Analysis of Water Quality Sampling of Twin Valley Reservoir, Clear Lake and Tributaries,

1999-2010

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Prepared for:

Alberta Environment and Water

December 2011

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ISBN 978-1-4601-1874-0 (Print)
ISBN 978-1-4601-1875-7 (Online)

SUMMARY

Water quality of Twin Valley Reservoir, Clear Lake, and their tributaries was evaluated using data from 1999 to 2010. Twin Valley Reservoir was first filled in 2003 by a new dam on the Little Bow River near its confluence with Mosquito Creek. Clear Lake levels were stabilized by a diversion from Mosquito Creek, which began operation in 2002.

As predicted by modelling, water temperature was slightly higher in the upstream Little Bow River in three of the seven years monitored hourly over the summer after impoundment, with elevated temperatures ranging up to 27.4^{o}C, compared to highs of 25.8^{o}C before impoundment. Peak water temperatures were roughly 3 to 4^{o}C lower downstream of Twin Valley Reservoir following impoundment, and always below a temperature guideline. Dissolved oxygen (DO) levels fell below the 5 mg/L Alberta guideline both before and after impoundment in the Little Bow River upstream from Twin Valley Reservoir, but did so less frequently after impoundment. Dissolved oxygen levels at the site on the Little Bow River downstream from Twin Valley Reservoir were extremely low after impoundment in 2003 and 2007, but were otherwise over the guideline. Declines in DO likely reflected oxygen demand from newly flooded soils in the reservoir, decomposition of plant material, and other factors.

The Central Basin of Twin Valley Reservoir had weak thermal stratification most summers. In contrast, relatively shallow Clear Lake displayed no evidence of thermal stratification, and very little anoxia. Much of the water column of the Central Basin of Twin Valley Reservoir was anoxic during the summer of 2003, after first filling. Periods of anoxia in summer decreased over time, and after 2006, there was no evidence of the predicted prolonged anoxia in winter.

Both total (TP) and dissolved phosphorus (TDP) increased significantly post-impoundment in the Little Bow River upstream and downstream from Twin Valley Reservoir to peak levels in 2006. This increase was likely a result of release from newly flooded soils, and discharge from Frank Lake, which occurred every summer but 2004. Discharge from Frank Lake is not related to the construction or operation of Twin Valley Reservoir. In contrast TP and TDP levels in Mosquito Creek declined post-impoundment, because of greatly-improved wastewater treatment at the Nanton WWTP.

A phosphorus budget that accounted for all sources and losses of TP in Twin Valley Reservoir was prepared by mass balance analysis. Results of the mass balance indicated that Mosquito Creek generally contributed a greater TP mass during 2004 to 2010 (on average 9305 kg) than the Little Bow River (average 8681 kg). Most of this came from nonpoint sources in this basin such as erosion on Women's Coulee and various agricultural sources. Although discharge from the Nanton WWTP was by far the largest point source of TDP entering Mosquito Creek historically, following implementation of tertiary treatment this was a relatively minor point source of TP. Frank Lake was the most important point source of nutrients entering the Little Bow River, accounting for 20 to 58% of the loading in summer from the Little Bow Basin to Twin Valley Reservoir.

All basins of Twin Valley Reservoir had very high levels of TP and TDP, well above the ASWQ guideline except for 2010, due to phosphorus release from newly-flooded soils and discharge from Frank Lake. TP concentrations and mass peaked in 2006, and have since declined, perhaps

because trophic upsurge has ended. Results from a mass balance using 2004 to 2010 data, indicated that Twin Valley Reservoir retained most of the TP that entered, on average a net deposition of 3116 kg per year. These results also indicate that internal phosphorus loading occurred every summer except 2010. Clear Lake had even higher TP and TDP levels than Twin Valley Reservoir, from Mosquito Creek phosphorus loadings, and because it is a terminal basin and constituents will concentrate over time with evaporation.

All forms of nitrogen increased significantly in the Little Bow River and Mosquito Creek post-impoundment, but declined in 2010 at most sites. In spite of the increase, guidelines for the protection of aquatic life were seldom exceeded for any form of nitrogen except for TN, which was also exceeded before impoundment. Elevated nitrogen in the Little Bow River from 2003 to 2008 likely reflected decomposition during trophic upsurge. Reasons for increased nitrogen levels in Mosquito Creek after 2003 are not understood at this time. Total ammonia and nitrate+nitrite never exceeded guidelines for the protection of aquatic life in the euphotic zone of Twin Valley Reservoir or Clear Lake. Levels of various forms of nitrogen were highest after first filling then declined in 2010. This suggests the temporary increase in nitrogen was due to trophic upsurge. Nitrogen levels have not declined to the same extent in recent years in Clear Lake, presumably because this water body did not undergo the same process of trophic upsurge after levels were stabilized.

Periphytic algae declined above the reservoir at Highway 533 after impoundment, probably as a result of higher flows and scouring. There was no significant change in this variable at other sites, or the abundance of aquatic macrophytes at any site. High levels of nutrients and suitable habitat likely provided ideal conditions for growth of aquatic plants, both before and after impoundment. Twin Valley Reservoir and Clear Lake are productive water bodies, with high phosphorus levels and nuisance algal blooms that sometimes exceeded the maximum phytoplankton chl *a* levels predicted by modelling. However, both Clear Lake and the Central Basin of Twin Valley Reservoir were eutrophic most sampling years, rather than the hypertrophic conditions that were predicted. Results suggest that non-algal turbidity inhibits phytoplankton biomass in these water bodies, and Clear Lake appears to be a nitrogen-limited water body. It will likely not respond to external phosphorus loading as a phosphorus-limited lake would respond.

Both *E. coli* and fecal coliforms increased significantly post-impoundment at sites on the Little Bow River and in Mosquito Creek, and exceeded both contact recreation and irrigation guidelines at various sites, most often in Mosquito Creek. Higher coliform counts appeared to be related to precipitation, rather than reservoir operations, as the highest counts occurred in two of the wettest years (2006, 2009). Increased loadings of coliforms from the Nanton WWTP have likely also occurred over time. Coliform counts were generally not a concern in the reservoirs.

Water transparency (as Secchi depth) in Clear Lake and the Central Basin of Twin Valley Reservoir was generally within a range typical of eutrophic lakes. However, there were individual years with much higher clarity in separate basins of Twin Valley Reservoir. This seldom occurred in Clear Lake, which had reduced clarity due to fine suspended inorganic material.

As predicted, turbidity and suspended sediments have increased significantly and exceeded guidelines following impoundment in the Little Bow River upstream from Twin Valley Reservoir, due to the higher flows required to fill the reservoir and scouring of the upstream channel. These variables also increased and exceeded guidelines in lower Mosquito Creek, where no change in water quality was predicted. Previous work in 1999 determined that sources along Women's Coulee contributed more suspended sediment than any other source along Mosquito Creek. Surveys during 2003 to 2006 suggest that erosion near the buffalo jump on Women's Coulee contributes the bulk of the suspended sediment from that coulee.

Both Twin Valley Reservoir and Clear Lake have moderately high levels of suspended solids and turbidity, perhaps related to wind-induced resuspension of sediments, bank erosion, or loading of increasingly-turbid water from tributaries. Non-algal turbidity in these reservoirs appears to inhibit phytoplankton biomass and this effect is strongest in Clear Lake.

Salinity, as indicated by TDS, increased significantly after impoundment at sites on the Little Bow River upstream and downstream from Twin Valley Reservoir at Carmangay. This may reflect release of salts from newly-flooded soils, and discharge of saline water from Frank Lake. TDS also increased after impoundment in Mosquito Creek, and levels were higher than in the Little Bow River. Sodium, sulphate and conductivity increased significantly post-impoundment at most sites on running water, while chloride only increased in the Little Bow River at Highway 533, and in Mosquito Creek. TDS levels were somewhat lower in 2010 at all sites, but still at times over the irrigation guideline.

TDS at all these sites exceeded the 500 mg/L guideline for the irrigation of sensitive crops (raspberries, strawberries, beans, carrots), but remained within a range acceptable for more salinity-tolerant crops (wheat and other grains). Suitability of water from these sites for irrigation should be evaluated based on the salinity-tolerance of individual crops.

TDS in Clear Lake was above the water quality guideline to protect sensitive crops before filling in 2002, briefly fell below the guideline, and then was again above the guideline from 2006 to 2008. In 2008, TDS in Clear Lake was not at levels that would impact more salinity-tolerant crops. Individual ions and conductivity followed the same pattern as TDS in Clear Lake. This increase may reflect increased salt concentration from evaporation, without sufficient withdrawal for irrigation and other uses.

Total selenium increased significantly in the Little Bow River upstream and downstream from Twin Valley Reservoir and in Mosquito Creek after impoundment, and sometimes exceeded the aquatic life guideline until 2007-2008, but remained below this guideline thereafter. Accordingly, the increase in selenium may be temporary. Similarly, total mercury levels were sometimes above the guideline for inorganic mercury until 2008 at all sites on running water, but not thereafter. These mercury results appear to reflect the predicted mobilization of mercury from newly-flooded soils due to reservoir operation. Total arsenic increased significantly in the Little Bow River upstream and downstream from Twin Valley Reservoir. However, at both locations total arsenic generally remained below the water quality guideline. Other metals such as aluminum and iron also exceeded guidelines at various locations on running water both before and after impoundment, and accordingly high levels of these metals appear to reflect natural sources rather than reservoir operation.

Total selenium and mercury also temporarily increased above guidelines in Twin Valley Reservoir after first filling and in Clear Lake after stabilization. This likely reflects release of these metals from newly-flooded soils. Nearly all arsenic results from Clear Lake after lake stabilization exceeded the aquatic life guideline, but not the CCME livestock guideline. Total arsenic levels in Clear Lake declined somewhat after 2004, but remained well above the guideline. Although arsenic exceeded the aquatic life guideline, it remained below levels known to cause acute and chronic toxic effects on aquatic life.

High levels of organic carbon in drinking water supplies treated with chlorine can result in carcinogenic disinfection byproducts. Total (TOC) and dissolved organic carbon (DOC) increased significantly, doubling in the lower Little Bow at Carmangay following the impoundment of Twin Valley Reservoir. Levels of these variables declined somewhat in 2010, but remained well above the water quality objective used to evaluate these results. Levels also increased in the Little Bow River upstream after impoundment, but there was not a significant increase in Mosquito Creek. DOC levels in Twin Valley Reservoir were also relatively high and peaked around 12 mg/L in 2006. DOC levels were higher still in Clear Lake. Increased organic carbon at the sites on running water could be due to discharge from Frank Lake, increased algal production in Twin Valley Reservoir, or runoff during wet years. If primary production in Twin Valley Reservoir continues to decline, there could be a decrease in TOC downstream over time. However, since Frank Lake appears to be an important source of organic carbon, water treatment could remain a concern when Frank Lake discharges.

Water quality predictions from the environmental impact assessment before approval of this project, were evaluated using results of this study. Modelling predictions were correct in four of the 19 cases that were evaluated (21%). Notable cases where conditions were better than forecast (47%) included lower productivity in both Twin Valley Reservoir and Clear Lake, less extensive winter anoxia, no evidence of toxic levels of ammonia downstream, and no significant increase in the growth of aquatic plants in the Little Bow River upstream from the reservoir. Water quality deteriorated in about a third of the cases evaluated (32%), including coliforms, salinity, suspended solids in Mosquito Creek, increased salinity in Clear Lake, and fish mercury levels that exceeded consumption guidelines in Twin Valley Reservoir.

