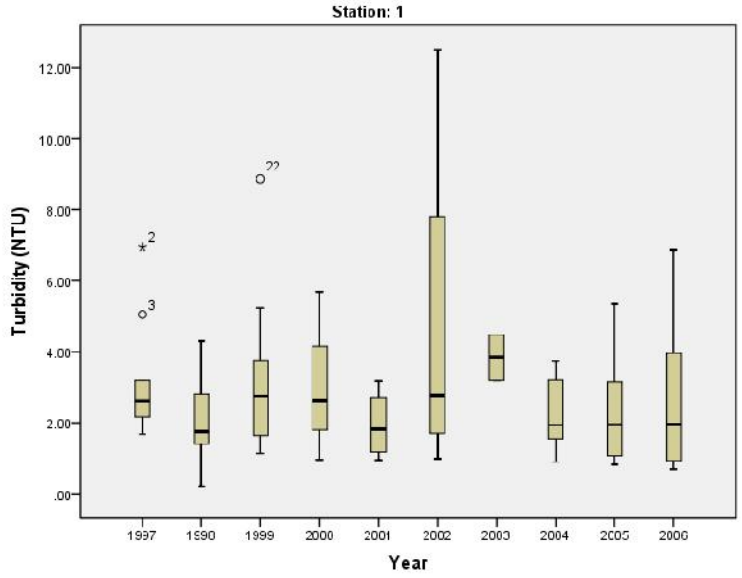
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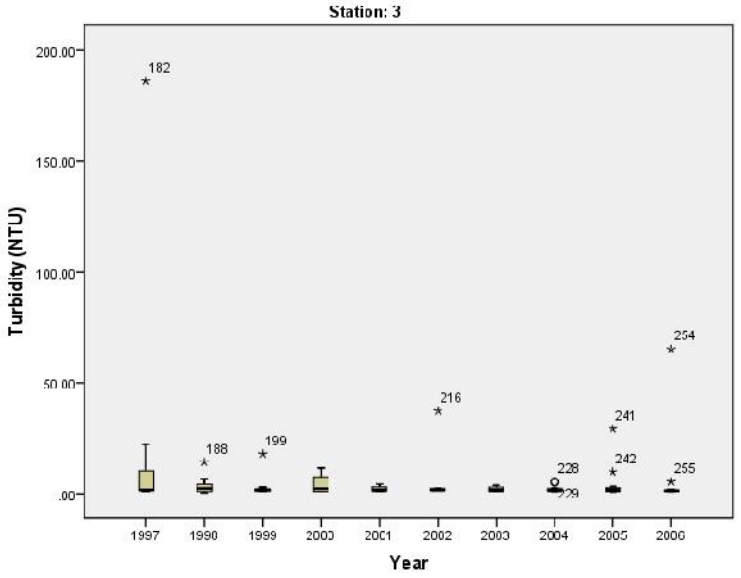
Station: 3
Turbidity (NTU)
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255
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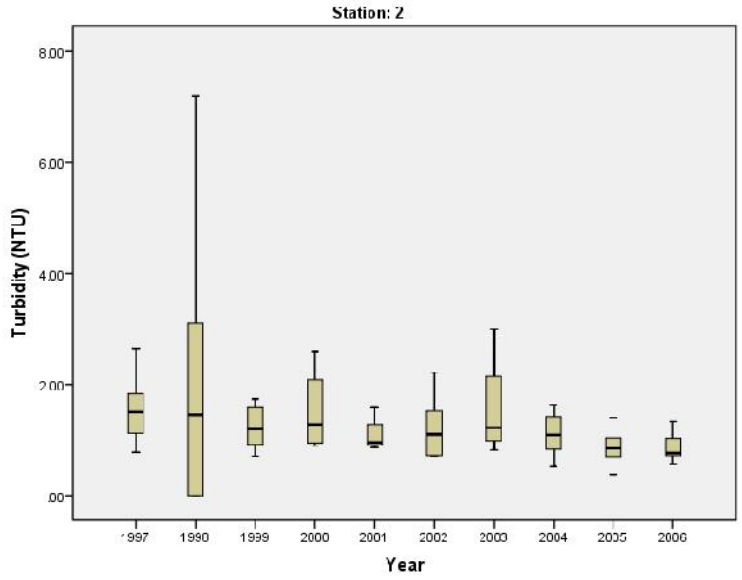
Station: 2
Turbidity (NTU)
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4.00
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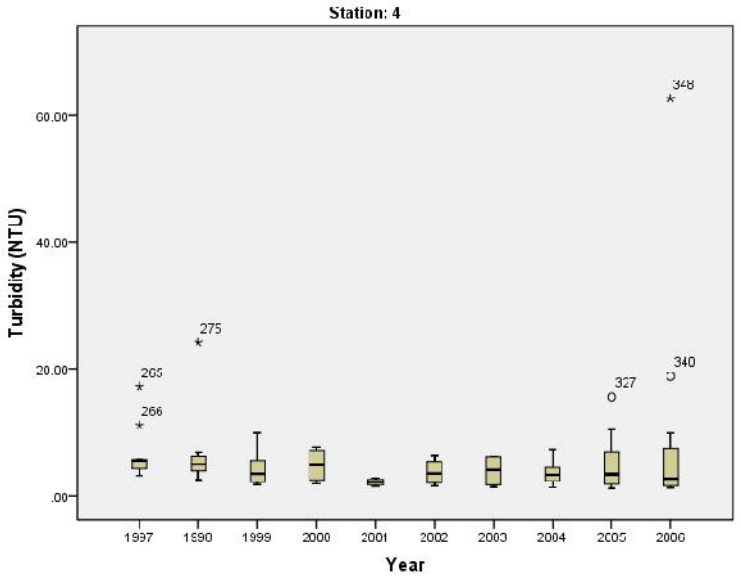
2006
Year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2006
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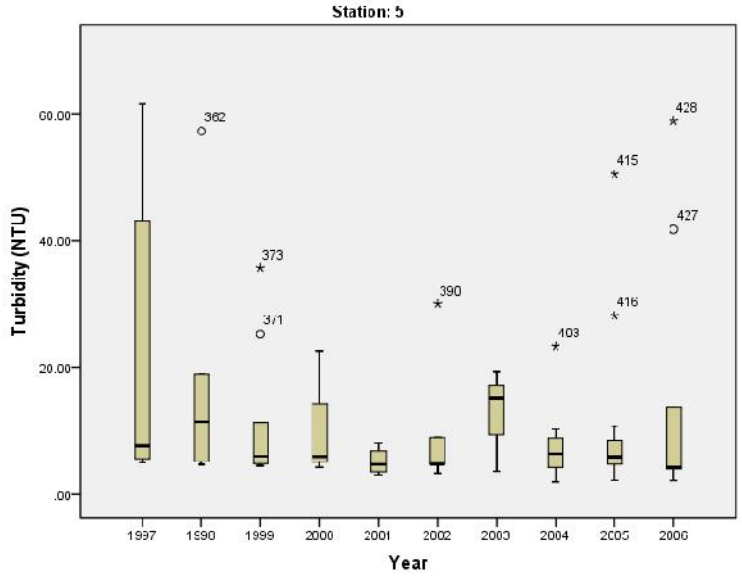
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Turbidity (NTU)
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2006
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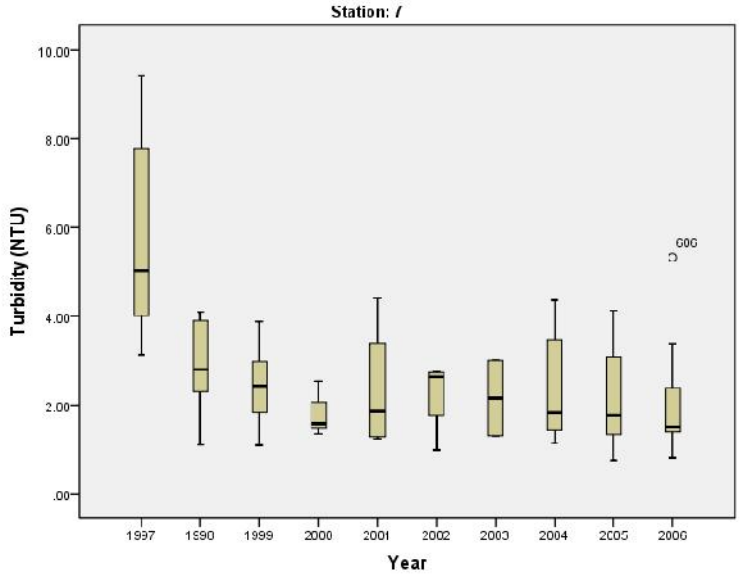
Station: 7
Turbidity (NTU)
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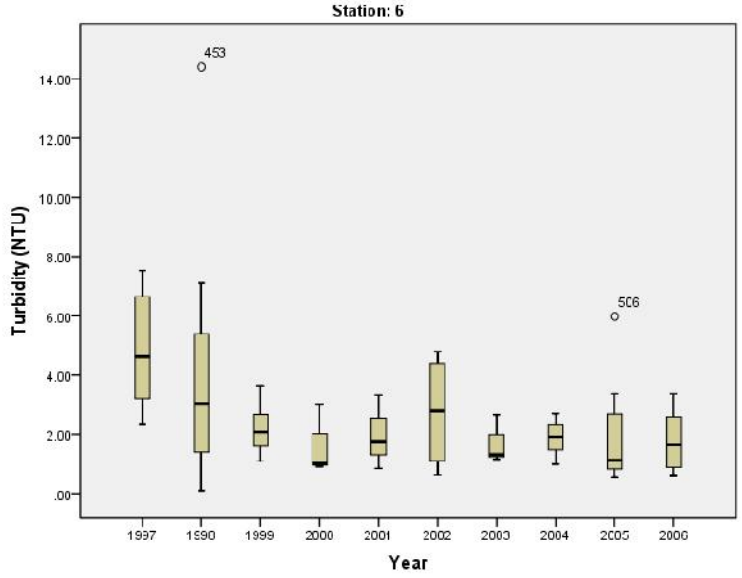
2006
Year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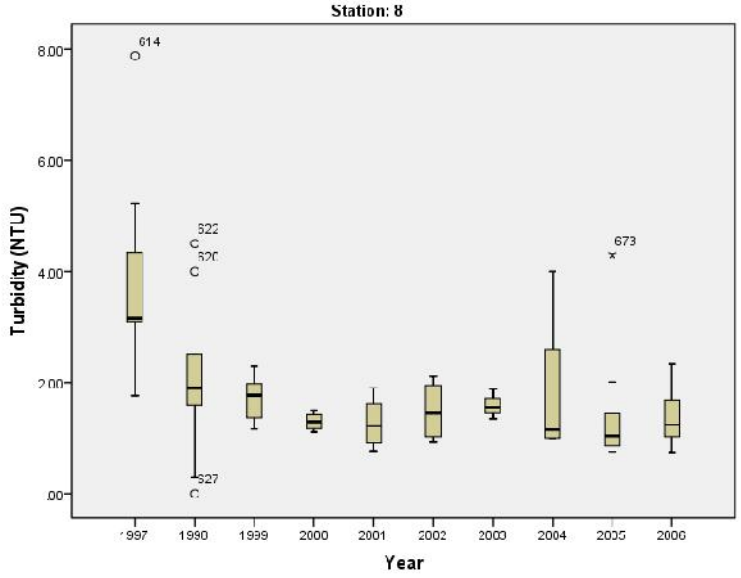
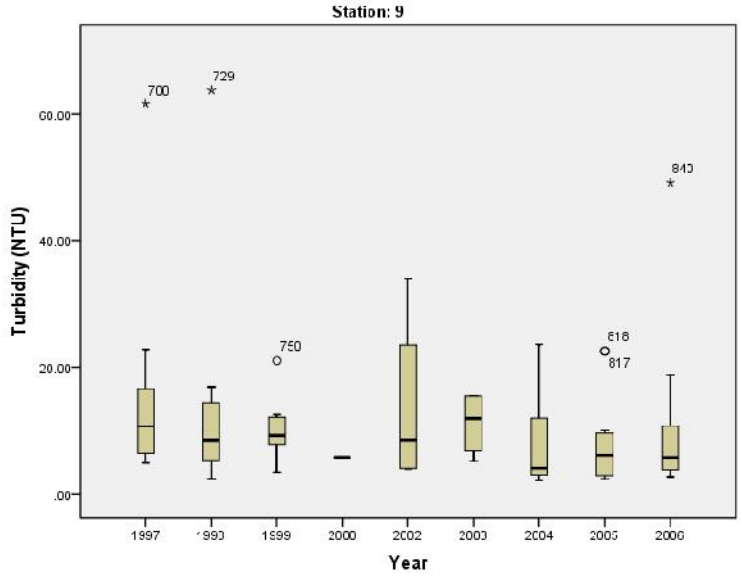
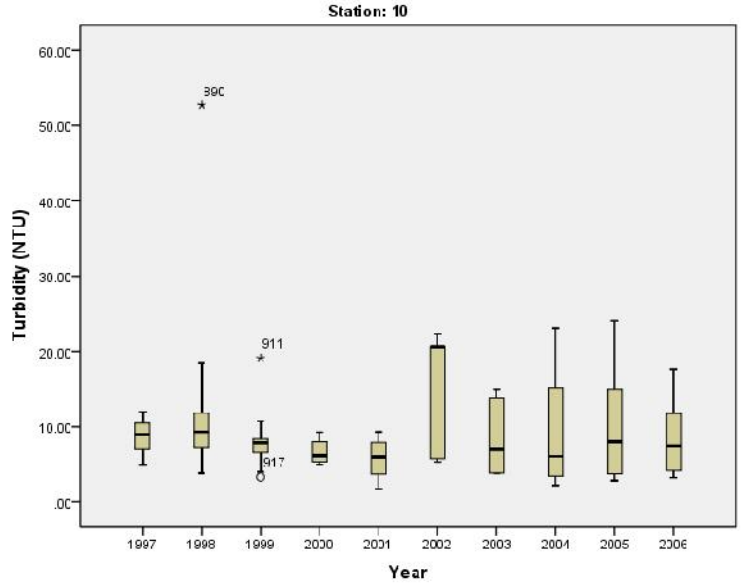
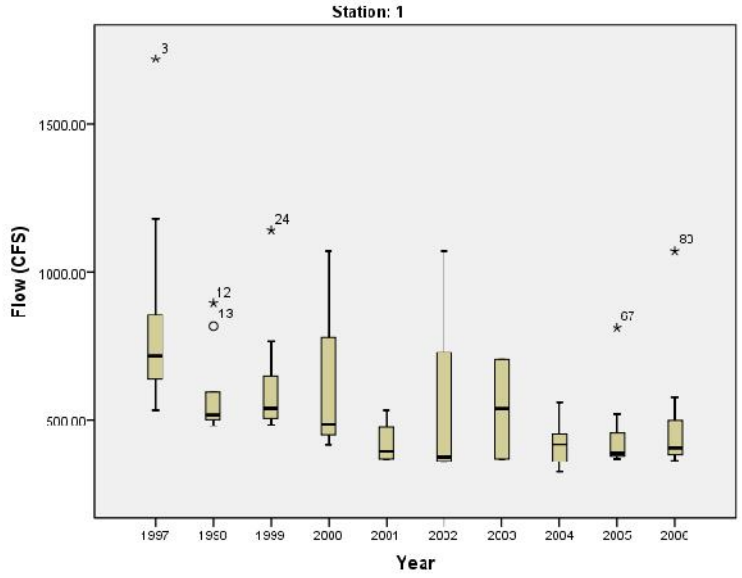
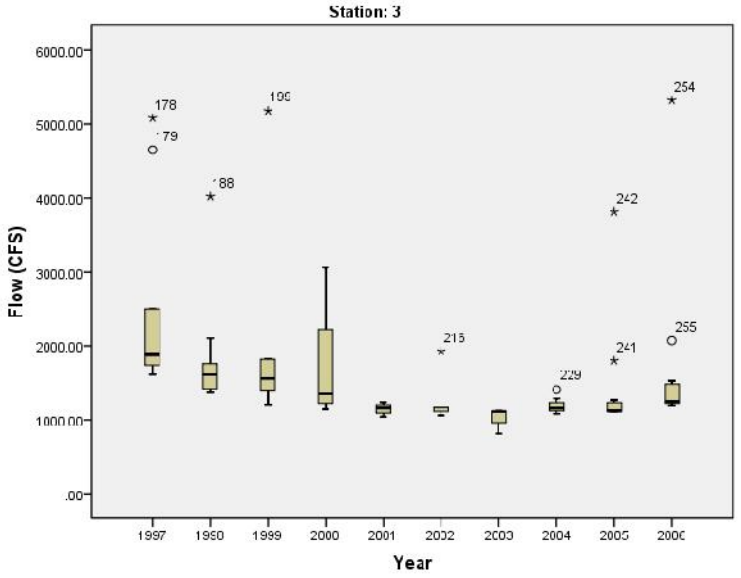
2006
Year

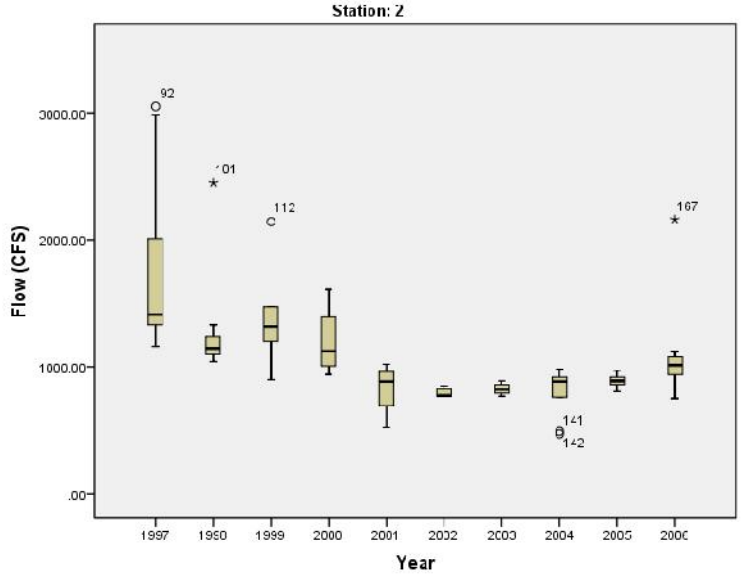

Station: 8
Turbidity (NTU)
8.00
6.00
4.00
.00
614
522
520
527
673
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

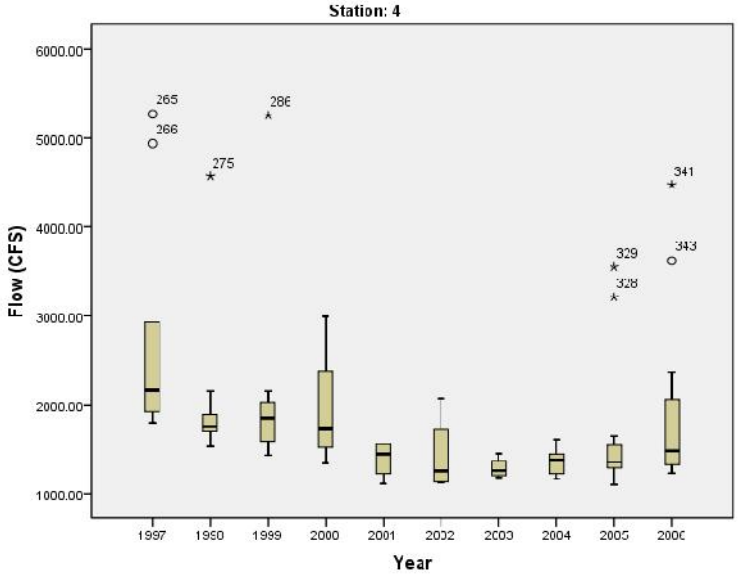

Station: 9
Turbidity (NTU)
60.00
40.00
20.00
.00
700
729
750
817
Year

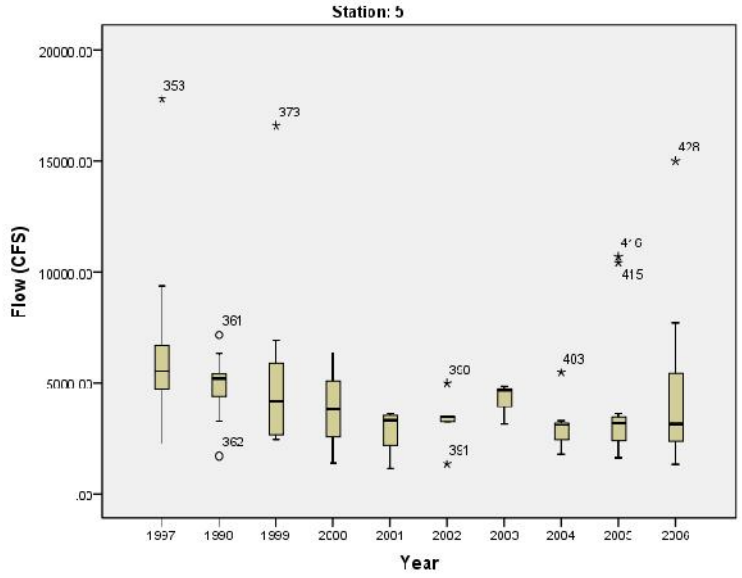

Station: 10
Turbidity (NTU)
60.0C
50.0C
40.0C
30.0C
20.0C
10.0C
.0C
390
911
917
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year

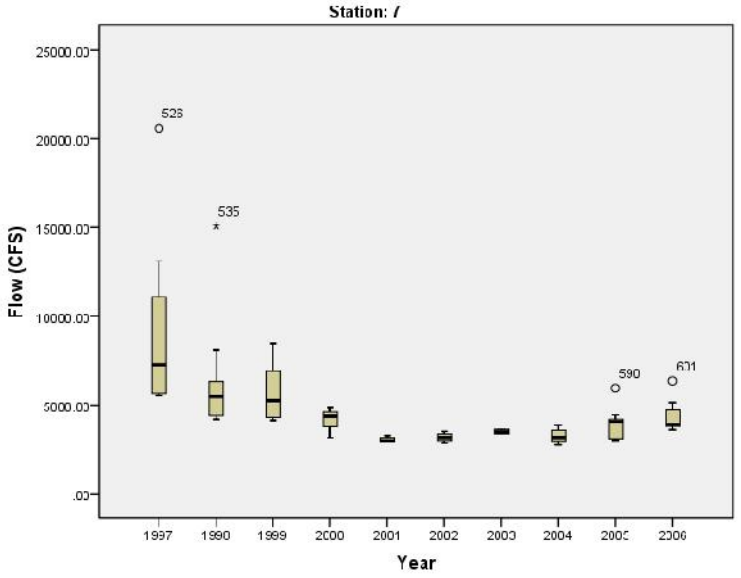

Station: 1
Flow (CFS)
1500.00
1000.00
500.00
Year
1997
1999
2000
2001
2004
2005

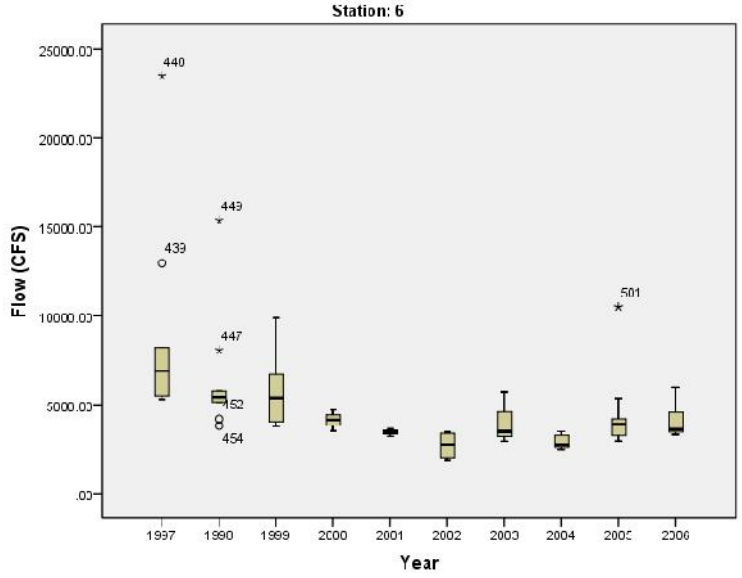

Station: 3
Flow (CFS)
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
.00
Year
1997
1999
2000
2001
2004
2005

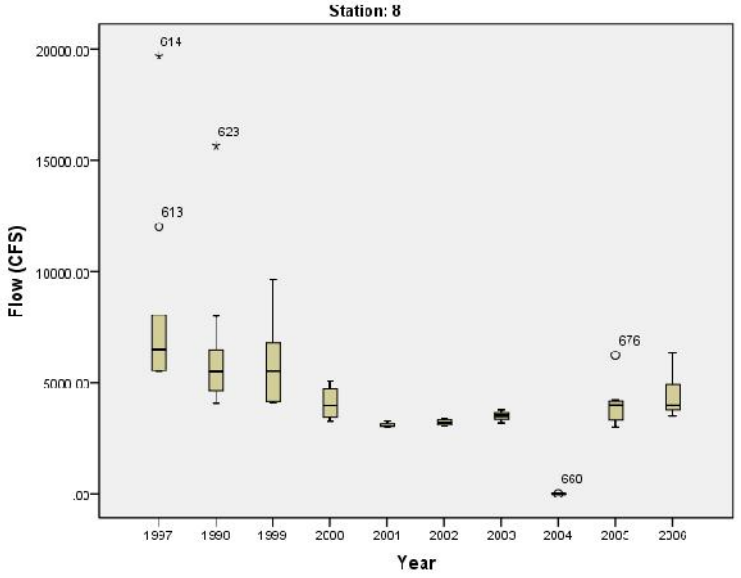

Station: 2
Flow (CFS)
3000.00
2000.00
1000.00
.00
Year
1997
1999
2000
2001
2004
2005

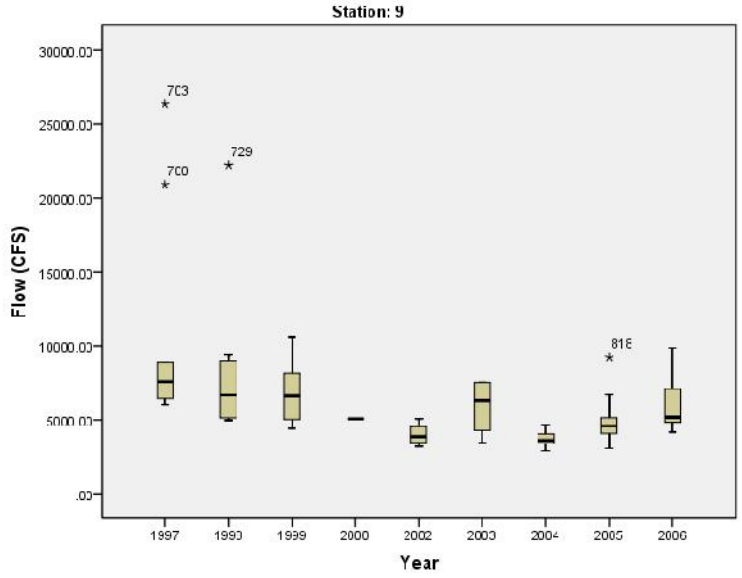

Station: 4
Flow (CFS)
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
Year
1997
1999
2000
2001
2004
2005

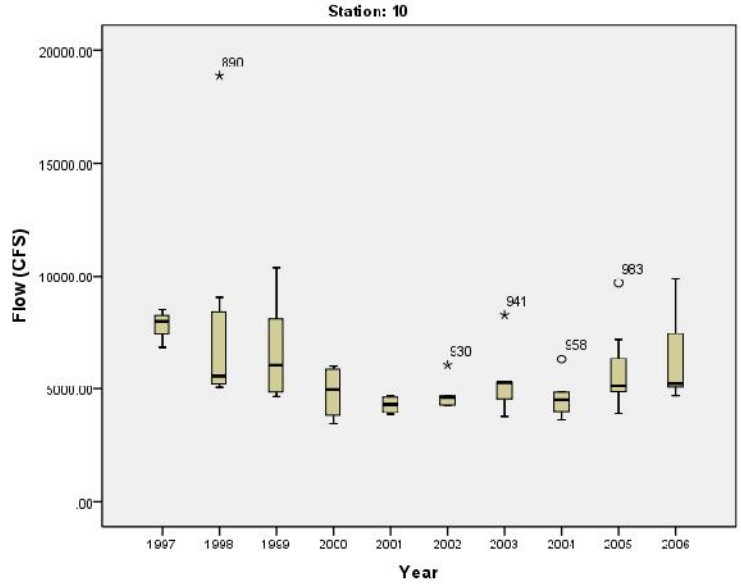

Station: 5
Flow (CFS)
20000.00
15000.00
10000.00
5000.00
.00
353
373
428
361
362
300
381
403
415
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

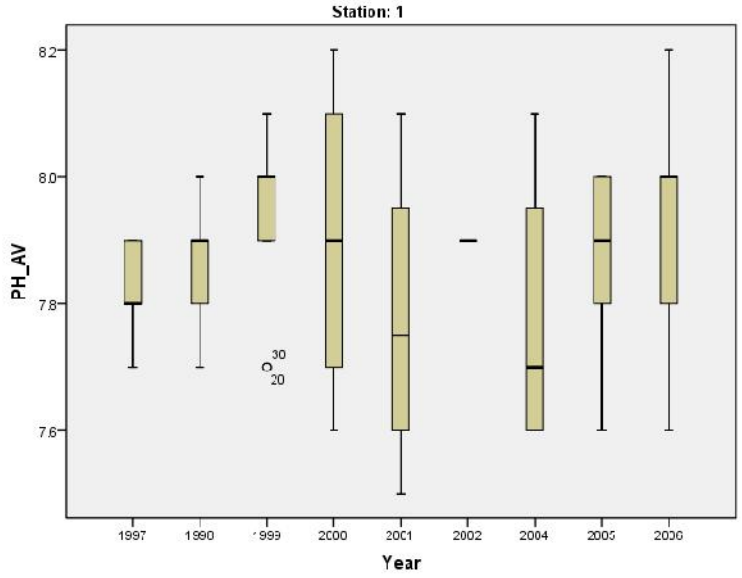

Station: 7
Flow (CFS)
25000.00
20000.00
15000.00
10000.00
5000.00
.00
528
535
590
601
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

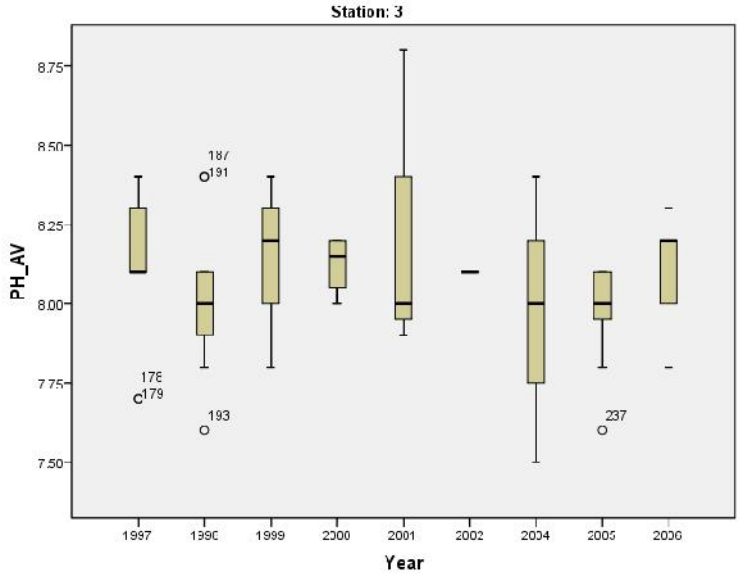

Station: 6
Flow (CFS)
25000.00
20000.00
15000.00
10000.00
5000.00
.00
440
449
439
447
452
454
501
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

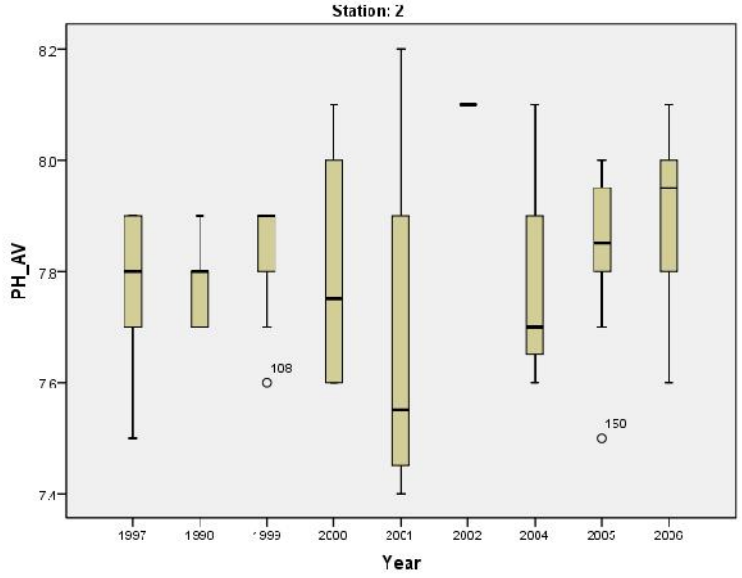

Station: 8
Flow (CFS)
20000.00
15000.00
10000.00
5000.00
.00
614
623
613
660
676
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

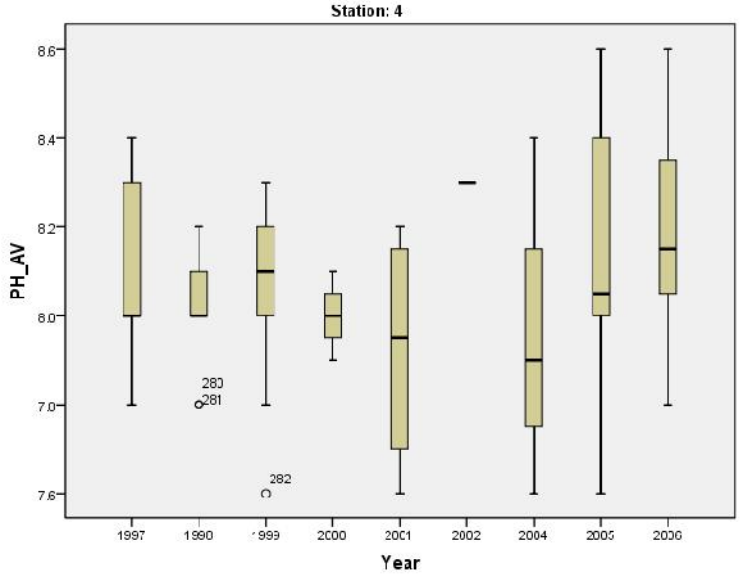

Station: 9
Flow (CFS)
30000.00
25000.00
20000.00
15000.00
10000.00
5000.00
.00
703
729
700
816
1997
1998
1999
2000
2002
2003
2004
2005
2006
Year

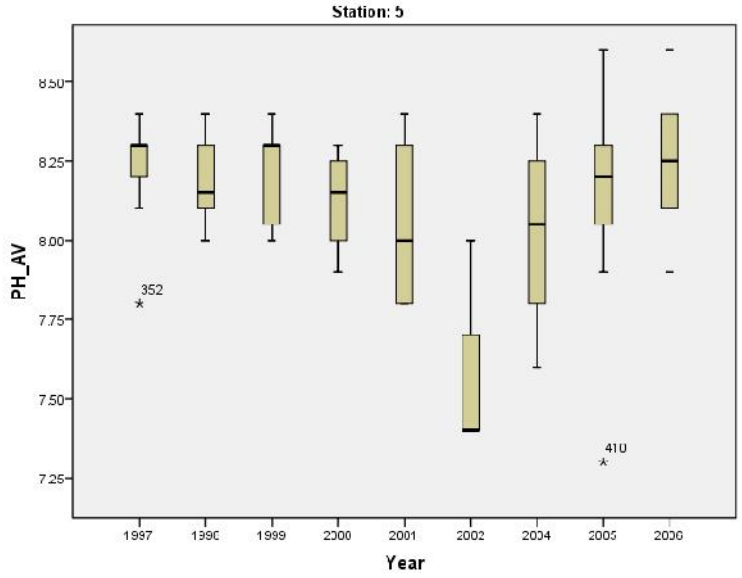

Station: 10
Flow (CFS)
20000.00
15000.00
10000.00
5000.00
.00
890
941
930
858
983
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

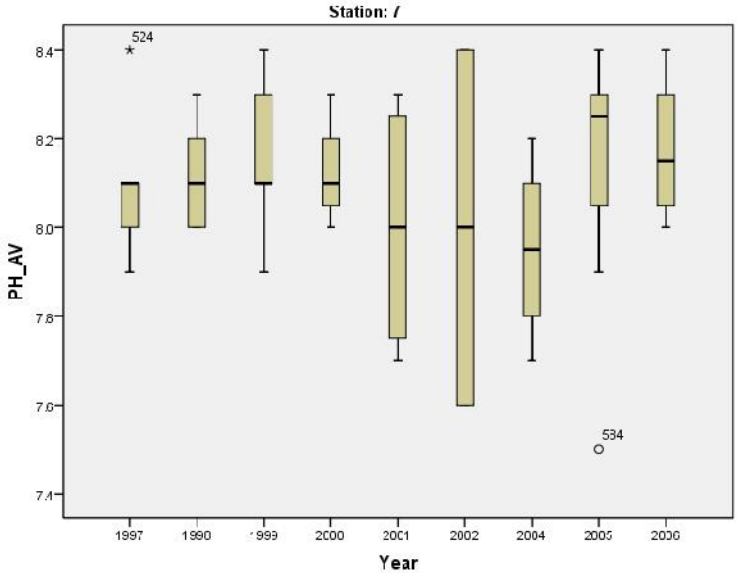

Station: 1
PH_AV
8.2
8.0
7.8
7.6
30
20
1997
1999
2000
2001
2002
2004
2005
2006
Year

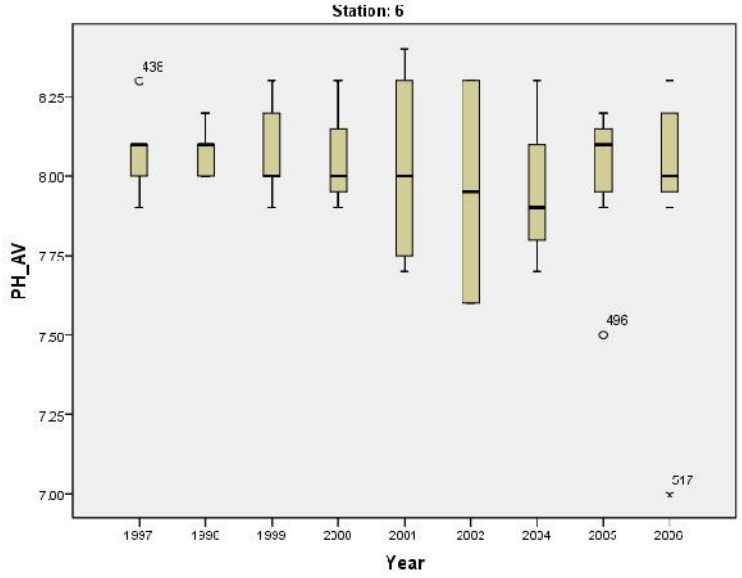

Station: 3
PH_AV
8.75
8.50
8.25
8.00
7.75
7.50
191
179
193
237
1997
1999
2000
2001
2002
2004
2005
2006
Year

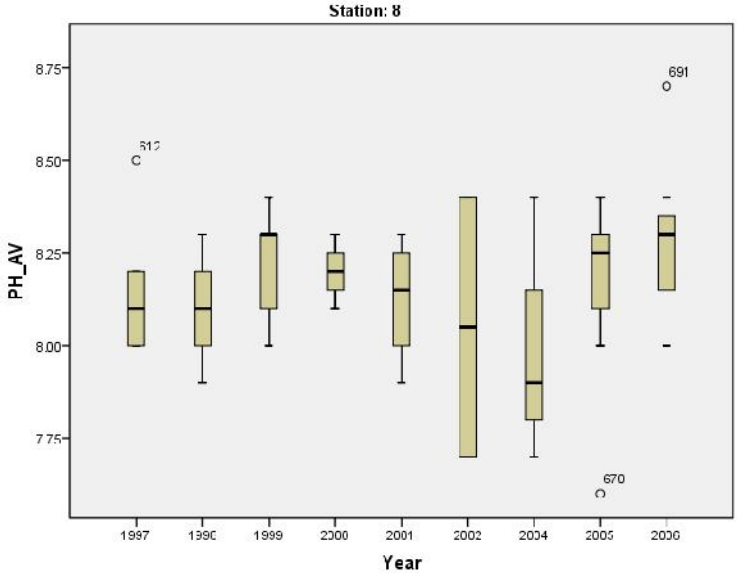

Station: 2
PH_AV
8.2
8.0
7.8
7.6
7.4
108
150
1997
1999
2000
2001
2002
2004
2005
2006
Year

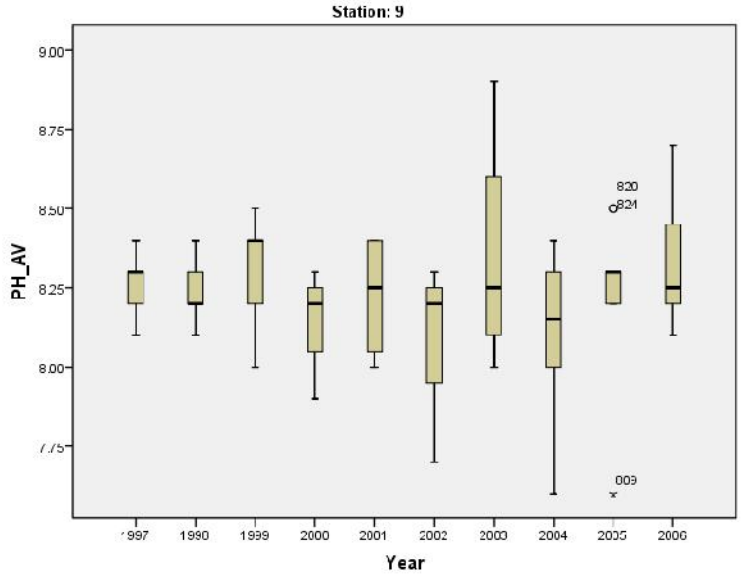

Station: 4
PH_AV
8.6
8.4
8.2
8.0
7.8
280
281
282
1997
1999
2000
2001
2002
2004
2005
2006
Year

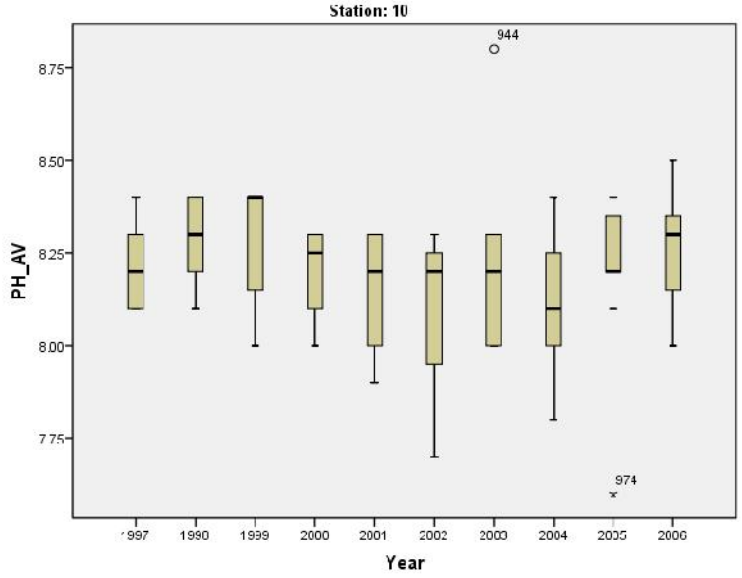

Station: 5
PH_AV
8.50
8.25
8.00
7.75
7.50
7.25
352
410
1997
1999
2000
2001
2002
2004
2005
2006
Year

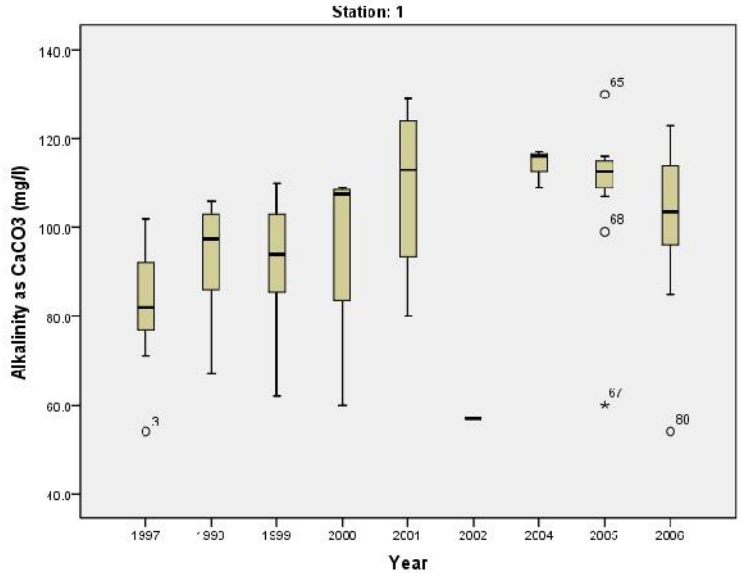

Station: 7
PH_AV
8.4
8.2
8.0
7.8
7.6
7.4
524
534
1997
1999
2000
2001
2002
2004
2005
2006
Year

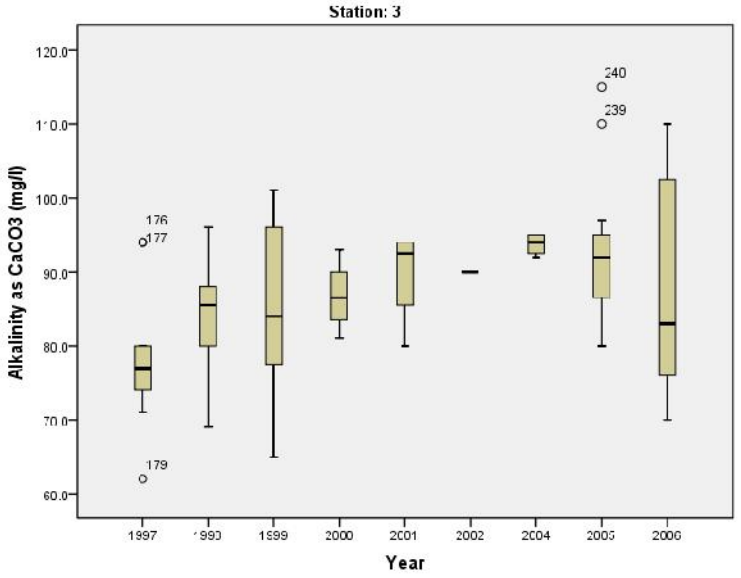

Station: 6
PH_AV
8.25
8.00
7.75
7.50
7.25
7.00
436
496
517
1997
1999
2000
2001
2002
2004
2005
2006
Year

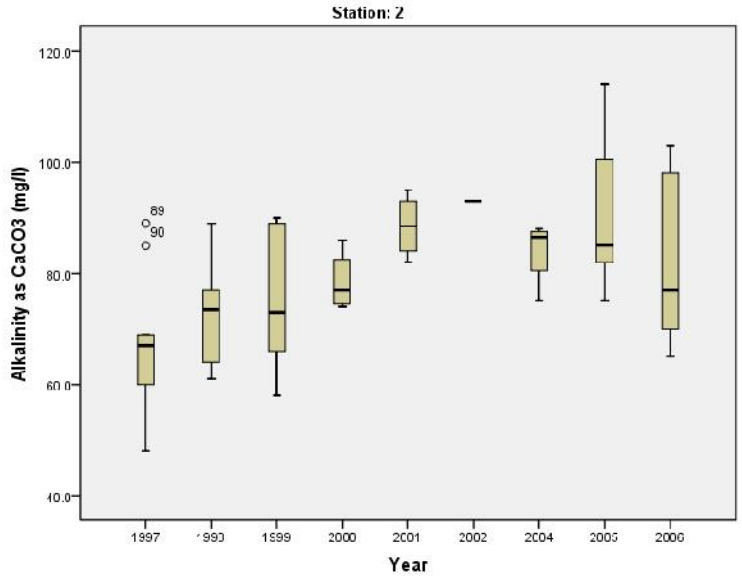

Station: 8
PH_AV
8.75
8.50
8.25
8.00
7.75
691
670
1997
1999
2000
2001
2002
2004
2005
2006
Year

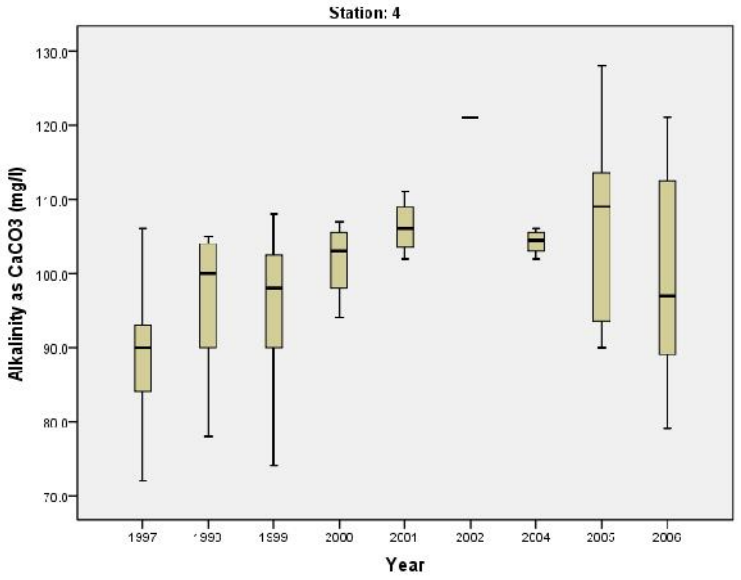

Station: 9
9.00
8.75
8.50
8.25
8.00
PH_AV
820
821
009
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

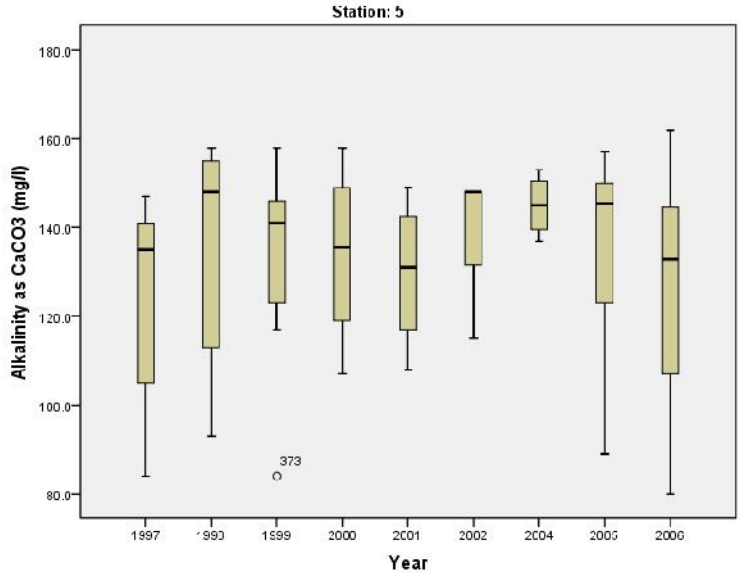

Station: 10
944
8.75
8.50
8.25
8.00
7.75
PH_AV
974
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

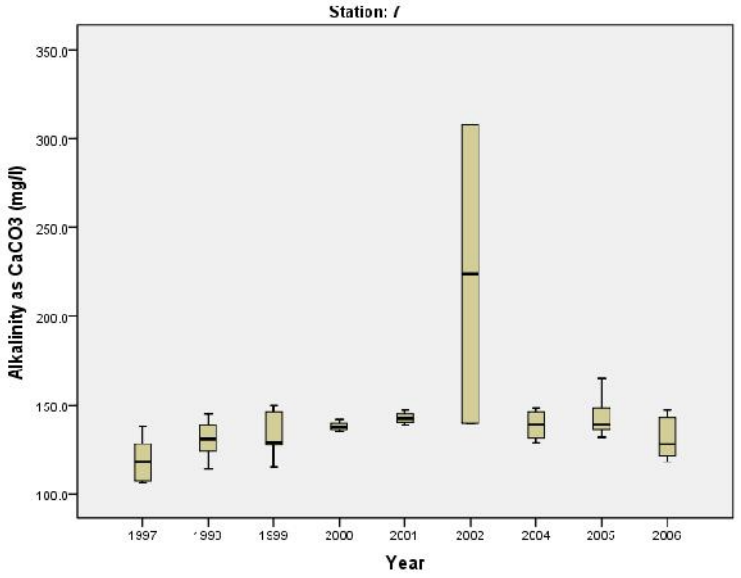

Station: 1
Alkalinity as CaCO3 (mg/l)
140.0
120.0
100.0
80.0
60.0
40.0
65
68
67
3
80
1997
1999
2000
2001
2002
2004
2005
2006
Year

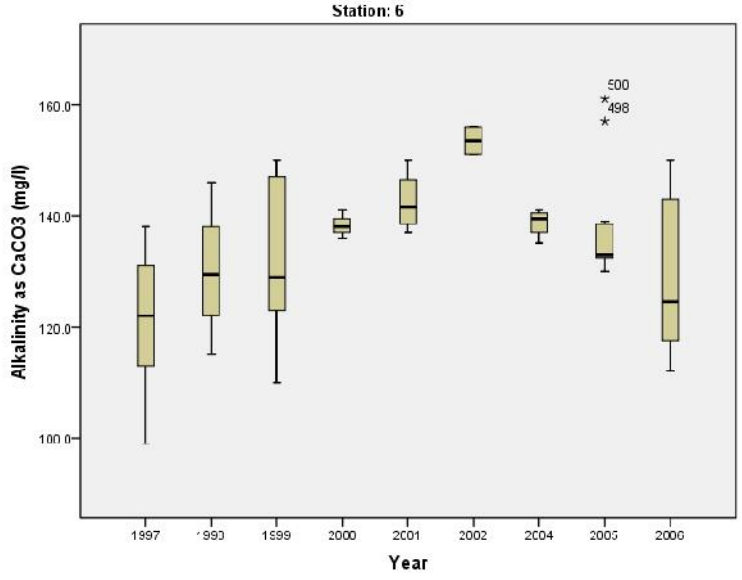

Station: 3
Alkalinity as CaCO3 (mg/l)
120.0
100.0
90.0
80.0
70.0
60.0
240
239
176
177
179
1997
1999
2000
2001
2002
2004
2005
2006
Year

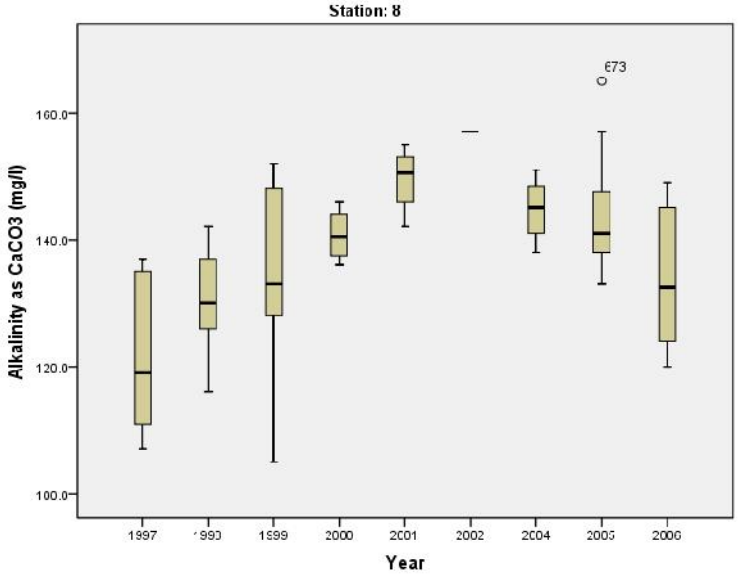

Station: 2
Alkalinity as CaCO3 (mg/l)
120.0
100.0
80.0
60.0
40.0
89
90
1997
1999
2000
2001
2002
2004
2005
2006
Year

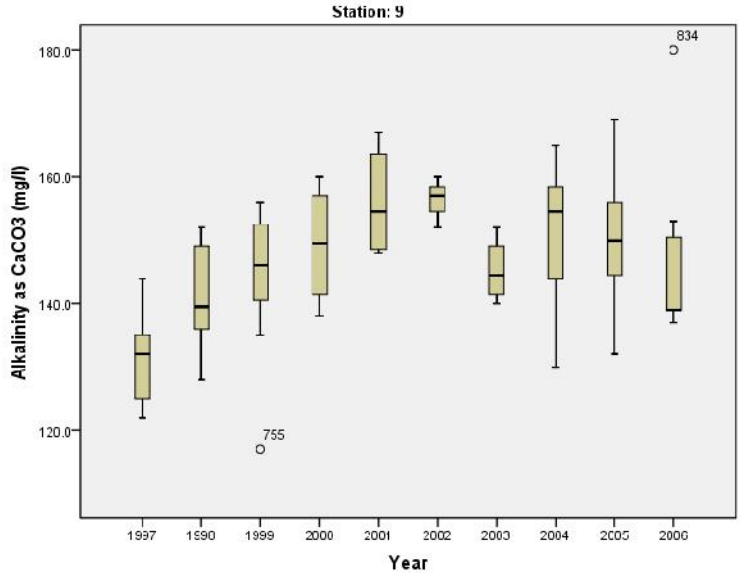

Station: 4
Alkalinity as CaCO3 (mg/l)
130.0
120.0
100.0
90.0
80.0
70.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

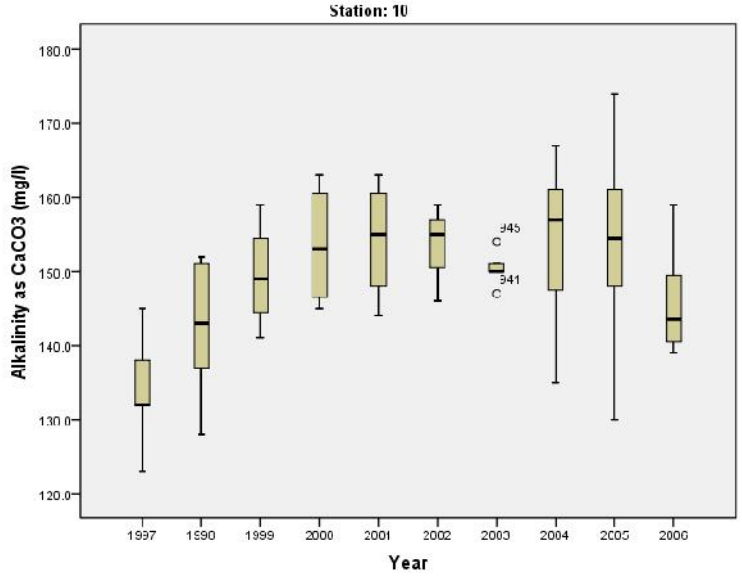

Station: 5
Alkalinity as CaCO3 (mg/l)
180.0
160.0
140.0
120.0
100.0
80.0
373
1997
1998
1999
2000
2001
2002
2004
2005
2006
Year

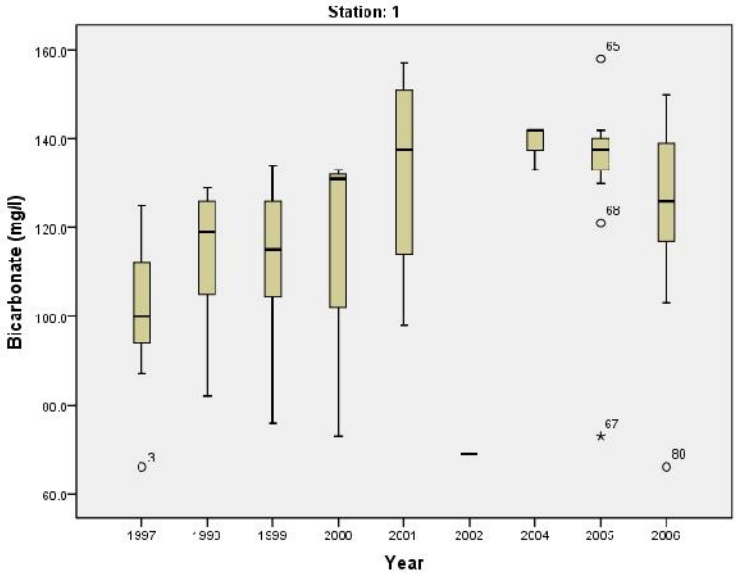

Station: 7
Alkalinity as CaCO3 (mg/l)
350.0
300.0
250.0
200.0
150.0
100.0
1997
1998
1999
2000
2001
2002
2004
2005
2006
Year

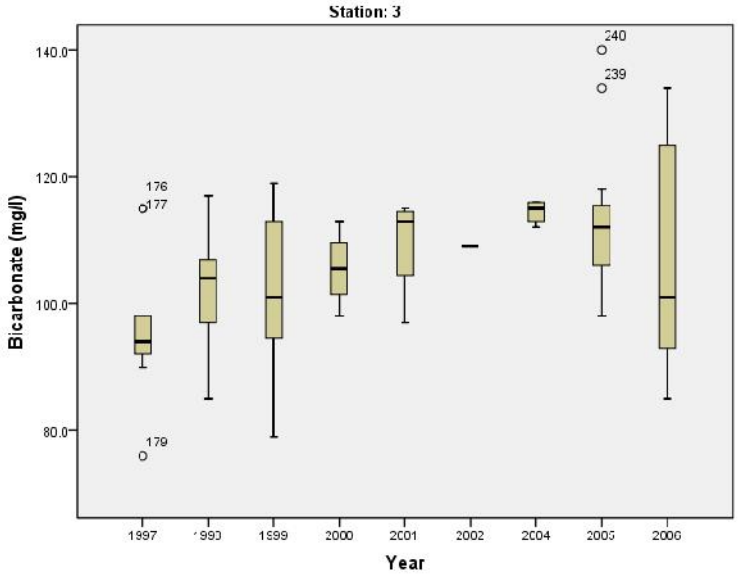

Station: 6
Alkalinity as CaCO3 (mg/l)
160.0
140.0
120.0
100.0
500
498
1997
1998
1999
2000
2001
2002
2004
2005
2006
Year

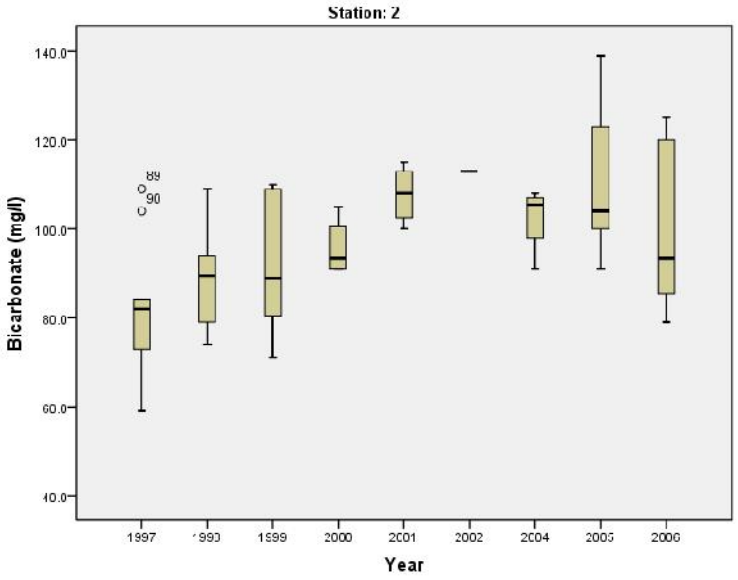

Station: 8
Alkalinity as CaCO3 (mg/l)
160.0
140.0
120.0
100.0
673
1997
1998
1999
2000
2001
2002
2004
2005
2006
Year

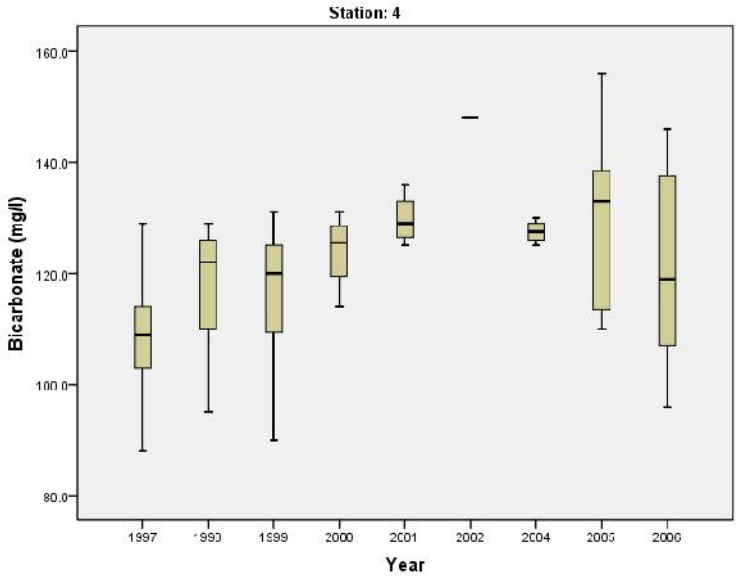

Station: 9
Alkalinity as CaCO3 (mg/l)
180.0
160.0
140.0
120.0
834
755
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

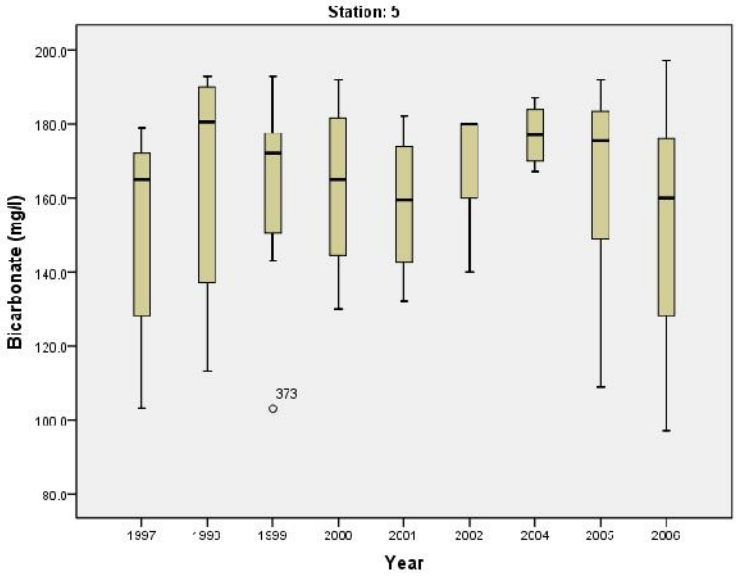

Station: 10
Alkalinity as CaCO3 (mg/l)
180.0
170.0
160.0
150.0
140.0
130.0
120.0
945
941
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

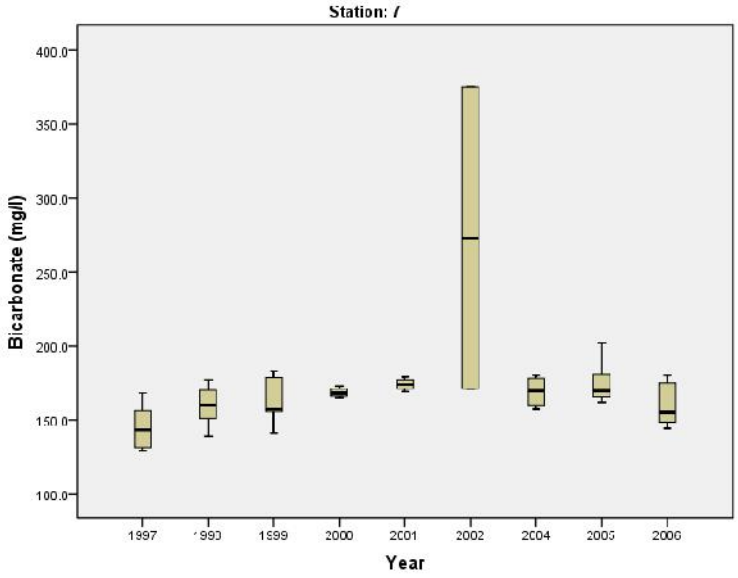

Station: 1
Bicarbonate (mg/l)
160.0
140.0
120.0
100.0
80.0
60.0
65
68
67
80
3
1997
1999
2000
2001
2002
2004
2005
2006
Year

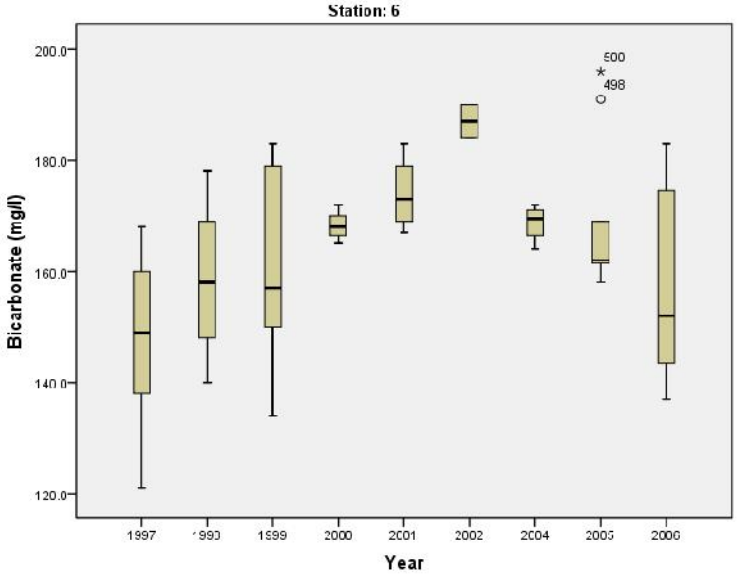

Station: 3
Bicarbonate (mg/l)
140.0
120.0
100.0
80.0
240
239
176
177
179
1997
1999
2000
2001
2002
2004
2005
2006
Year

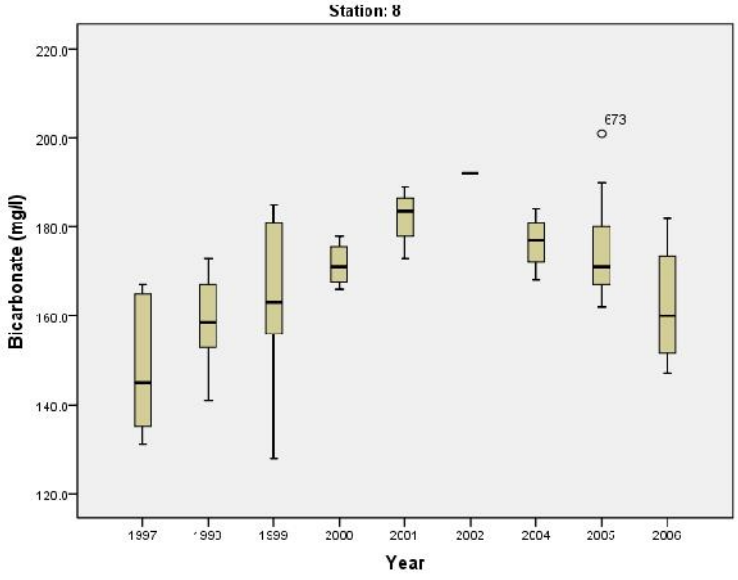

Station: 2
Bicarbonate (mg/l)
140.0
120.0
100.0
80.0
60.0
40.0
89
90
1997
1999
2000
2001
2002
2004
2005
2006
Year

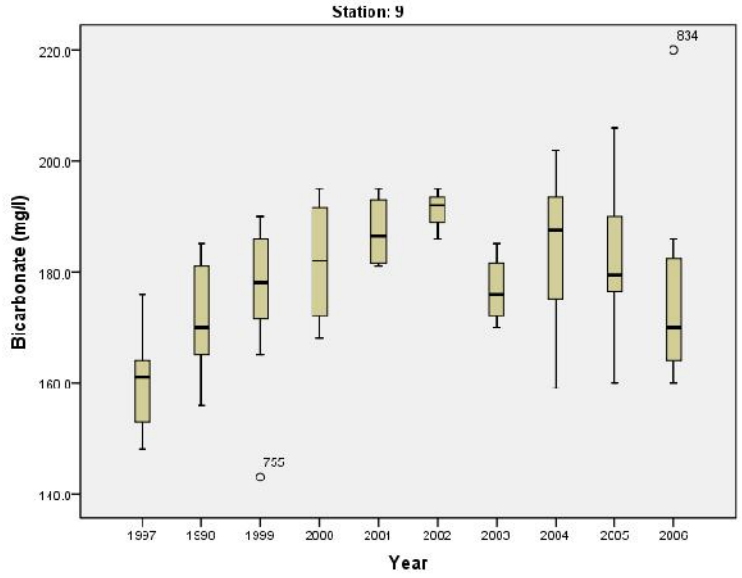

Station: 4
Bicarbonate (mg/l)
160.0
140.0
120.0
100.0
80.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

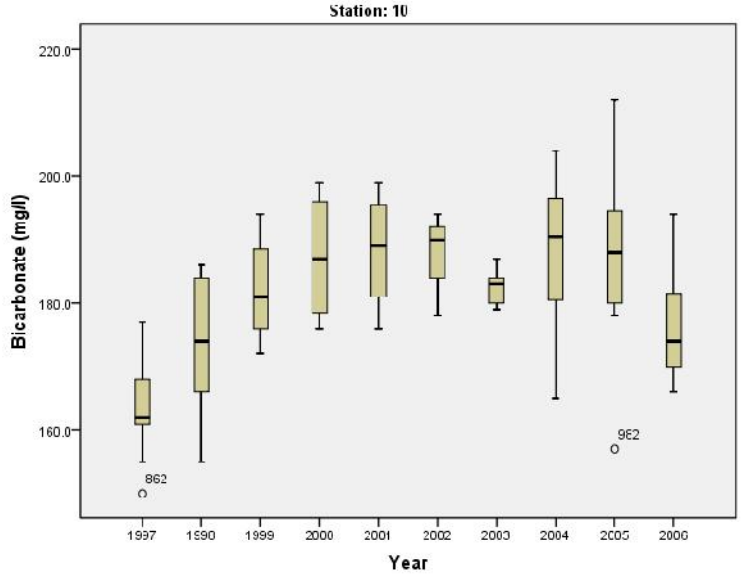

Station: 5
Bicarbonate (mg/l)
200.0
180.0
160.0
140.0
120.0
100.0
80.0
373
1997
1999
2000
2001
2002
2004
2005
2006
Year

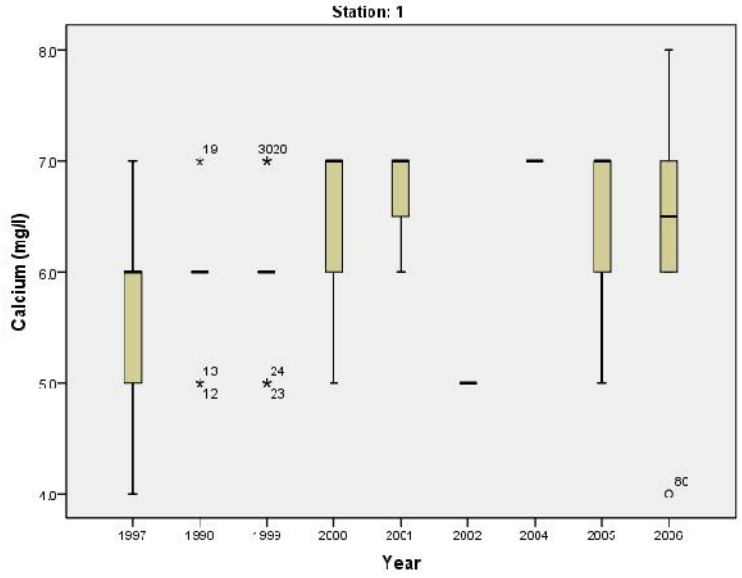

Station: 7
Bicarbonate (mg/l)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

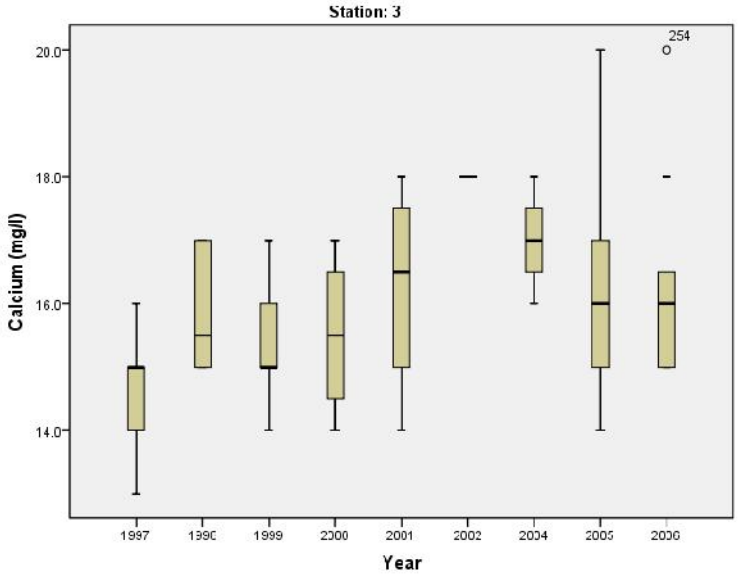

Station: 6
Bicarbonate (mg/l)
200.0
180.0
160.0
140.0
120.0
500
498
1997
1999
2000
2001
2002
2004
2005
2006
Year