It is recommended that monitoring continue with a focus on specific variables and sites of concern. Specific concerns that need to be evaluated by monitoring over the long term include arsenic and the effects of irrigation expansion on salinity in Clear Lake. Increasing levels of coliforms, salinity, and suspended sediments in Mosquito Creek also need to be monitored. Also of concern are the effects of increased organic carbon and reservoir productivity on drinking water supplies from Twin Valley Reservoir and downstream, along with temporal trends in mercury and selenium and other metals. Future efforts to reduce phosphorus loading to Twin Valley Reservoir should target nonpoint sources on Mosquito Creek and control of discharge from Frank Lake.

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ACKNOWLEDGEMENTS

I thank all technical and professional staff of Alberta Environment who assisted in the sampling of Twin Valley Reservoir and Clear Lake, and associated water bodies during this sampling program, from 1999 to 2010. Bridgette Halbig provided assistance in graphics and report preparation; Doreen LeClair, Chris Rickard, and Jay Parsons of Alberta Environment provided data compilation. Linh Duong, a Limnology Summer Student with Alberta Environment kindly prepared the sampling site map, with supervision by Natalie Kromrey. The manuscript was improved by comments from anonymous reviewers from Alberta Environment and Water.

ABBREVIATIONS

AENV	Alberta Environment
ASWQG	Alberta Surface Water Quality Guideline
BRBC	Bow River Basin Council
CCME	Canadian Council of Ministers of Environment
CEQG	Canadian Environmental Quality Guideline
Chl *a*	Chlorophyll *a*
dam^3	cubic decametres (1 dam^3 = 1000 m^3)
d/s	downstream
EIA	Environmental Impact Assessment
m	metres
mm	millimetres
m^3/s	cubic metres per second
NRCB/CEAA	Natural Resources Conservation Board and Canadian Environmental Assessment Agency
OECD	Organisation for Economic Co-operation and Development
PAL	Protection of Aquatic Life
µg/L	micrograms per litre
WSC	Water Survey of Canada
WWTP	Waste Water Treatment Plant

1.0 INTRODUCTION

Twin Valley Reservoir was first filled in 2003 following construction of a new dam on the Little Bow River near its confluence with Mosquito Creek. To fill and operate the new reservoir, increased diversion from the Highwood River to Women's Coulee and to the Little Bow River occurs in spring according to an approved water management plan (AENV 2008). An existing lake, Clear Lake, was also stabilized by diversion from Mosquito Creek near the mouth first operated in 2002, and additional enhancements. This lake is one of the few that naturally occurs in this relatively arid region, and stabilization provides recreational opportunities, and potential for irrigation expansion.

This report presents an evaluation and statistical analysis of water quality in Twin Valley Reservoir, Clear Lake, and their tributaries that was prepared using intensive monitoring data collected by Alberta Environment (AENV) from 1999 to 2010, with reference to previous baseline sampling where needed for statistical testing. Previous sampling included monthly sampling year-round in 1982 (Hamilton 1983) and 1990-1991 at the same sampling locations. The pre-impoundment sampling completed in 1999 and 2000 (Sosiak 2000) included sampling for water quality and flow gauging at more sites throughout the basin, and included automated daily sampling for total phosphorus and hourly monitoring for dissolved oxygen, water temperature, pH, and conductivity at key locations. This program was designed to document conditions basin-wide before impoundment, and provides information that could be used in future efforts to reduce nutrient loading from the watershed to Twin Valley Reservoir.

Sosiak Environmental Services was contracted by AENV (since renamed Alberta Environment and Water) to conduct this evaluation and analysis according to the following terms of reference:

1. Assemble all water quality and temperature data collected for the Twin Valley Water Management Project up to and including data collected in 2010. Data sources to include reservoir and river grab sampling and datasonde results. Water bodies to include Twin Valley Reservoir, Clear Lake, Little Bow River, and Mosquito Creek.
2. Describe the water quality characteristics for each water body including guideline exceedances and suitability for agriculture, recreation, and aquatic life. The description will focus on key variables of concern including nutrients, arsenic, selenium, salinity, and cyanobacterial toxins. The results will be compared to water quality predictions for the project water bodies.
3. Complete a phosphorus (P) mass balance for Twin Valley Reservoir. The analysis will identify the amount and significance of P loading from Frank Lake. The analysis will include total nitrogen if data are appropriate.
4. Describe the limnology of Twin Valley Reservoir and Clear Lake. Selected variables will be presented in detail. The report will focus on trophic state and factors that control productivity in the reservoirs. A data summary for all variables and isopleths for profile data will be provided. The results will be compared to water quality predictions for the project water bodies.

Although groundwater concerns were identified in the environmental impact assessment and a separate well monitoring program was conducted, this report is restricted to surface water quality as specified in the terms of reference in the contract.

Since Clear Lake has been artificially enhanced by diversion from Mosquito Creek, to store water and maintain a higher lake levels than would occur naturally, it now functions more like a reservoir and will be considered such in this report.

2.0 METHODS

2.1 Sampling Methods and Analysis

Locations of reservoir and tributary sampling locations are in Figure 1. All sampling followed field methods described in AENV (2006).

Twin Valley Reservoir and Clear Lake were sampled once per month in the open water season generally from May to October. A composite sample was collected from each of three basins in Twin Valley Reservoir from 2003 to 2010, except for 2009, when open water sampling was not done after the winter due to budget constraints. Clear Lake was sampled from 2002 to 2008. The riverine area near the inflow of the Little Bow River to Twin Valley Reservoir (West Basin) and the area near the inflow of Mosquito Creek (Mosquito Basin) were sampled separately for a subset of variables. These were reservoir zones influenced by rivers and isolated from the main central basin. Narrow constrictions in the reservoir formed the riverine basin boundaries. A profile site (described below, approximate locations in Figure 1) was also established at the deepest location in each of the basins. The central basin of Twin Valley Reservoir was sampled for all variables. The profile site was sampled consistently at the deepest location near the dam. A single composite sample was also collected once per month from Clear Lake along with profile measurements.

Grab samples were collected once per month year round at the Little Bow River at Highway 533, Little Bow River downstream of Twin Valley Reservoir, Little Bow River at Carmangay, and Mosquito Creek at Highway 529 (Figure 1) starting in 1999. The site on the Little Bow River downstream from Twin Valley Reservoir was the first well-mixed location with road access below the reservoir, and was sampled for nutrients and non-filterable residue (NFR). Other sites on running water were sampled for a comprehensive variable list similar to the long term river monitoring network in Alberta. Periphytic chlorophyll *a* (periphytic chl *a*) was sampled using a template scraping method (AENV 2006) throughout this program at key locations in this basin. Macrophytes within a 30.48 cm x 30.48 cm frame were uprooted by hand and collected in a 3-mm-mesh sampling net, at random locations along a transect across the river (AENV 2006).

The combined municipal and industrial influent to Frank Lake, and the discharge from Basin 3 were sampled monthly for nutrients, NFR, coliforms, mercury, dissolved organic carbon (DOC), BOD_5 and total dissolved solids (TDS) when Frank Lake discharged, along with sites on the Little Bow River immediately upstream and downstream from the confluence of the channel

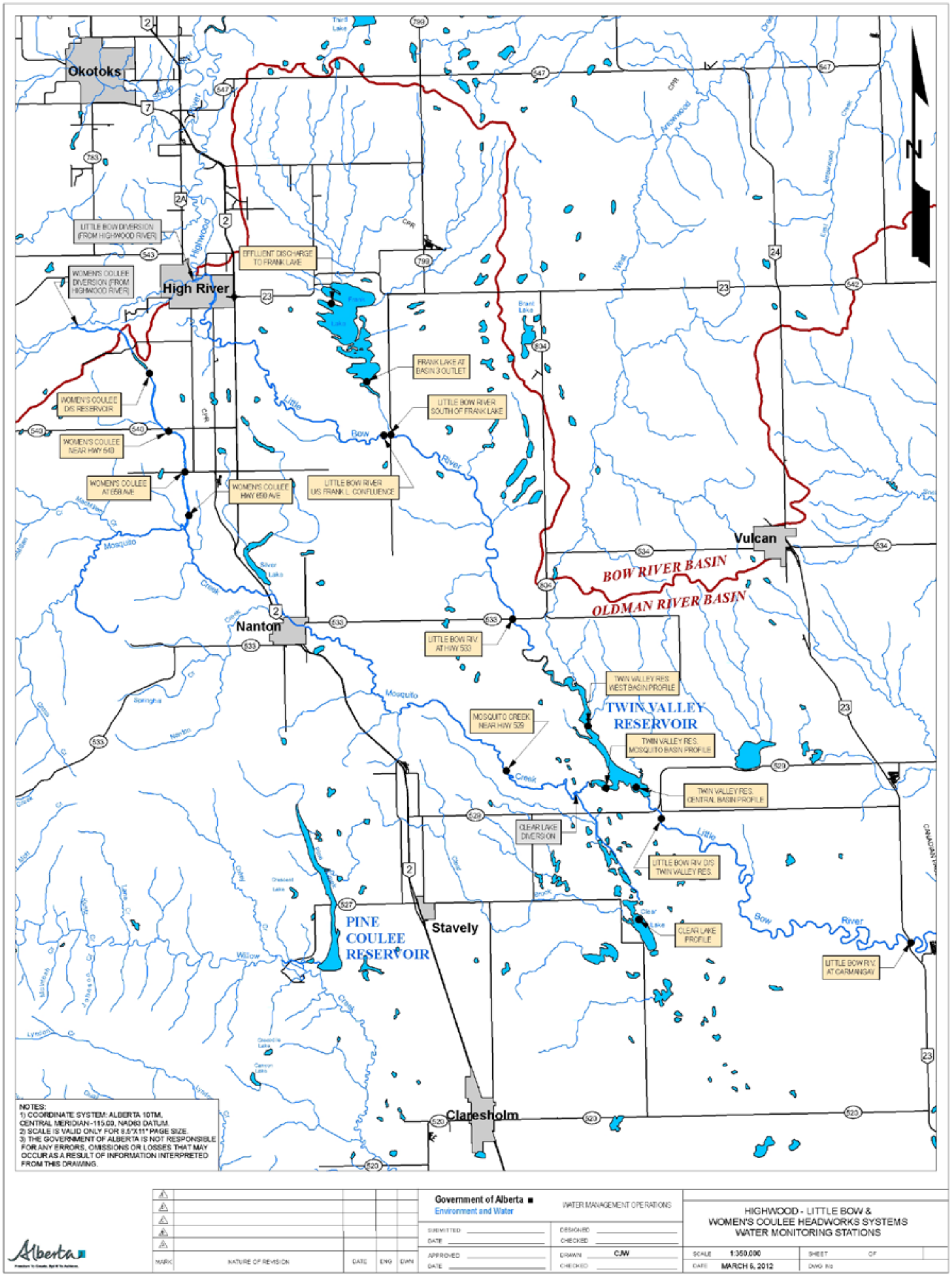


Figure 1 Water quality sampling on Twin Valley Reservoir, Clear Lake and tributaries

from Frank Lake (Figure 1). Sampling at Frank Lake began in 1996 when Frank Lake first began to discharge, and was designed to evaluate contributions from Frank Lake to the Little Bow basin. Four locations on Women's Coulee were sampled above and below a reach with extensive bank erosion for phosphorus and NFR. Locations are provided in Figure 1. Note that the name for station AB05AC1330 on Women's Coulee has been changed for this report, from that used in the provincial database because the name in the database includes the surname of an area resident.