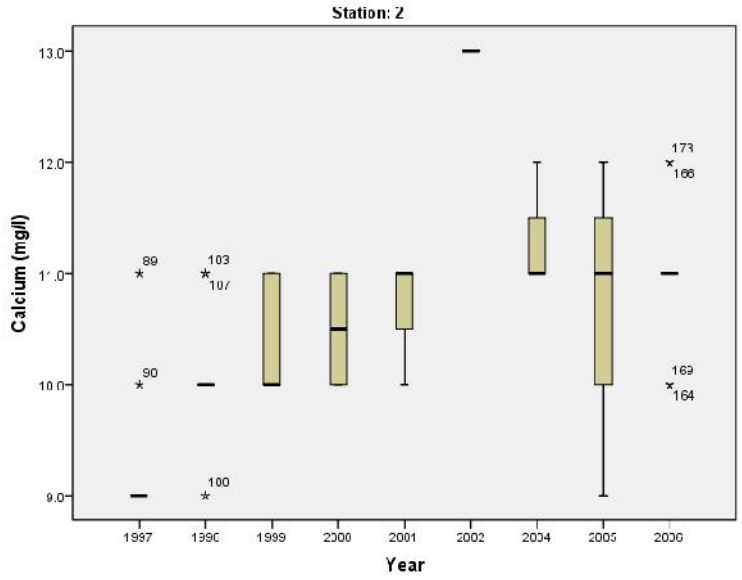

Station: 8
Bicarbonate (mg/l)
220.0
200.0
180.0
160.0
140.0
120.0
673
1997
1999
2000
2001
2002
2004
2005
2006
Year

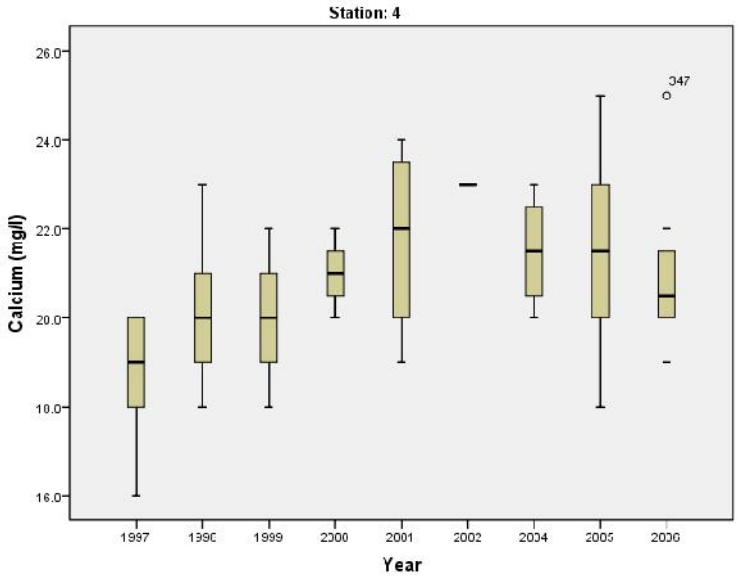

Station: 9
Bicarbonate (mg/l)
220.0
200.0
180.0
160.0
140.0
834
755
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

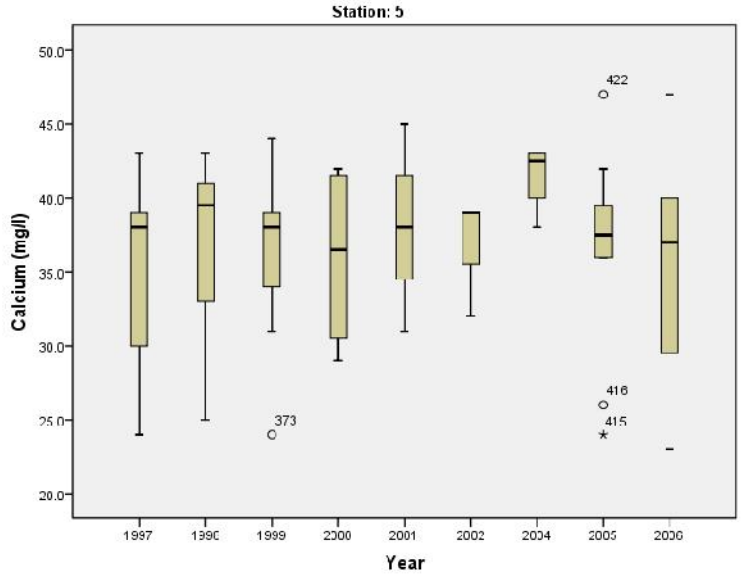

Station: 10
Bicarbonate (mg/l)
220.0
200.0
180.0
160.0
862
962
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

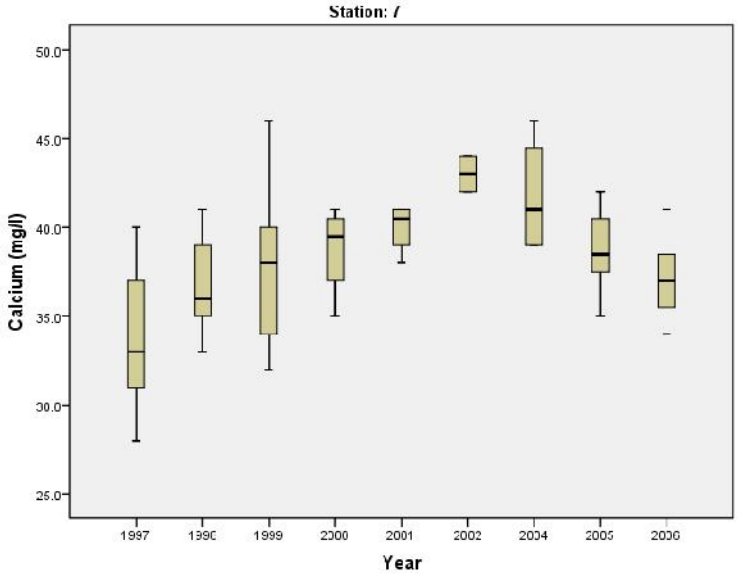

Station: 1
Calcium (mg/l)
Year
8.0
7.0
6.0
5.0
4.0
19
3020
13
12
24
23
60
1997
1999
2000
2001
2002
2004
2005
2006

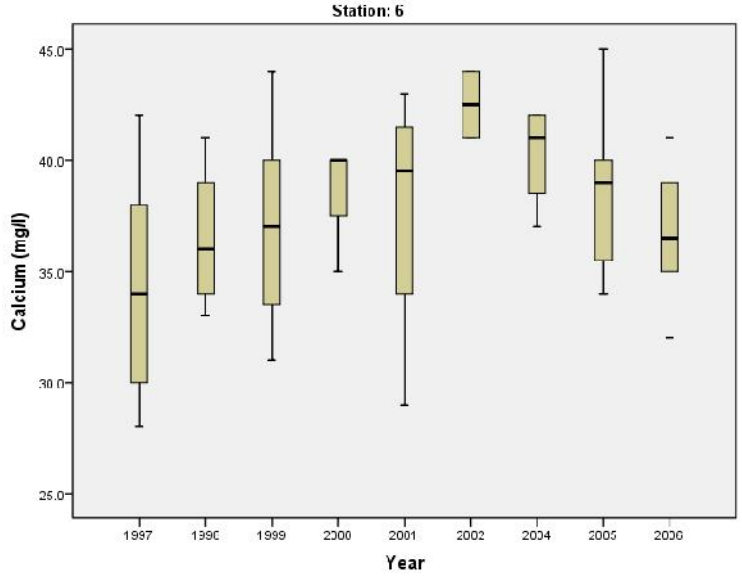

Station: 3
Calcium (mg/l)
Year
20.0
18.0
16.0
14.0
254
1997
1999
2000
2001
2002
2004
2005
2006

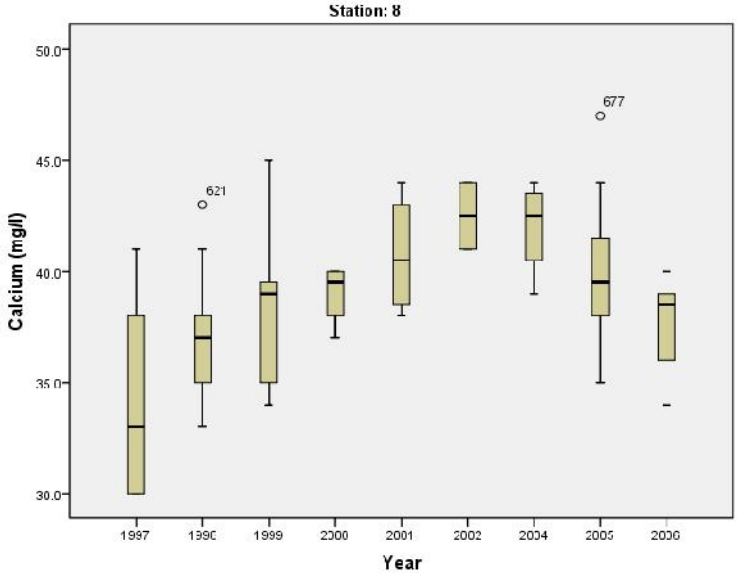

Station: 2
Calcium (mg/l)
Year
13.0
12.0
10.0
9.0
89
103
90
100
173
166
169
164
1997
1999
2000
2001
2002
2004
2005
2006

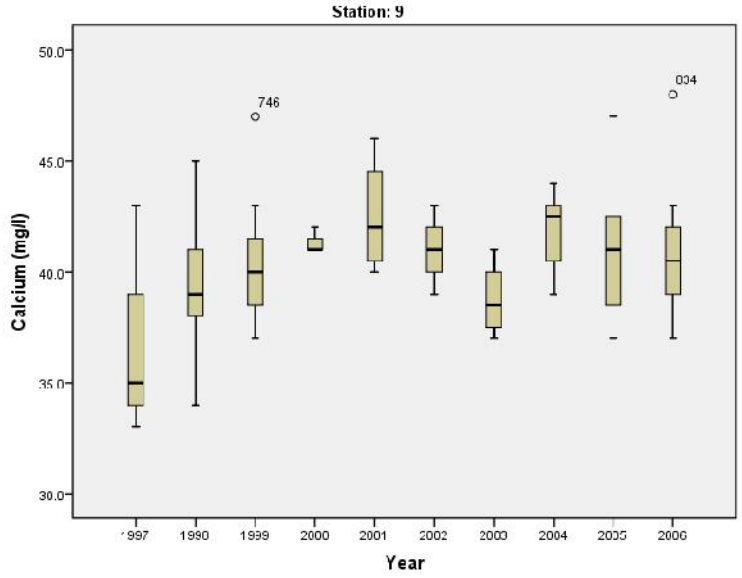

Station: 4
Calcium (mg/l)
Year
26.0
24.0
22.0
20.0
16.0
347
1997
1999
2000
2001
2002
2004
2005
2006

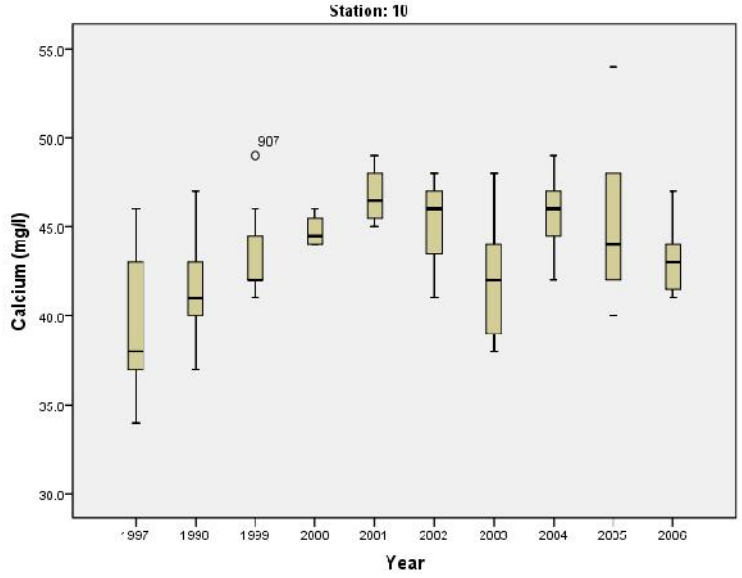

Station: 5
Calcium (mg/l)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
422
416
373
415
1997
1999
2000
2001
2002
2004
2005
2006
Year

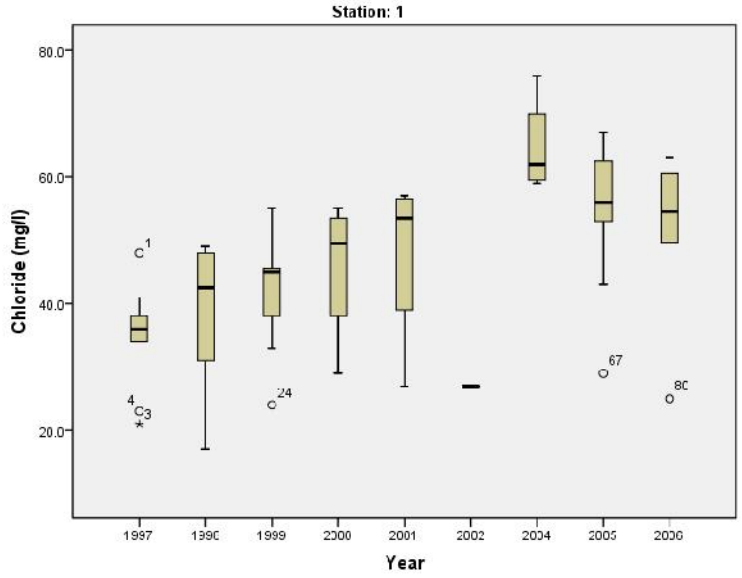

Station: 7
Calcium (mg/l)
50.0
45.0
40.0
35.0
30.0
25.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

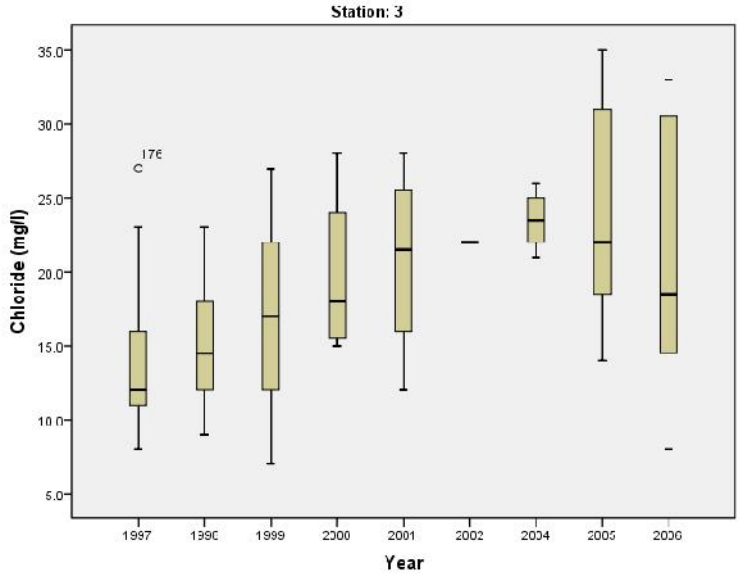

Station: 6
Calcium (mg/l)
45.0
40.0
35.0
30.0
25.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

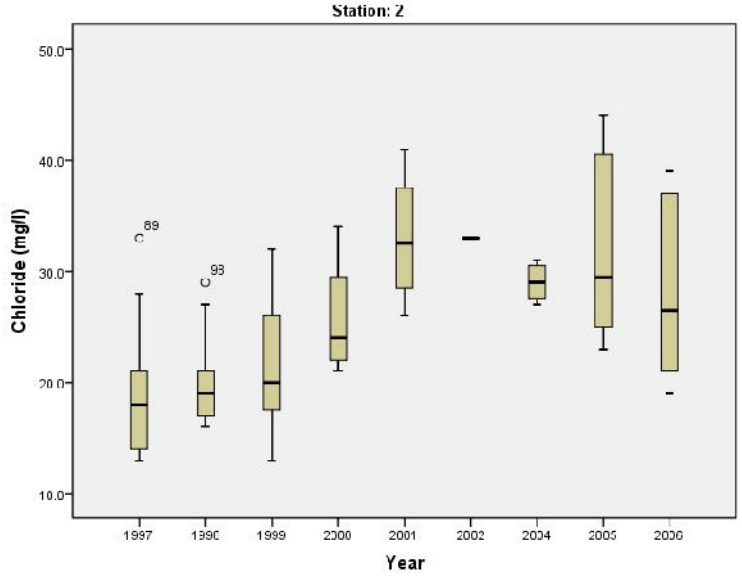

Station: 8
Calcium (mg/l)
50.0
45.0
40.0
35.0
30.0
677
621
1997
1999
2000
2001
2002
2004
2005
2006
Year

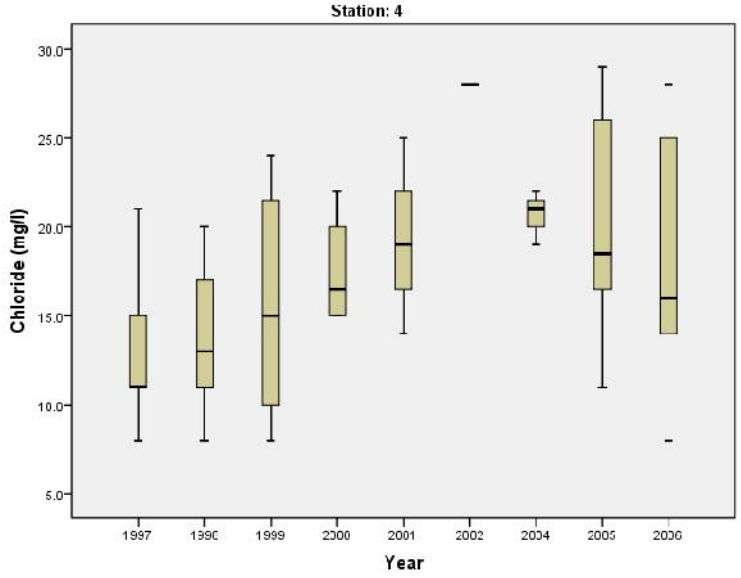

Station: 9
Calcium (mg/l)
50.0
45.0
40.0
35.0
30.0
746
034
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

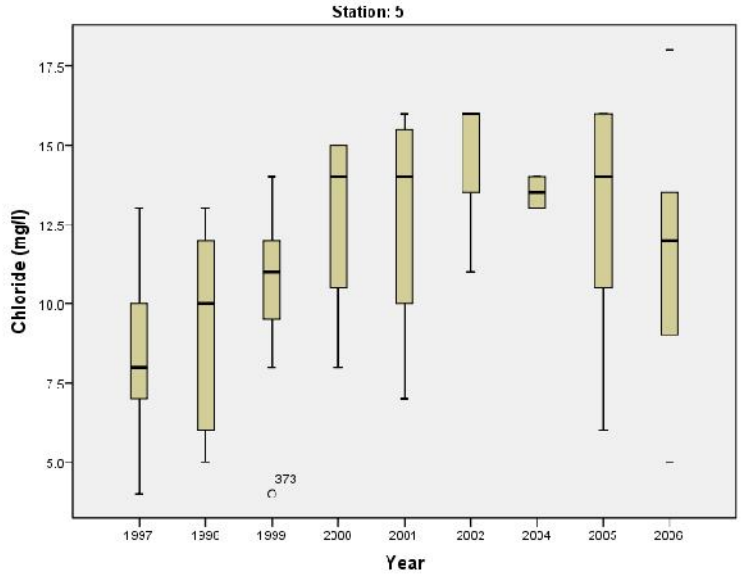

Station: 10
Calcium (mg/l)
55.0
50.0
45.0
40.0
35.0
30.0
907
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

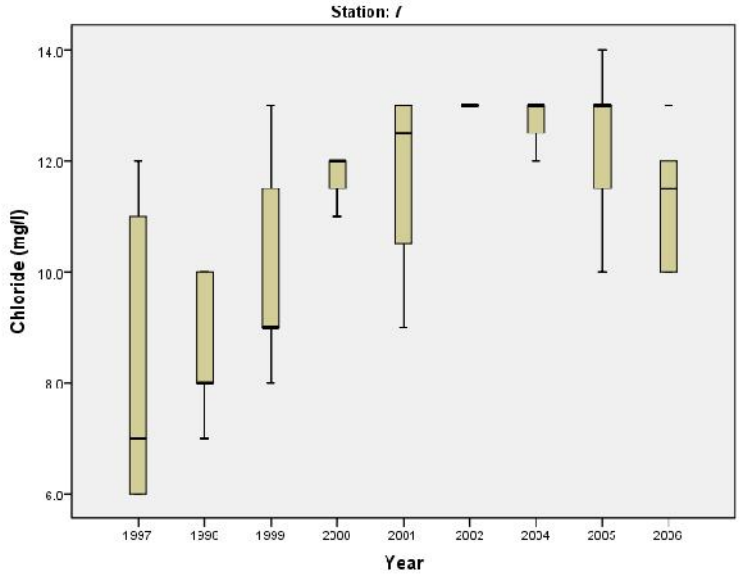

Station: 1
Chloride (mg/l)
80.0
60.0
40.0
20.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

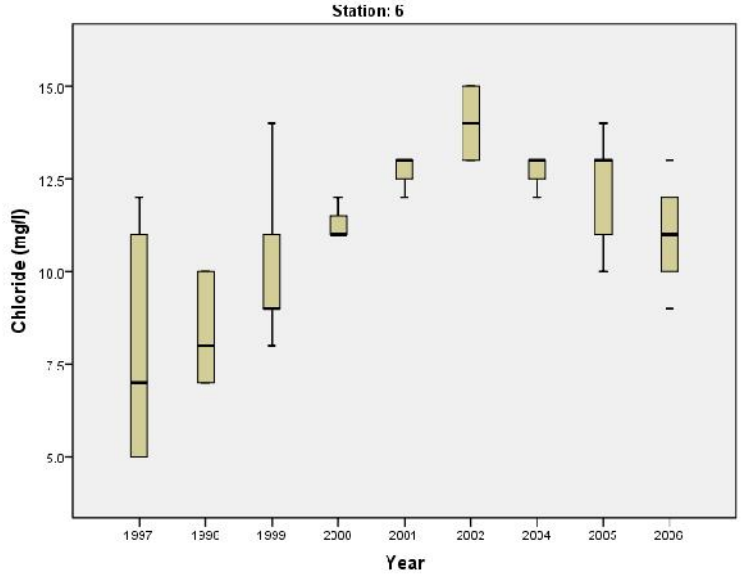

Station: 3
Chloride (mg/l)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

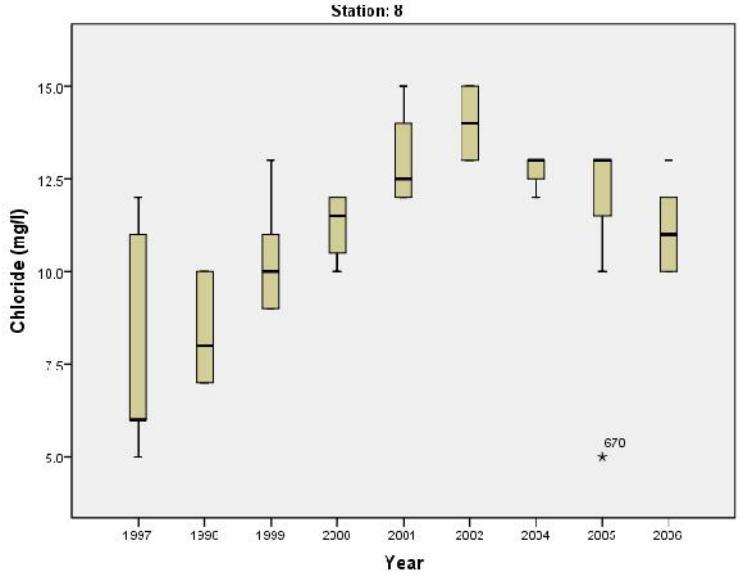

Station: 2
Chloride (mg/l)
50.0
40.0
30.0
10.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

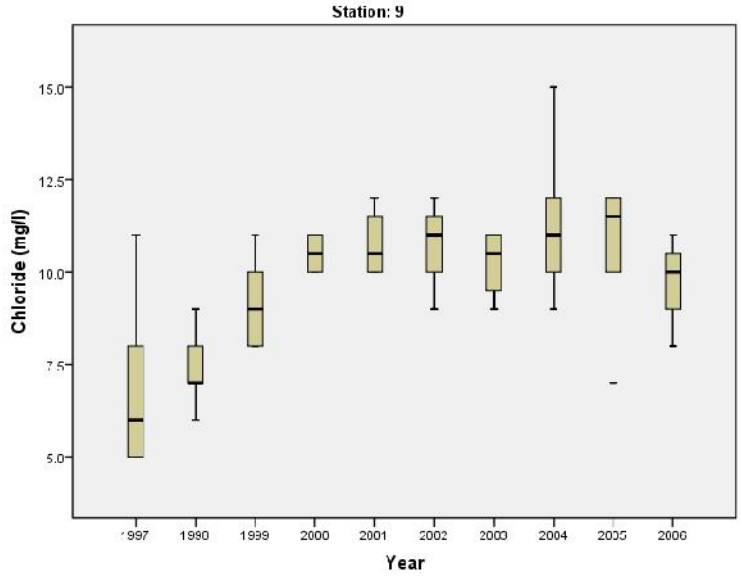

Station: 4
Chloride (mg/l)
30.0
25.0
20.0
15.0
10.0
5.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

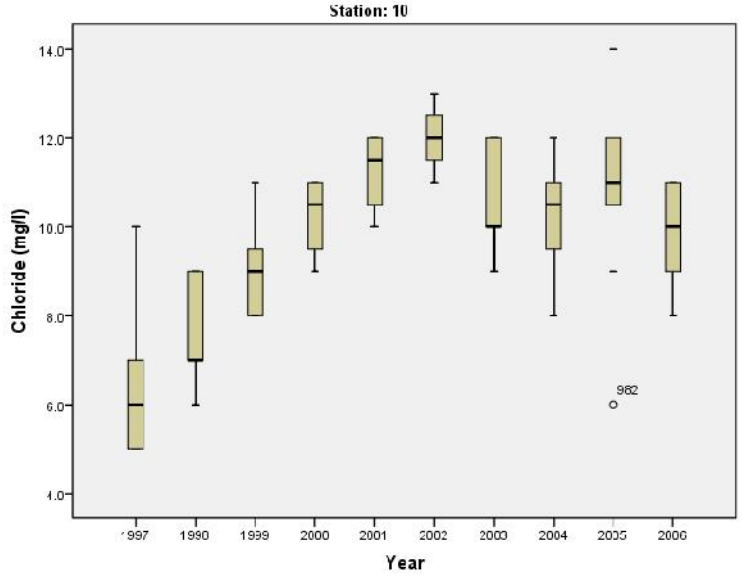

Station: 5
Chloride (mg/l)
17.5
15.0
12.5
10.0
7.5
5.0
373
1997
1999
2000
2001
2002
2004
2005
2006
Year

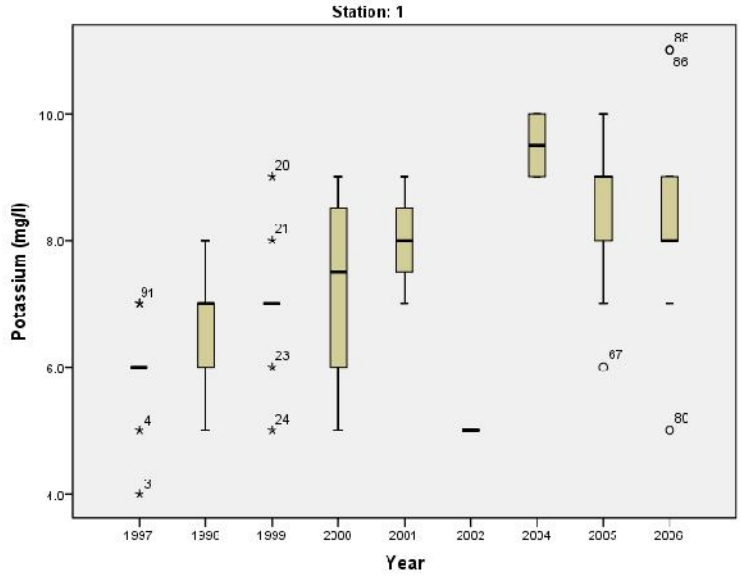

Station: 7
Chloride (mg/l)
14.0
12.0
10.0
8.0
6.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

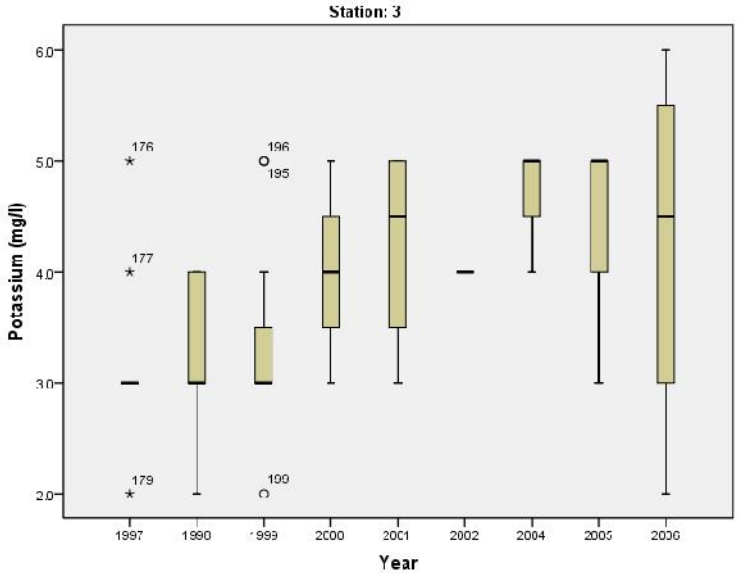

Station: 6
Chloride (mg/l)
15.0
12.5
10.0
7.5
5.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

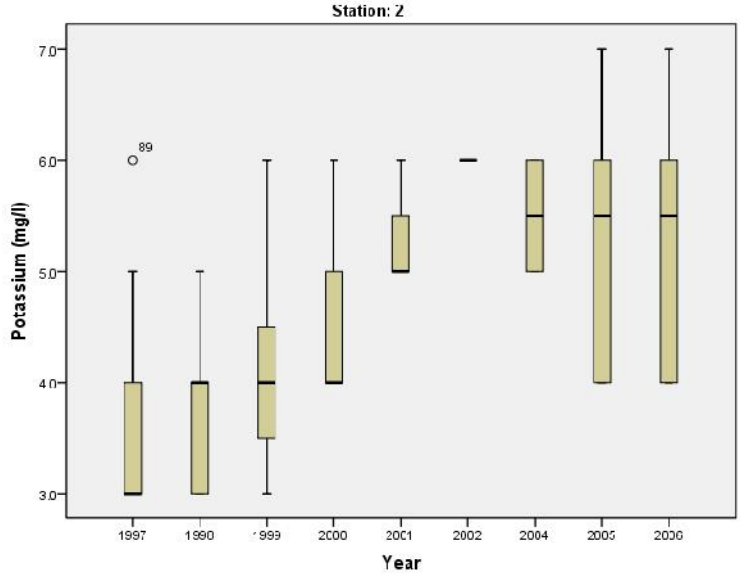

Station: 8
Chloride (mg/l)
15.0
12.5
10.0
7.5
5.0
670
1997
1999
2000
2001
2002
2004
2005
2006
Year

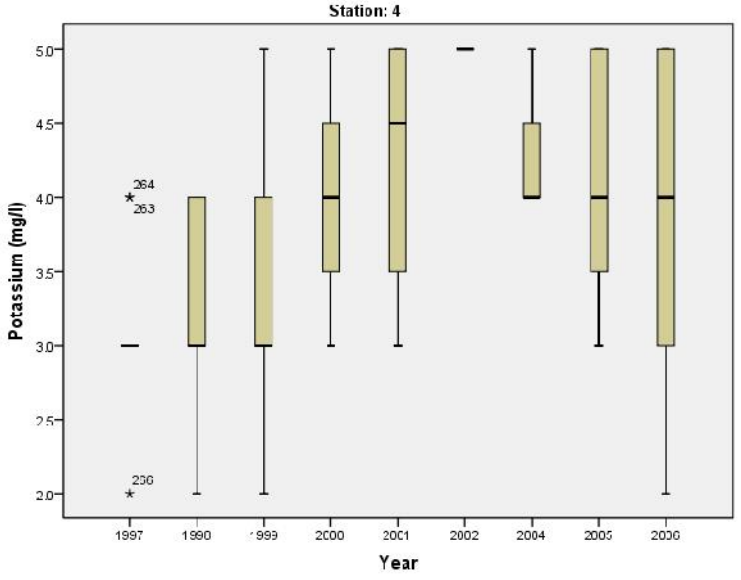

Station: 9
Chloride (mg/l)
15.0
12.5
10.0
7.5
5.0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

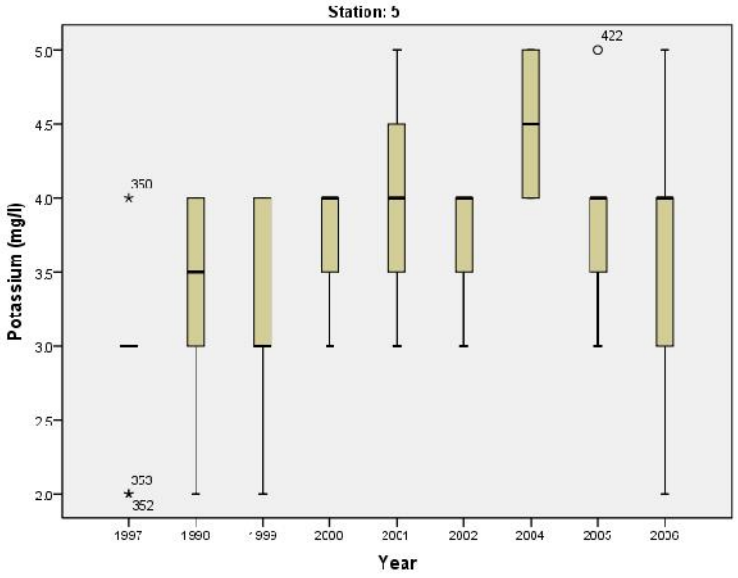

Station: 10
Chloride (mg/l)
14.0
12.0
10.0
8.0
6.0
4.0
982
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

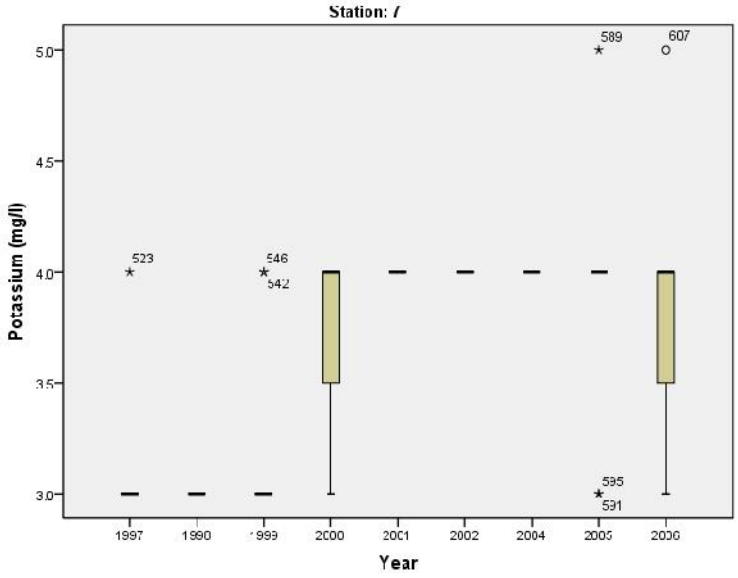

Station: 1
Potassium (mg/l)
10.0
8.0
6.0
4.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

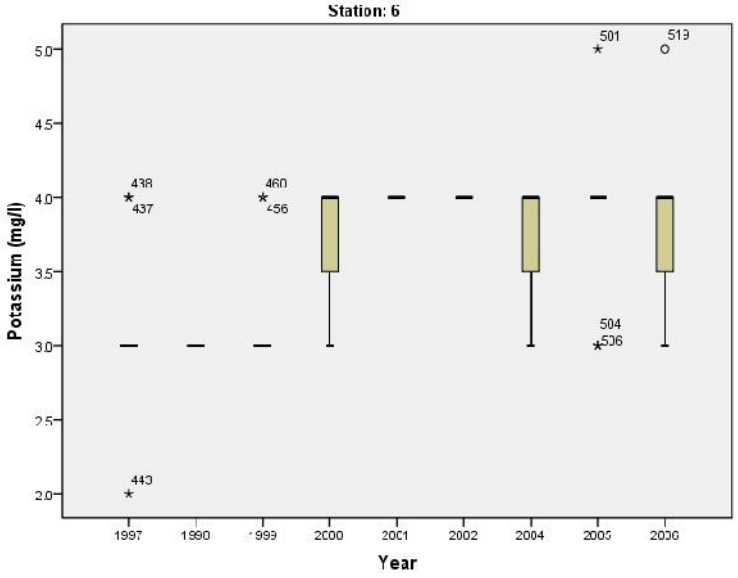

Station: 3
Potassium (mg/l)
6.0
5.0
4.0
3.0
2.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

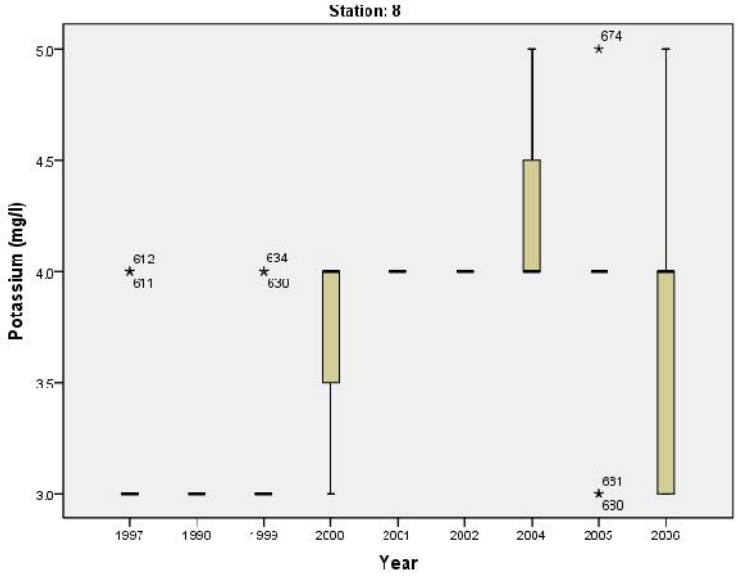

Station: 2
Potassium (mg/l)
7.0
6.0
5.0
4.0
3.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

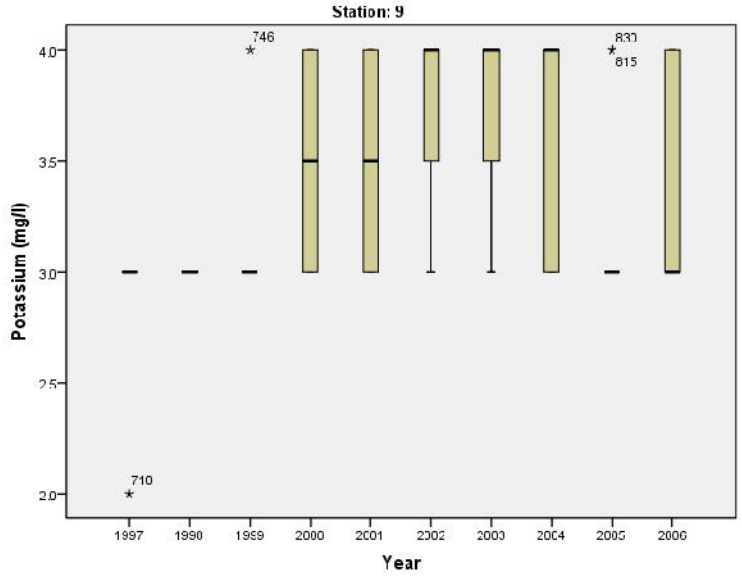

Station: 4
Potassium (mg/l)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

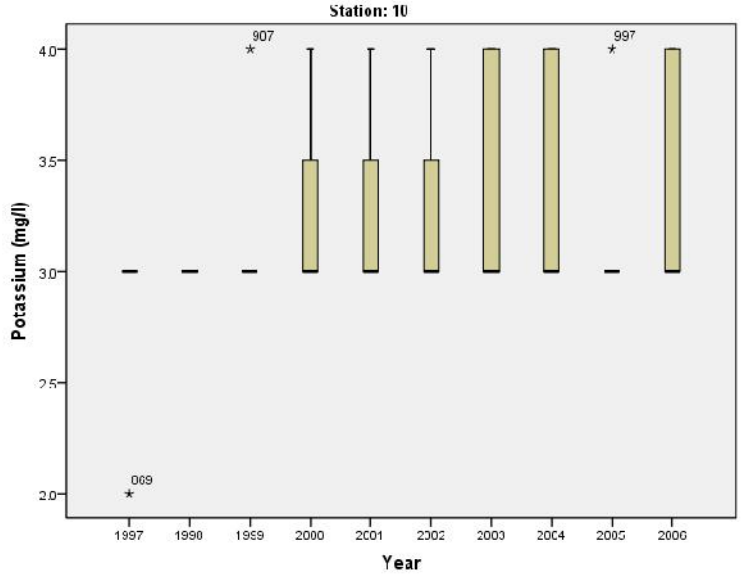

Station: 5
Potassium (mg/l)
Year
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1997
1990
1999
2000
2001
2002
2004
2005
2006
422
350
353
352

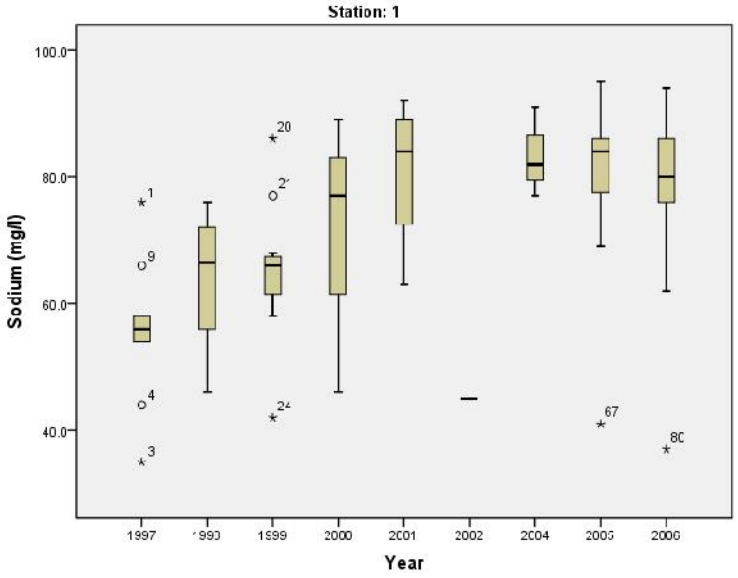

Station: 7
Potassium (mg/l)
Year
5.0
4.5
4.0
3.5
3.0
1997
1990
1999
2000
2001
2002
2004
2005
2006
589
607
523
546
542
595
591

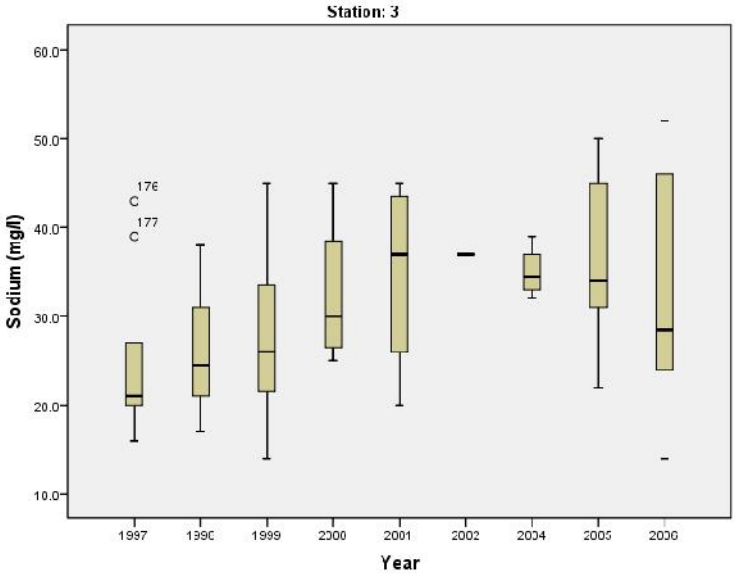

Station: 6
Potassium (mg/l)
Year
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1997
1990
1999
2000
2001
2002
2004
2005
2006
501
519
438
437
460
456
504
506
443

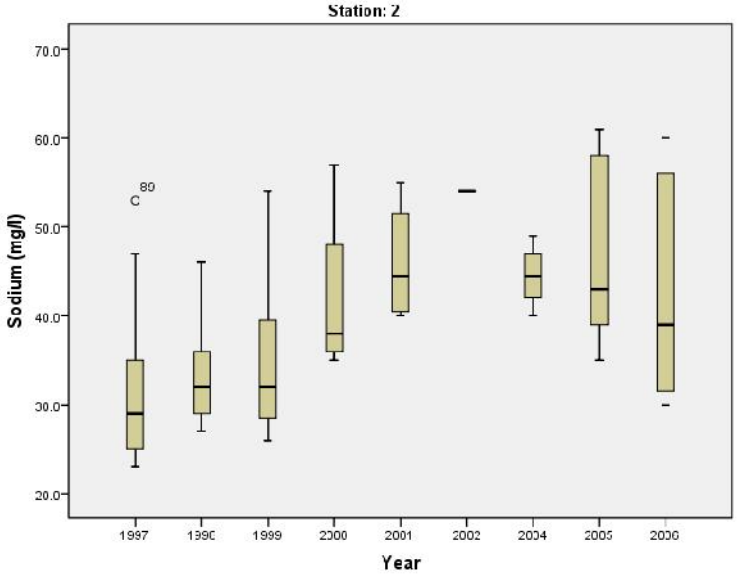

Station: 8
Potassium (mg/l)
Year
5.0
4.5
4.0
3.5
3.0
1997
1990
1999
2000
2001
2002
2004
2005
2006
674
612
611
634
630
631
630

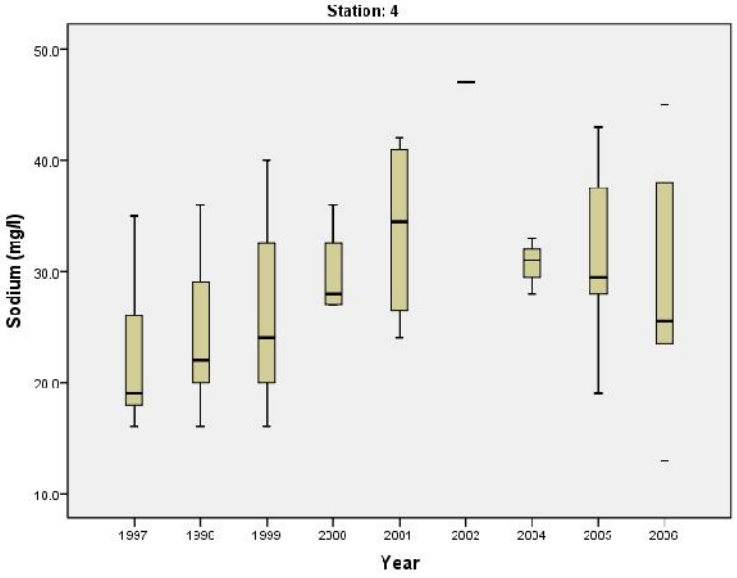

Station: 9
Potassium (mg/l)
4.0
3.5
3.0
2.5
2.0
746
710
815
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

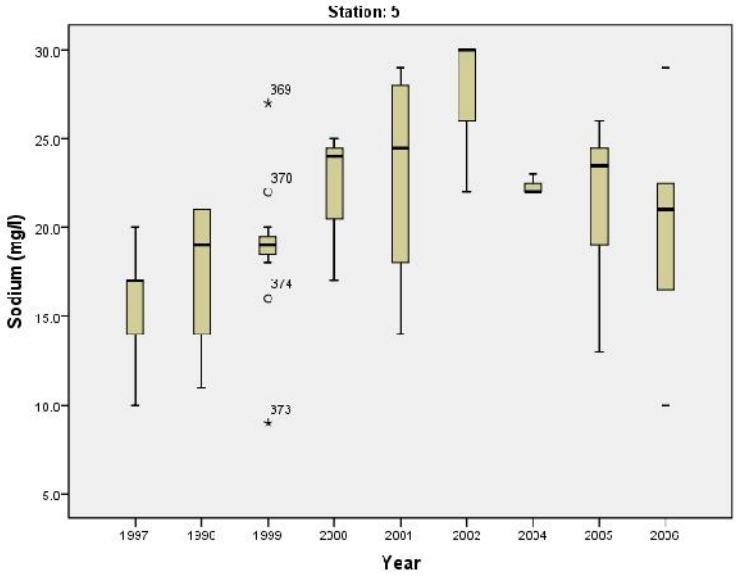

Station: 10
Potassium (mg/l)
4.0
3.5
3.0
2.5
2.0
907
997
069
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

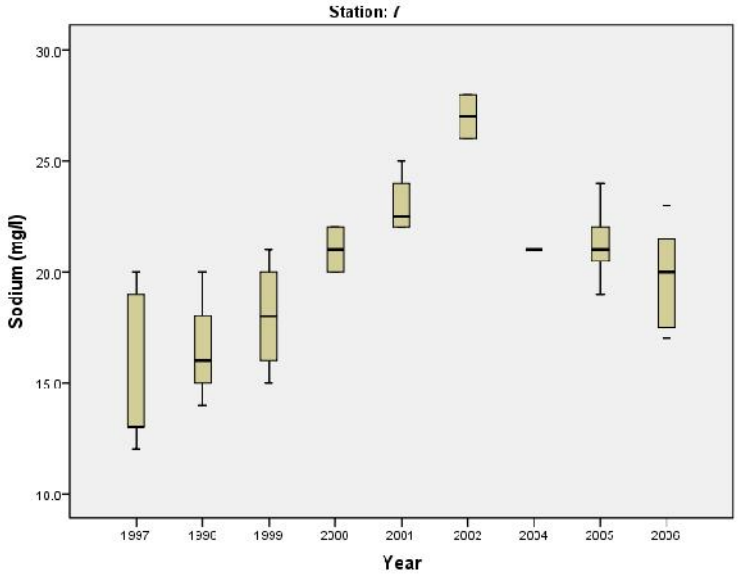

Station: 1
Sodium (mg/l)
100.0
80.0
60.0
40.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

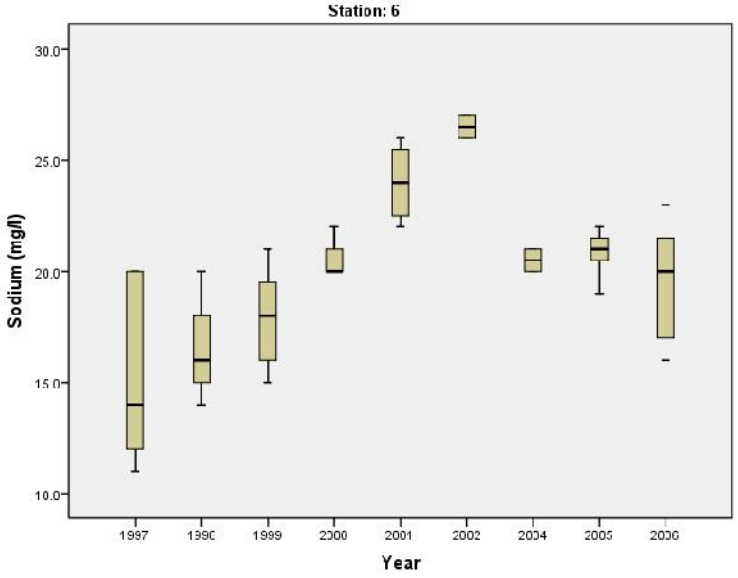

Station: 3
Sodium (mg/l)
60.0
50.0
40.0
30.0
20.0
10.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

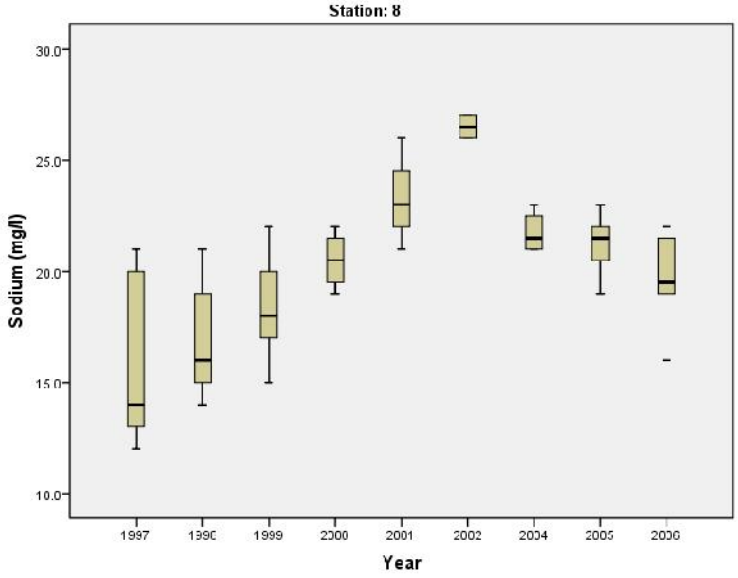

Station: 2
Sodium (mg/l)
70.0
60.0
50.0
40.0
30.0
20.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

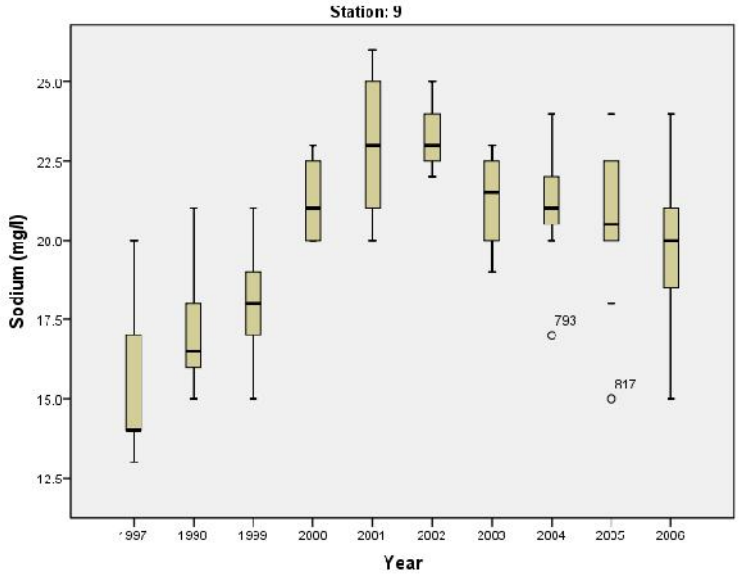

Station: 4
Sodium (mg/l)
50.0
40.0
30.0
10.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

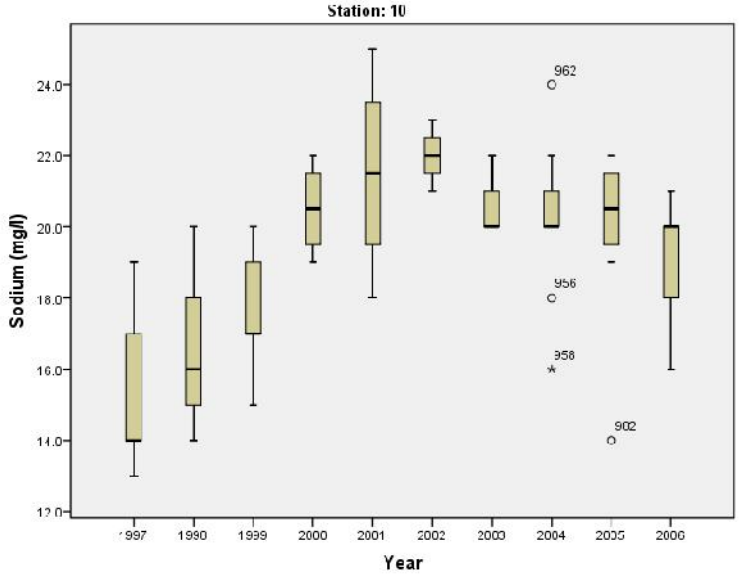

Station: 5
Sodium (mg/l)
30.0
25.0
20.0
15.0
10.0
5.0
369
370
374
373
1997
1998
1999
2000
2001
2002
2004
2005
2006
Year

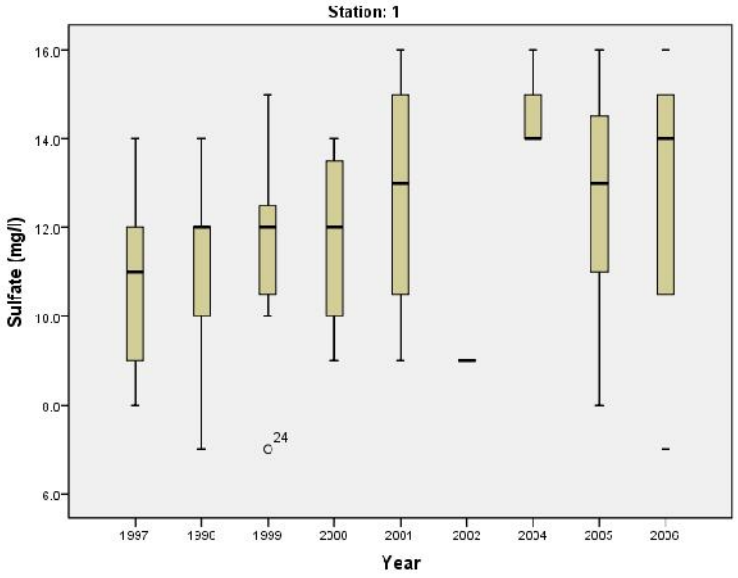

Station: 7
Sodium (mg/l)
30.0
25.0
20.0
15.0
10.0
1997
1998
1999
2000
2001
2002
2004
2005
2006
Year

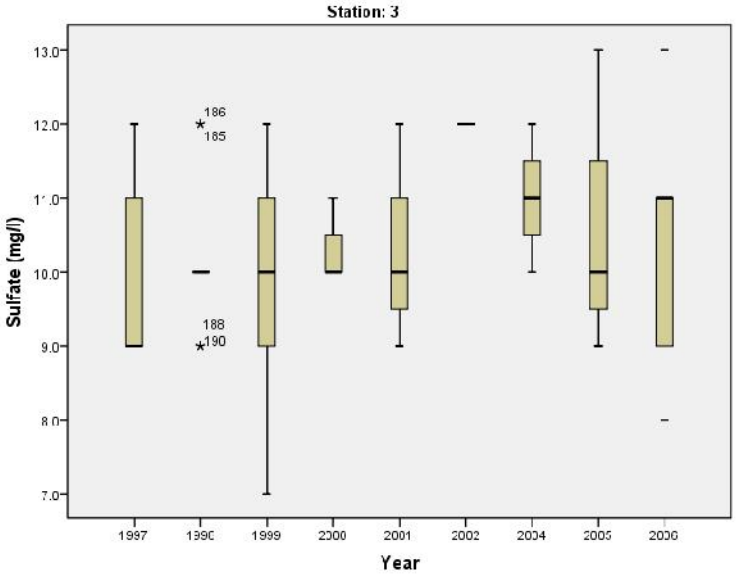

Station: 6
Sodium (mg/l)
30.0
25.0
20.0
15.0
10.0
1997
1998
1999
2000
2001
2002
2004
2005
2006
Year

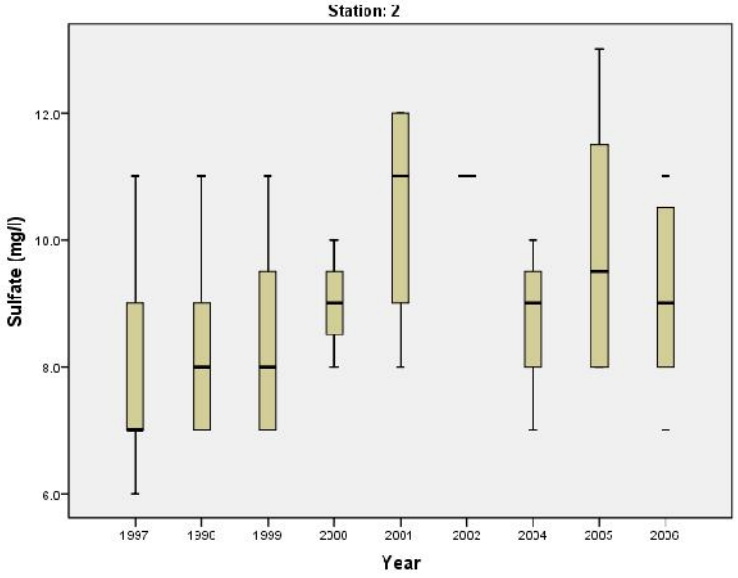

Station: 8
Sodium (mg/l)
30.0
25.0
20.0
15.0
10.0
1997
1998
1999
2000
2001
2002
2004
2005
2006
Year

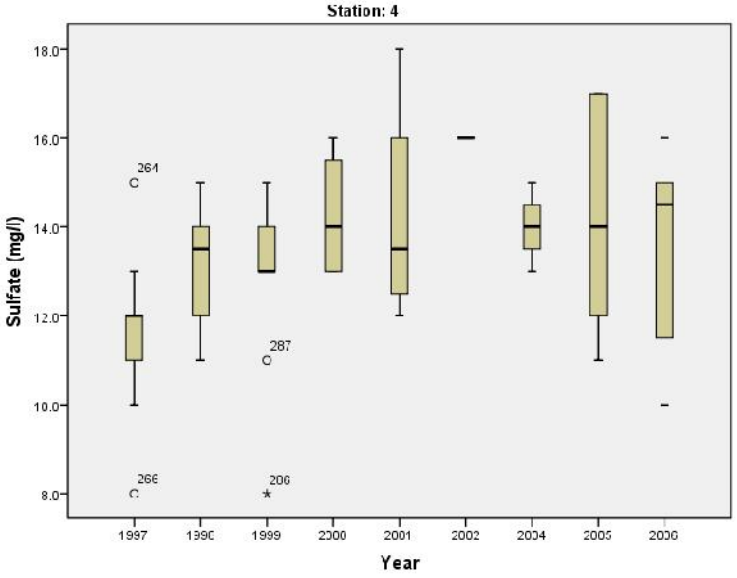

Station: 9
Sodium (mg/l)
25.0
22.5
20.0
17.5
15.0
12.5
793
817
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

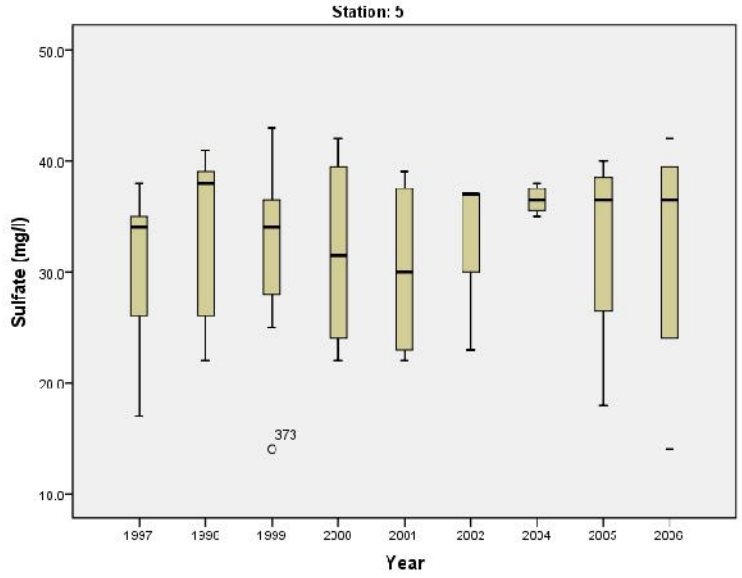

Station: 10
Sodium (mg/l)
24.0
22.0
20.0
18.0
16.0
14.0
962
956
958
902
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

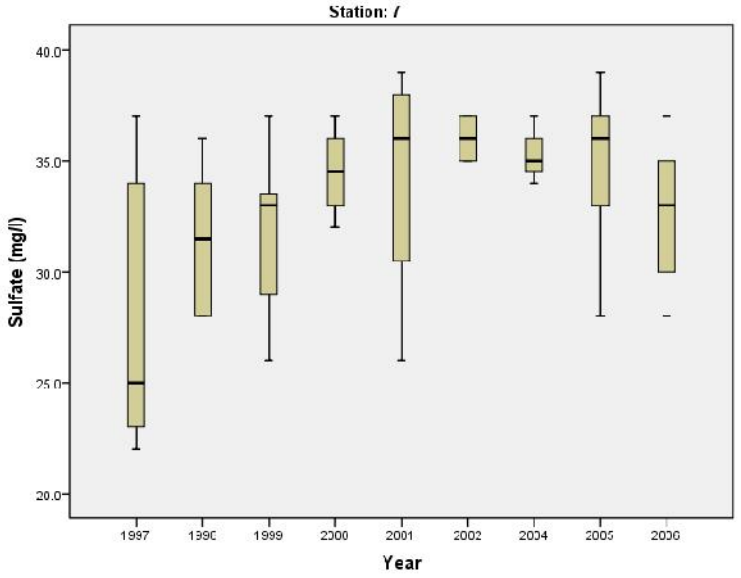

Station: 1
Sulfate (mg/l)
16.0
14.0
12.0
10.0
0.0
6.0
24
1997
1999
2000
2001
2002
2004
2005
2006
Year

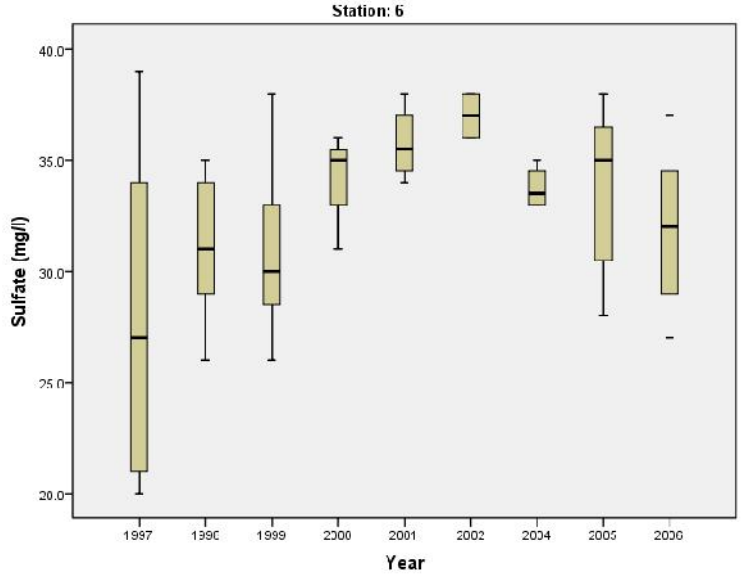

Station: 3
Sulfate (mg/l)
13.0
12.0
10.0
9.0
8.0
7.0
186
185
188
190
1997
1999
2000
2001
2002
2004
2005
2006
Year

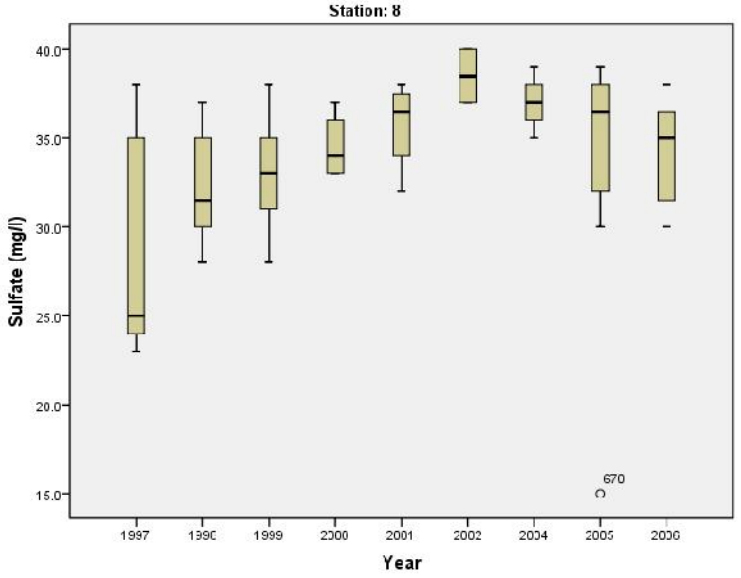

Station: 2
Sulfate (mg/l)
12.0
10.0
8.0
6.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

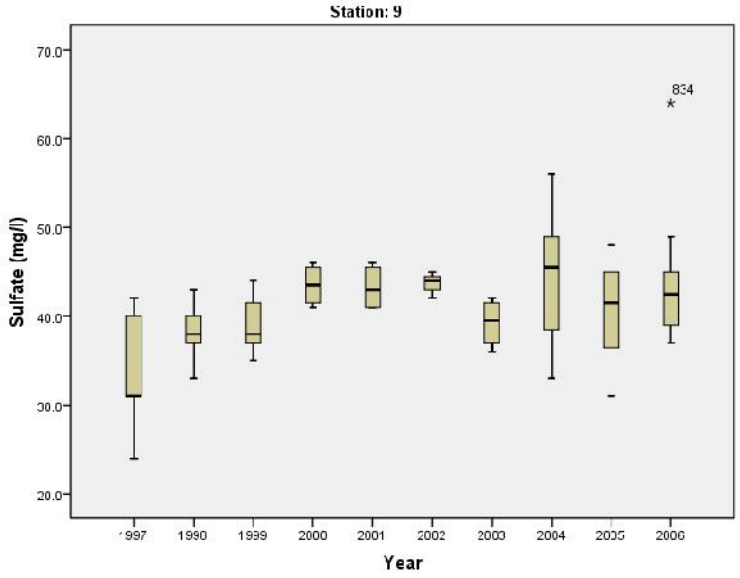

Station: 4
Sulfate (mg/l)
18.0
16.0
14.0
12.0
10.0
8.0
261
287
266
206
1997
1999
2000
2001
2002
2004
2005
2006
Year

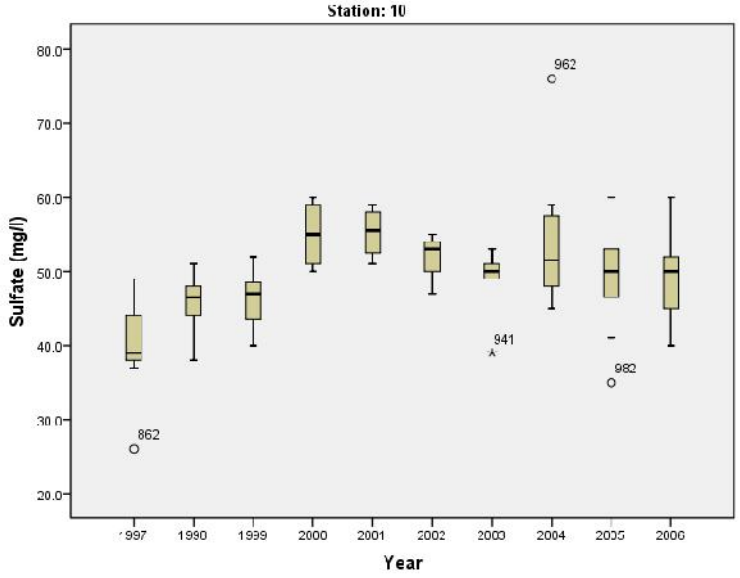

Station: 5
Sulfate (mg/l)
50.0
40.0
30.0
20.0
10.0
373
1997
1999
2000
2001
2002
2004
2005
2006
Year

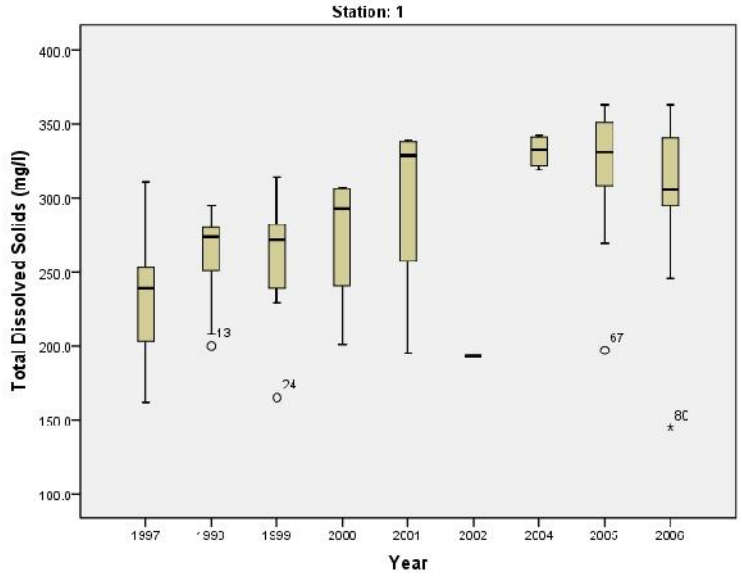

Station: 7
Sulfate (mg/l)
40.0
35.0
30.0
25.0
20.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

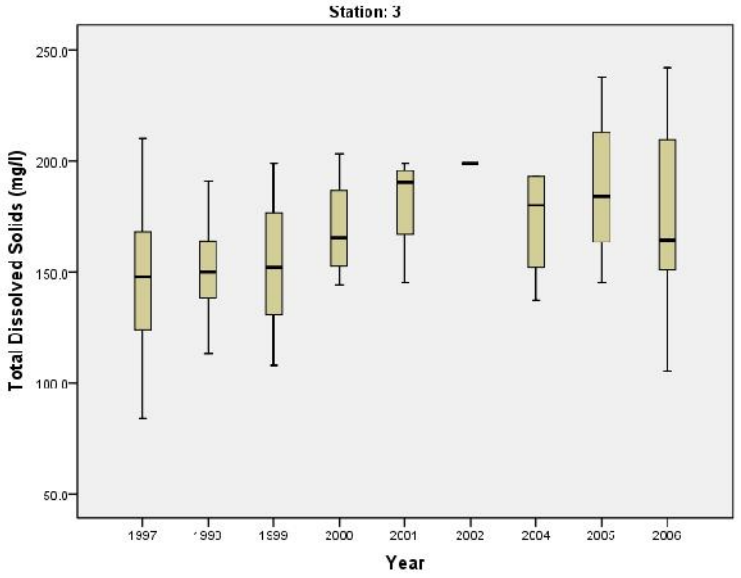

Station: 6
Sulfate (mg/l)
40.0
35.0
30.0
25.0
20.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

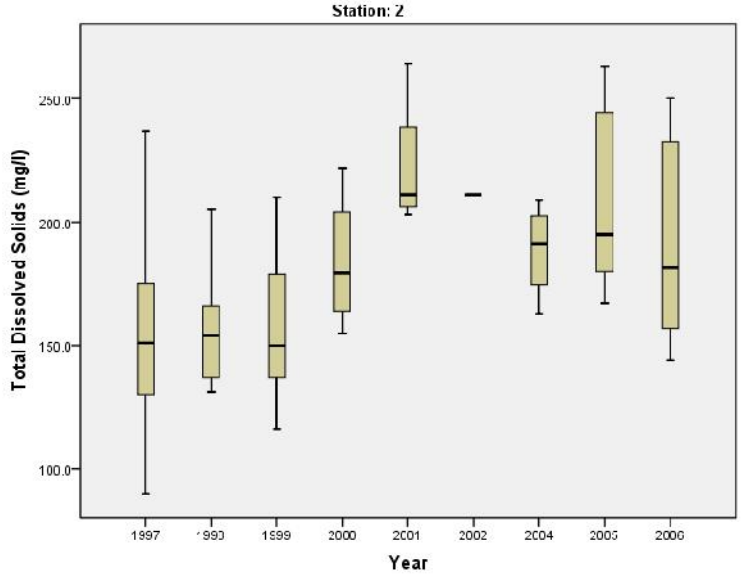

Station: 8
Sulfate (mg/l)
40.0
35.0
30.0
25.0
20.0
15.0
670
1997
1999
2000
2001
2002
2004
2005
2006
Year

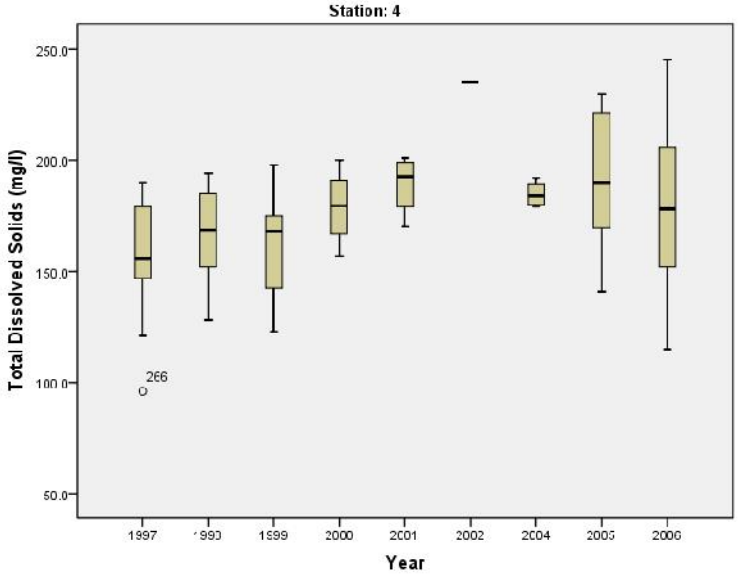

Station: 9
Sulfate (mg/l)
70.0
60.0
50.0
40.0
30.0
20.0
834
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