Water temperature, dissolved oxygen, pH, and specific conductance were measured on all sampling trips on running water using Hydrolab or Yellow Springs Instruments (YSI) minisonde meters. Hydrolab or YSI datasondes were installed during the open water season (usually late June to the end of September), and used to record water temperature, dissolved oxygen (DO), pH, and specific conductance at least hourly. Datasondes were installed at the Little Bow River at Highway 533, Little Bow River downstream from Twin Valley Reservoir and Mosquito Creek at Highway 529 each year from 1999 to 2010, except 2002 and 2009. Datasonde temperature measurements were verified when instruments were changed with a certified thermometer and DO was verified by Winkler titration. Datasondes and minisondes were calibrated prior to each deployment.

Winter samples were collected once per month at the deepest site in each basin, in February or March, as ice conditions allowed. Samples were collected at mid-depth in winter for all variables except for phosphorus and phytoplankton chlorophyll *a*, which were also sampled just below the ice and within one metre of the lake bottom.

Depth profiles of temperature, DO, pH, specific conductance, and redox were measured at a one meter depth interval at the deepest site in each basin with Hydrolab meters (Hydrolab, Austin, Tx), with regular verification of DO by Winkler titration. Water samples were also collected at discrete two-metre intervals throughout the water column, except for the final three metres from the bottom, which were sampled at a one-meter interval. These samples from these profile sites were analyzed for total phosphorus (TP) and total ammonia at the deepest interval.

To sample nutrients and related variables throughout the depth of light penetration (euphotic zone), and algal growth, vertically integrated, composite water samples were collected using a tube sampler from 10 sites in each basin and pooled by basin for chemical analysis. The euphotic zone was defined as the interval between the surface and the depth of 1% of surface penetrating light. Light penetration was routinely measured with either a Protomatic (Protomatic, Dexter, MI) or a Li-Cor (Li-Cor Biosciences, Lincoln, NEB) underwater photometer.

Euphotic zone composite samples from these reservoirs were analyzed for TP, TDP, and chlorophyll *a* concentration during 2003 to November 2005 at the Monitoring Branch, Alberta Environment (AENV) laboratory in Edmonton. Thereafter chlorophyll *a* alone was done at the Alberta Research Council (formerly the Alberta Environmental Centre) laboratory in Vegreville, Alberta. Except for microbiology, all analysis was done at Maxxam Analytics Inc., Calgary. Grab samples were collected from the surface at the profile sampling sites and all running water sites, and analyzed for fecal coliform bacteria and *E. coli* counts at the Provincial Health Laboratory for Southern Alberta.

2.2 Data Analysis

To permit numerical analysis, values less than analytical detection limits were replaced by values one-half the detection limit. Data were then compared to the Alberta Surface Water Quality Guidelines (ASWQG), (AENV 1999) or Canadian Environmental Quality Guidelines (CEQG) (CCME 2011a). These guidelines included the recently released CEQG chloride for the protection of aquatic life (PAL) (CCME 2011). For Total Organic Carbon (TOC), which has no national guideline, a 5.0 mg/L objective recommended by the Bow River Basin Council (BRBC 2008), and accepted by Bow River basin stakeholders, has been used to evaluate effects on municipal water supplies. SAR was evaluated using the safety threshold of 4 units, recommended by AENV (2002). To evaluate turbidity data relative to the CCME guideline, pre-impoundment measurements were used to calculate background concentration.

Guidelines for the most sensitive use, appropriate to aquatic species and water uses in this basin, were used. The guidelines used in this review are stated on the individual figures and tables.

To evaluate changes in TP mass in Twin Valley Reservoir over time, the mass in the reservoir basin for each sampling date was estimated from measured TP concentrations and volume estimates at all depth intervals, based on an area-capacity table and curve supplied by Water Management Operations, AENV. Surface interval volumes were adjusted to reflect the actual lake level on each sampling date.

To evaluate the impacts on water quality in running water of impoundment and revised diversions through tributaries, changes in chemistry before and after first filling of Twin Valley Reservoir in 2003 were evaluated using step trend analysis. Step trend analysis tests for immediate incremental changes in water quality, and was completed using procedures in the computer program WQHYDRO (Aroner 2011). Statistically-significant changes in concentration were tested using the Seasonal Wilcoxon-Mann-Whitney test, and changes in mean concentration were calculated using the Seasonal Hodges-Lehman estimator. As recommended by Ward et al. (1990), a $P = 0.10$ level of statistical significance was used to assess the results of all trend tests. Data were not flow-adjusted to compensate for changing flows over time, which can influence typically flow-dependant variables such as suspended solids. All step trend analysis used nonparametric statistical tests corrected for seasonality, which are not affected by concerns such as data that are not normally distributed, and hence data were not transformed.

The OECD fixed boundaries (OECD 1982) for TP, phytoplankton chlorophyll (chl) *a*, and Secchi depth were used to evaluate the trophic state of the various basins in Twin Valley Reservoir and Clear Lake. These data were compared to the predictions for water quality and trophic state in the environmental impact assessment prepared for these reservoir projects by Alberta Public Works Supplies and Services (APWSS) (1995).

To evaluate the degree of phosphorus and nitrogen limitation in these reservoirs, and understand the response of phytoplankton, the ratio of biologically-available nitrogen to phosphorus concentrations was calculated, as: [total ammonia]+[nitrate+nitrite]/[total dissolved phosphorus] (TDP). Euphotic zone composite sample results were used for this calculation.

The effects of non-algal turbidity on phytoplankton biomass, as phytoplankton chl *a*, were evaluated in 2006 (Sosiak et al. 2006) by regressing light extinction against phytoplankton chl *a* with a linear model. The magnitude of the Y-intercept indicates the amount of light extinction due to factors other than chlorophyll.

Light extinction (E) was estimated using the following equation:

$$E = \frac{\ln(Io) - \ln(I)}{z}$$

Where:

Io is the initial light intensity, usually the sub-surface light reading

I is the intensity at depth z

z is the thickness of the water column through which the light passes, the euphotic zone

Mass balance analysis allows one to evaluate TP loadings and export from a lake or reservoir, including internal sources such as sediment phosphorus release. This type of analysis allows one to evaluate the relative importance of various sources from a management perspective, and develop a phosphorus budget for a reservoir. This analysis is generally done for phosphorus, on the assumption that phosphorus is the nutrient that is most often in short supply, and thus likely to limit algal growth. This assumption is generally correct for lakes from temperate northern regions of the world.

Net internal phosphorus loading (or deposition) in Twin Valley Reservoir was estimated using a conventional mass balance equation, where for each sampling interval[a]:

Deposition/Release = outflow P load [c] - (atmospheric P-loading to lake surface[b] + sum of all stream loadings[d])+/- (change in lake P mass[e])

[a] = interval refers to loading during days prior to and including each lake sampling day;

[b] = average of TP mass deposited for each sampling interval in wet and dry precipitation directly onto the 8.6 km^2 reservoir surface area at full supply level. Since the reservoir was generally maintained close to FSL, and atmospheric deposition was small compared to other external sources, a constant 8.6 km^2 surface area was used for all time periods;

[c] = based on regular grab sampling of the Little Bow River immediately downstream of the new reservoir, the outflow site.

[d] = based on regular grab sampling of Mosquito Creek at Highway 529 and the Little Bow River at Highway 533. Daily flow estimates were supplied by AENV and Water Survey of Canada for all tributary locations. Clear Lake Diversion Canal flows were subtracted from Mosquito Creek flows near the mouth. Diffuse loadings directly to the reservoir from seasonal runoff channels were assumed to be negligible as this is relatively dry region and there is no data on ephemeral channels. Diffuse loadings have not been included in the analysis;

[e] = profile [TP] in the Central Basin times stratum volume over the entire reservoir based on an area capacity table and curve supplied by AENV. Volume in the surface stratum was adjusted for measured fluctuations in water level between sampling dates.

A positive residual was taken as an estimate of net internal loading, mainly from sediments. Negative value was taken as an estimate of deposition to sediments and uptake by organisms. Groundwater loading is not separately included in this calculation, as accurate estimates are not available, but would be included in the residual. The mass balance spreadsheet with the results of calculations for each cell is provided in Table 2 in Section 3.3.3.

Median TP concentrations in wet and dry precipitation samples collected at Eagle Lake, Alberta in 1988 (Bonke and Sosiak 1989) were applied to precipitation data from the Environment Canada weather station at Champion, Alberta, and used to estimate the dry aerial deposition and precipitation TP loading directly onto the surface of Twin Valley Reservoir during 2003 to 2010. The Eagle Lake data appear to be the only available TP deposition data for this region of Alberta, and best represent deposition at Twin Valley Reservoir for the mass balance analysis.

Sodium adsorption ratio (SAR) was calculated using the following formula:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Where:

concentrations of sodium, calcium, and magnesium are expressed in milliequivalents per litre.

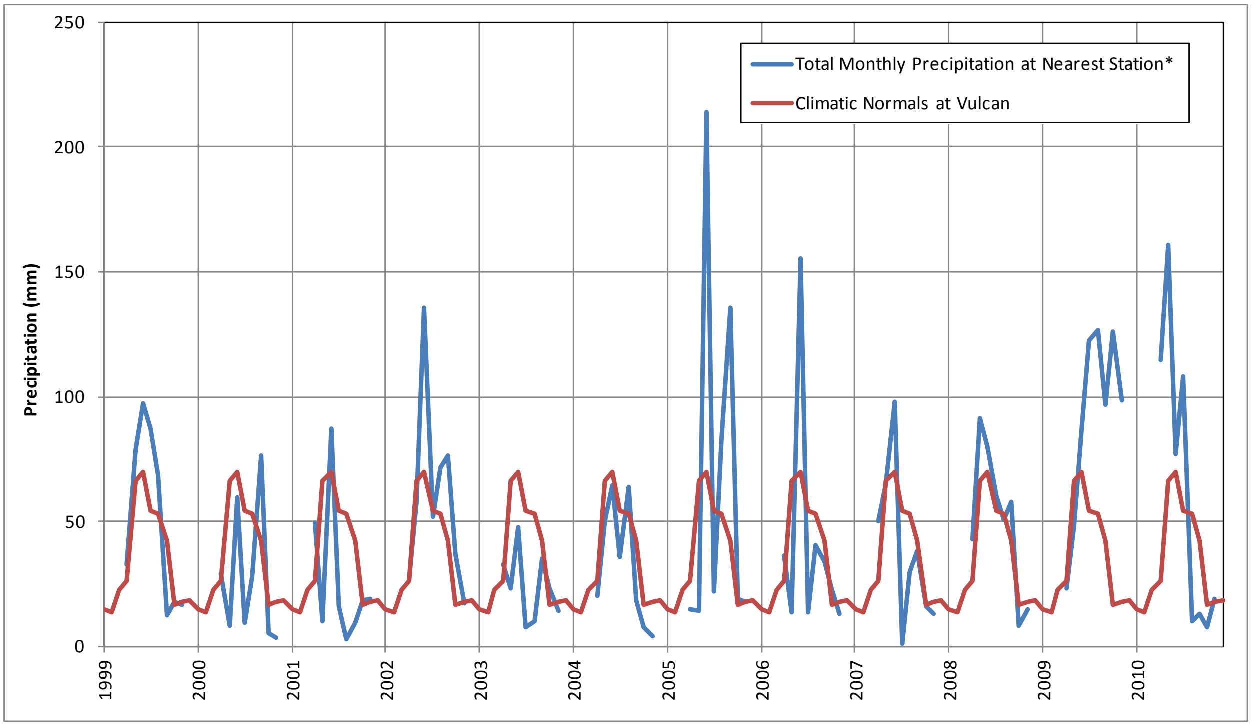
3.0 RESULTS AND DISCUSSION

Changes in key physical, chemical, and biological variables in Twin Valley Reservoir, Clear Lake and tributaries after impoundment are discussed in the following sections. Variables selected for intensive statistical analysis were those that were evaluated in modelling for the reservoir EIA (APWSS 1995), which regularly exceeded guidelines at a sampling site, or those for which there was a particular water quality concern.