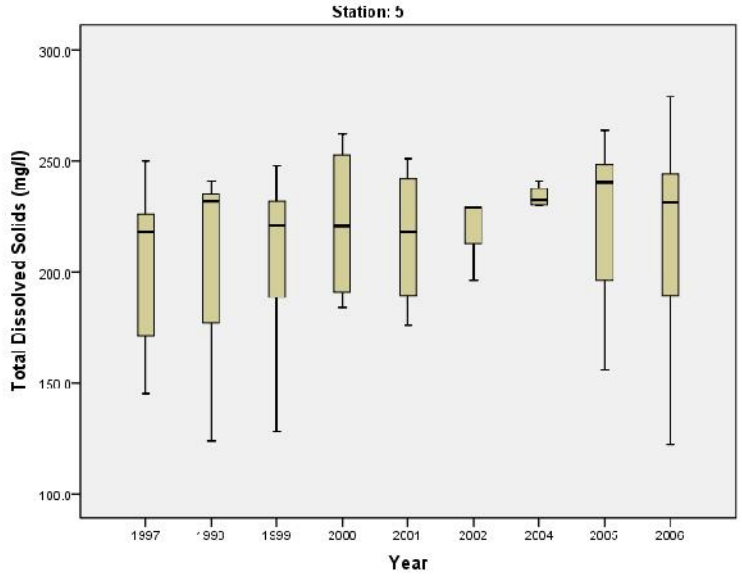

Station: 10
Sulfate (mg/l)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
962
941
982
862
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

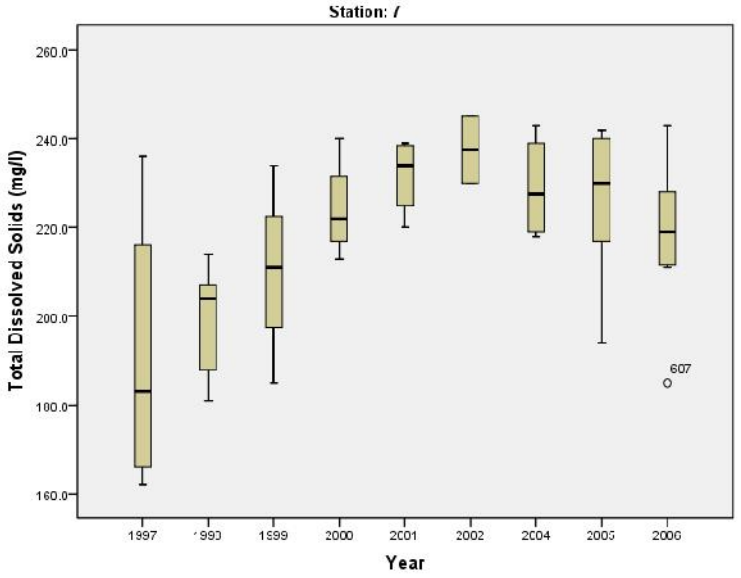

Station: 1
Total Dissolved Solids (mg/l)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
13
24
67
80
1997
1999
2000
2001
2002
2004
2005
2006
Year

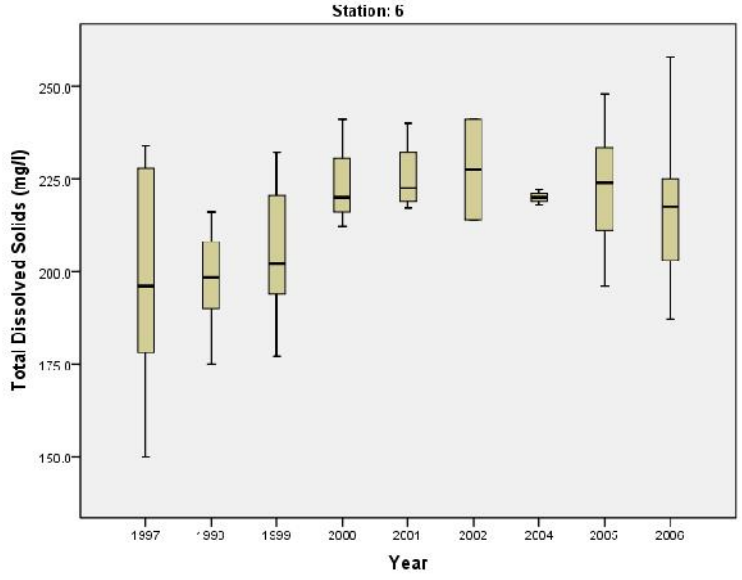

Station: 3
Total Dissolved Solids (mg/l)
250.0
200.0
150.0
100.0
50.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

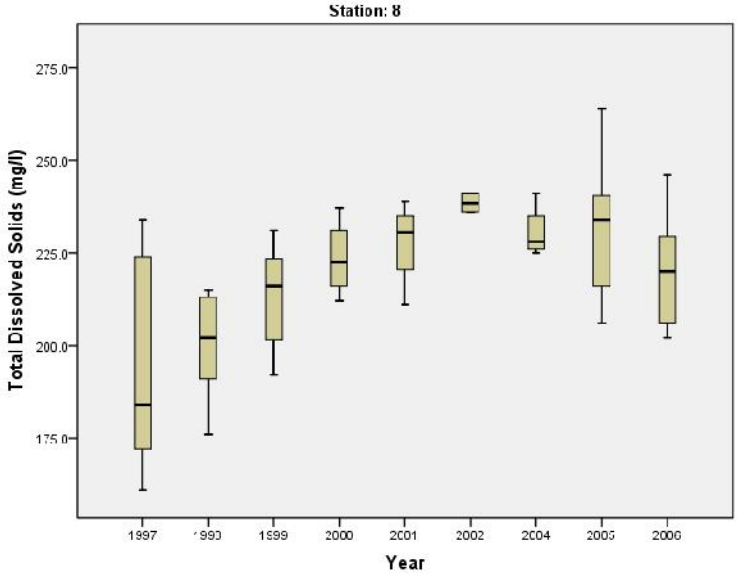

Station: 2
Total Dissolved Solids (mg/l)
250.0
200.0
150.0
100.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

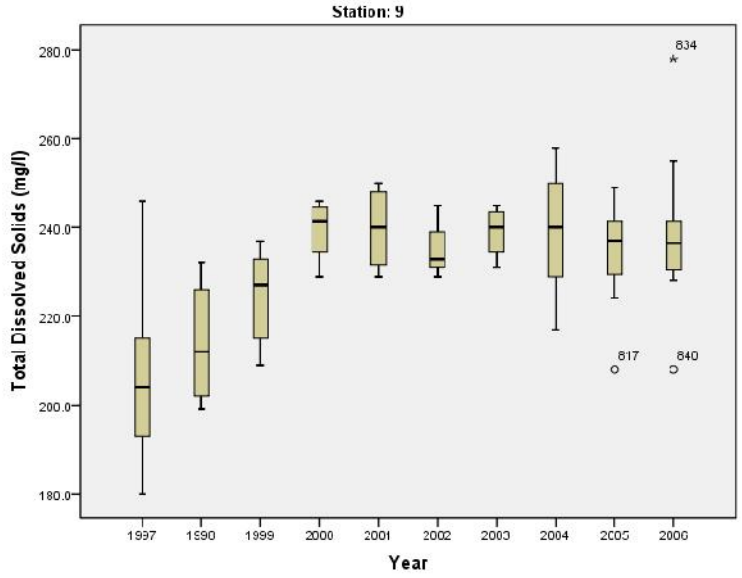

Station: 4
Total Dissolved Solids (mg/l)
250.0
200.0
150.0
100.0
50.0
266
1997
1999
2000
2001
2002
2004
2005
2006
Year

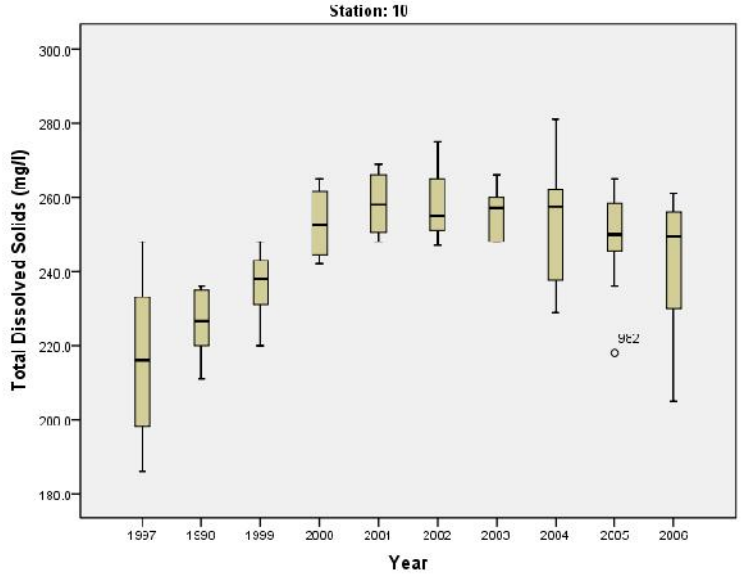

Station: 5
Total Dissolved Solids (mg/l)
300.0
250.0
200.0
150.0
100.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

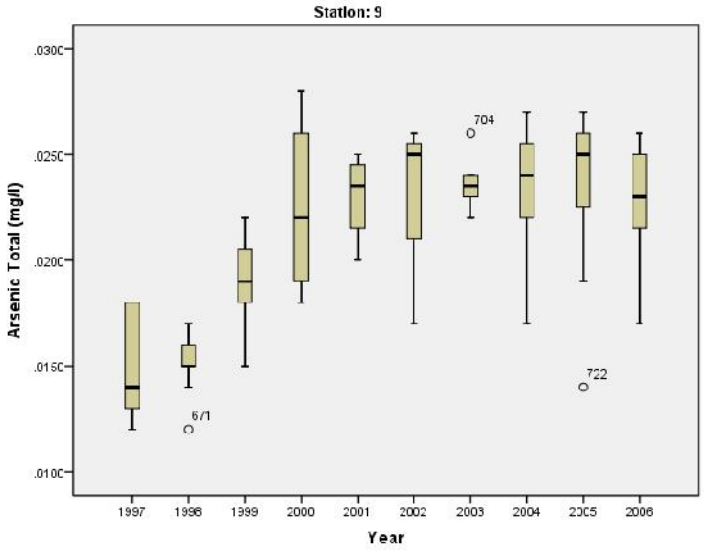

Station: 7
Total Dissolved Solids (mg/l)
260.0
240.0
220.0
200.0
180.0
160.0
607
1997
1999
2000
2001
2002
2004
2005
2006
Year

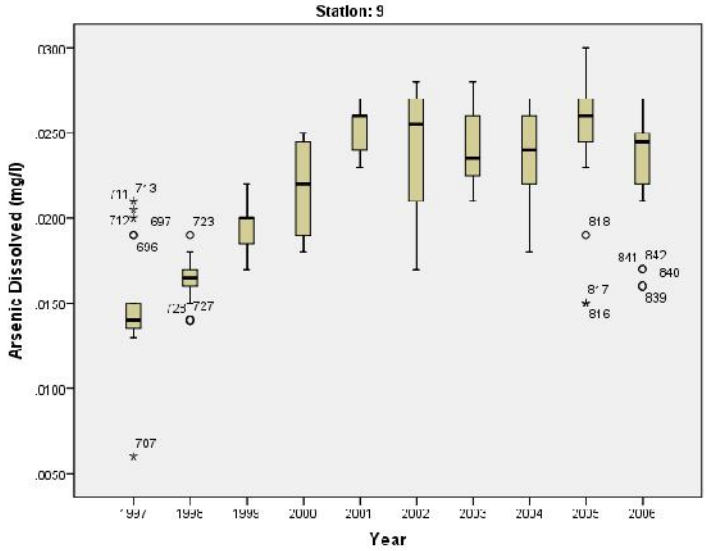

Station: 6
Total Dissolved Solids (mg/l)
250.0
225.0
200.0
175.0
150.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

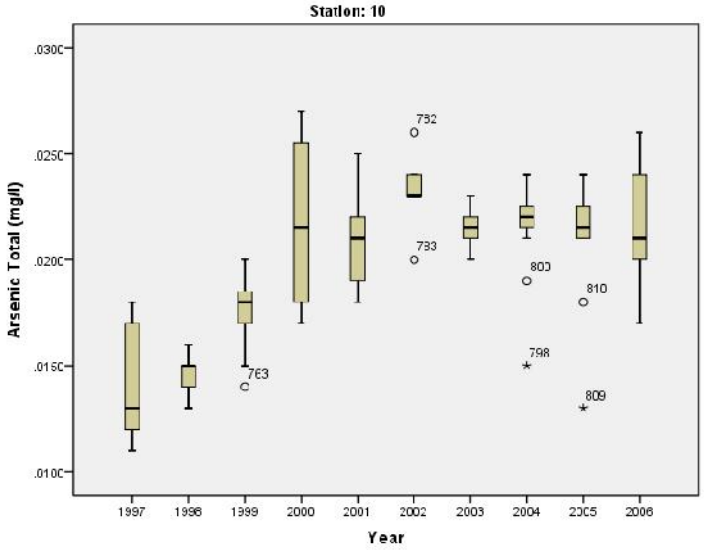

Station: 8
Total Dissolved Solids (mg/l)
275.0
250.0
225.0
200.0
175.0
1997
1999
2000
2001
2002
2004
2005
2006
Year

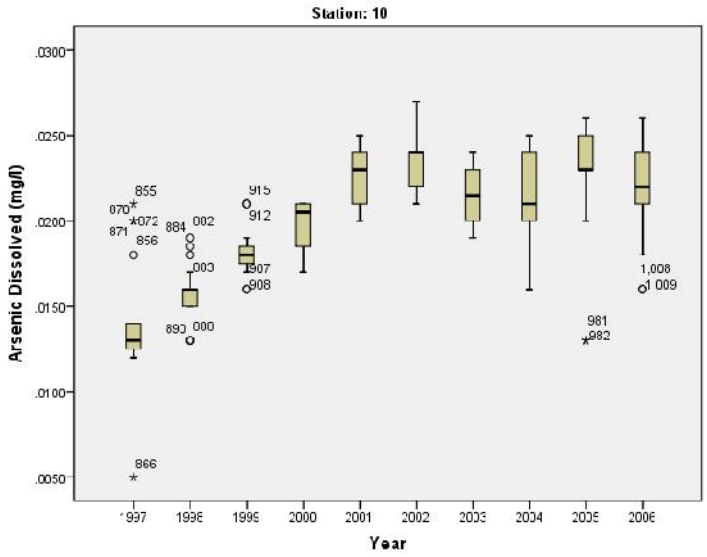

Station: 9
Total Dissolved Solids (mg/l)
280.0
260.0
240.0
220.0
200.0
180.0
634
617
840
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

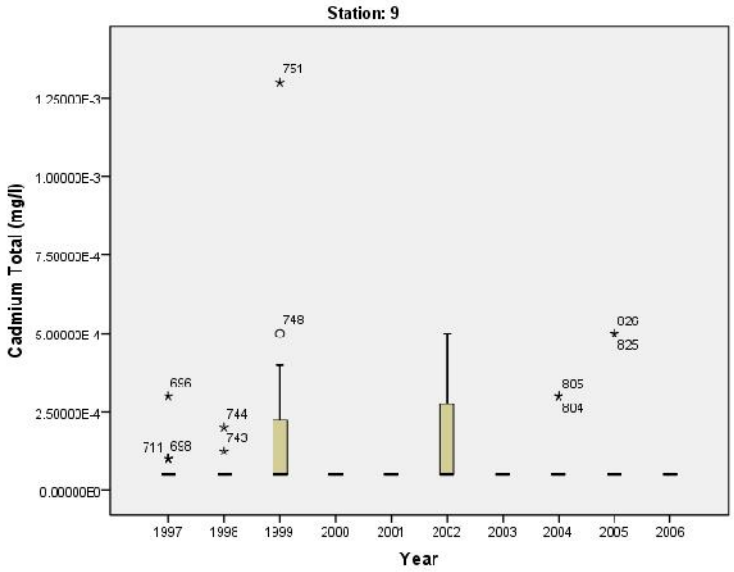

Station: 10
Total Dissolved Solids (mg/l)
300.0
280.0
260.0
240.0
220.0
200.0
180.0
982
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

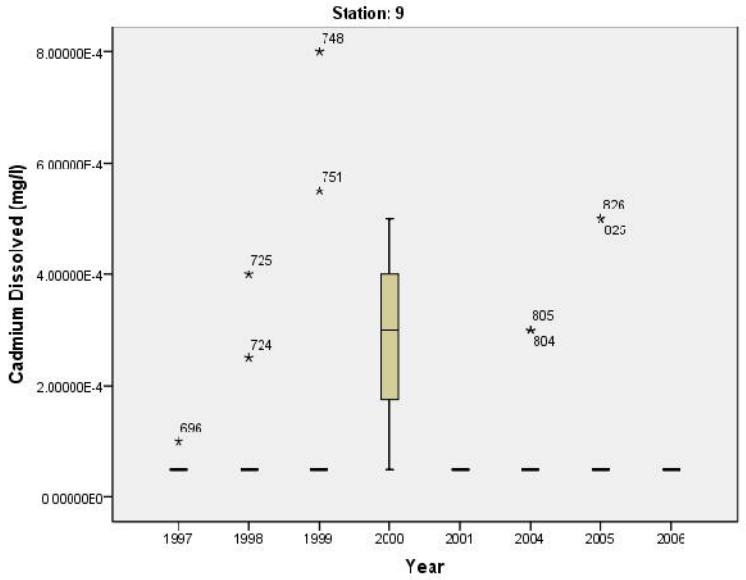

Station: 9
Arsenic Total (mg/l)
.030C
.025C
.020C
.015C
.010C
704
722
671
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

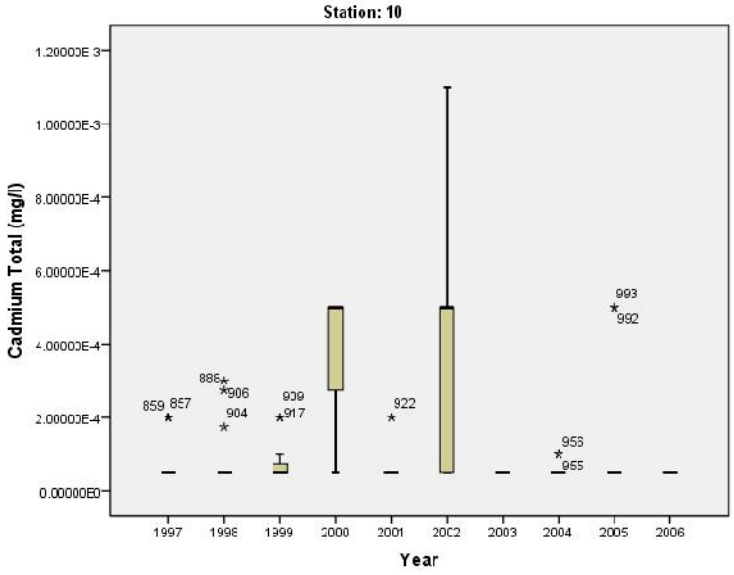

Station: 9
Arsenic Dissolved (mg/l)
.0300
.0250
.0200
.0150
.0100
.0050
697
696
723
727
707
818
816
841
842
840
839
Year

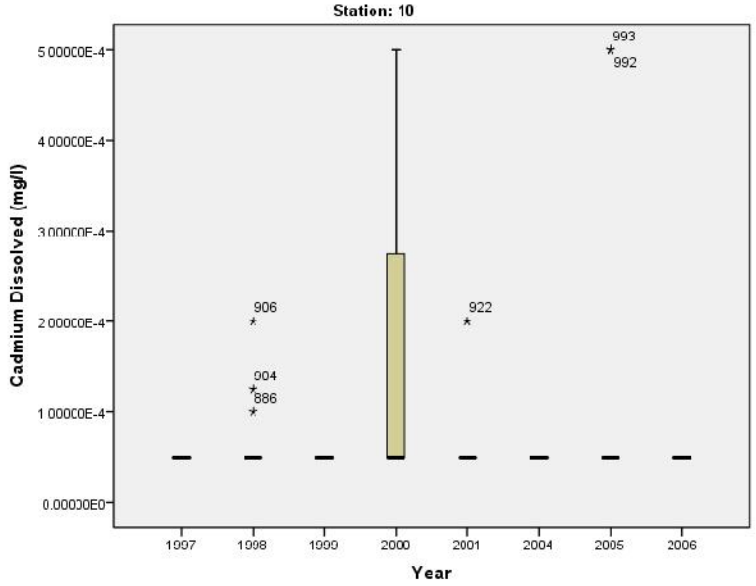

Station: 10
Arsenic Total (mg/l)
.030C
.025C
.020C
.015C
.010C
732
733
800
798
810
809
763
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

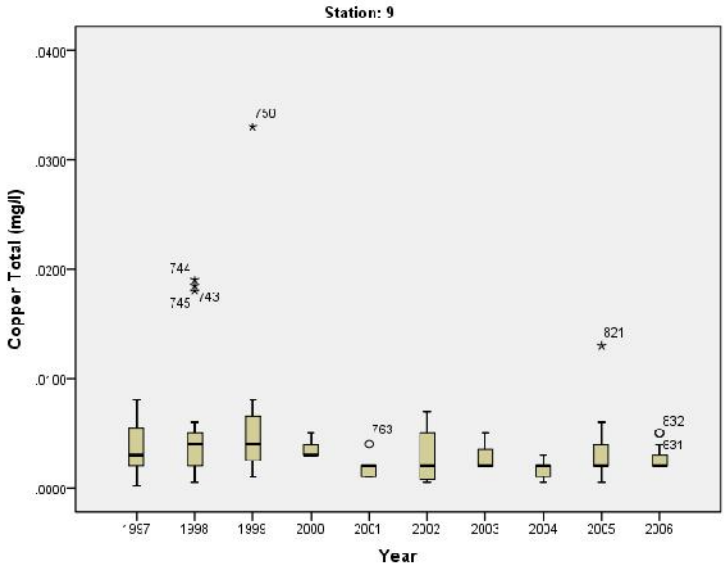

Station: 10
Arsenic Dissolved (mg/l)
.0300
.0250
.0200
.0150
.0100
.0050
855
884
915
912
907
908
981
982
1,008
1 009
866
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

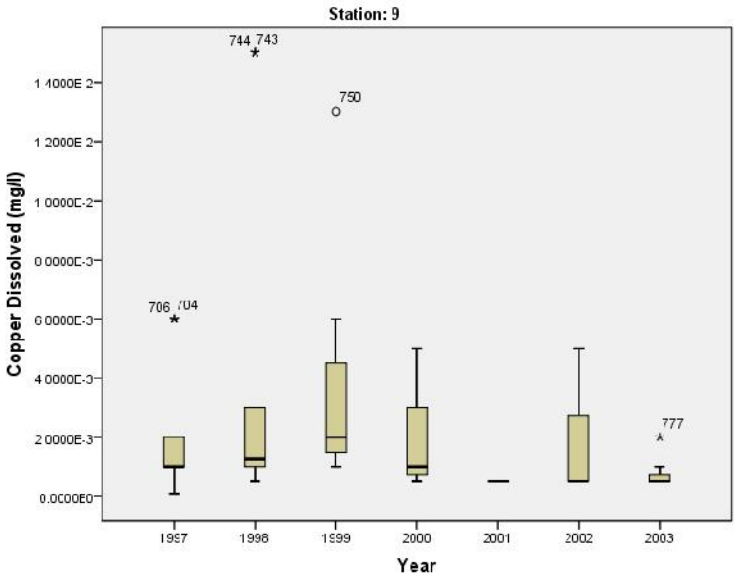

Station: 9
Cadmium Total (mg/l)
1.25000E-3
1.00000E-3
7.50000E-4
5.00000E-4
2.50000E-4
0.00000E0
751
748
826
825
696
744
743
711
698
805
804
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

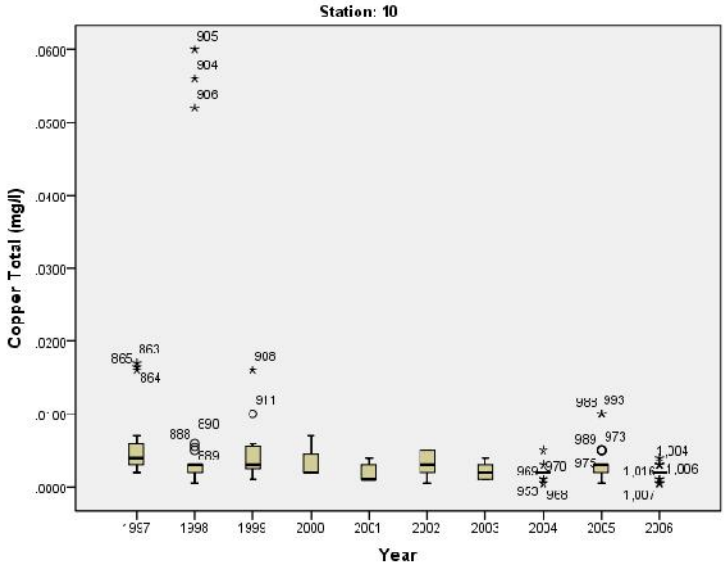

Station: 9
Cadmium Dissolved (mg/l)
8.00000E-4
6.00000E-4
4.00000E-4
2.00000E-4
0.00000E0
748
751
826
825
725
724
805
804
696
1997
1998
1999
2000
2001
2004
2005
2006
Year

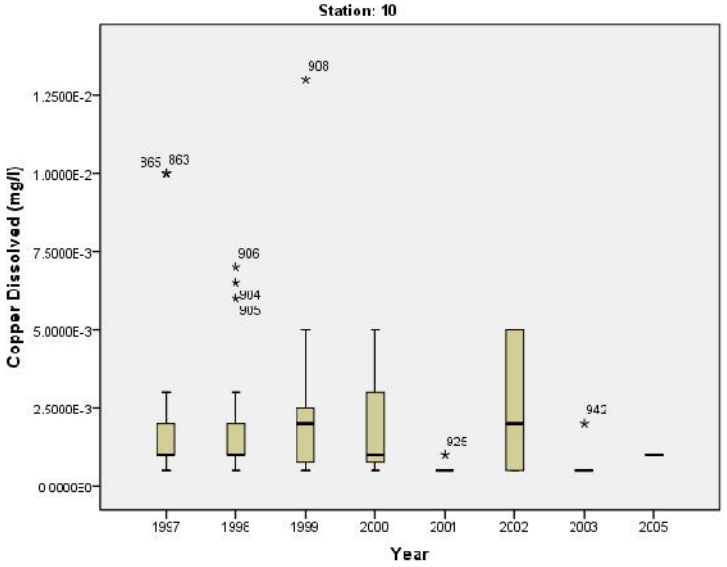

Station: 10
Cadmium Total (mg/l)
1.20000E-3
1.00000E-3
8.00000E-4
6.00000E-4
4.00000E-4
2.00000E-4
0.00000E0
993
992
886
906
859
857
904
909
917
922
958
955
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

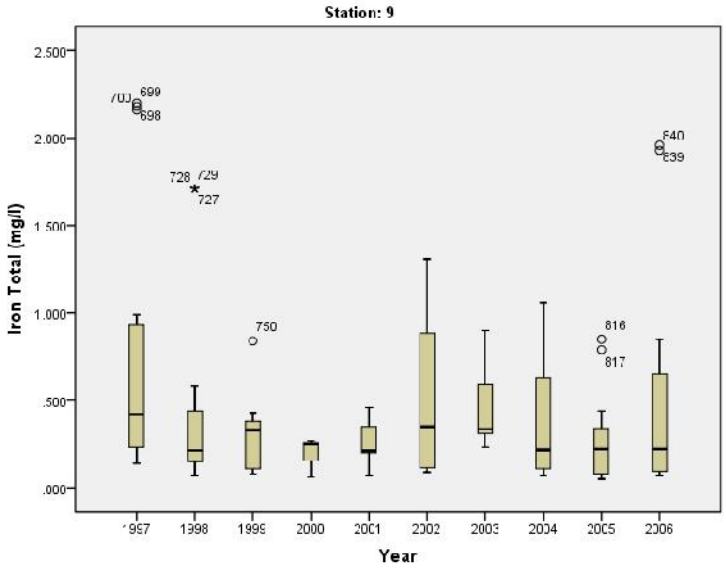

Station: 10
Cadmium Dissolved (mg/l)
5.00000E-4
4.00000E-4
3.00000E-4
2.00000E-4
1.00000E-4
0.00000E0
993
992
906
922
904
886
1997
1998
1999
2000
2001
2004
2005
2006
Year

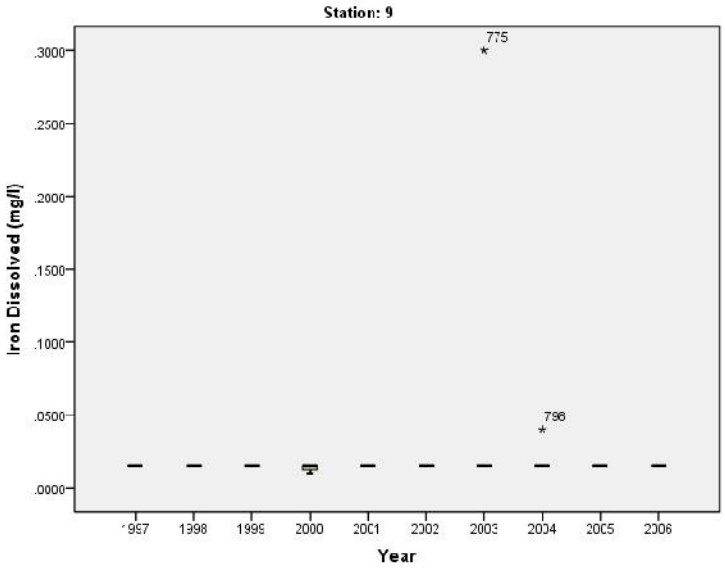

Station: 9
Copper Total (mg/l)
.0400
.0300
.0200
.0000
Year
1998
1999
2000
2001
2002
2003
2004
2005
2006

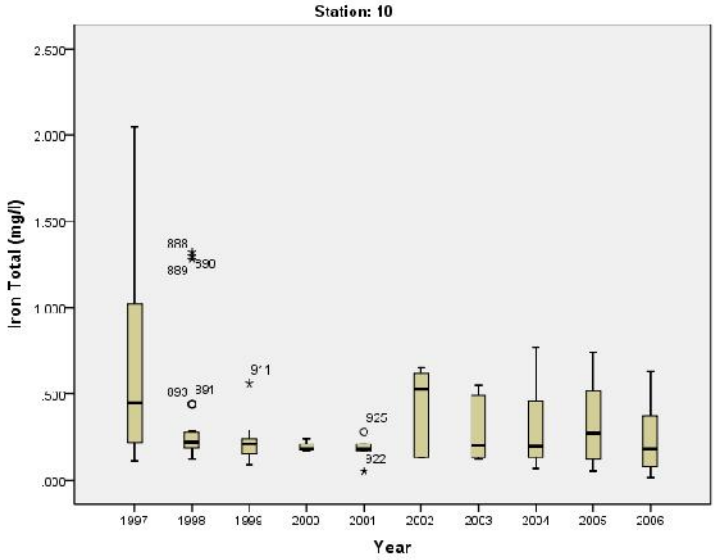

Station: 9
Copper Dissolved (mg/l)
1.4000E-2
1.2000E-2
1.0000E-2
8.0000E-3
6.0000E-3
4.0000E-3
2.0000E-3
0.0000E0
744
743
750
706
704
777
Year
1997
1998
1999
2000
2001
2002
2003

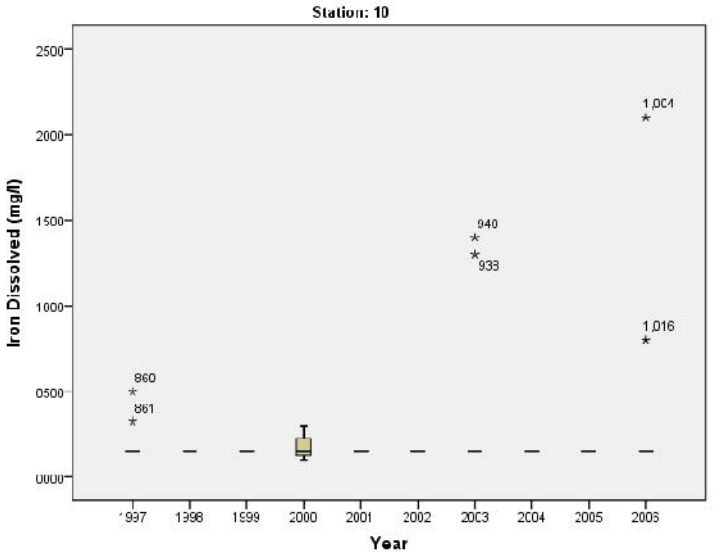

Station: 10
Copper Total (mg/l)
.0600
.0500
.0400
.0300
.0200
.0000
905
904
906
865
863
864
908
911
888
890
889
989
993
973
970
1,004
1,006
Year
1998
1999
2000
2001
2002
2003
2004
2005
2006

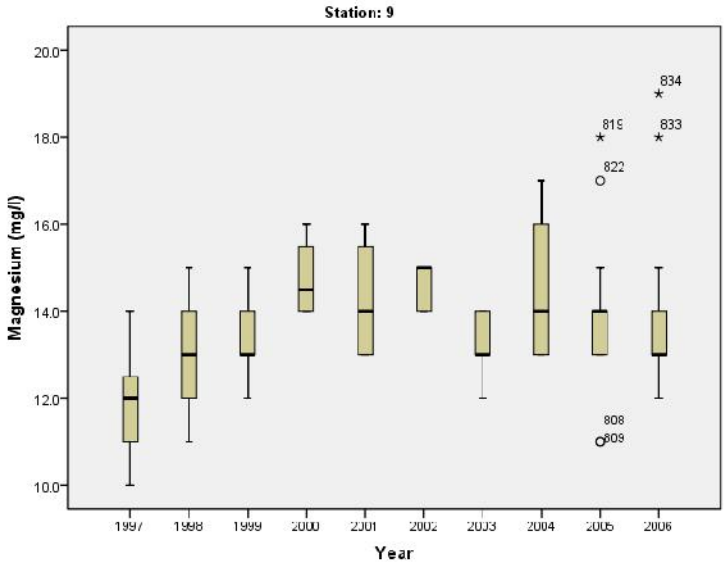

Station: 10
Copper Dissolved (mg/l)
1.2500E-2
1.0000E-2
7.5000E-3
5.0000E-3
2.5000E-3
0.0000E0
908
865
863
906
904
905
942
925
Year
1997
1998
1999
2000
2001
2002
2003
2005

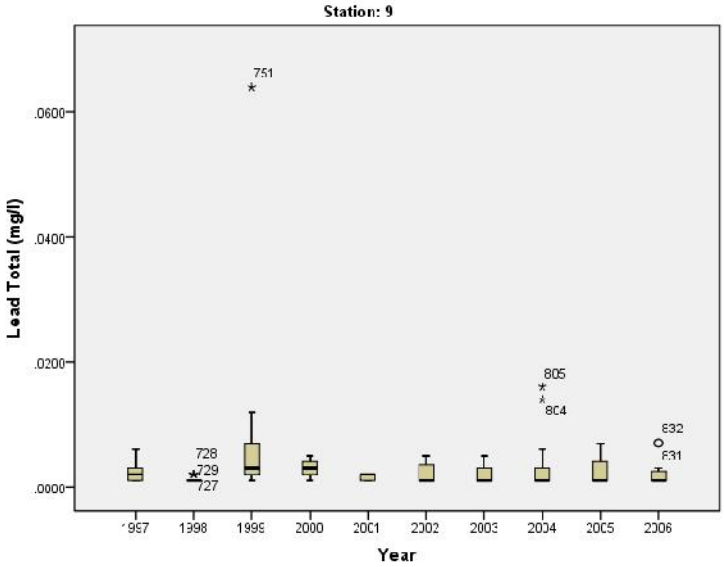

Station: 9
Iron Total (mg/l)
Year
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006

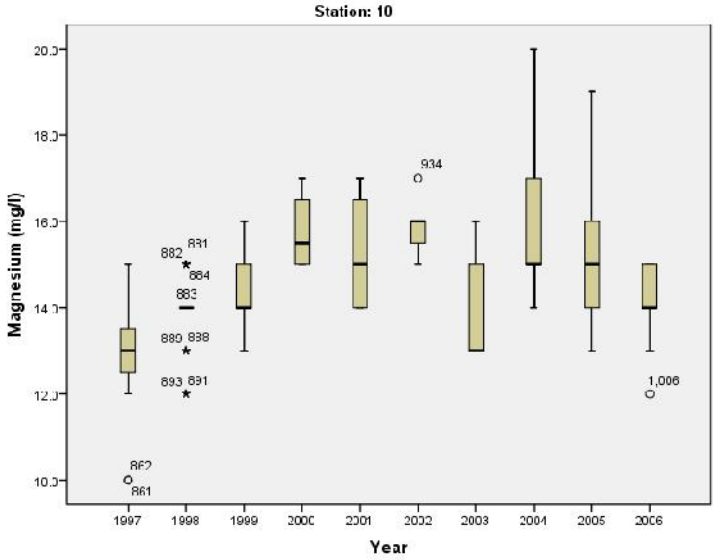

Station: 9
Iron Dissolved (mg/l)
Year
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006

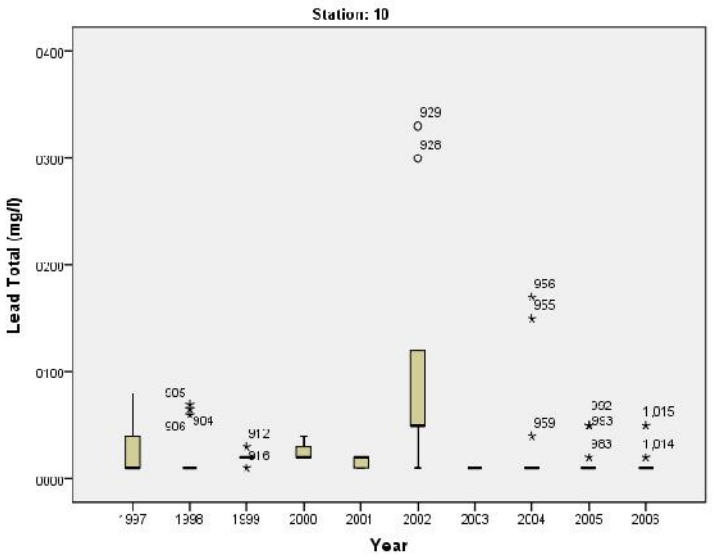

Station: 10
Iron Total (mg/l)
Year
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006