Plots that compare the different basins of Twin Valley Reservoir and Clear Lake, and tributaries after impoundment are included in each section. Where important variables changed significantly in running water after impoundment, separate plots of long-term change at individual sites are also included in each section, and statistically-significant changes are summarized in Table 1. This table is first presented in section 3.3.2 (Dissolved Oxygen). Data extended back to 1982 for some variables and were included in the statistical analysis. Median concentrations for other water quality variables not discussed in detail are summarized in Appendix I. A detailed mass balance analysis for reservoir phosphorus is included in section 3.3.3 (Phosphorus). Finally changes in water quality are compared to model predictions in section 3.4.

3.1 Climate

Half the eight post-impoundment years (2005, 2006, 2009, 2010) were wetter than normal in the region near Twin Valley Reservoir (Figure 2), with major rainfall events (>60 mm rainfall per day) in 2005, 2006, and 2010 (Figure 3). One would expect more groundwater recharge, runoff and loading of some constituents to these water bodies during these wetter years. Other years had close to average precipitation. Three of these other years (2003, 2007, 2008) had maximum monthly air temperatures well above maximum climate normals for this region (Figure 4) from Environment Canada. Rainfall and air temperature data for the Environment Canada station at Champion was compared to the nearest available climate normals from Vulcan for the years 2003 to 2010. Because data were not available for the Champion station before 2003, weather data for the nearest sites at Vulcan (1999-2000) and Herronton East (2001-2002) were used.



*Vulcan (1999-2000), Herronton East (2001-2002), Champion (2003-2010)

Figure 2 Comparison of monthly precipitation at Champion and other regional weather stations* to climatic normals at the Environment Canada weather station at Vulcan, AB (climate ID 3036881).

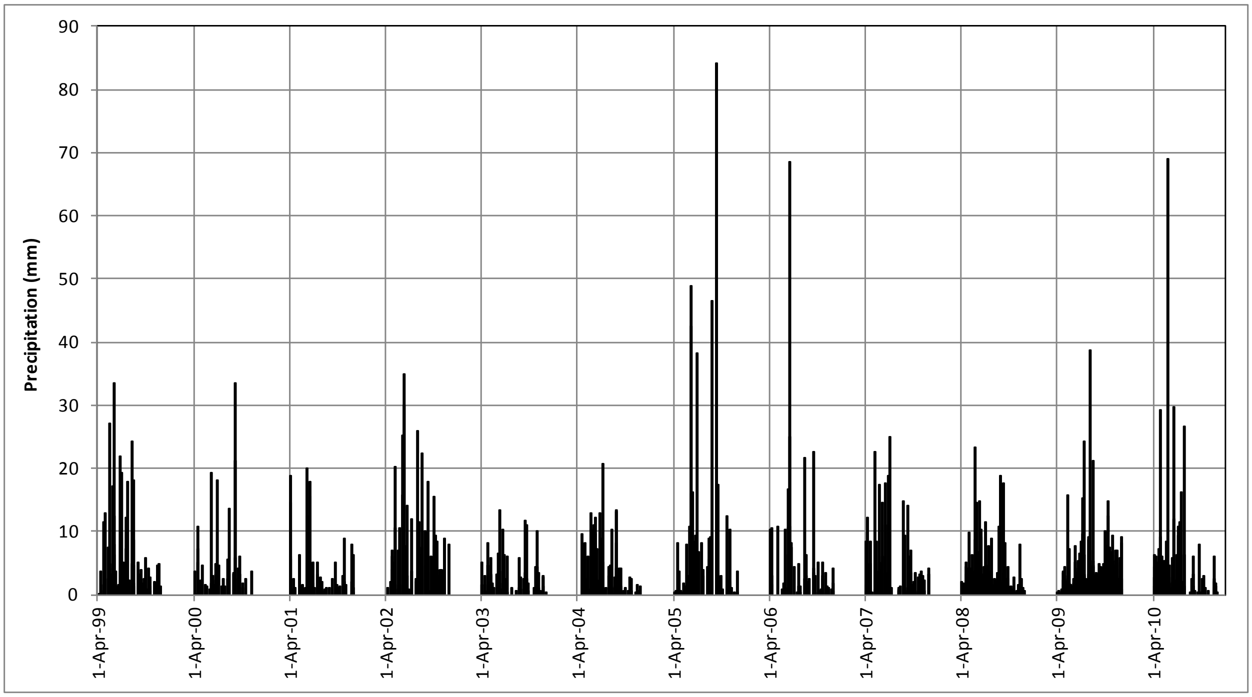
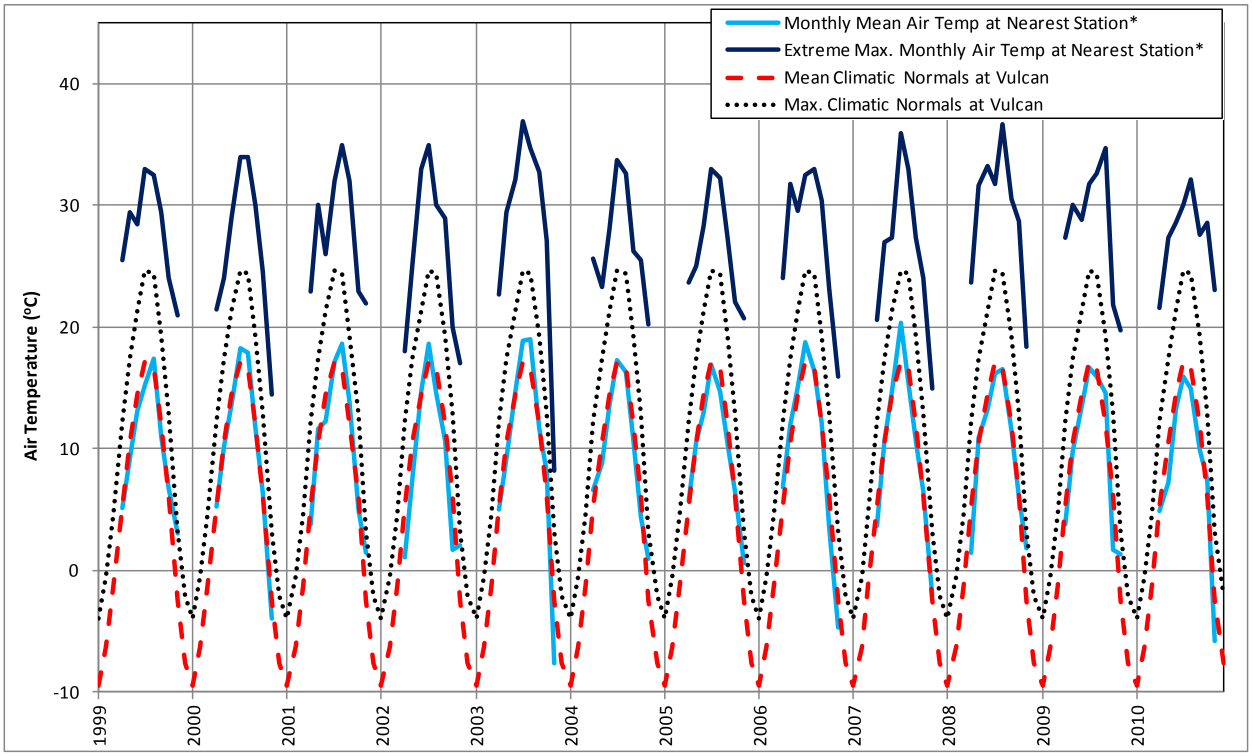


Figure 3 Daily precipitation at the Vulcan (1999-2000), Herronton East (2001-2002) and Champion (2003-2010) Environment Canada weather stations



*Vulcan (1999-2000), Herronton East (2001-2002), Champion (2003-2010)

Figure 4 Comparison of mean and extreme maximum monthly air temperature at Champion and other regional weather stations* to climatic normals at Vulcan

3.2 Hydrology

3.2.1 Inflow Tributaries

Flows and reservoir operation can have a large impact on water quality and aquatic ecosystems. This section provides a brief summary of measured flows and reservoir levels.

Flows in the Little Bow River at Highway 533 were elevated during first filling of Twin Valley Reservoir, and for the following three years, and peaked above 8 m^3/s (about 300 ft^3/s)(Figure 5). These high flows were intended to enlarge the channel to more easily convey larger spring flows. After the higher rainfall in 2006, flows were generally maintained at a much lower level, even during relatively wet periods in 2009 and 2010. Flows in Mosquito Creek near the mouth more reflected local precipitation pattern in the early years of reservoir operation, with peak flows during the relatively wet years in 2005 and 2006 (Figure 6).

3.2.2 Flow from Frank Lake

Outflow from Frank Lake was not routinely measured throughout the sampling program. However, flows were measured below Frank Lake Basin 3 most sampling trips in 2008 and 2010 and on two sampling trips in 2007.

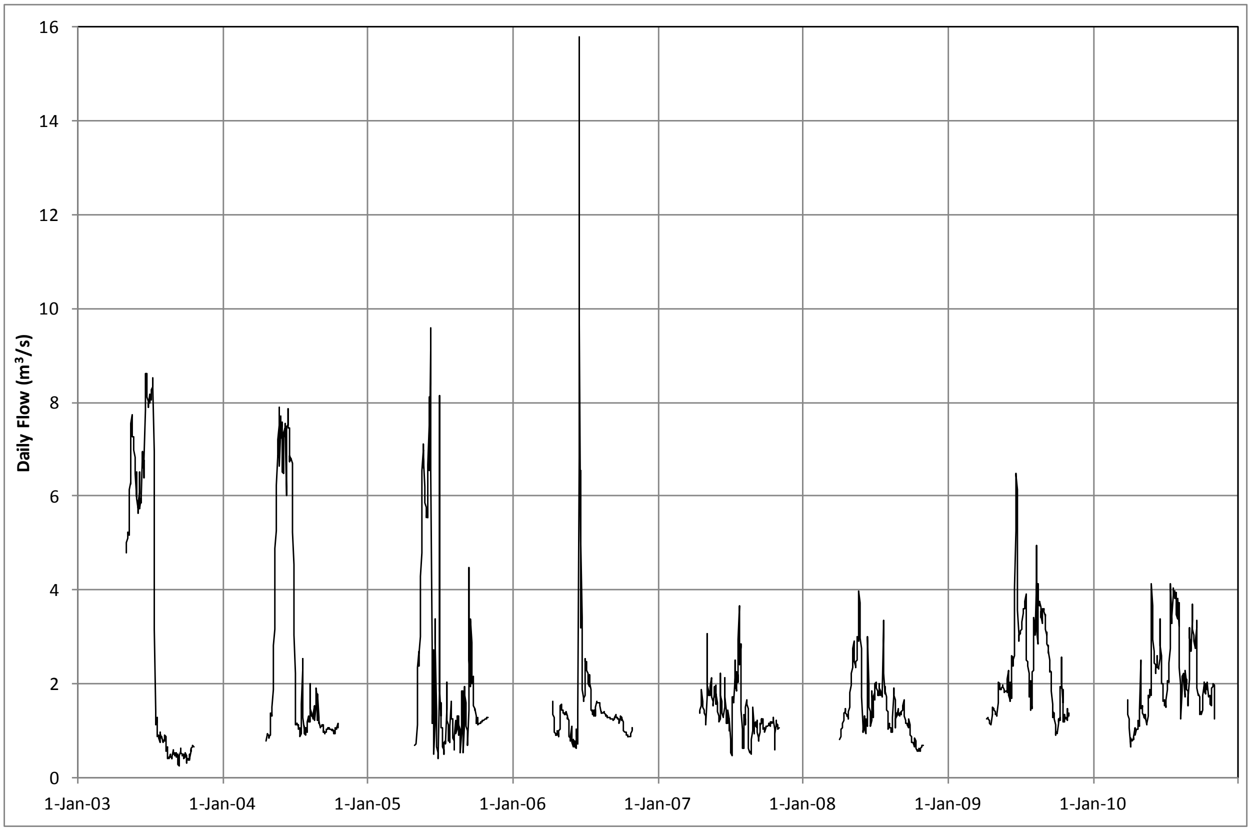


Figure 5 Daily flows for the Little Bow River at Highway 533 (05AC930), 2003-2010