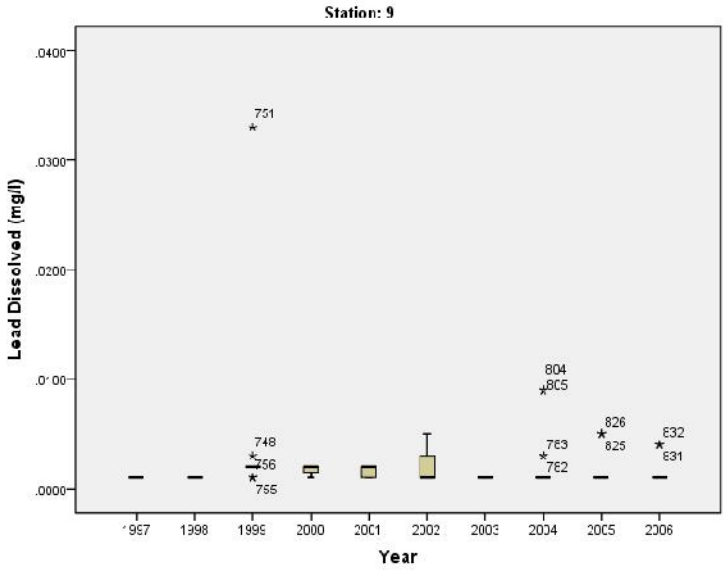

Station: 10
Iron Dissolved (mg/l)
Year
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006

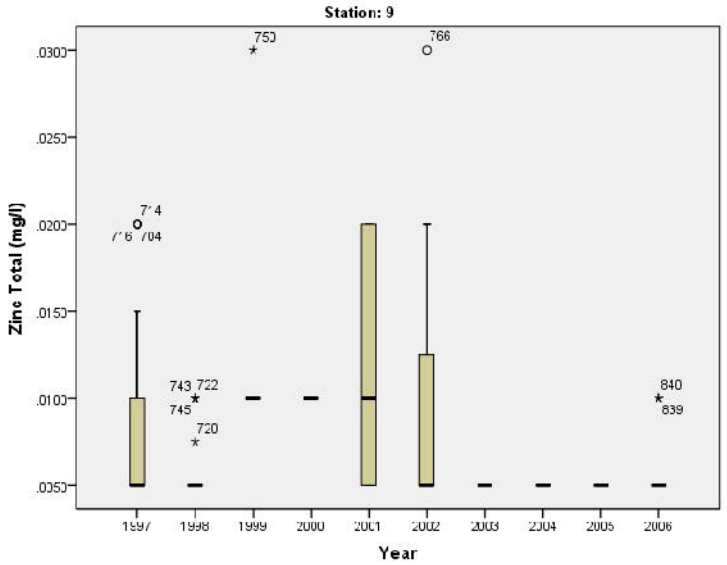

Station: 9
Magnesium (mg/l)
20.0
18.0
16.0
14.0
12.0
10.0
834
819
833
822
808
809
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

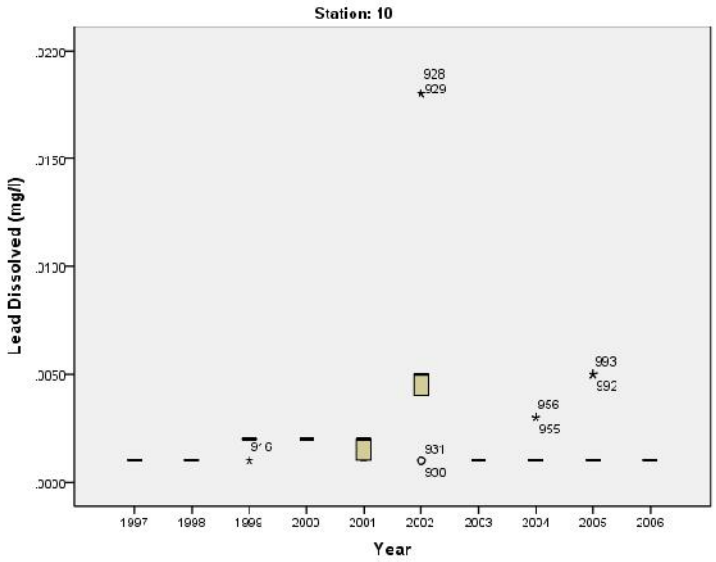

Station: 9
Lead Total (mg/l)
.0600
.0400
.0200
.0000
751
805
804
728
729
727
832
831
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

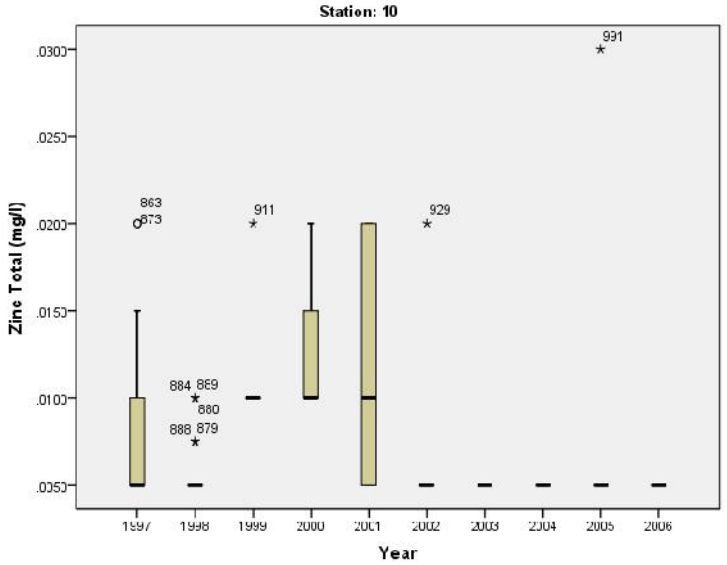

Station: 10
Magnesium (mg/l)
20.0
18.0
16.0
14.0
12.0
10.0
934
882
881
884
883
880
888
893
891
862
861
1,006
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

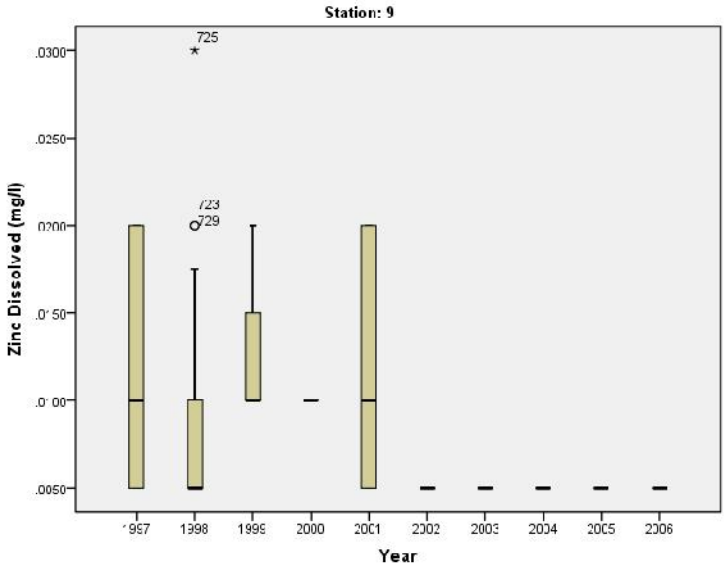

Station: 10
Lead Total (mg/l)
0400
0300
0200
0100
0000
929
928
956
955
905
904
912
916
959
963
1,015
1,014
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year

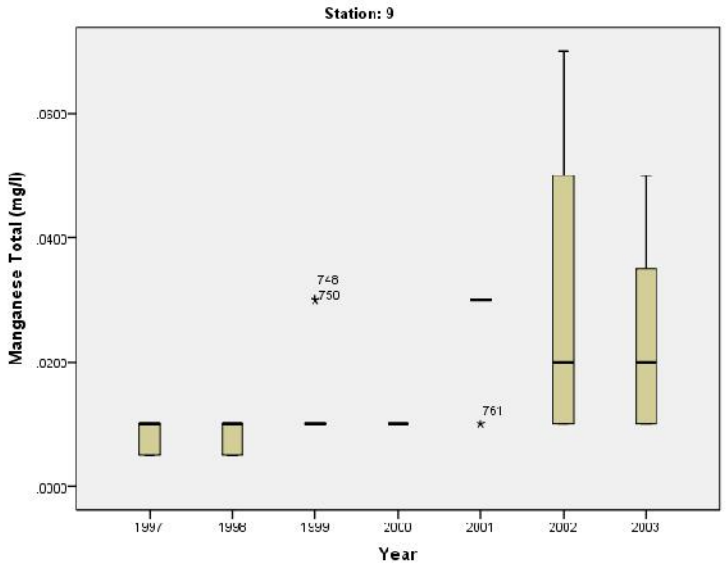

Station: 9
Lead Dissolved (mg/l)
Year

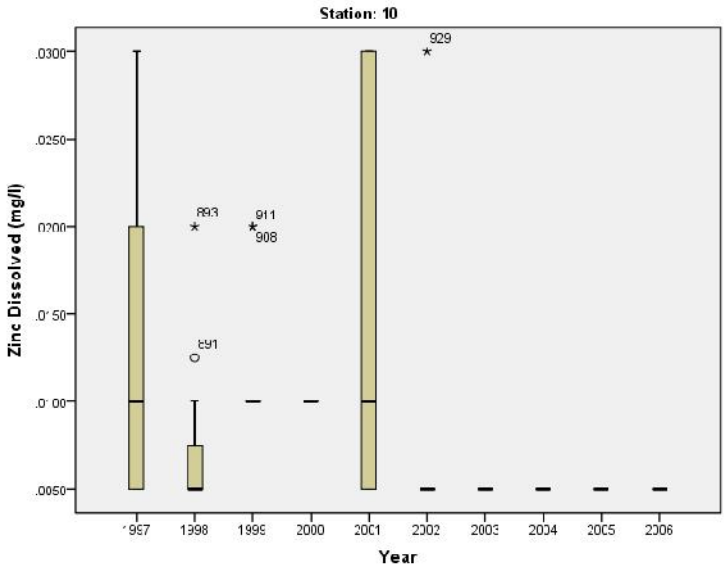

Station: 9
Zinc Total (mg/l)
Year

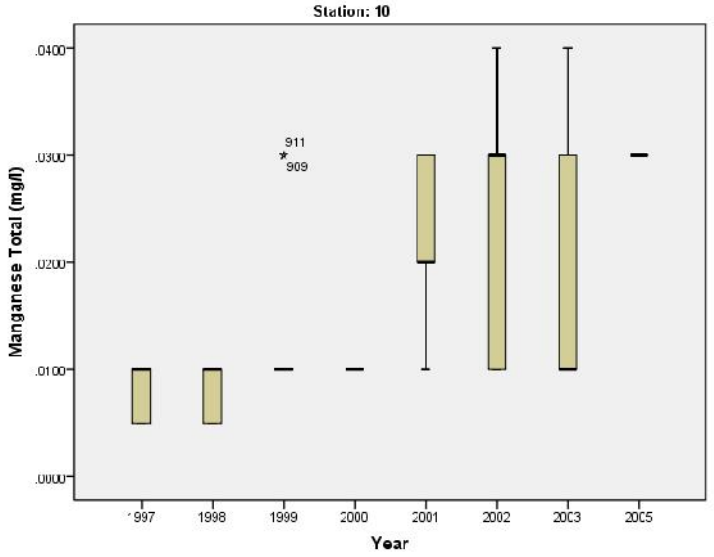

Station: 10
Lead Dissolved (mg/l)
Year

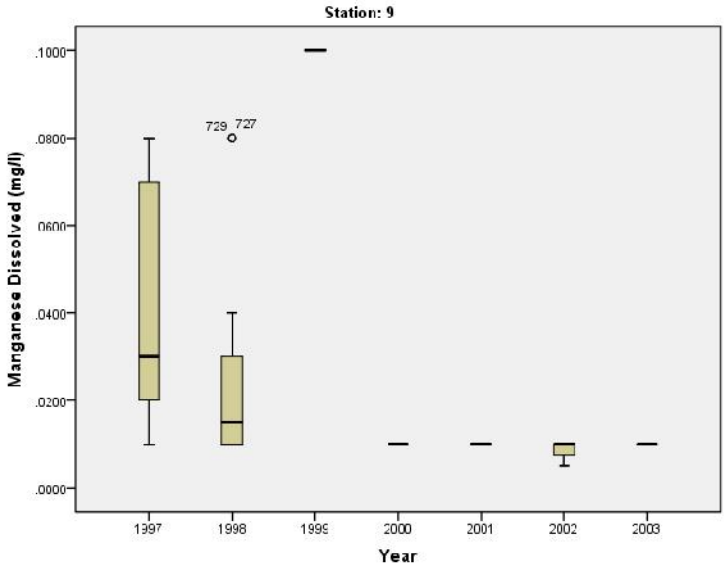

Station: 10
Zinc Total (mg/l)
Year

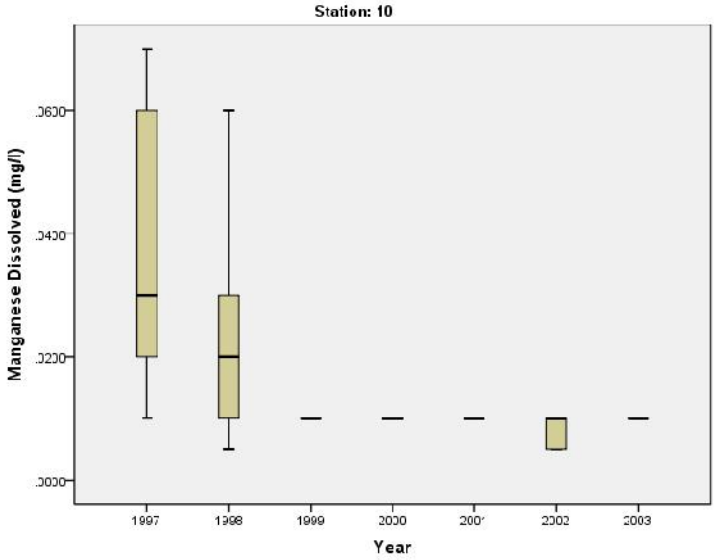

Station: 9
Zinc Dissolved (mg/l)
.0300
.0250
.0200
.0150
.0100
.0050
725
723
729
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year


Station: 9
Manganese Total (mg/l)
.0600
.0400
.0200
.0000
748
750
761
1997
1998
1999
2000
2001
2002
2003
Year


Station: 10
Zinc Dissolved (mg/l)
.0300
.0250
.0200
.0150
.0100
.0050
929
893
911
908
891
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year


Station: 10
Manganese Total (mg/l)
.0400
.0300
.0200
.0100
.0000
911
909
1997
1998
1999
2000
2001
2002
2003
2005
Year


Station: 9
Manganese Dissolved (mg/l)
.1000
.0800
.0600
.0400
.0200
.0000
729
727
1997
1998
1999
2000
2001
2002
2003
Year


Station: 10
Manganese Dissolved (mg/l)
.0600
.0400
.0200
.0000
1997
1998
1999
2000
2001
2002
2003
Year

### *6.1.5 Flow Adjusted Trends*

Correlation analyses (**Table 6-8**) showed that parameters including conductivity, turbidity, alkalinity as bicarbonate, total arsenic, chloride, sodium, sulfate, and total suspended sediment were generally correlated to flow (**Section 6.1.3**). Turbidity and TSS tend to increase with discharge (i.e. release), and conductivity, alkalinity as bicarbonate, total arsenic, chloride, sodium, and sulfate tend to decrease with discharge (i.e. dilution).

Trend analyses of raw data showed increases in these parameters from 1997-2006. However, flow also tended to decrease over the same time period. Because of lower flows during the monitoring period, increasing trends may potentially be related primarily to changes in flow rather than physical watershed processes driving the supply or loading.

To account for the effects of flow, parameters were adjusted and normalized to account for the influence of flow. Parameters that dilute with increased discharge were modeled with an inverse function, and parameters that increase (i.e. TSS, turbidity) were modeled with a linear function. The residuals of the individual station/parameter regressions were then tested for trends over time. This analysis removed the release or dilution effects, and allowed for testing of trends independent of flow.

Results of the flow adjusted analysis showed that conductivity had an increasing trend at stations 2, 6, 8, 9, and 10. The raw data showed increasing trends at all stations in the network. Trends in flow appeared to explain corresponding trends in conductivity at half of the monitoring stations.

Turbidity decreased at station 8, and increased at station 3. Recall that those stations with statistically significant decreasing trends in raw turbidity data included stations 2, 4, 5, 6, 7, 8, 9 and 10. These decreasing trends in raw turbidity data appear to be related to changing flow conditions, and after accounting for flow effects, turbidity generally appeared to either decreasing or unchanged. Station 3 was the exception and showed an increasing trend with flow adjusted turbidity.

Based on flow adjusted data, total suspended sediment increased at stations 3 and 5. Raw total suspended sediment decreased at stations 4, 5, 9, and 10.

Alkalinity as bicarbonate decreased at station 1, but increased at station 2 using flow adjusted data. No other stations showed trends in alkalinity as bicarbonate. Using raw data, alkalinity as bicarbonate showed a statistically significant increase at all ten stations with the exception of stations 5 and 6. Decreasing trends in flow thus appeared to explain increasing trends in raw alkalinity for most monitoring stations.

Flow adjusted datasets showed total arsenic and chloride increased at stations 2, 5, 6, 7, 8, 9, and 10. Raw data showed statistically increasing concentrations at all stations in the network for total arsenic and chloride. With the exception of stations 1, 3, and 4 accounting for the effects of flow did not explain the increasing trends in sodium and total arsenic.

Arsenic concentration (as well as several other parameters) did not show uniform, linear monotonic trends over the monitoring period. Instead, concentration tended to change over the period from 1997-2001/2002, and subsequently stabilize or decrease slightly. This non-linear response did not lend itself to fitting a trend line/slope in order to provide interpretation such as “arsenic increased an average of 10%/year over the monitoring period.”

A simplified approach to characterizing magnitude of change was undertaken. The mean values of the first 3 and last 3 years of monitoring data were compared (**Table 6-9**). This provided a % change

between the endpoints of the monitoring period. Because the results depend on the endpoints selected rather than an averaging or smoothing function, the calculated magnitude of change can be misleading. For example, 1997 was the 5th greatest peak discharge since 1952 for the Missouri at Great Falls. Using analyte results from 1997 as the baseline to calculate magnitude of change could be expected to show bias especially for raw data. Bias might remain using flow-adjusted data, although it would be reduced. Despite limitations, this approach does provide a means to present information on the magnitude of change during the monitoring period.

Time-series trends in raw or flow-adjusted data which were statistically significant (**Tables 6-4 to 6-8**) were used to flag values in the following magnitude of change table (**Table 6-9**). This is intended to guide the reader to analytes that showed statistically significant trends in the time series analyses. Note that the reported magnitude of change may have suggested a large change but was not statistically significant using the time series analysis. This resulted in part from underlying high variability in the data. Also, as previously noted the magnitude of change was calculated using the average of 3-yr endpoints and excluded four years of data in the middle of the monitoring cycle.

Magnitude values in **Table 6-9** are intended to provide a simple quantitative perspective of relative change. Trend analyses of preceding sections should be relied upon for a robust analysis or interpretation of shifts in water quality.

Alkalinity as CaCO3 showed changes of 7-21%, with the larger changes at the upstream stations. Total and dissolved arsenic increased from 29 to 59%. When adjusted for the effects of flow changes in total arsenic were more modest, ranging from 15 to 24% for those stations with statistically significant trends. Raw data for alkalinity-bicarbonate was similar to alkalinity-CaCO3, and adjusted for flow effects, the only the upper two stations showed changes from -5% to 11%. Cadmium, copper, manganese, and lead analytes were generally below detection limits and are not reported for this analysis. Iron showed a decrease of 29% when adjusted for flow.

Calcium showed increases ranging from 6 to 11% for stations with significant trends. Changes in chloride ranged from 32 to 49%. Adjusting for flow reduced this apparent change to 13-24% at the lower 5 stations. Changes in dissolved oxygen were generally small (i.e. <10%), and the only statistically significant trend was in dissolved oxygen saturation (-7%) at station 10. Flow declined at all stations from 25 to 60%.

Changes in magnesium associated with statistically significant trends were a decrease of 28% at station 1, and increases of 10 and 11% at the lowermost stations. Total nitrate-nitrite decreased 18% at station 6, and 28% and 26% at stations 8 and 10. Total persulfate nitrogen values are not reported because sampling for this parameter did not begin until 1999. Field and lab pH showed less than 2% change. Field pH showed statistically significant trends at stations 9 and 10, but the percent change value was 0%. This is an artifact of applying 3-yr endpoint averages to small changes, and comparing them to non-parametric analyses employing the entire dataset.

Dissolved ortho-phosphorus showed an increase of 71% at the uppermost station, and decreases of 33 and 30% at stations 5 and 6. None of the apparent changes in total phosphorus (-35% to 169%) were statistically significant. Potassium, sodium, and total dissolved solids were similar with increases ranging from 7 to 32%. Adjusted for the effects of flow, the lower three stations showed statistically significant trends in sodium. Percent change in sodium ranged from 8 to 19% at these stations.

Sulfate generally showed increases for raw data ranging from 13 to 17%. Adjusted for the effects of flow, these changes were not statistically significant and were less than 8%. Temperature tended to show a decrease of 14 to 40% using the 3-yr end point averages. Trends in temperature were significant only at

stations 1 and 3. Total suspended sediment showed changes in magnitude of -14 to -55% for statistically significant trends at stations 4,5, 9 and 10. Adjusted for the effects of flow, TSS showed an increase of 224% at station 3, and 2% at station 5. The apparent high value for station three is largely an artifact of two outlier data points in 2005 and 2006. Turbidity raw data showed a decrease at most stations ranging from -37 to -42%. Station 4 increased 4%. Adjusted for the effects of flow, trends in turbidity were present at stations 2 and 3. Corresponding changes in 3-yr endpoint values were -36% and -14%, respectively. Specific conductivity increased at all stations from 6 to 29% for raw data. Adjusted for the effects of flow, conductivity increased from 5 to16% at stations 2, 6, 8, 9 and 10.

**Table 6-8. Flow Adjusted Trend Analyses**

| Parameter | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| uS_cm_Z | Correlation Coefficient | -.072 | .199** | .036 | .142 | .122 | .198* | .144 | .327** | .277** | .247** |
| | Sig. (2-tailed) | .349 | .008 | .639 | .062 | .114 | .013 | .063 | .000 | .001 | .001 |
| | N | 78 | 82 | 81 | 80 | 78 | 73 | 78 | 80 | 72 | 79 |
| Turbidity_Z | Correlation Coefficient | .094 | -.180* | .284** | -.038 | .133 | -.189* | -.119 | -.165* | .107 | .098 |
| | Sig. (2-tailed) | .225 | .017 | .000 | .619 | .084 | .018 | .125 | .030 | .181 | .203 |
| | N | 78 | 82 | 81 | 81 | 78 | 73 | 78 | 80 | 73 | 78 |
| Bicarbonate_Z | Correlation Coefficient | -.314** | .154* | -.040 | .065 | .022 | .034 | -.020 | .122 | .043 | .063 |
| | Sig. (2-tailed) | .000 | .043 | .604 | .394 | .775 | .669 | .795 | .110 | .595 | .422 |
| | N | 77 | 80 | 80 | 80 | 77 | 72 | 76 | 79 | 70 | 76 |
| Arsenic_Total_Z | Correlation Coefficient | .022 | .172* | .011 | .093 | .171* | .348** | .272** | .476** | .360** | .384** |
| | Sig. (2-tailed) | .779 | .022 | .880 | .221 | .027 | .000 | .000 | .000 | .000 | .000 |
| | N | 78 | 82 | 81 | 81 | 78 | 73 | 78 | 80 | 72 | 79 |
| Chloride_Z | Correlation Coefficient | -.012 | .151* | .049 | .103 | .162* | .200* | .186* | .287** | .243** | .284** |
| | Sig. (2-tailed) | .877 | .047 | .517 | .173 | .036 | .012 | .016 | .000 | .003 | .000 |
| | N | 78 | 81 | 81 | 81 | 78 | 73 | 78 | 80 | 71 | 77 |
| Sodium_Z | Correlation Coefficient | -.131 | .151 | .009 | .076 | .157 | .163 | .095 | .265** | .201* | .241** |
| | Sig. (2-tailed) | .120 | .071 | .912 | .360 | .063 | .053 | .258 | .001 | .013 | .002 |
| | N | 66 | 67 | 66 | 67 | 66 | 66 | 67 | 68 | 72 | 78 |
| Sulfate_Z | Correlation Coefficient | -.044 | -.009 | -.044 | .017 | .060 | .065 | .057 | .139 | .141 | .130 |
| | Sig. (2-tailed) | .569 | .903 | .564 | .823 | .440 | .415 | .458 | .068 | .081 | .094 |
| | N | 78 | 81 | 80 | 81 | 78 | 73 | 78 | 80 | 71 | 77 |
| TSS_Z | Correlation Coefficient | .049 | -.037 | .228** | -.148 | .161* | -.085 | -.096 | -.032 | .042 | .025 |
| | Sig. (2-tailed) | .529 | .624 | .003 | .050 | .037 | .286 | .214 | .678 | .602 | .751 |
| | N | 78 | 81 | 80 | 81 | 78 | 73 | 78 | 80 | 71 | 77 |

**Table 6-9. Percent (%) Change in Analyte Concentration using Endpoint 3-Yr Averages**

| Analyte | Station | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Alkalinity as CaCO3 | 19% | 21% | 11% | 12% | 6% | 7% | 8% | 8% | 8% | 7% |
| Arsenic Dissolved | 29% | 40% | 39% | 36% | 59% | 46% | 45% | 45% | 46% | 41% |
| Arsenic Total | 29% | 33% | 36% | 36% | 56% | 45% | 38% | 39% | 49% | 43% |
| Arsenic_Total_Z | 3% | 20% | 8% | 16% | 34% | 23% | 15% | 32% | 18% | 24% |
| Bicarbonate | 19% | 21% | 12% | 12% | 5% | 7% | 8% | 8% | 7% | 7% |
| Bicarbonate_Z | -5% | 11% | 1% | 2% | 5% | 3% | 0% | 6% | 1% | 2% |
| Calcium | 11% | 9% | 6% | 9% | 3% | 6% | 6% | 7% | 7% | 9% |
| Chloride | 46% | 49% | 44% | 41% | 34% | 36% | 34% | 32% | 41% | 39% |
| Chloride_Z | 6% | 22% | 13% | 16% | 24% | 21% | 15% | 25% | 13% | 22% |
| DO_mgl | 4% | 2% | 11% | 7% | 3% | 10% | -2% | 2% | 5% | 2% |
| DO_Sat | -3% | -2% | 1% | 3% | -3% | 5% | -7% | -3% | -1% | -7% |
| Flow | -35% | -38% | -32% | -29% | -32% | -44% | -46% | -60% | -43% | -25% |
| Iron Dissolved | | | | | | | | | 2% | 16% |
| Iron Total | | | | | | | | | -29% | -37% |
| Magnesium | -28% | 1% | -1% | 3% | -1% | 4% | 4% | 5% | 11% | 10% |
| Nitrate Nitrite Total | 7% | -5% | 32% | 18% | 13% | -18% | -28% | -38% | -35% | -26% |
| PH_lab | 0% | 1% | -1% | 1% | -1% | -1% | 0% | 0% | 0% | -1% |
| pH_field | 0% | 1% | -1% | 1% | 0% | 1% | 1% | 2% | 0% | 0% |
| Phosphorus Ortho Dissolved | 71% | 26% | 20% | 15% | -33% | -30% | -31% | -28% | -52% | -32% |
| Phosphorus Total | 169% | 78% | 53% | 41% | -32% | -15% | -3% | -14% | -35% | -27% |
| Potassium | 30% | 32% | 32% | 29% | 23% | 25% | 26% | 26% | 14% | 11% |
| Sodium | 26% | 29% | 28% | 24% | 22% | 21% | 22% | 23% | 25% | 23% |
| Sodium_Z | -2% | 18% | 6% | 10% | 14% | 14% | 10% | 19% | 8% | 13% |
| Sulfate | 17% | 14% | 7% | 13% | 2% | 11% | 13% | 11% | 17% | 16% |
| Sulfate_Z | 0% | 1% | 0% | 1% | 2% | 7% | 5% | 7% | 4% | 4% |
| Temp_C | -27% | -17% | -40% | -14% | -20% | -21% | -20% | -19% | -19% | -18% |

**Table 6-9. Percent (%) Change in Analyte Concentration using Endpoint 3-Yr Averages**

| Analyte | Station | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Total Dissolved Solids | 23% | 26% | 21% | 18% | 7% | 10% | 12% | 11% | 12% | 11% |
| Total Suspended Sediment | -23% | -8% | -3% | -14% | -40% | -26% | -26% | -36% | -40% | -55% |
| TSS_Z | 14% | -12% | 224% | 3% | 2% | -26% | -20% | -24% | 27% | 9% |
| Turbidity | -14% | -42% | -56% | 4% | -34% | -52% | -40% | -39% | -37% | -39% |
| Turbidity_Z | 24% | -36% | -14% | 33% | -6% | -44% | -18% | -12% | 43% | 27% |
| Specific Conductivity | 26% | 29% | 19% | 19% | 6% | 11% | 12% | 11% | 11% | 11% |
| Specific Conductivity_Z | -2% | 16% | 3% | 7% | 4% | 8% | 5% | 11% | 5% | 5% |

Flow adjusted sodium increased at stations 8, 9, and 10. Raw data for sodium showed statistically significant increases at all stations. Flow appeared to account for some but not all observed increasing trends in sodium.

Sulfate did not show any statistically significant trends when adjusted for flow effects. Raw sulfate data showed statistically significant increasing trends for 7 of ten stations, with the exception of stations 3, 5 and 6. Flow appeared to account for observed trends in raw sulfate data.

Flow adjusted data showed total suspended sediment increased at stations 3 and 5. Raw data showed total suspended sediment increased at stations 5, 6, 9, and 10.

Overall, the effects of decreasing flow from 1997-2006 appeared to account for some of the observed trends in raw data for turbidity, alkalinity as bicarbonate, sodium, sulfate, and total suspended sediment. Changes in conductivity were explained by flow at half the stations. Decreasing flow did not generally account for changes in total arsenic or chloride.

The absolute in-stream concentrations for many parameter/stations increased during the monitoring period. Changes in flow rather than in loading, supply, or physical watershed processes (other than runoff) appeared to be driving concentrations of many of these parameters. Notably, chloride and total arsenic tended to show persistent increasing trends even after accounting for flow effects.

Adjusting for flow effects can assist in interpretation of shifts in water quality. However, it should be noted that changes in flow regime may not account for a variety of other factors. Adjusting for flow if another covariate is present could actually mask underlying effects. For example, if decreases in flow over the monitoring period were also associated with increasing geothermal activity (i.e. sources of arsenic and chloride) in Yellowstone Park, elevated concentrations in arsenic and chloride might be attributed to decreasing flow, rather than increases in loading. Other factors associated with changes in runoff volume and timing such as contributing source area for runoff, changes in groundwater contribution, etc. potentially each play a role. Adjusting for flow effects assists with interpretation of water quality, but does not explain all potential factors.

A review of water quality literature in Yellowstone National Park (YNP) suggests that increased hydrothermal loading of arsenic and sodium did not likely explain observed trends in either raw or flow-adjusted sodium or total arsenic concentrations. Relying on data from 1982 to 2001, Ingebritsen et al (2001) suggested that a declining trend in thermal chloride flux was characteristic of the Gibbon, Firehole, and Madison rivers. The Madison River at the gage near West Yellowstone, almost entirely reflects inputs from the Firehole and Gibbon Rivers. Water discharge from the Madison River accounts for only 9–10% of the total water discharge from YNP, but accounts for 46–47% of the chloride leaving the park (Hurwitz et al 2007).

Beginning in 2004, the Yellowstone caldera experienced accelerated uplift from 2006-2008 (Chang, et. al. 2010). However, the relative steadiness in long term chloride flux appears to be largely independent of volcanic activity such as uplift cycles (Ingebritsen 2001). Trend analyses reported in the literature did not directly address either sodium or arsenic trends. Chloride may be considered a proxy for hydrothermal activity, however.

Finally, it is worthwhile to note that with the exception of alkalinity as bicarbonate, the uppermost station #1 near the YNP (Madison at Hwy 287) did not show any statistically significant trends in flow adjusted conductivity, turbidity, alkalinity as bicarbonate, total arsenic, chloride, sodium, sulfate, and total suspended sediment. Observed trends in these parameters at downstream stations did not appear directly related to changes in the headwaters.

## 6.2 Periphyton Chlorophyll *a* and AFDW

Data were evaluated for normality using Shapiro-Wilk test. Mean annual Chlorophyll *a* and AFDW were not normally were generally not normally distributed at monitoring sites. High variability is characteristic of periphyton metrics and contributes to non-normal distributions within replicates. This variability also persists in replicates averaged to create annual means.

The non-parametric Kendall Tau test was used to evaluate whether statistically significant trends were present in annual mean periphyton metrics.

The non-parametric correlation coefficient shows the relative degree of association between year, and Chlorophyll *a*, and AFDW (**Table 6-10**). The Morony site showed a statistically significant decreasing trend for the Chlorophyll *a* (**Table 6-10**). The remaining locations showed no statistically significant trends for Chlorophyll *a*. None of the stations showed statistically significant trends for ash free dry weight.

**Table 6-10. Summary of Periphyton Trends**

| Site | ChlaA (mg/m2) | AFDW (mg/m2) |
|---|---|---|
| Hebgen | 0.071 | 0.214 |
| Ennis | 0.000 | -0.286 |
| Madison | 0.056 | 0.333 |
| Toston | -0.222 | 0.278 |
| Hauser | 0.000 | -0.333 |
| Holter | -0.56 | -0.111 |
| Morony | **-0.611*** | 0.167 |

*Statistically significant at the 5% level.

Box plots for Chlorophyll *a* and AFDW are shown in **Figures 1** through **14**. Box plots display the replicate data by year for individual monitoring locations. Replicate data provided the source for annual means used in the trend analysis discussed above.

Overall, the median values and variability of replicates (typically 10/year at each site) for Chlorophyll *a* and AFDW were fairly consistent from 1997-2006. The notable outlier is 2002, when AFDW was distinctly elevated at all sites, and Chlorophyll *a* was elevated at the Ennis site. The Madison site also had elevated AFDW in 2003 (**Figure 6**).