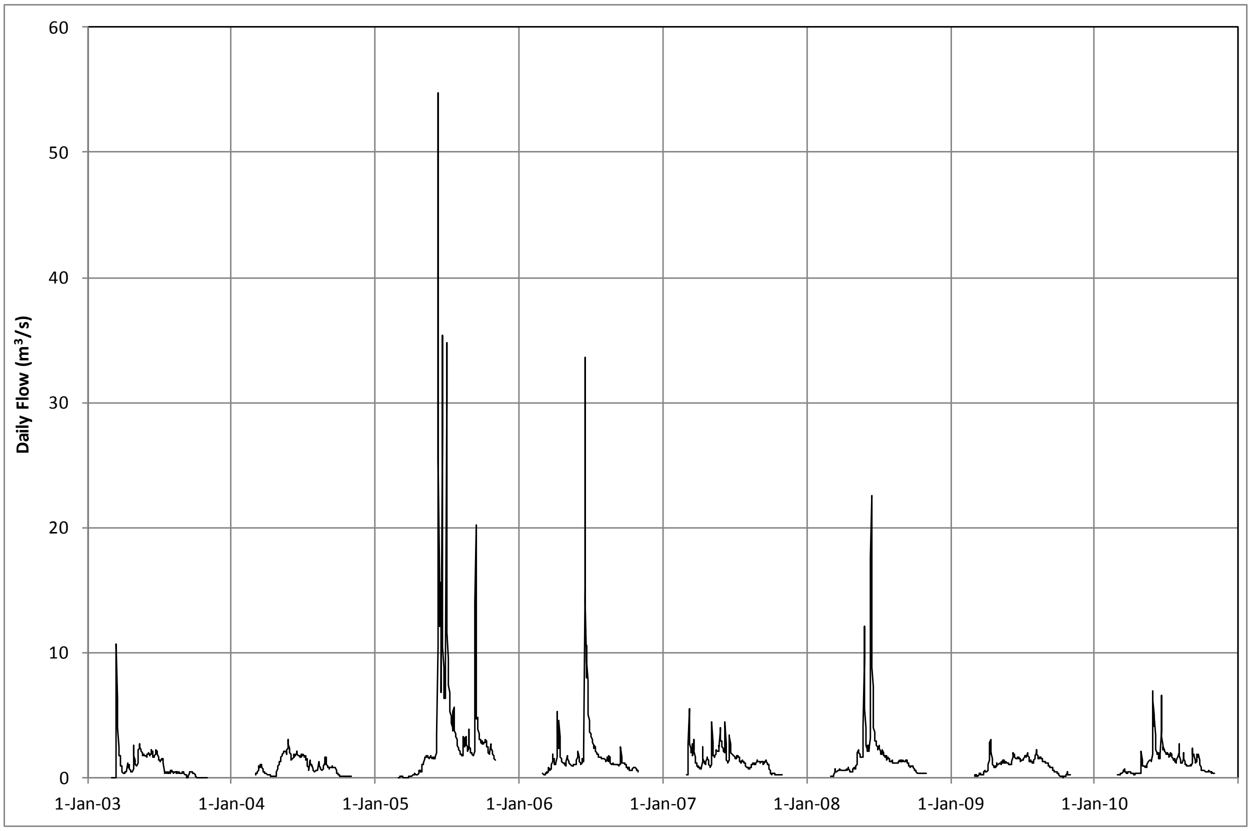


Figure 6 Daily flows for Mosquito Creek near the Mouth (05AC031), 2003-2010

Frank Lake discharged every year during 2003 to 2010 except 2004, and water quality was sampled below the Basin 3 outfall when discharge occurred. Some indication of the duration of discharge is provided by the number of sampling days at this location, which is compiled in the mass balance analysis (Table 2, in Section 3.3.3). A mass balance was not prepared for 2003 due to data constraints, but the Basin 3 outfall was sampled for 102 days that year. The three longest sampling periods for Frank Lake discharge occurred in 2006 (116 days), 2008 (118 days), and 2010 (136 days). Two of these years (2006 and 2010) had rainfall well above average. The duration of discharge from Frank Lake reflects both the amount of local precipitation and operation of the weir system at Frank Lake by Ducks Unlimited, for optimal waterfowl habitat. In particular, some of the basins are drawn down to provide better habitat for shore birds, resulting in more discharge from Basin 3 some years.

3.2.3 Lake Level

Twin Valley Reservoir was first filled in the spring of 2003, but levels did not exceed the full supply level of 964.8 m until 2005 (Figure 7). Thereafter levels fluctuated around full supply over the course of each year. Clear Lake water levels increased at least 1.5 m from 2002 to 2005, after the completion of the project and first operation of the diversion from Mosquito Creek in 2002 (Figure 8). Levels have since fluctuated annually by at least 0.5 m. Stabilization of levels in Clear Lake was one of the key objectives of the Clear Lake component of this project.

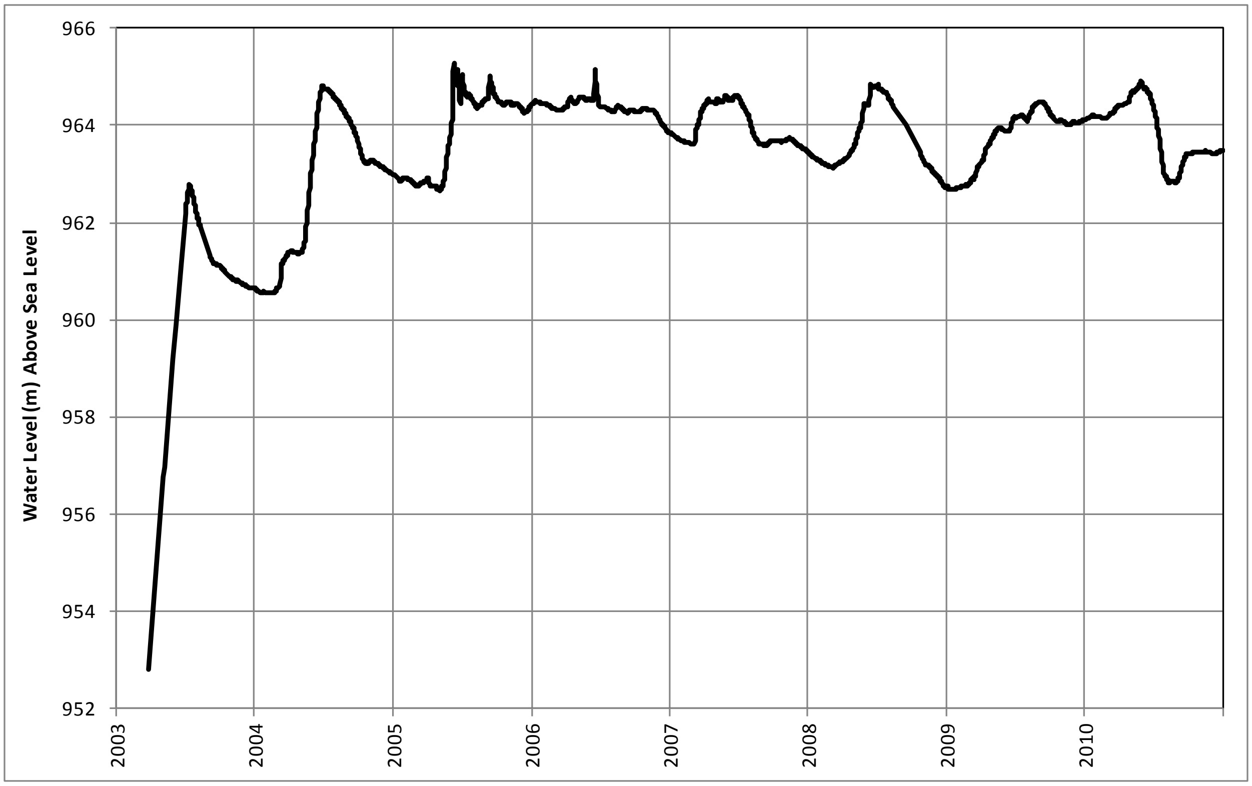


Figure 7 Daily water levels for Twin Valley Reservoir (05AC940), 2003-2010

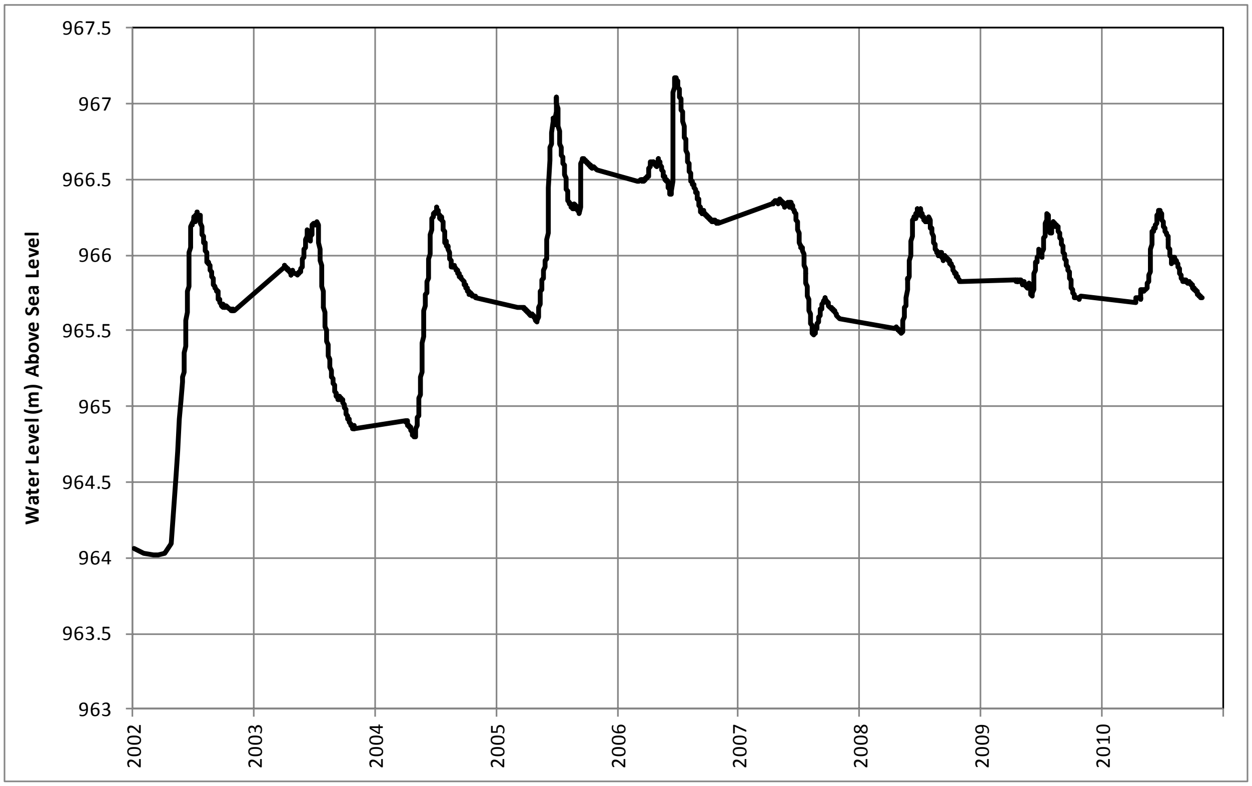


Figure 8 Daily water levels for Clear Lake near Stavely (05AC901), 2002-2010

3.3 Physical, Chemical and Biological Characteristics

3.3.1 Water Temperature and Stratification

Water temperature and thermal density stratification are important regulators of nearly all physical and chemical processes in a lake or river (Wetzel, 1983).

Running Water

Hourly water temperature was recorded during the summer before and after impoundment by datasondes installed at sites in the Little Bow River at Highway 533 and just downstream from Twin Valley Reservoir, and in Mosquito Creek at Highway 529. Although upstream tributaries are not directly affected by impoundment, except for flow alteration, for simplicity these tributaries will be described before and after the impoundment of Twin Valley Reservoir.

As predicted by modelling, water temperature was slightly higher at this upstream site in three summers (2003, 2004, and 2007) of the seven post-impoundment years (Appendix II). During those three years with elevated temperatures, maximum temperatures ranged up to 27.4^{o}C, compared to highs of 25.8^{o}C in 2000 and 2001. Higher temperatures in summer were predicted because under the operating plan for the proposed reservoir, higher rates of diversion from the Highwood River would result in 8.50 m^3/s in the Little Bow River above the reservoir during the spring (mid-April to mid-June) then lower flows than pre-impoundment and more warming in summer. Summer flows at Highway 533 seemed to influence maximum water temperatures, as one of the years with lowest summer flows (2007) had prolonged periods well above the temperature guideline used to screen the data. This was also a year with mean and maximum air temperatures well above average (Figure 4).

As expected for a bottom discharge reservoir, peak water temperatures were roughly 3 to 4^{o}C lower downstream following impoundment (Appendix II). While water temperatures often exceeded the lowest acute temperature guideline for adult fish (22^{o}C) (Taylor and Barton 1992) before impoundment, this guideline was never exceeded after impoundment and daily oscillations in water temperature were greatly reduced.

Water temperatures in Mosquito Creek at Highway 529 exceeded the guideline both before and after impoundment, but peak temperatures were slightly higher after impoundment (27.9^{o}C) than before (26.3^{o}C) (Appendix II).

Reservoirs

The Central Basin of Twin Valley Reservoir had weak thermal stratification most summers, with peak surface temperatures 22.6^{o}C during the warmest summer in July 2007, and bottom water at 15.8^{o}C (a difference of 6.8^{o}C) on the same sampling date. Warmer temperatures (around 20^{o}C) are shown as orange in the isopleths in Figure 9, and temperatures around 22^{o}C are shades of red. Water masses with equal temperatures are shaded the same colour throughout the water column. Summers such as 2003, 2004, and 2005 had more thermal stratification in the Central

Basin, which is reflected in the green shading at depth in Figure 9. In contrast there was less of a temperature gradient (yellow contours) at the bottom in 2006 to 2010.

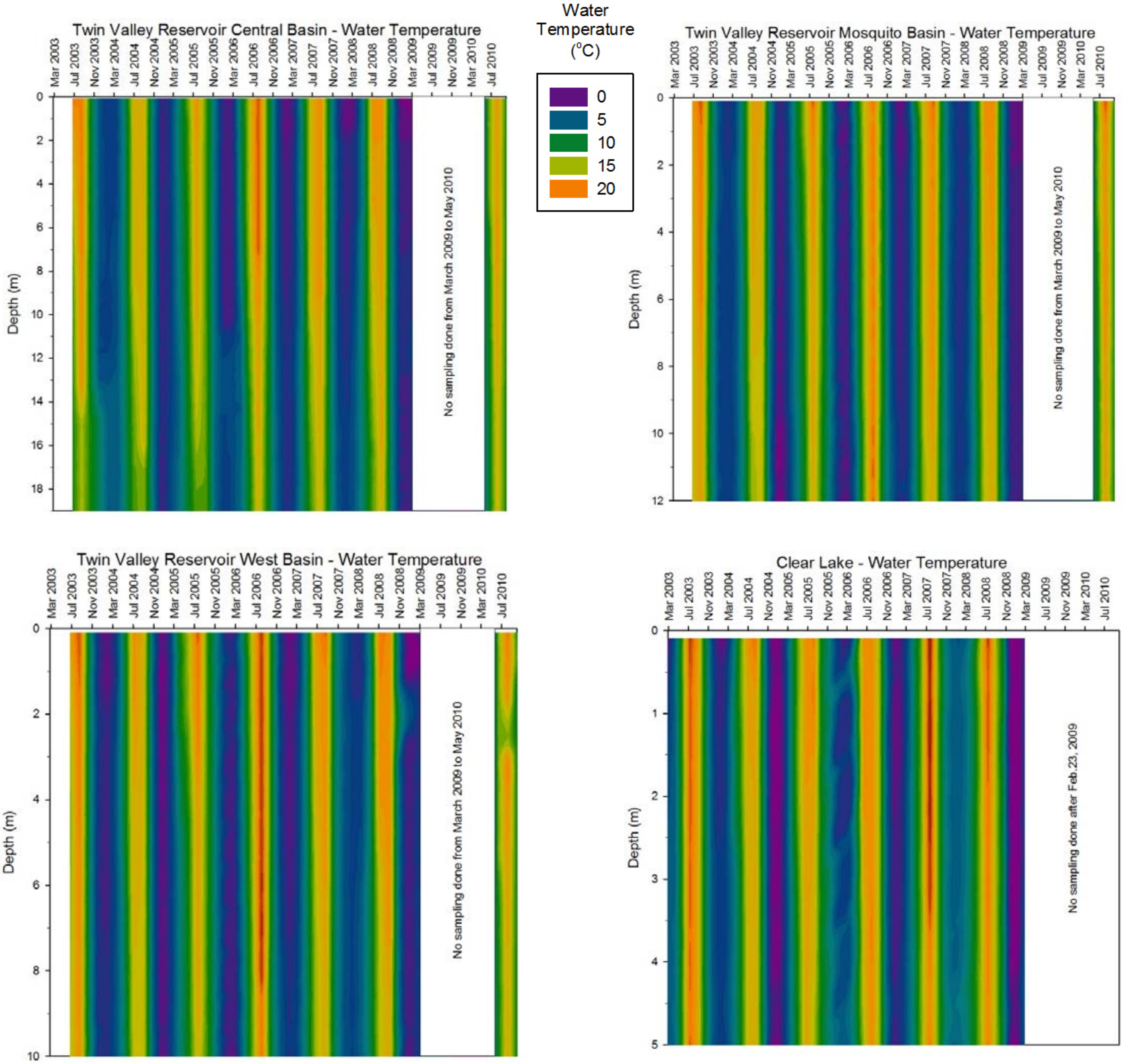


Figure 9 Water temperature profiles for Clear Lake and Twin Valley Reservoir sites, 2003-2010

In contrast, the relatively shallow West and Mosquito Basins, both likely zones of riverine influence, had less evidence of thermal stratification than the Central Basin (Figure 9). There was only a difference of 3.7°C and 4.1°C between surface and bottom water in the West and Mosquito Basins respectively on the same date. This is likely because shallow lakes are generally less apt to thermally stratify. In addition, peak surface temperatures were slightly higher in the West and Mosquito Basins than the Central Basin, at 23.2 and 22.9°C respectively. As a result of less thermal stratification, these two basins became anoxic in bottom waters infrequently compared to the Central Basin (Section 3.2.2), but anoxia did occur there in the years immediately after first flooding.

Clear Lake is even shallower than the West Basin of Twin Valley Reservoir, and displayed no evidence of thermal stratification, with peak temperatures of 23.2°C in July 2007 and only a 3.3°C difference between surface and bottom water temperatures. Most of the water column was above 20°C during the summer of 2007 (Figure 9).

3.3.2 Dissolved Oxygen

Adequate levels of dissolved oxygen (DO) are essential for the survival of fish and other aquatic organisms. Furthermore, oxygen distribution affects the solubility and availability of many nutrients, and therefore the productivity of aquatic ecosystems (Wetzel 1983).

Running Water

Hourly DO was recorded during the summer pre and post-impoundment by datasondes installed at sites in the Little Bow River at Highway 533, just downstream from Twin Valley Reservoir, and in Mosquito Creek at Highway 529. Detailed plots of datasonde results from each site are in Appendix II. Dissolved oxygen levels fell below the 5 mg/L Alberta guideline every year before impoundment (1999-2001) in the Little Bow River at Highway 533, and dropped as low as 3.29 mg/L. Following impoundment, this variable still fell below this guideline some years (2005 to 2010), but nocturnal oxygen levels fell no lower than 3.9 mg/L, and did not fall below the guidelines during monitoring in 2003 to 2004.

Minimum DO levels at the site downstream from Twin Valley Reservoir were extremely low for several weeks after impoundment in 2003, as expected due to high oxygen demand from newly flooded soils. There was also a similar drop in DO at the downstream site in 2007, which followed algal blooms in Twin Valley Reservoir in 2006 (Section 3.3.5), when phytoplankton chl *a* levels were highest during this sampling program. This decline in DO could have been caused by decomposition of plant material from the previous year. In other years, DO at this location was generally above the 5 mg/L guideline both before and after impoundment.

There were occasional DO measurements below the 5 mg/L guideline in Mosquito Creek at Highway 529 before and after impoundment. However, minimum DO levels were generally well above the guideline. This site was relatively turbid and had high levels of suspended solids throughout the sampling program, especially post-impoundment. This turbidity likely suppressed the growth of aquatic macrophytes (Section 3.3.5), and at times interfered with datasonde operation, by coating sensors. Some records from 2005 to 2010 were deleted because they did not meet QAQC acceptance criteria, and could not be corrected. DO just below the guideline in 2008 likely reflect these operating concerns that year, and may not be genuine, considering the much higher oxygen levels measured at this site in other years.

Reservoirs

Much of the water column within the Central Basin of Twin Valley Reservoir was anoxic during the summer of 2003, after first filling. For example, the entire water column was anoxic (<1.0 mg/L, in August 2003, and below 5 m in July 2003). This likely reflected high oxygen demand from decomposition and other sources of oxygen demand, and is common in newly-flooded reservoirs. Areas of negligible oxygen in the water column are coloured purple in the DO isopleths in Figure 10. There was also prolonged anoxia in the hypolimnion of Twin Valley Reservoir in 2006. Otherwise periods of anoxia were intermittent in summer, and generally restricted to bottom waters. The duration and extent of hypolimnetic anoxia in the Central Basin declined over time. After 2006, there was no evidence of prolonged anoxia in winter, which was predicted to have the potential to cause fish kills. The entire water column had negative redox during winter profiles until 2006, but was never electronegative thereafter.