**Figure 1. Hebgen Chla (mg/m2)**

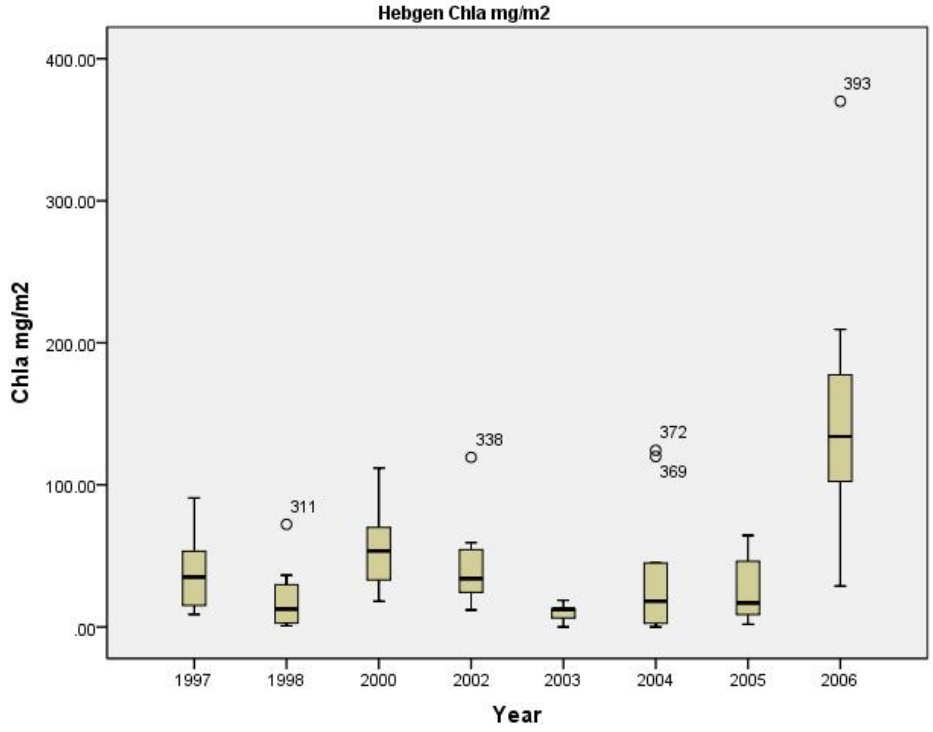



**Figure 2. Hebgen AFDW (mg/m2)**

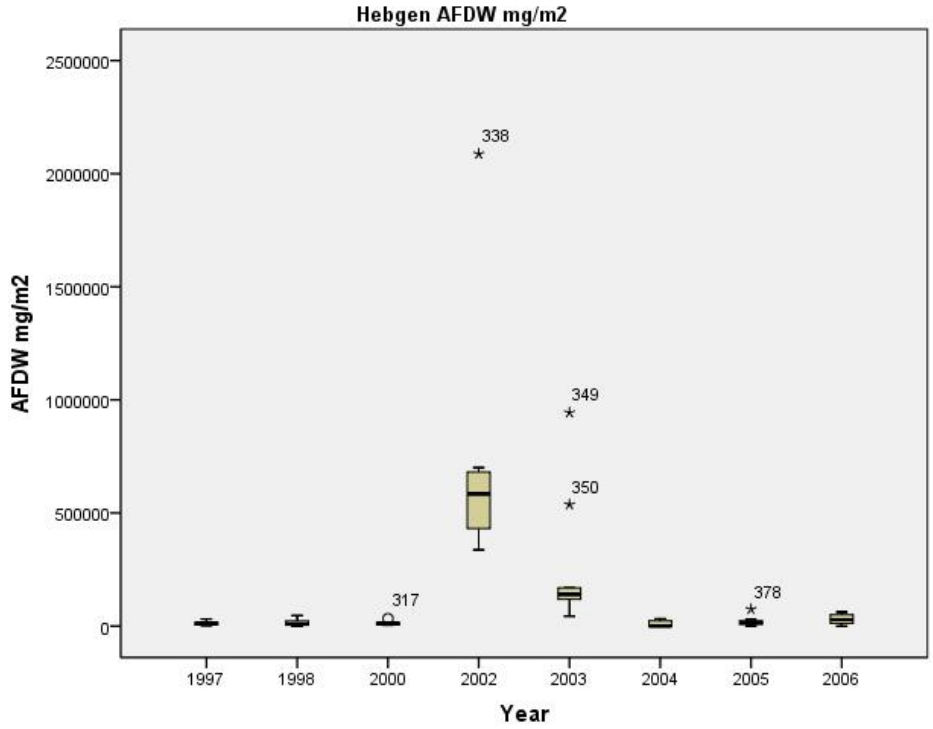


**Figure 3. Ennis Chla (mg/m2)**

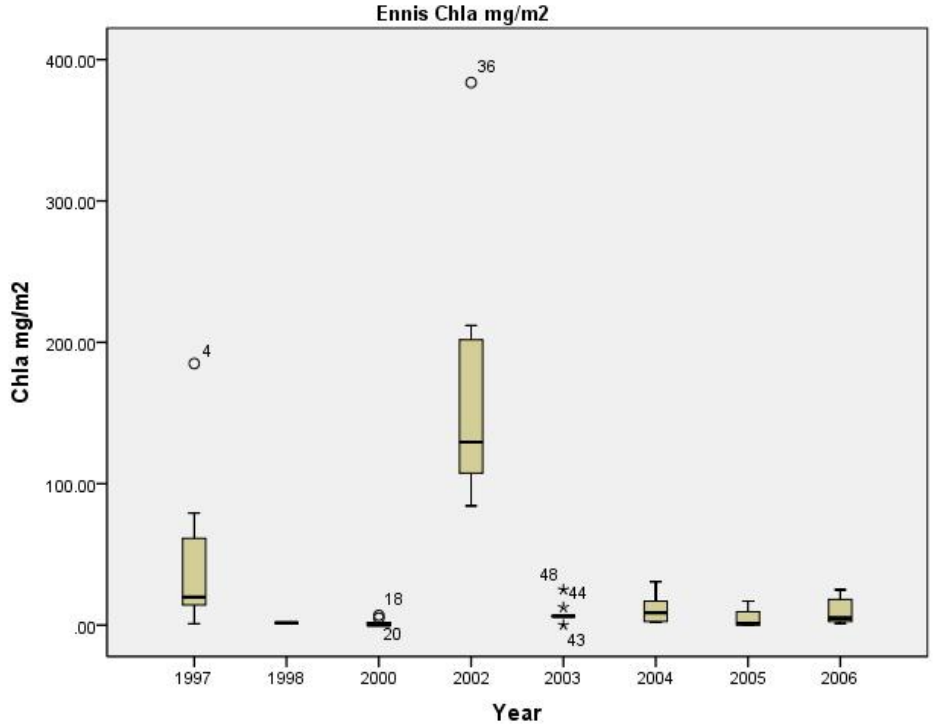



**Figure 4. Ennis AFDW (mg/m2)**

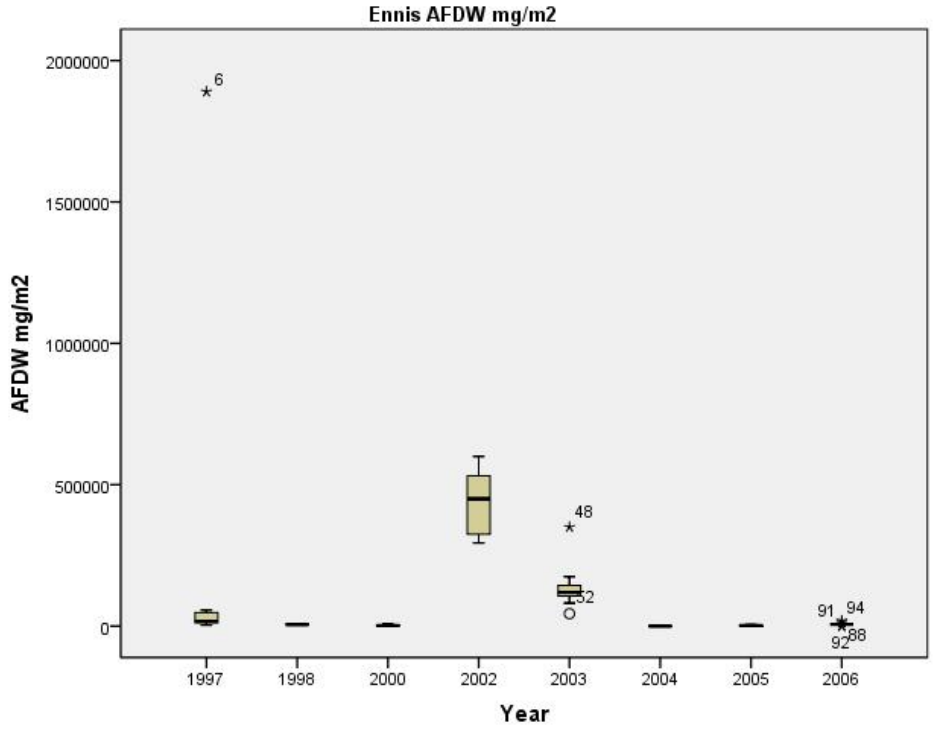


**Figure 5. Madison Chla (mg/m2)**

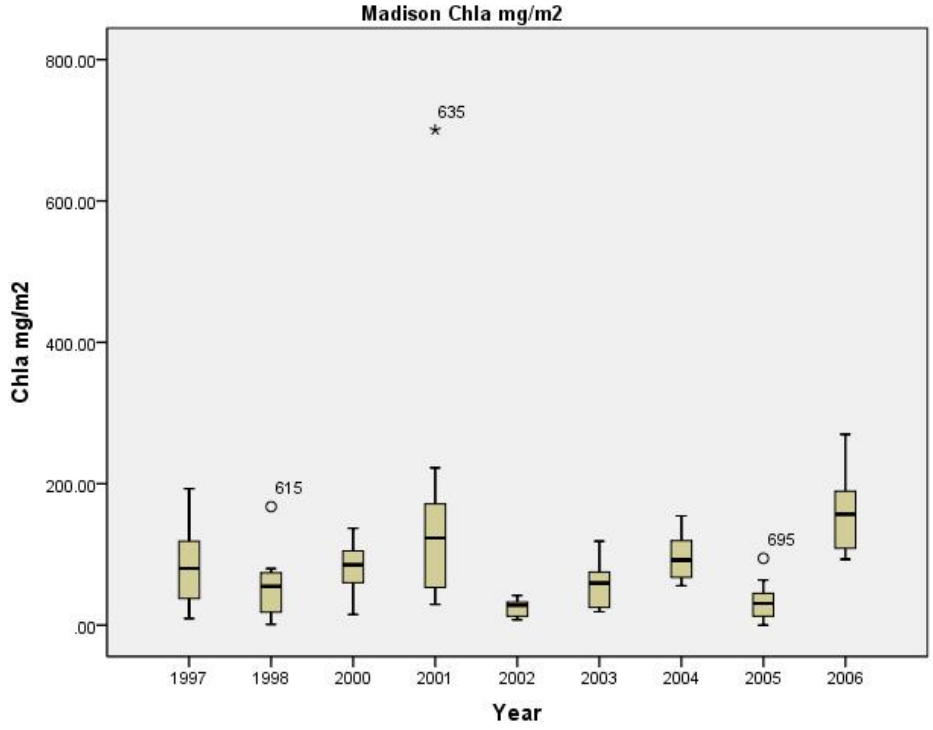



**Figure 6. Madison AFDW (mg/m2)**

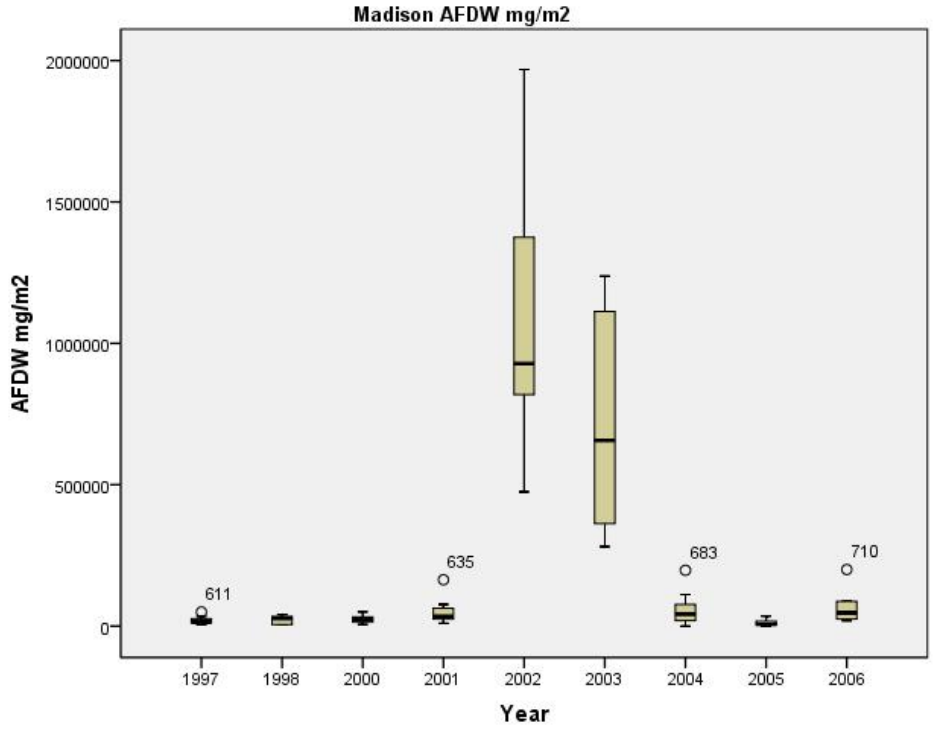


**Figure 7. Toston Chla (mg/m2)**

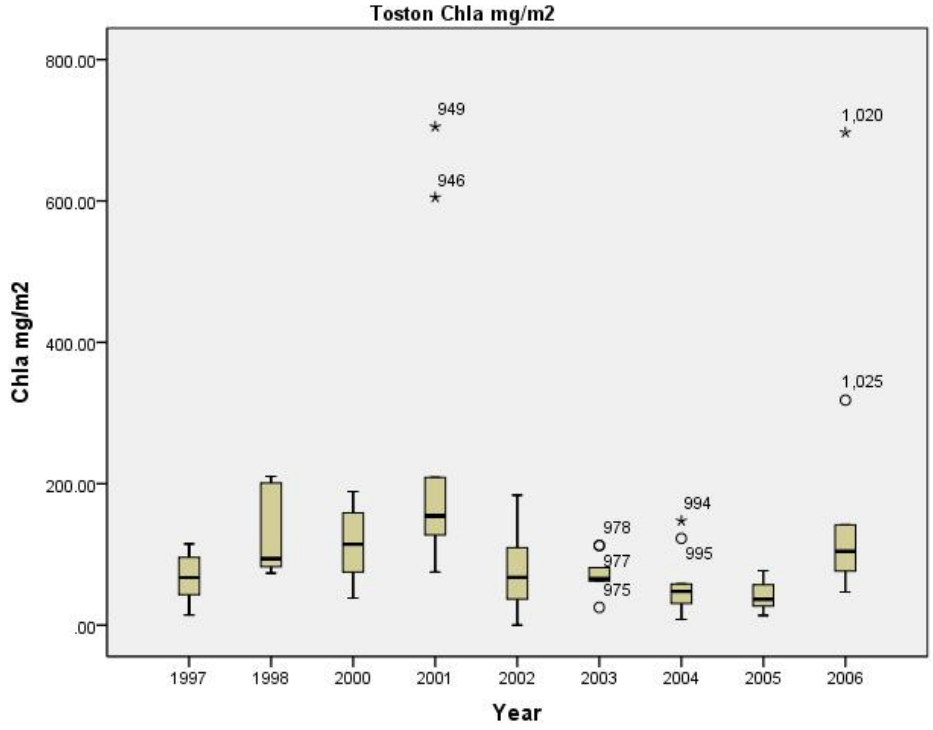



**Figure 8. Toston AFDW (mg/m2)**

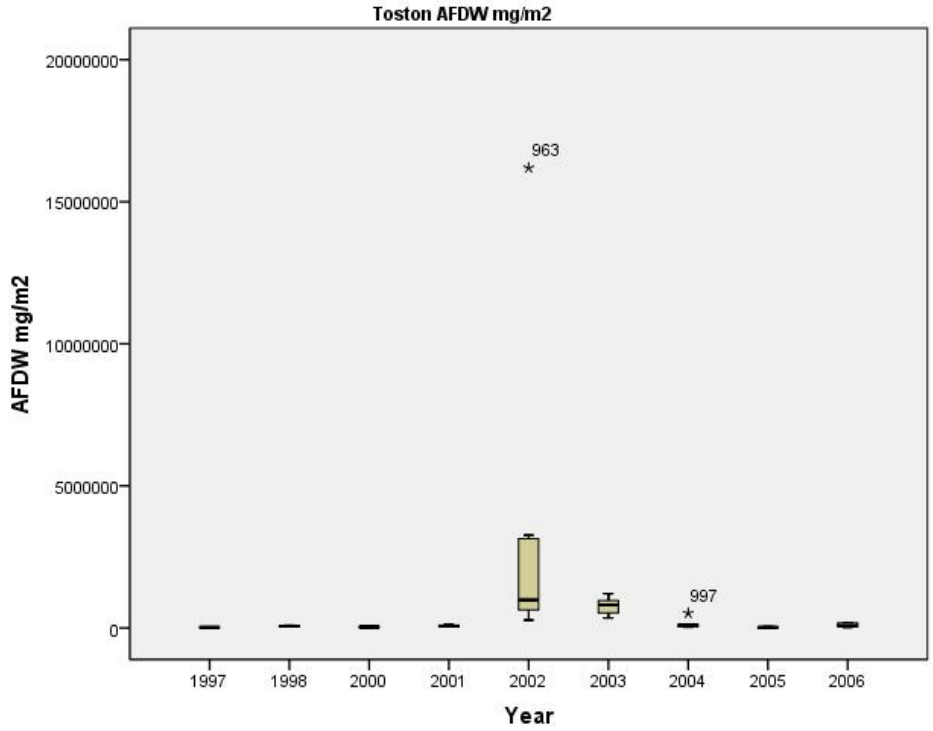


**Figure 9. Hauser Chla (mg/m2)**

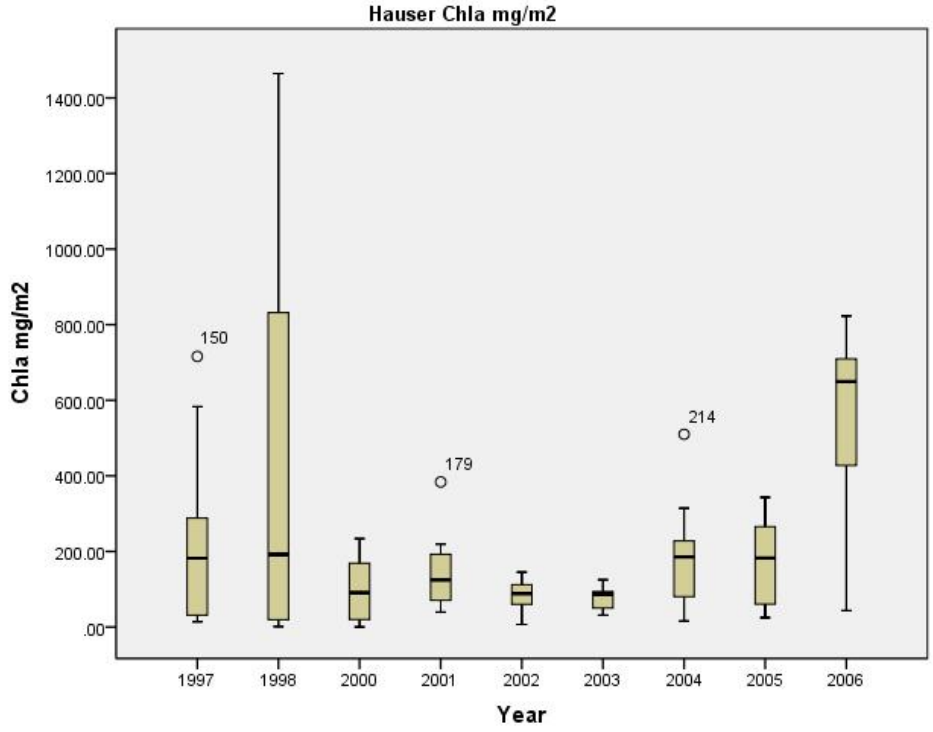



**Figure 10. Hauser AFDW (mg/m2)**

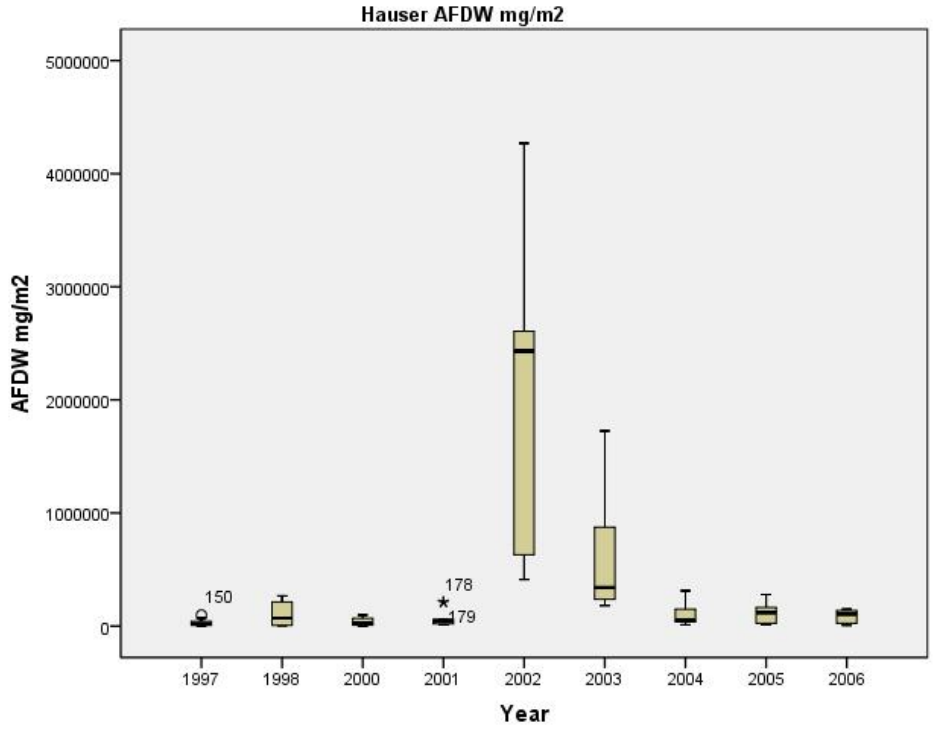


**Figure 11. Holter Chla (mg/m2)**

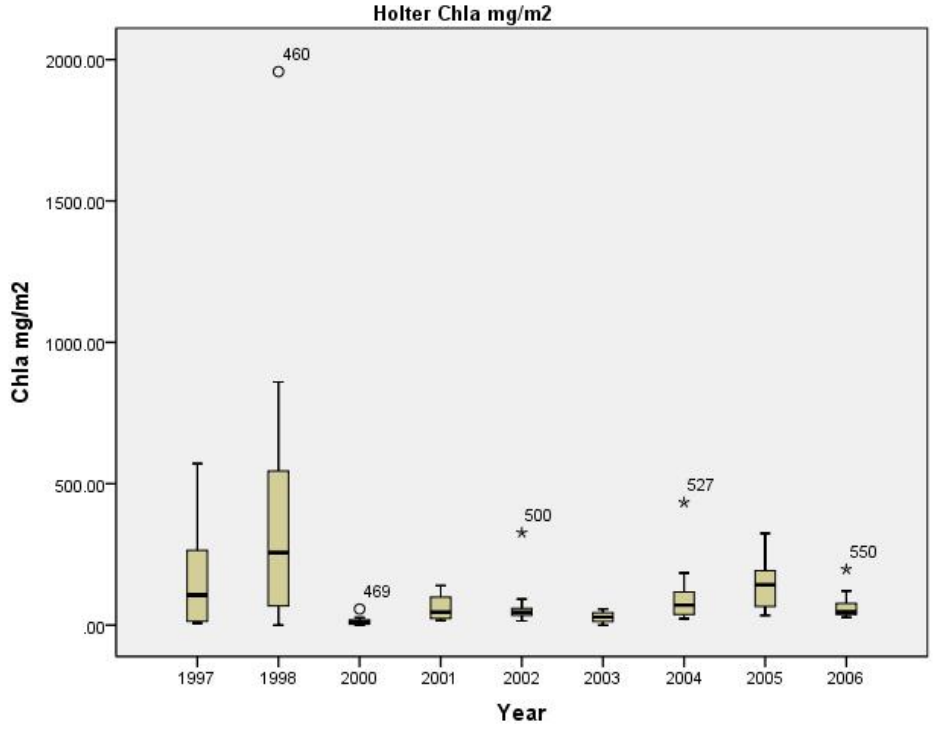



**Figure 12. Holter AFDW( mg/m2)**

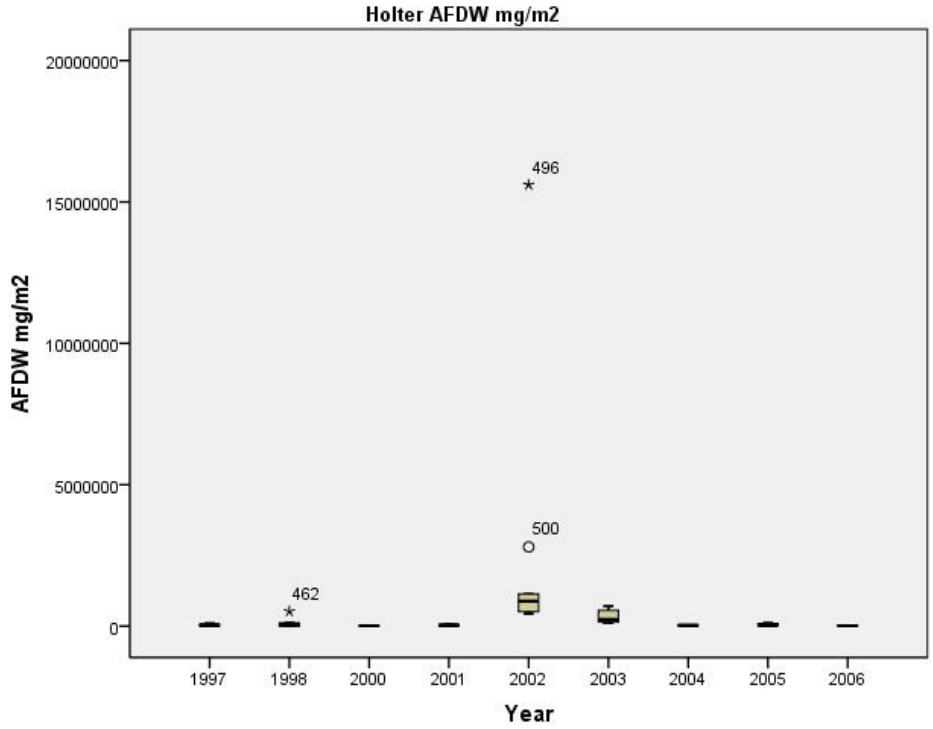


**Figure 13. Morony Chla (mg/m2)**

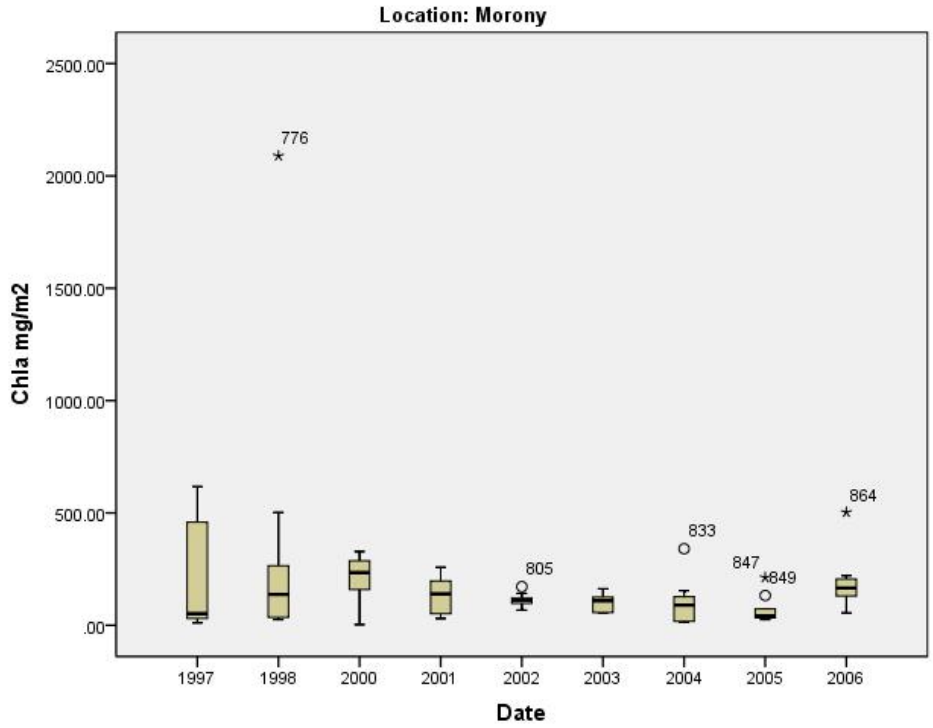
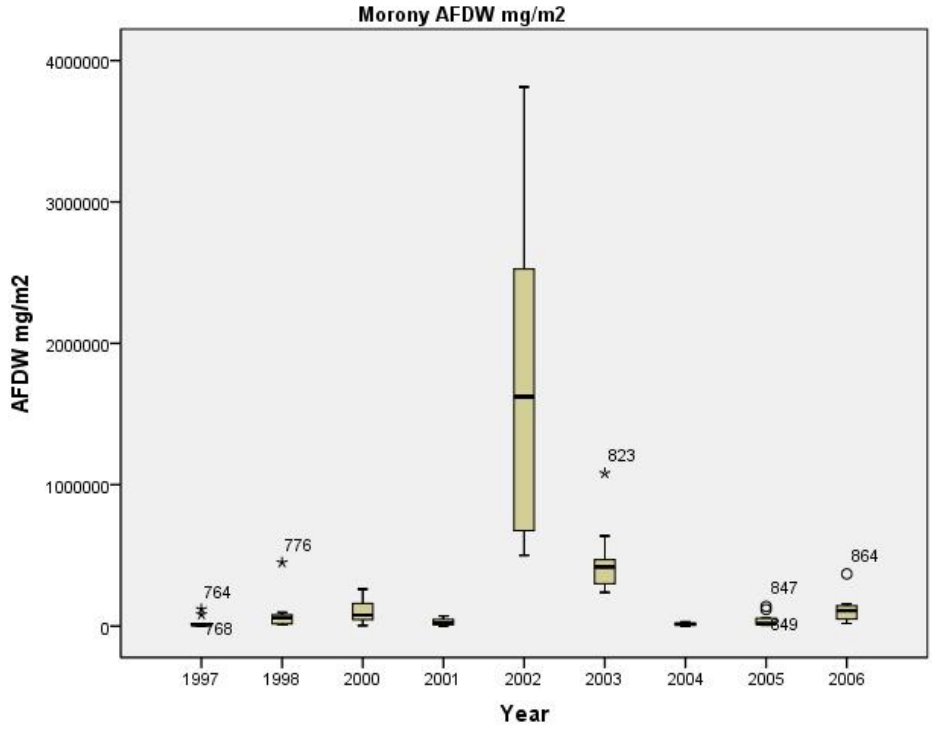



**Figure 14. Morony AFDW (mg/m2)**




The consistently elevated values for AFDW across all sites in 2002 suggested either a basin wide environmental factor, or potentially sampling bias. Note that Chlorophyll *a* was not similarly elevated at most sites in 2002.

Rhithron (2010) cited Montana guidelines for periphyton standing crop as "*problematic levels of AFDM (50,000 mg/m2) and the threshold of severe impairment with problematic levels of Chl-a (100 mg/m2).*"

These values formed the basis of the following discussion of 1997 to 2006 data provided by Rhithron (2010).

"*Overall impairment from excessive periphyton biomass can be determined through analysis of total Ash Free Dry Mass (AFDM) biomass of the attached periphyton as well as the Chlorophyll a (Chl-a) content in the sample. These two generally agree with each other but can at times differ in their determination of status for an individual site.*

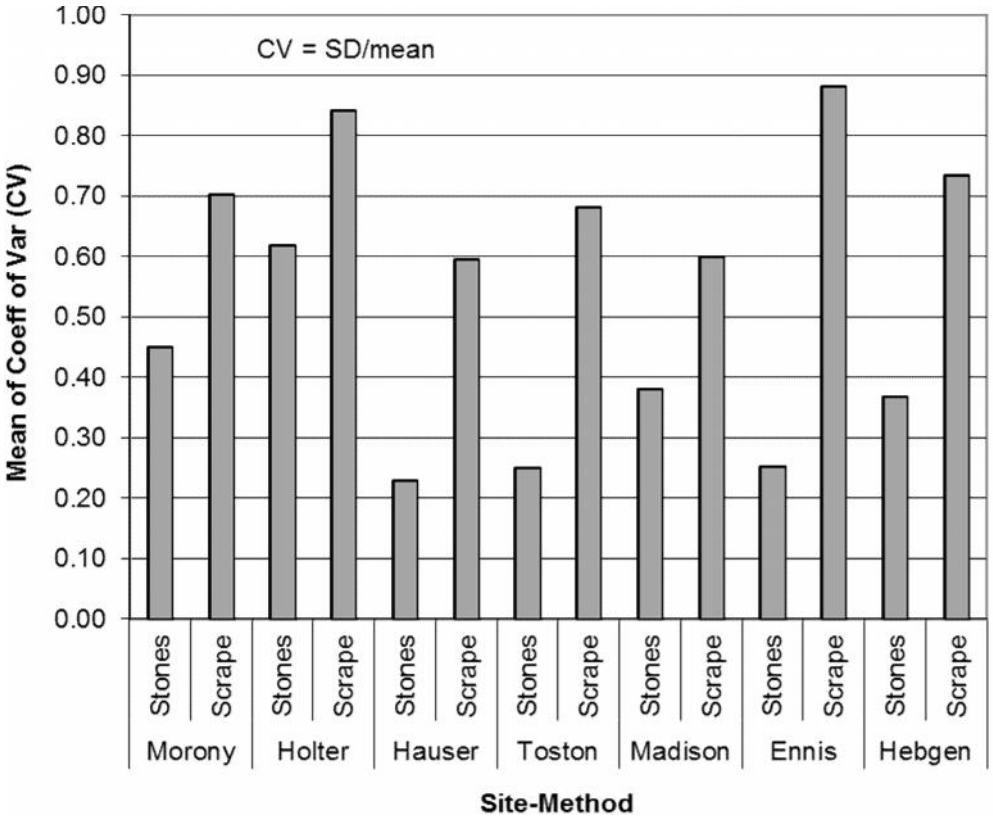
*The mean values of samples from all three sites on the Madison River fall below the values indicative of problematic levels of algae for 1997-2001. The sites on the Missouri River have mean values close to and slightly above these levels for the same time period. The years 2002 and 2003 have the highest AFDM biomass values for the ten year period at all sites, well above impairment levels. Mean Chl-a values though do not indicate impairment at any of the sites for these same two years. Values for both return back to the pre-2002 levels in the following three years."*

In summary, median ash free dry weight (or mass) indicated that with the exception of 2002 and 2003, these metrics were below levels indicating impairment at all stations. Median chlorophyll a was below the impairment threshold in all years from 1997-2006. The sole statistically significant trend was a tendency for chlorophyll a to decrease at the Morony site over this same time period.

In an effort to reduce sampling variability and observer bias, PPLM implemented an alternative method for sampling periphyton Chlorophyll *a* and AFDW in 2001. The conventional scrape method of periphyton sampling requires selecting a spatially representative set of ten substrate materials. All biomass within a template placed on the substrate is removed for analysis. The alternative method involves selecting entire rocks and submitting them for analysis. The surface area of the exposed substrate is calculated and the resulting metrics reflect an integrated measure of Chlorophyll *a* and AFDW. The whole rock method helps to reduce variability and sampler bias inherent with placing the template on the substrate.

Both scrape and rock samples were collected in parallel from monitoring sites from 2001-2008 by PPLM. Based on analysis provided by Frank Pickett at PPLM, these data indicated that variability is reduced by using the rock method. The coefficient of variation the scrape method and the whole rock method were compared for Chlorophyll *a* (**Figure 15**).

**Figure 15. Mean of Coefficient of Variation (CV) of Chlorophyll *a*, 2001 – 2008**




Comparison of scrape and rock methods from 2001-2008 indicated that on average the CV for Chlorophyll *a* was reduced by half, from approximately 40% to 20%. Concurrent with the reduced variability, the results of whole rock sampling showed that analytical values for the scrape method were on average 35% higher than the rock method. This upward bias of the scrape method may be a function of samplers' bias to select substrate with an accessible, biomass-rich surface.

By implementing the whole rock method to reduce variability (CV) of sample results, bias, consistency and repeatability of periphyton data would be expected to improve relative to the scrape method. The whole rock method is expected to provide an improved metric for periphyton monitoring. However, because of the tendency for the scrape method to be biased high relative to the rock method, scrape and whole data are not directly comparable. Scrape data are presented in the present trend analysis since whole rock data are not available prior to 2001.

In summary, no trends in either Chlorophyll *a* or AFDW were apparent from 1997-2006, with the exception of a decrease in Chlorophyll *a* at the Morony site. A paired sampling using whole rocks and scrape methods from 2001-2008 suggested that future sampling for Chlorophyll *a* and AFDW would be improved by using the rock method. Variability of replicate results was reduced, potential sampling bias is minimized, and the ability to detect trends in periphyton metrics is increased.

### *6.2.1 Macroinvertebrate Trend Analysis*

Comprehensive analysis and interpretation of macroinvertebrate populations for the 1997-2006 period was conducted by McGuire (2010). This section provides supplemental analysis of trends in

macroinvertebrates. Macroinvertebrate metrics were evaluated for trends using Kendall's test from 1997-2006 based on annual sampling results. Macroinvertebrate metrics included bioassessment index, taxa richness, EPT richness, Shannon diversity, biotic index, %EPT, and % Chironomidae. Spatial and time series plots for macroinvertebrate metrics are found in **Appendices H and I**.

Results of this analysis showed few trends in metrics over the monitoring period (**Table 6-11**). The Madison Hebgen station showed an increase in biotic index, and decreases in bioassessment index, EPT richness and % EPT. The Madison/Ennis station did not show any trends in macroinvertebrate metrics. The Madison powerhouse showed an increase in biotic index, and decrease in %EPT. No statistically significant trends were observed at the Toston station. The Hauser and Holter sites showed a decrease in %EPT, but no statistically significant trends otherwise. The Morony site showed an increase in the biotic index but no statistically significant trends otherwise.

Correlations between individual periphyton metrics were evaluated at each station to determine the extent to which metrics were independent measures, or were closely related. For the Madison Hebgen station, bioassessment index was positively correlated to EPT richness and % EPT **(Table 6-12)**. Bioassessment index was inversely correlated to biotic index and % Chironomidae. Taxa richness and EPT richness were positively correlated to Shannon diversity. EPT richness was also positively correlated to % EPT, and inversely correlated to biotic index. Biotic index was inversely correlated to % EPT. Overall, % Chironomidae and taxa richness were independent of most metrics. Bioassessment and biotic index were correlated, and more consistently related to other metrics as well.

For the Madison Ennis station, bioassessment index was positively correlated to taxa richness and EPT richness **(Table 6-13)**. Taxa richness was also correlated to EPT richness. EPT richness was also positively correlated to % EPT. Shannon diversity and biotic index were independent of other metrics. Percent (%) EPT was inversely correlated to % Chironomidae. Overall, periphyton metrics were largely independent of one another at Ennis.

For the Madison Powerhouse station, bioassessment index was inversely correlated to biotic index **(Table 6-14)**. Taxa richness was positively correlated to Shannon diversity. EPT richness and (%) Chironomidae were independent of other metrics. Biotic index was inversely correlated to % EPT and bioassessment index. Overall, periphyton metrics tended to be independent measures at the Powerhouse station.

For the Missouri Toston station, bioassessment index was positively correlated to % EPT **(Table 6-15)**. Bioassessment index was inversely correlated to biotic index and % Chironomidae. Taxa richness was positively correlated to EPT richness and Shannon diversity. EPT richness was also positively correlated to Shannon diversity. Biotic index was inversely correlated to bioassessment index and % EPT. Percent (%) EPT was inversely correlated to % Chironomidae. The Toston station showed increased correlation between metrics relative to upstream stations. In particular bioassessment index and biotic index were correlated with each other, and showed the tendency to correlate with other metrics.

For the Missouri Hauser station, bioassessment index, Shannon diversity, and % Chironomidae were not correlated to other metrics **(Table 6-16)**. Taxa richness was inversely correlated to % EPT. EPT richness was positively correlated to %EPT. Biotic index was inversely correlated to % EPT. Overall, the Missouri Hauser station showed relatively few correlations between other metrics and suggested these metrics were largely independent.

For the Missouri Holter station, bioassessment index was positively correlated to taxa richness, EPT richness, Shannon diversity, % Chironomidae and % EPT **(Table 6-17)**. Taxa richness was positively correlated to bioassessment index, EPT richness, Shannon diversity and % Chironomidae. EPT richness

was also positively correlated % EPT, taxa richness, % EPT, and % Chironomidae. Biotic index was inversely correlated to % EPT. The Holter station showed strong correlations between metrics. Percent (%) Chironomidae was positively correlated with bioassessment index, taxa richness, and EPT richness. This was an unusual result as the correlation at other stations tended to be inverse, rather than positive.

For the Missouri Morony station, bioassessment index was positively correlated to % EPT **(Table 6-18)**. Bioassessment index was inversely correlated to % Chironomidae. Taxa richness was positively correlated to EPT richness and Shannon diversity. EPT richness was positively correlated to taxa richness and inversely correlated to biotic index. Shannon diversity and taxa richness were positively correlated. Biotic index was inversely correlated to EPT richness and % EPT. Percent (%) EPT was inversely correlated to biotic index. The Morony station showed relatively few correlations between periphyton metrics, suggested that metrics are largely independent.

In summary, the association between periphyton metrics varied between sites. Monitoring sites showing the greatest number of closely related metrics were Madison Hebgen, Missouri Toston, and Missouri Holter. Metrics at other stations tended to be more frequently independent and not show close statistical associations. In many cases, periphyton metrics appeared to be largely independent of one another.

Despite lack of statistical association, metrics generally showed expected relationships. For example, increasing biotic index (i.e. degrading health) was typically associated with declines in other metrics such as bioassessment index, EPT richness, and others. Percent (%) Chironomidae results were variable, often associated with declines in other metrics such as bioassessment index (as expected), but sometimes showing positive correlation to metrics indicating health. The changing macroinvertebrate assemblages between stations along with annual variability likely accounted for much of the independence observed between at-a-station metrics. In addition, sample size in this analysis was 10 (i.e. 1 sample averaged per site/year). Small sample size meant that only the strongest associations were likely to be statistically significant.