Electronegative redox is indicative of reducing conditions, caused by anoxia in a lake or reservoir. Redox was generally electronegative when a given depth in the hypolimnion was anoxic. However, redox was sometimes also electronegative when there was no sign of anoxia. This suggests that a calibration problem at times rendered redox results from these sites less reliable.

By the summer of 2010, no anoxia was measured in the Central Basin down to 14 m, the deepest interval measured that summer. However, there was likely some anoxia in deeper parts of the reservoir, and at the sediment-water interface. Although there was extensive anoxia through much of the water column of the West and Mosquito Basins just after first filling in 2003, anoxia occurred less frequently over time in the West Basin. Aside from a single sampling day in July 2007, no anoxia was measured in the Mosquito Basin after 2004. After the initial oxygen demand from first filling, anoxia likely reflected decomposition of organic material or sediment oxygen demand in the Central Basin of Twin Valley Reservoir, and to a lesser extent the West Basin.

All three basins of Twin Valley Reservoir had supersaturation (21.7-26.8 mg/L) under ice on March 21, 2006, which is plotted in red in the isopleths in Figure 10. This range of supersaturation is well above that normally found during the open water season in north temperate lakes and rivers. However, oxygen supersaturation in that range has been measured before on rivers in southern Alberta during late winter. One possible cause is air entrainment under the ice within moving water, which could also occur through cracks in ice on a reservoir. Another possibility is gas release from photosynthesis under ice, as phytoplankton chl *a* ranged from 1.21 to 12.95 µg/L that day in the three basins of Twin Valley Reservoir.

Except for a single measurement <1.0 mg/L in the bottom water of Clear Lake during an algal bloom in July 2005 (phytoplankton chl *a* of 33 µg/L), anoxic conditions were never measured in Clear Lake during the summer time (Figure 10). This would be expected due to shallow depth and well-mixed conditions. Oxygen supersaturation was not found in Clear Lake in winter. Clear

Lake was not sampled in March 2006 when supersaturation was measured in Twin Valley Reservoir, but phytoplankton chl *a* was much lower in Clear Lake during the four years when it was sampled in winter (median 0.67 µg/L, range 0.3 to 6.8 µg/L).

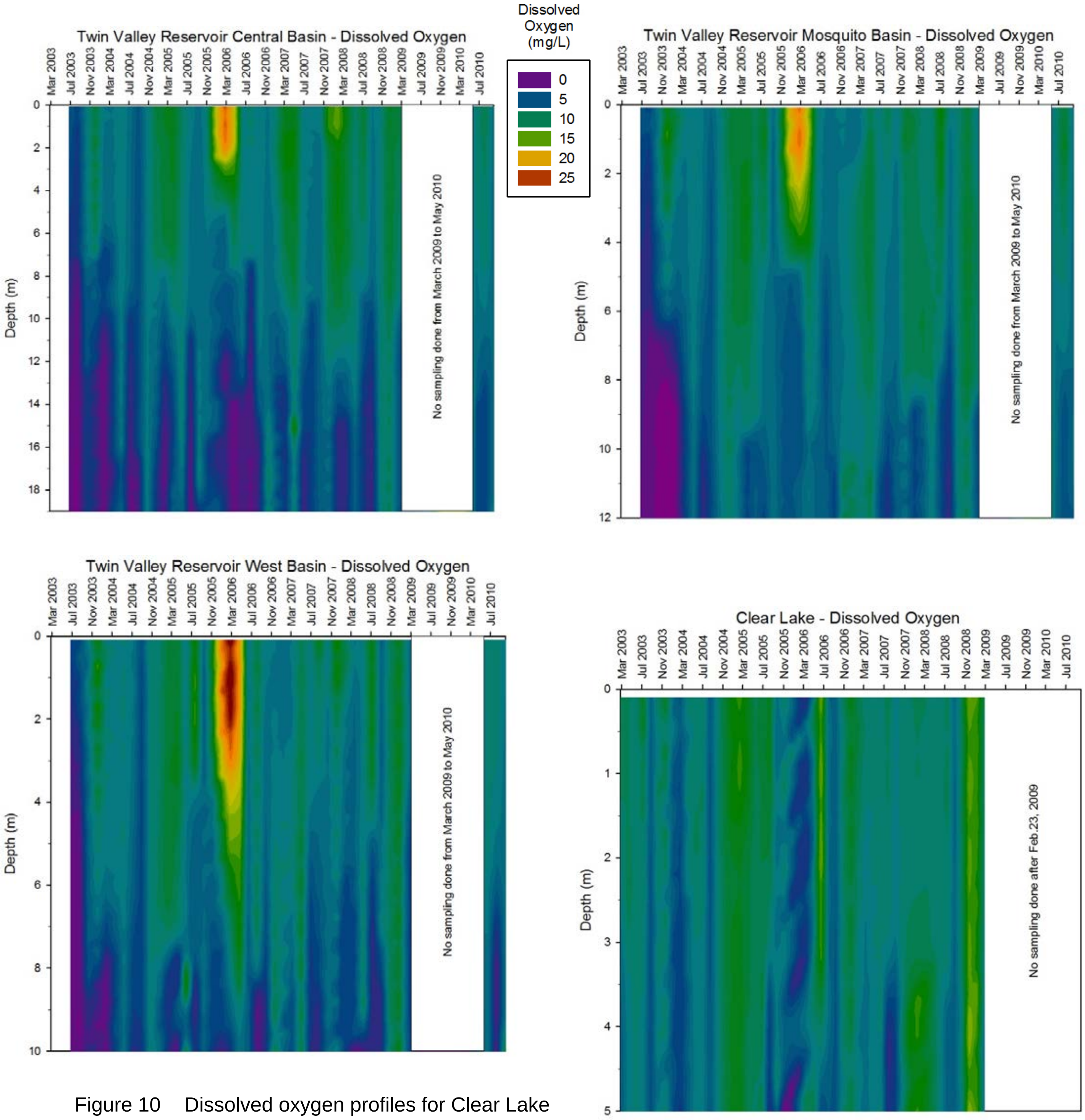


Figure 10 Dissolved oxygen profiles for Clear Lake and Twin Valley Reservoir sites, 2003-2010

Anoxia in the bottom water of Twin Valley Reservoir facilitates sediment phosphorus release, and the more anoxic parts of the reservoir such as the Central Basin may subsequently have more internal phosphorus loading. Sediment phosphorus release occurs at a much higher rate under anoxic conditions, than under well-oxygenated conditions. Phosphorus release can also occur under well-oxygenated conditions at high water temperatures, above 17-21^{o}C (Marsden 1989) regardless of dissolved oxygen concentration. Temperatures that high were rare in deeper waters of these relatively-cool reservoirs, but likely occurred in shallow shoreline areas.

3.3.3 Phosphorus

Phosphorus is an essential plant nutrient. However, excessive phosphorus can cause an increase in the growth of aquatic plants and phytoplankton (algae and cyanobacteria). Phosphorus is usually the nutrient in short supply in north temperate lakes and reservoirs, and thus the nutrient that limits the growth of phytoplankton. TP includes both particulate and dissolved forms of this nutrient, and is the most commonly measured form of phosphorus in lakes. Total dissolved phosphorus (TDP) is a better indicator of the amount of phosphorus available for aquatic plant growth than TP (Bradford and Peters 1987). Orthophosphorus (SRP) is the only form of phosphorus that may be directly utilized by aquatic plants (Wetzel 1983). This section includes an analysis of changes in TP mass, and a mass balance analysis which allows one to prepare a phosphorus budget for Twin Valley Reservoir. This provides a detailed accounting of the cumulative loading and export of phosphorus, and more insight into how the reservoir functions than a simple comparison of concentrations.

Running Water

Statistically-significant increases in concentration compared to pre-impoundment sampling (also known as step trends), are summarized in Table 1. Both total and dissolved phosphorus increased significantly post-impoundment in the Little Bow River upstream from Twin Valley Reservoir at Highway 533 (Figure 11 and 12), below the reservoir (Figure 13 and 14) and downstream at Carmangay (Figure 15 and 16), reaching peak levels in 2006. Median TP post-impoundment was well above the mesotrophic boundary for running waters from Dodds et al. (1997), and above the AQWQ guideline. This increase in phosphorus was likely a result of release of these constituents from newly flooded soils, and discharge from Frank Lake. The timing of peak TP and TDP concentrations in Figure 11 and 12, correspond well with periods of high discharge from Frank Lake, which first began to discharge in 1996 and had a high outflow rate in 1997, when phosphorus concentrations peaked in the Little Bow River at Highway 533.

In contrast to the Little Bow River, total and dissolved phosphorus levels in Mosquito Creek declined post-impoundment, because of improved wastewater treatment in Nanton (Table 1). Total and dissolved phosphorus levels in this creek are now quite low in Mosquito Creek compared to historical levels (Figure 17, 18), and extremely high in the Little Bow River at Highway 533 (Figure 19).

Table 1 Summary of significant changes[a] in mean concentration in the upper Little Bow basin after filling of Twin Valley Reservoir in the spring of 2003, compared to pre-impoundment data (1982 to spring 2003). Variables that typically exceeded water quality guidelines following impoundment are indicated by the abbreviation GL.

Variables[c]	**Guidelines, Units**	**LBR at HW 533 (Upstream Reservoir)**	**Little Bow River Downstream Twin Valley Reservoir**	**Little Bow River at Carmangay**	**Mosquito Ck at Highway 529**
TP	0.05 mg/L	↑ 0.036 GL	↑ 0.094	↑ 0.073	↓-0.014
TDP	mg/L	↑ 0.013	↑ 0.084	↑ 0.064	↓-0.012
TKN	mg/L	↑ 0.125	↑ 0.530	↑ 0.400	↑ 0.09
TN	1.0 mg/L	↑ 0.158	↑ 0.676 GL	↑ 0.544 GL	↑ 0.206 GL
Nitrate+Nitrite	2.94 mg/L	ns	↑ 0.210	↑ 0.114	↑ 0.119
Total Ammonia	1.04, mg/L	↑ 0.015	↑ 0.120	↑ 0.037	↑ 0.020
TDS, mg/L	500 mg/L	↑ 52.0		↑ 112.0 GL	↑ 61.5 GL
E. coli	400/100 mL	↑ 21.0		↑ 8.0	↑ 49.5
Fecal Coliforms	100/100 mL	↑ 16.0		↑ 7.0	↑ 47.0, GL
pH[b]	9 units	ns	ns	↑ 0.2	ns
DO[b]	5 mg/L	ns	↑ 0.98	↑ 0.89	ns
Conductivity[b]	µS/cm	↑97.5	↑ 209.0	↑ 176.0	↑ 102.5
Sodium	mg/L	↑ 8.55		↑ 28.05	↑ 7.80
Chloride	120, 178 mg/L	↑ 3.6		↑ 12.10	ns
Sulphate	1000 mg/L	↑ 25.7		↑ 39.0	↑ 20.7
Total Selenium	0.001 mg/L	↑ 0.0004		↑ 0.002	↑0.0003, GL
Total Aluminum	0.1 mg/L	ns, GL		↑0.039, GL	↑0.152, GL
Total Iron	0.3 mg/L	ns, GL		ns, GL	ns,GL
Total Mercury	0.026 µg/L	ns		ns	ns
Total Arsenic	0.005 mg/L	↑ 0.0004		↑ 0.0012	ns
DOC	mg/L	↑ 0.875		↑ 4.10	ns
TOC	5.0 mg/L	↑ 1.2		↑ 4.57	ns
Fluoride	0.12 mg/L	↓0.02, GL		↓ 0.02, GL	ns, GL
Aquatic Macrophytes	g/m^2	ns		ns	
Periphytic Chl *a*	150 mg/m^2	↓ -50.71		ns	ns
NFR	22.75, 12.5, 17.75 mg/L respectively	↑ 4.8 GL,		ns	↑ 9.6 GL
Turbidity	17.85, 8.75, 15 NTU respectively	↑ 3.95 GL		↑ 1.85	↑ 9.77 GL

[a] Seasonal Hodges-Lehmann estimate of change in mean concentration, comparing 1982-February 2003 to March 2003- 2010

[b] spot measurements during the day.