**Table 6-11. Macroinvertebrate Metrics Station Trends Summary**

| Correlation of metrics with year by station | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Station 1: Madison Hebgen | Station 2: Madison Ennis | Station 4: Madison Powerhouse | Station 5: Missouri Toston | Station 7: Missouri Hauser | Station 8: Missouri Holter | Station 10: Missouri Morony |
| Kendall's tau_b | Bio-assessment Index | Correlation Coefficient | -.494* | -.442 | -.263 | -.215 | .283 | -.090 | .023 |
| | | Sig. (2-tailed) | .048 | .083 | .311 | .407 | .272 | .719 | .927 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | TAXA Richness | Correlation Coefficient | -.135 | -.250 | .067 | .159 | .467 | -.135 | -.289 |
| | | Sig. (2-tailed) | .590 | .321 | .788 | .528 | .060 | .590 | .245 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | EPT Richness | Correlation Coefficient | -.494* | -.270 | -.111 | .250 | -.386 | -.368 | -.378 |
| | | Sig. (2-tailed) | .048 | .281 | .655 | .321 | .125 | .147 | .128 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | SHAN. Diversity | Correlation Coefficient | -.244 | .111 | -.156 | .022 | .022 | .244 | -.111 |
| | | Sig. (2-tailed) | .325 | .655 | .531 | .929 | .929 | .325 | .655 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | BIOTIC Index | Correlation Coefficient | .644** | .244 | .511* | .244 | .467 | .333 | .511* |
| | | Sig. (2-tailed) | .009 | .325 | .040 | .325 | .060 | .180 | .040 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % EPT | Correlation Coefficient | -.689** | -.378 | -.600* | -.244 | -.778** | -.511* | -.378 |
| | | Sig. (2-tailed) | .006 | .128 | .016 | .325 | .002 | .040 | .128 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % Chironomidae | Correlation Coefficient | .200 | .022 | -.067 | .289 | -.333 | -.200 | -.467 |
| | | Sig. (2-tailed) | .421 | .929 | .788 | .245 | .180 | .421 | .060 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

**Table 6-12. Station 1: Madison/Hebgen**

| Correlations[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Year | Bio-assessment Index | TAXA Richness | EPT Richness | SHAN. Diversity | Biotic Index | % EPT | % Chironomidae |
| Kendall's tau_b | Year | Correlation Coefficient | 1.000 | -.494* | -.135 | -.494* | -.244 | .644** | -.689** | .200 |
| | | Sig. (2-tailed) | . | .048 | .590 | .048 | .325 | .009 | .006 | .421 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | Bio-assessment Index | Correlation Coefficient | -.494* | 1.000 | .114 | .523* | .360 | -.584* | .809** | -.539* |
| | | Sig. (2-tailed) | .048 | . | .652 | .038 | .151 | .020 | .001 | .031 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | TAXA Richness | Correlation Coefficient | -.135 | .114 | 1.000 | .341 | .539* | -.135 | .090 | -.045 |
| | | Sig. (2-tailed) | .590 | .652 | . | .176 | .031 | .590 | .719 | .857 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | EPT Richness | Correlation Coefficient | -.494* | .523* | .341 | 1.000 | .539* | -.764** | .629* | -.045 |
| | | Sig. (2-tailed) | .048 | .038 | .176 | . | .031 | .002 | .012 | .857 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | SHAN. Diversity | Correlation Coefficient | -.244 | .360 | .539* | .539* | 1.000 | -.333 | .378 | -.067 |
| | | Sig. (2-tailed) | .325 | .151 | .031 | .031 | . | .180 | .128 | .788 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | BIOTIC Index | Correlation Coefficient | .644** | -.584* | -.135 | -.764** | -.333 | 1.000 | -.778** | .111 |
| | | Sig. (2-tailed) | .009 | .020 | .590 | .002 | .180 | . | .002 | .655 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % EPT | Correlation Coefficient | -.689** | .809** | .090 | .629* | .378 | -.778** | 1.000 | -.333 |
| | | Sig. (2-tailed) | .006 | .001 | .719 | .012 | .128 | .002 | . | .180 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % Chironomidae | Correlation Coefficient | .200 | -.539* | -.045 | -.045 | -.067 | .111 | -.333 | 1.000 |
| | | Sig. (2-tailed) | .421 | .031 | .857 | .857 | .788 | .655 | .180 | . |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). a. StationID = 1

**Table 6-13. Station 2: Madison/Ennis**

| Correlations[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Year | Bio-assessment Index | TAXA Richness | EPT Richness | SHAN. Diversity | BIOTIC Index | % EPT | % Chironomidae |
| Kendall's tau_b | Year | Correlation Coefficient | 1.000 | -.442 | -.250 | -.270 | .111 | .244 | -.378 | .022 |
| | | Sig. (2-tailed) | . | .083 | .321 | .281 | .655 | .325 | .128 | .929 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | Bio-assessment Index | Correlation Coefficient | -.442 | 1.000 | .643* | .565* | .163 | -.442 | .442 | -.023 |
| | | Sig. (2-tailed) | .083 | . | .013 | .028 | .523 | .083 | .083 | .927 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | TAXA Richness | Correlation Coefficient | -.250 | .643* | 1.000 | .828** | .477 | -.296 | .250 | .114 |
| | | Sig. (2-tailed) | .321 | .013 | . | .001 | .058 | .241 | .321 | .652 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | EPT Richness | Correlation Coefficient | -.270 | .565* | .828** | 1.000 | .360 | -.360 | .360 | .000 |
| | | Sig. (2-tailed) | .281 | .028 | .001 | . | .151 | .151 | .151 | 1.000 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | SHAN. Diversity | Correlation Coefficient | .111 | .163 | .477 | .360 | 1.000 | -.022 | -.111 | .022 |
| | | Sig. (2-tailed) | .655 | .523 | .058 | .151 | . | .929 | .655 | .929 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | BIOTIC Index | Correlation Coefficient | .244 | -.442 | -.296 | -.360 | -.022 | 1.000 | -.333 | .156 |
| | | Sig. (2-tailed) | .325 | .083 | .241 | .151 | .929 | . | .180 | .531 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % EPT | Correlation Coefficient | -.378 | .442 | .250 | .360 | -.111 | -.333 | 1.000 | -.556* |
| | | Sig. (2-tailed) | .128 | .083 | .321 | .151 | .655 | .180 | . | .025 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % Chironomidae | Correlation Coefficient | .022 | -.023 | .114 | .000 | .022 | .156 | -.556* | 1.000 |
| | | Sig. (2-tailed) | .929 | .927 | .652 | 1.000 | .929 | .531 | .025 | . |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). a. StationID = 2

**Table 6-14. Station 4: Madison/Powerhouse**

| Correlations[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Year | Bio-assessment Index | TAXA Richness | EPT Richness | SHAN. Diversity | BIOTIC Index | % EPT | % Chironomidae |
| Kendall's tau_b | Year | Correlation Coefficient | 1.000 | -.263 | .067 | -.111 | -.156 | .511* | -.600* | -.067 |
| | | Sig. (2-tailed) | . | .311 | .788 | .655 | .531 | .040 | .016 | .788 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | Bio-assessment Index | Correlation Coefficient | -.263 | 1.000 | .263 | .501 | .263 | -.645* | .501 | -.119 |
| | | Sig. (2-tailed) | .311 | . | .311 | .053 | .311 | .013 | .053 | .645 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | TAXA Richness | Correlation Coefficient | .067 | .263 | 1.000 | .289 | .689** | .111 | -.022 | .244 |
| | | Sig. (2-tailed) | .788 | .311 | . | .245 | .006 | .655 | .929 | .325 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | EPT Richness | Correlation Coefficient | -.111 | .501 | .289 | 1.000 | .422 | -.244 | .244 | .244 |
| | | Sig. (2-tailed) | .655 | .053 | .245 | . | .089 | .325 | .325 | .325 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | SHAN. Diversity | Correlation Coefficient | -.156 | .263 | .689** | .422 | 1.000 | .067 | .111 | .467 |
| | | Sig. (2-tailed) | .531 | .311 | .006 | .089 | . | .788 | .655 | .060 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | BIOTIC Index | Correlation Coefficient | .511* | -.645* | .111 | -.244 | .067 | 1.000 | -.733** | .244 |
| | | Sig. (2-tailed) | .040 | .013 | .655 | .325 | .788 | . | .003 | .325 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % EPT | Correlation Coefficient | -.600* | .501 | -.022 | .244 | .111 | -.733** | 1.000 | -.067 |
| | | Sig. (2-tailed) | .016 | .053 | .929 | .325 | .655 | .003 | . | .788 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % Chironomidae | Correlation Coefficient | -.067 | -.119 | .244 | .244 | .467 | .244 | -.067 | 1.000 |
| | | Sig. (2-tailed) | .788 | .645 | .325 | .325 | .060 | .325 | .788 | . |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). a. StationID = 4

**Table 6-15. Station 5: Missouri/Toston**

| Correlations[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Year | Bio-assessment Index | TAXA Richness | EPT Richness | SHAN. Diversity | BIOTIC Index | % EPT | % Chironomidae |
| Kendall's tau_b | Year | Correlation Coefficient | 1.000 | -.215 | .159 | .250 | .022 | .244 | -.244 | .289 |
| | | Sig. (2-tailed) | . | .407 | .528 | .321 | .929 | .325 | .325 | .245 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | Bio-assessment Index | Correlation Coefficient | -.215 | 1.000 | .195 | .366 | .072 | -.692** | .597* | -.692** |
| | | Sig. (2-tailed) | .407 | . | .457 | .164 | .782 | .008 | .021 | .008 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | TAXA Richness | Correlation Coefficient | .159 | .195 | 1.000 | .674** | .750** | .068 | -.250 | .068 |
| | | Sig. (2-tailed) | .528 | .457 | . | .008 | .003 | .787 | .321 | .787 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | EPT Richness | Correlation Coefficient | .250 | .366 | .674** | 1.000 | .568* | -.205 | -.023 | -.114 |
| | | Sig. (2-tailed) | .321 | .164 | .008 | . | .024 | .417 | .928 | .652 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | SHAN. Diversity | Correlation Coefficient | .022 | .072 | .750** | .568* | 1.000 | .244 | -.333 | .200 |
| | | Sig. (2-tailed) | .929 | .782 | .003 | .024 | . | .325 | .180 | .421 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | BIOTIC Index | Correlation Coefficient | .244 | -.692** | .068 | -.205 | .244 | 1.000 | -.556* | .600* |
| | | Sig. (2-tailed) | .325 | .008 | .787 | .417 | .325 | . | .025 | .016 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % EPT | Correlation Coefficient | -.244 | .597* | -.250 | -.023 | -.333 | -.556* | 1.000 | -.778** |
| | | Sig. (2-tailed) | .325 | .021 | .321 | .928 | .180 | .025 | . | .002 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % Chironomidae | Correlation Coefficient | .289 | -.692** | .068 | -.114 | .200 | .600* | -.778** | 1.000 |
| | | Sig. (2-tailed) | .245 | .008 | .787 | .652 | .421 | .016 | .002 | . |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed). a. StationID = 5

**Table 6-16. Station 7: Missouri/Hauser**

| Correlations[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Year | Bio-assessment Index | TAXA Richness | EPT Richness | SHAN. Diversity | BIOTIC Index | % EPT | % Chironomidae |
| Kendall's tau_b | Year | Correlation Coefficient | 1.000 | .283 | .467 | -.386 | .022 | .467 | -.778** | -.333 |
| | | Sig. (2-tailed) | . | .272 | .060 | .125 | .929 | .060 | .002 | .180 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | Bio-assessment Index | Correlation Coefficient | .283 | 1.000 | .377 | .338 | .047 | -.189 | -.047 | -.424 |
| | | Sig. (2-tailed) | .272 | . | .143 | .197 | .855 | .464 | .855 | .099 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | TAXA Richness | Correlation Coefficient | .467 | .377 | 1.000 | -.114 | .467 | .467 | -.511* | -.244 |
| | | Sig. (2-tailed) | .060 | .143 | . | .652 | .060 | .060 | .040 | .325 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | EPT Richness | Correlation Coefficient | -.386 | .338 | -.114 | 1.000 | -.068 | -.386 | .614* | .023 |
| | | Sig. (2-tailed) | .125 | .197 | .652 | . | .787 | .125 | .015 | .928 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | SHAN. Diversity | Correlation Coefficient | .022 | .047 | .467 | -.068 | 1.000 | .200 | -.067 | .111 |
| | | Sig. (2-tailed) | .929 | .855 | .060 | .787 | . | .421 | .788 | .655 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | BIOTIC Index | Correlation Coefficient | .467 | -.189 | .467 | -.386 | .200 | 1.000 | -.689** | .022 |
| | | Sig. (2-tailed) | .060 | .464 | .060 | .125 | .421 | . | .006 | .929 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % EPT | Correlation Coefficient | -.778** | -.047 | -.511* | .614* | -.067 | -.689** | 1.000 | .200 |
| | | Sig. (2-tailed) | .002 | .855 | .040 | .015 | .788 | .006 | . | .421 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % Chironomidae | Correlation Coefficient | -.333 | -.424 | -.244 | .023 | .111 | .022 | .200 | 1.000 |
| | | Sig. (2-tailed) | .180 | .099 | .325 | .928 | .655 | .929 | .421 | . |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed). a. StationID = 7

**Table 6-17. Station 8: Missouri/Holter**

| Correlations[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Year | Bio-assessment Index | TAXA Richness | EPT Richness | SHAN. Diversity | BIOTIC Index | % EPT | % Chironomidae |
| Kendall's tau_b | Year | Correlation Coefficient | 1.000 | -.090 | -.135 | -.368 | .244 | .333 | -.511* | -.200 |
| | | Sig. (2-tailed) | . | .719 | .590 | .147 | .325 | .180 | .040 | .421 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | Bio-assessment Index | Correlation Coefficient | -.090 | 1.000 | .523* | .651* | .494* | -.315 | .494* | .494* |
| | | Sig. (2-tailed) | .719 | . | .038 | .011 | .048 | .209 | .048 | .048 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | TAXA Richness | Correlation Coefficient | -.135 | .523* | 1.000 | .628* | .584* | .090 | .270 | .584* |
| | | Sig. (2-tailed) | .590 | .038 | . | .014 | .020 | .719 | .281 | .020 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | EPT Richness | Correlation Coefficient | -.368 | .651* | .628* | 1.000 | .414 | -.322 | .690** | .644* |
| | | Sig. (2-tailed) | .147 | .011 | .014 | . | .103 | .205 | .007 | .011 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | SHAN. Diversity | Correlation Coefficient | .244 | .494* | .584* | .414 | 1.000 | .111 | .156 | .467 |
| | | Sig. (2-tailed) | .325 | .048 | .020 | .103 | . | .655 | .531 | .060 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | BIOTIC Index | Correlation Coefficient | .333 | -.315 | .090 | -.322 | .111 | 1.000 | -.556* | -.067 |
| | | Sig. (2-tailed) | .180 | .209 | .719 | .205 | .655 | . | .025 | .788 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % EPT | Correlation Coefficient | -.511* | .494* | .270 | .690** | .156 | -.556* | 1.000 | .422 |
| | | Sig. (2-tailed) | .040 | .048 | .281 | .007 | .531 | .025 | . | .089 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % Chironomidae | Correlation Coefficient | -.200 | .494* | .584* | .644* | .467 | -.067 | .422 | 1.000 |
| | | Sig. (2-tailed) | .421 | .048 | .020 | .011 | .060 | .788 | .089 | . |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). a. StationID = 8

**Table 6-18. Station 10: Missouri/Morony**

| Correlations[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Year | Bio-assessment Index | TAXA Richness | EPT Richness | SHAN. Diversity | BIOTIC Index | % EPT | % Chironomidae |
| Kendall's tau_b | Year | Correlation Coefficient | 1.000 | .023 | -.289 | -.378 | -.111 | .511* | -.378 | -.467 |
| | | Sig. (2-tailed) | . | .927 | .245 | .128 | .655 | .040 | .128 | .060 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | Bio-assessment Index | Correlation Coefficient | .023 | 1.000 | -.070 | .116 | .116 | -.163 | .210 | -.582* |
| | | Sig. (2-tailed) | .927 | . | .784 | .649 | .649 | .523 | .412 | .023 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | TAXA Richness | Correlation Coefficient | -.289 | -.070 | 1.000 | .556* | .644** | -.244 | .022 | .467 |
| | | Sig. (2-tailed) | .245 | .784 | . | .025 | .009 | .325 | .929 | .060 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | EPT Richness | Correlation Coefficient | -.378 | .116 | .556* | 1.000 | .378 | -.600* | .378 | .289 |
| | | Sig. (2-tailed) | .128 | .649 | .025 | . | .128 | .016 | .128 | .245 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | SHAN. Diversity | Correlation Coefficient | -.111 | .116 | .644** | .378 | 1.000 | -.067 | -.156 | .111 |
| | | Sig. (2-tailed) | .655 | .649 | .009 | .128 | . | .788 | .531 | .655 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | BIOTIC Index | Correlation Coefficient | .511* | -.163 | -.244 | -.600* | -.067 | 1.000 | -.689** | -.156 |
| | | Sig. (2-tailed) | .040 | .523 | .325 | .016 | .788 | . | .006 | .531 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % EPT | Correlation Coefficient | -.378 | .210 | .022 | .378 | -.156 | -.689** | 1.000 | .111 |
| | | Sig. (2-tailed) | .128 | .412 | .929 | .128 | .531 | .006 | . | .655 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | % Chironomidae | Correlation Coefficient | -.467 | -.582* | .467 | .289 | .111 | -.156 | .111 | 1.000 |
| | | Sig. (2-tailed) | .060 | .023 | .060 | .245 | .655 | .531 | .655 | . |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). a. StationID = 10

In general, macroinvertebrate metrics indicated stability over the monitoring period. The uppermost station Madison/Hebgen showed trends in the greatest number of metrics. A decline in %EPT and increase in biotic index was the most prevalent trend throughout the monitoring network, but was limited to a handful of stations. These changes appeared to be related to the tendency for declining flows over the same period. Comprehensive analysis and interpretation of macroinvertebrate populations for the 1997-2006 period is detailed in additional analysis (Rhithron 2010).

### *6.2.2 Fish Tissue Analysis*

Fish were sampled at 8 locations in 2009, and analyzed for the following metals, pesticides, and PCB congeners.

**Table 6-19. Fish Tissue, Pesticides and PCB Congeners**

| Parameter | Detection Limit | Parameter | Detection Limit |
|---|---|---|---|
| Iron | 9 mg/kg | beta-BHC | 0.034 mg/kg |
| Magnesium | 50 mg/kg | delta-BHC | 0.034 mg/kg |
| Aluminum | 5 mg/kg | Endosulfan I | 0.034 mg/kg |
| Arsenic | 5 mg/kg | Endosulfan II | 0.034 mg/kg |
| Chromium | 5 mg/kg | Endosulfan sulfate | 0.034 mg/kg |
| Copper | 5 mg/kg | Endrin | 0.034 mg/kg |
| Lead | 5 mg/kg | Endrin aldehyde | 0.034 mg/kg |
| Manganese | 5 mg/kg | gamma-BHC (Lindane) | 0.034 mg/kg |
| Nickel | 5 mg/kg | gamma-Chlordane | 0.034 mg/kg |
| Selenium | 5 mg/kg | Heptachlor | 0.034 mg/kg |
| Strontium | 5 mg/kg | Heptachlor epoxide | 0.034 mg/kg |
| Zinc | 5 mg/kg | Methoxychlor | 0.034 mg/kg |
| Toxaphene | 3.3 mg/kg | Mirex | 0.034 mg/kg |
| Cadmium | 1 mg/kg | Aroclor 1016 | 0.034 mg/kg |
| Mercury | 1 mg/kg | Aroclor 1221 | 0.034 mg/kg |
| Chlordane | 0.34 mg/kg | Aroclor 1232 | 0.034 mg/kg |
| 4,4´-DDD | 0.034 mg/kg | Aroclor 1242 | 0.034 mg/kg |
| 4,4´-DDE | 0.034 mg/kg | Aroclor 1248 | 0.034 mg/kg |
| 4,4´-DDT | 0.034 mg/kg | Aroclor 1254 | 0.034 mg/kg |
| Aldrin | 0.034 mg/kg | Aroclor 1260 | 0.034 mg/kg |
| alpha-BHC | 0.034 mg/kg | Aroclor 1262 | 0.034 mg/kg |
| alpha-Chlordane | 0.034 mg/kg | Aroclor 1268 | 0.034 mg/kg |

Fish sampled included the following species:

**Table 6-20. Fish Tissue, Species**

| Species | Code |
|---|---|
| Utah Chub | UC |
| Rainbow Trout | RB |
| Brown Trout | LL |
| Walleye | WE |
| Long Nose Sucker | LNS |
| White Sucker | WS |
| Bullhead | BH |

Fish samples were composites of individuals collected from the Hebgen, Madison, Hauser, Holter, Cochrane, Rainbow, and Morony sites. The Hauser and Holter fish were analyzed individually. Weight and length by species and location were as follows:

**Table 6-21. Fish Tissue Weight and Length by Species**

| Location | Species (N) | Length | | | | Weight | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Max (in) | Min (in) | Avg (in) | Std Dev | Max (lbs) | Min (lbs) | Avg (lbs) | Std Dev |
| Hauser | WS (5) | 15.9 | 14.8 | 15.18 | 0.47 | 1.85 | 1.54 | 1.69 | 0.11 |
| Hauser | RB (5) | 16 | 14.9 | 15.48 | 0.41 | 1.77 | 1.4 | 1.63 | 0.15 |
| Holter | WS (5) | 14.7 | 14.2 | 14.5 | 0.21 | 1.76 | 1.33 | 1.54 | 0.16 |
| Holter | RB (5) | 19.2 | 17.7 | 18.44 | 0.55 | 2.85 | 2.27 | 2.57 | 0.21 |
| Cochrane | RB (5) | 18.1 | 12.9 | 15.62 | 1.91 | 2.11 | 0.86 | 1.47 | 0.46 |
| Cochrane | WS (5) | 15.2 | 14.3 | 14.80 | 0.36 | 1.69 | 1.35 | 1.55 | 0.18 |
| Rainbow | WS (5) | 15.2 | 14.5 | 14.88 | 0.28 | 1.64 | 1.44 | 1.56 | 0.08 |
| Rainbow | BH (5) | 10.4 | 9.7 | 10.10 | 0.25 | 0.48 | 0.38 | 0.41 | 0.04 |
| Morony | WE (5) | 12.6 | 11.3 | 11.96 | 0.09 | 0.64 | 0.42 | 0.54 | 0.09 |
| Morony | WS (5) | 14.9 | 13.7 | 14.22 | 0.45 | 1.7 | 1.25 | 1.49 | 0.20 |
| Ryan | RB (4) | 16.8 | 11.8 | 15.13 | 2.31 | 1.74 | 0.68 | 1.28 | 0.46 |
| Ryan | LNS (5) | 16.5 | 14.3 | 15.08 | 0.87 | 1.86 | 1.17 | 1.52 | 0.25 |
| Madison | RB (4) | 17.6 | 15.6 | 16.9 | 0.95 | 2.2 | 1.33 | 1.86 | 0.37 |
| Madison | WS/UC (4) | 16.3 | 12.2 | 14.28 | 1.68 | 1.97 | 0.94 | 1.5 | 0.46 |
| Hebgen | LL (5) | 19.5 | 15 | 16.70 | 1.69 | 2.29 | 1.22 | 1.56 | 0.43 |
| Hebgen | UC (5) | 13.4 | 12.6 | 12.90 | 0.41 | 1.1 | 0.84 | 0.96 | 0.13 |

Fish tissue composites were analyzed for metals and PCB congeners. Results by location are found in the following tables. Small sample sizes preclude statistical analysis of data for trends. The Hebgen samples showed magnesium, manganese, iron and zinc in Utah chub and brown trout. Aluminum and strontium were also present in Utah chub. No organic parameters were detected.

**Table 6-22. Hebgen Lake Fish Tissue Samples**

| Parameter | Species | mg/kg |
|---|---|---|
| Magnesium | UC | 388 |
| Magnesium | LL | 289 |
| Aluminum | UC | 5 |
| Iron | UC | 29 |
| Manganese | UC | 8 |
| Strontium | UC | 11 |
| Zinc | UC | 26 |
| Iron | LL | 30 |
| Manganese | LL | 5 |
| Zinc | LL | 40 |

The Madison samples showed magnesium, manganese, iron, strontium, aluminum and zinc in bullhead and rainbow trout. Manganese was also present in bullhead. No organic parameters were detected.

**Table 6-23. Madison Reservoir Fish Tissue Samples**

| Parameter | Species | mg/kg |
|---|---|---|
| Iron | RB | 29 |
| Magnesium | BF | 376 |
| Magnesium | RB | 362 |
| Aluminum | BF | 8 |
| Iron | BF | 27 |
| Manganese | BF | 7 |
| Strontium | BF | 13 |
| Zinc | BF | 16 |
| Aluminum | RB | 7 |
| Strontium | RB | 6 |
| Zinc | RB | 34 |

The Madison samples showed magnesium, iron, and zinc in longnose suckers and rainbow trout. Strontium was also present in longnose suckers. No organic parameters were detected.

**Table 6-24. Ryan Development Fish Tissue Samples**

| Parameter | Species | mg/kg |
|---|---|---|
| Iron | RB | 13 |
| Iron | LNS | 35 |
| Magnesium | LNS | 330 |
| Magnesium | RB | 291 |
| Aluminum | LNS | 22 |
| Strontium | LNS | 11 |
| Zinc | LNS | 16 |
| Zinc | RB | 13 |

The Rainbow samples showed magnesium, strontium, iron and zinc in white suckers and bullhead. Aluminum was also present in white suckers. Trace amounts of Arochlor 1254 were detected in both white sucker and bullhead samples, estimated from a result below the detection limit.

**Table 6-25. Rainbow Development Fish Tissue Samples**

| Parameter | Species | mg/kg |
|---|---|---|
| Magnesium | BH | 327 |
| Magnesium | WS | 364 |
| Strontium | BH | 14 |
| Zinc | BH | 16 |
| Aluminum | WS | 6 |
| Iron | WS | 18 |
| Strontium | WS | 19 |
| Zinc | WS | 13 |
| Iron | BH | 30 |
| Aroclor 1254[J] | BH | 0.029 |
| Aroclor 1254[J] | WS | 0.028 |

J = Below detection limit, estimated value

The Cochrane samples showed magnesium, strontium, iron, aluminum, and zinc in white suckers and rainbow trout. Trace amounts of Arochlor 1254 was detected in the white sucker sample, estimated from a result below the detection limit.

**Table 6-26. Cochrane Development Lake Fish Tissue Samples**

| Parameter | Species | mg/kg |
|---|---|---|
| Iron | WS | 68 |
| Iron | RB | 24 |
| Magnesium | RB | 293 |
| Magnesium | WS | 413 |
| Aluminum | RB | 6 |
| Strontium | RB | 6 |
| Zinc | RB | 27 |
| Aluminum | WS | 38 |
| Strontium | WS | 20 |
| Zinc | WS | 14 |
| Aroclor 1254[J] | WS | 0.027 |

J = Below detection limit, estimated value

The Morony samples showed magnesium, iron, strontium, aluminum and zinc in walleye and white sucker. No organic constituents were detected.

**Table 6-27. Morony Reservoir Lake Fish Tissue Samples**

| Parameter | Species | mg/kg |
|---|---|---|
| Iron | WE | 16 |
| Iron | WS | 30 |
| Magnesium | WE | 440 |
| Magnesium | WS | 395 |
| Aluminum | WE | 7 |
| Strontium | WE | 25 |
| Zinc | WE | 16 |
| Aluminum | WS | 17 |
| Strontium | WS | 24 |
| Zinc | WS | 15 |

The Holter samples showed magnesium, strontium, iron, and zinc in white suckers and rainbow trout. Aluminum and manganese were detected in white suckers. Trace amounts of Arochlor 1254 were detected in both white sucker and rainbow samples, estimated from results below the detection limit.

**Table 6-28. Holter Lake Fish Tissue Samples**

| Parameter | Species | mg/kg |
|---|---|---|
| Iron | WS | 15 |
| Iron | WS | 90 |
| Iron | WS | 14 |
| Magnesium | WS | 332 |
| Magnesium | WS | 238 |
| Magnesium | WS | 320 |
| Magnesium | WS | 337 |
| Magnesium | WS | 332 |
| Magnesium | RB | 333 |
| Magnesium | RB | 356 |
| Magnesium | RB | 301 |
| Magnesium | RB | 231 |
| Magnesium | RB | 300 |
| Aluminum | WS | 17 |
| Iron | WS | 32 |
| Manganese | WS | 9 |
| Strontium | WS | 9 |
| Zinc | WS | 13 |
| Zinc | WS | 8 |
| Aluminum | WS | 31 |
| Iron | WS | 55 |
| Manganese | WS | 8 |
| Strontium | WS | 10 |
| Zinc | WS | 12 |

**Table 6-28. Holter Lake Fish Tissue Samples**

| Parameter | Species | mg/kg |
|---|---|---|
| Aluminum | WS | 36 |
| Iron | WS | 50 |
| Manganese | WS | 12 |
| Strontium | WS | 11 |
| Zinc | WS | 15 |
| Aluminum | WS | 41 |
| Manganese | WS | 25 |
| Strontium | WS | 11 |
| Zinc | WS | 12 |
| Iron | RB | 18 |
| Strontium | RB | 11 |
| Zinc | RB | 29 |
| Iron | RB | 17 |
| Strontium | RB | 11 |
| Zinc | RB | 23 |
| Iron | RB | 20 |
| Strontium | RB | 8 |
| Zinc | RB | 21 |
| Iron | RB | 24 |
| Zinc | RB | 34 |
| Iron | RB | 26 |
| Manganese | RB | 6 |
| Strontium | RB | 9 |
| Zinc | RB | 23 |
| Aroclor 1254 | WS | 0.022[j] |
| Aroclor 1254 | WS | 0.023[j] |
| Aroclor 1254 | WS | 0.018[j] |
| Aroclor 1254 | WS | 0.021[j] |
| Aroclor 1254 | WS | 0.018[j] |
| Aroclor 1254 | RB | 0.022[j] |
| Aroclor 1254 | RB | 0.02[j] |
| Aroclor 1254 | RB | 0.018[j] |
| Aroclor 1254 | RB | 0.029[j] |
| Aroclor 1254 | RB | 0.025[j] |

J = Below detection limit, estimated value

The Hauser samples showed magnesium, strontium, iron, and zinc in white suckers and rainbow trout. Aluminum was detected in white suckers. Trace amounts of Aroclor 1254 were detected in both white sucker and rainbow samples.

**Table 6-29. Hauser Fish Tissue Samples**

| Parameter | Species | mg/kg |
|---|---|---|
| Iron | WS | 24 |
| Iron | WS | 14 |
| Magnesium | WS | 373 |
| Magnesium | WS | 290 |
| Magnesium | RB | 266 |
| Magnesium | WS | 265 |
| Magnesium | RB | 279 |
| Magnesium | WS | 341 |
| Magnesium | RB | 279 |
| Magnesium | RB | 211 |
| Magnesium | WS | 362 |
| Magnesium | RB | 275 |
| Aluminum | WS | 6 |
| Strontium | WS | 14 |
| Zinc | WS | 13 |
| Iron | WS | 14 |
| Strontium | WS | 8 |
| Zinc | WS | 13 |
| Iron | RB | 20 |
| Zinc | RB | 34 |
| Iron | WS | 15 |
| Strontium | WS | 7 |
| Zinc | WS | 12 |
| Iron | RB | 25 |
| Strontium | RB | 6 |
| Zinc | RB | 43 |
| Aluminum | WS | 5 |
| Iron | WS | 16 |
| Strontium | WS | 13 |
| Zinc | WS | 12 |
| Iron | RB | 19 |
| Strontium | RB | 5 |
| Zinc | RB | 31 |
| Iron | RB | 19 |
| Zinc | RB | 25 |
| Strontium | WS | 12 |
| Zinc | WS | 14 |
| Iron | RB | 16 |
| Zinc | RB | 27 |
| Aroclor 1254 | WS | 0.051 |

**Table 6-29. Hauser Fish Tissue Samples**

| Parameter | Species | mg/kg |
|---|---|---|
| Aroclor 1254 | WS | 0.11 |
| Aroclor 1254 | RB | 0.05 |
| Aroclor 1254 | WS | 0.064 |
| Aroclor 1254 | RB | 0.031[j] |
| Aroclor 1254 | WS | 0.078 |
| Aroclor 1254 | RB | 0.055 |
| Aroclor 1254 | RB | 0.06 |
| Aroclor 1254 | WS | 0.089 |
| Aroclor 1254 | RB | 0.05 |

J = Below detection limit, estimated value

Overall, magnesium, strontium, iron, and zinc were commonly detected in fish species throughout the monitoring network. Aluminum and manganese were less frequently detected. The only organic constituent detected in 2009 sampling was the PCB congener Aroclor 1254 in trace amounts at the Rainbow, Cochrane, and Holter sites. The Hauser site showed Aroclor 1254 at levels above detection limits in both rainbow trout and white suckers. No other organics in the analysis suite were detected.

The Montana Department of Public Health and Human Services published sport fish consumption guidelines in 2005 for mercury and PCBs (MDPHHS 2005). This bulletin included fish sample results from 29 Montana waterbodies, including Canyon Ferry, Hauser, Holter and Hebgen. Consumption guidelines for mercury and PCB were presented. The bulletin advises an unlimited consumption of fish below 0.025 PCB, a weekly portion of 8 oz for fish containing from 0.025 to 0.10 mg/kg of PCB, and a monthly portion for 0.11 to 0.47 mg/kg PCB.

Values of Arochlor 1254 observed in rainbow trout at the Hauser site were near detection limits, but higher than the results reported for Hauser in the 2005 MDPHHS bulletin. Rainbow trout from Hauser fell into the weekly consumption category (0.025-0.10 mg/kg PCB). Holter rainbows were between unlimited consumption (<0.025 mg/kg PCB) and weekly consumption PCB levels.

The MDPHHS guidelines for mercury have six ranges for mercury with varying levels of fish consumption depending on exposure duration (vacation, seasonal or annual consumption) and adults vs. children or pregnant/nursing mothers. Fish with mercury in the 1.01-2.8 mg/kg range have suggested guidelines of from 1 meal/wk for short exposure to 1 meal/month for adults. Children under 6 and pregnant or nursing mothers should generally avoid eating fish in this category. Levels greater than 2.81 mg/kg of mercury should generally be avoided by all groups. No consumption guidelines are available for metals such as iron, zinc, magnesium, or others in the monitoring suite.

No mercury was detected in any fish samples in the Missouri Madison system. The detection limit was 1 mg/kg, and was adequate to reveal any higher concentration mercury contamination. Lower level contamination (i.e. < 1 mg/kg) was beyond the resolution of the lab analysis method. MDPHHS data indicated that low level mercury is widely present in Montana waterbodies, including the Missouri Madison. Lowering the mercury detection limit to 0.1 mg/kg would enable expanded interpretation of consumption guidelines for sport fish in future monitoring.

## 7.0 SUMMARY and RECOMMENDATIONS

The following summary and recommendations are based on analyses of monitoring data from 1997-2006.

Concentrations of numerous constituents tended to either increase or decrease in the downstream direction throughout the monitoring period. These observations in spatial trends were consistent with previous studies (Land & Water 1999). The change in water quality in the downstream direction can be largely attributed to geologic factors and contributing watersheds/source areas. For example, elevated concentrations of arsenic, sodium, and chloride originated largely within Yellowstone National Park were related to volcanic geology in the headwaters. Elevated calcium, sulfates, and other parameters in downstream direction were a function of shifts in geology from the headwaters to a geology of lower elevation source areas. With few exceptions, parameters such as temperature, pH, and dissolved oxygen were typically stationary in the downstream direction.

Statistically significant changes in concentrations of constituents between monitoring stations was common between upstream stations 1-5. These shifts were largely a function of changing geology and corresponding sources or dilution of constituents. Stations lower in the watershed tended to show increasing stability in constituent concentrations and less change between stations. Few shifts in water quality appeared to be directly related to hydro facility operations. Station 6 that showed an apparent sag in average dissolved oxygen concentration relative to upstream and downstream stations.

Concentrations of constituents were closely correlated with one another. These correlations included geology-related factors (e.g. a strong association of sodium, chloride, and arsenic). Strong correlations also included derivative constituents such as total phosphorus/dissolved phosphorus, total N/dissolved N fractions, and total metals/dissolved metals. In addition, many constituent concentrations were strongly related to flow either through dilution or release.

Trends in both field and analytical constituents were analyzed for raw data and data adjusted for the effects of flow. Depending on monitoring location, concentration of numerous constituents showed statistically significant trends over 1997-2010. Discharge over the same period also showed statistically significant trends. Changes in annual discharge accounted for many of the observed trends in raw data for analyte concentrations. Adjusted for the effects of flow, trends in analyte concentration were commonly explained by runoff. Changes in underlying watershed processes or potential hydro facility effects did not explain trends for in-stream concentrations.

Adjusted for the influence of discharge, parameters that showed a persistent tendency for increasing concentration included arsenic and chloride. Changes in upstream sources/loading did not appear to account for these trends.

Data collection included monthly and quarterly monitoring from 1996-2007. Analysis of monthly and quarterly data provided comparable statistical results for trend analyses from 1997-2006. These results suggest that a quarterly monitoring schedule would be sufficient for discerning significant annual or long-term trends in water quality.

Total and dissolved analytes are very closely related. Both metal and nutrient parameters had total and dissolved analyses. This redundancy is largely unnecessary from the standpoint of documenting underlying trends in water quality. They provide comparable results in terms of both status and trends in water quality. Either total or dissolved metals analyses should be sufficient to document water quality. For nitrogen parameters, total persulfate nitrogen and either total or dissolved nitrate/nitrate should be sufficient. Detectable levels of ammonia are not characteristic of the Missouri-Madison system and are probably unnecessary to monitor. Total phosphorus along with either dissolved or total ortho-phosphate

should be sufficient. Monitoring both dissolved and total fraction of phosphorus does not provide additional information.

Periphyton metrics included ash free dry weight and Chlorophyll *a*. These metrics showed year to year variability, but no persistent trends with the exception of a decrease in Chlorophyll *a* and the lowermost station (Morony). The change on methodology from the "scrape" method to the "whole rock" method improved consistency of data collection.

Macroinvertebrates showed a limited number of trends in various metrics. Several sites showed a decrease in %EPT and increase in biotic index. These shifts may be largely related to a tendency for decreasing discharge during the 1997-2006 monitoring period.

Overall, monitoring from 1997-2006 showed relatively stationary results for periphyton and macroinvertebrates. Variable trends in water quality parameters appeared to be largely a function of trends in discharge over the monitoring period. Trends in arsenic and chloride appeared to be independent of discharge effects.

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# Appendix A

# *Monitoring Protocols*

# Appendix B

## *Mean Water Quality Statistics by Parameter/Station/Year*

# Appendix C

## *Paired Station Statistical Analyses*

# Appendix D

## *Parameter Cross-correlations by Station*

# Appendix E

## *Quarterly Data Trend Tests*

# Appendix F

## *Macroinvertebrate Spatial Plots*

# Appendix G

## *Macroinvertebrate Time Series Plots*