[c] Abbreviations: LBR: Little Bow River, TP: total phosphorus, TDP: total dissolved phosphorus, TKN: total Kjeldahl nitrogen, TN: total nitrogen, TDS: total dissolved solids, ↑ statistically-significant increasing, or ↓ decreasing step trend in concentration, with Sen slope of trend, GL: frequently did not meet water quality guideline, NFR: nonfilterable residue (equivalent to total suspended solids), ns: no significant change, blank: insufficient data for testing

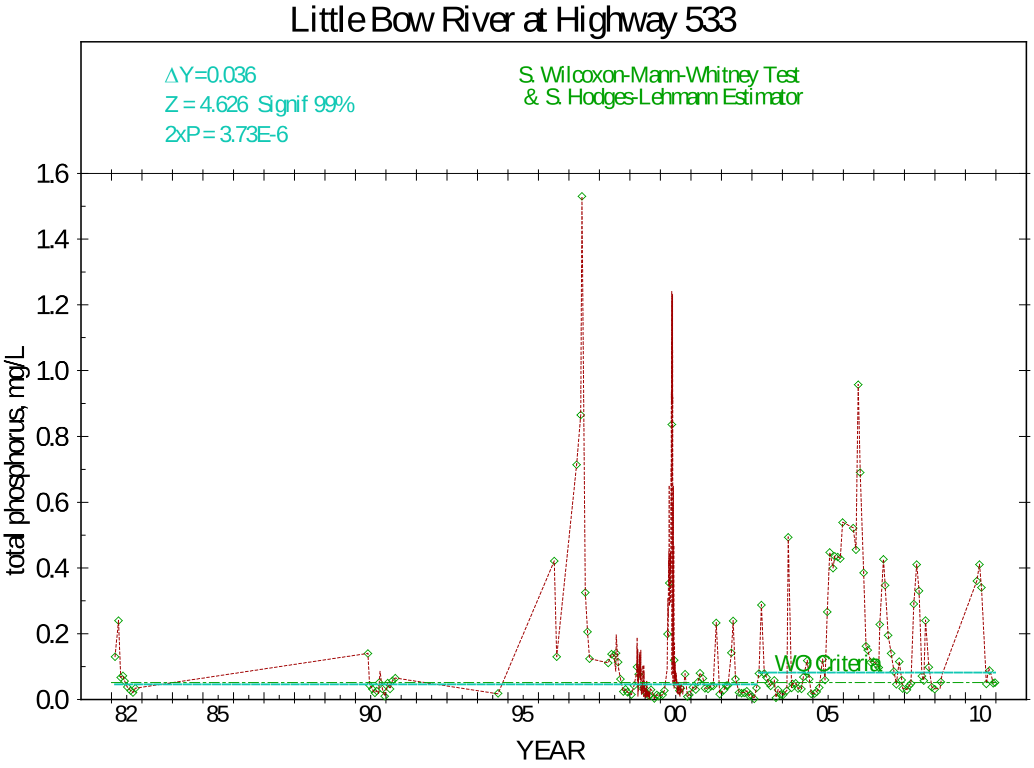


Figure 11 Total phosphorus in the Little Bow River at Highway 533, 1982-2010

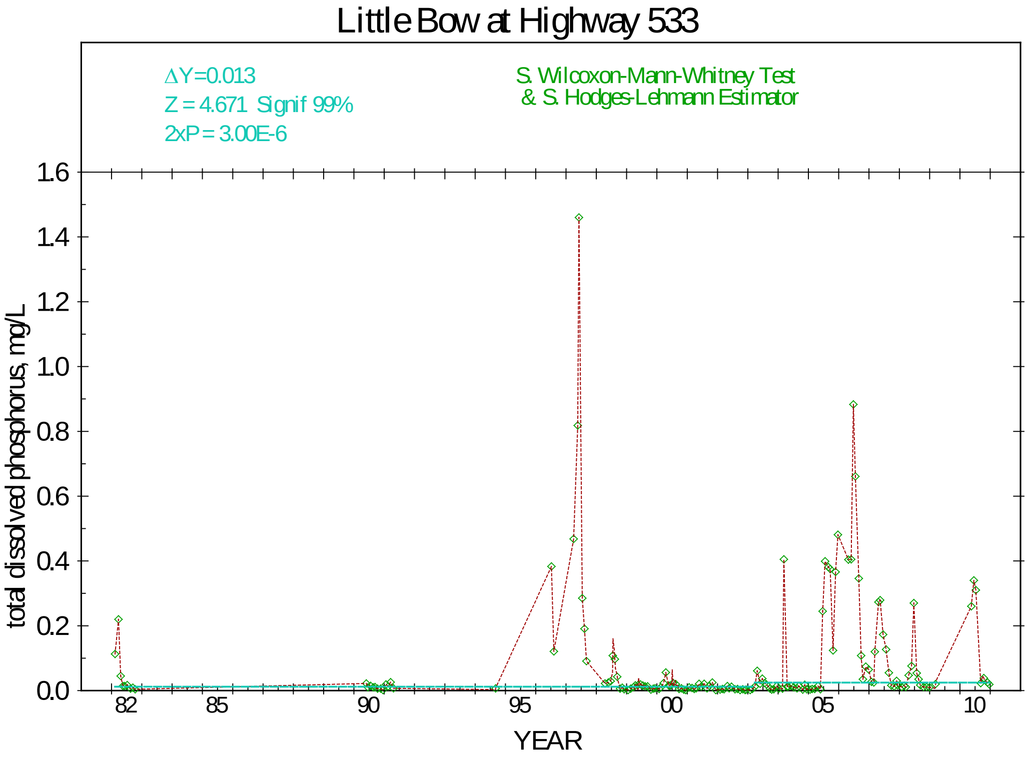


Figure 12 Total dissolved phosphorus in the Little Bow River at Highway 533, 1982-2010

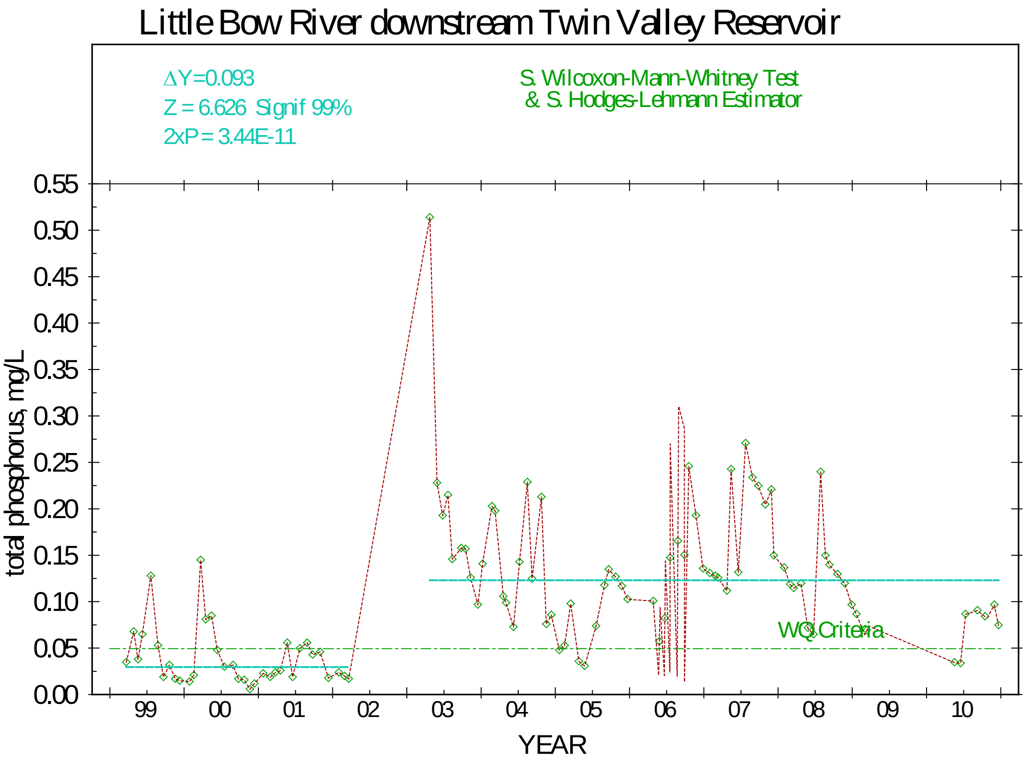


Figure 13 Total phosphorus in Little Bow River downstream from Twin Valley Reservoir, 1999-2010

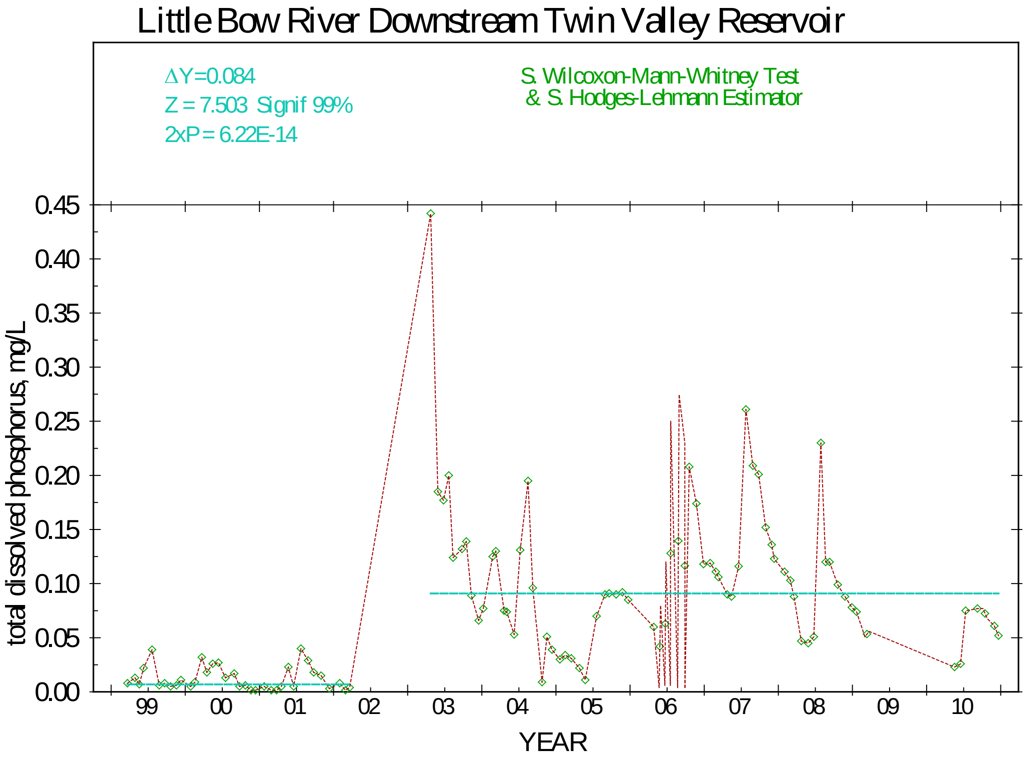


Figure 14 Total dissolved phosphorus in Little Bow River downstream from Twin Valley Reservoir, 1999-2010

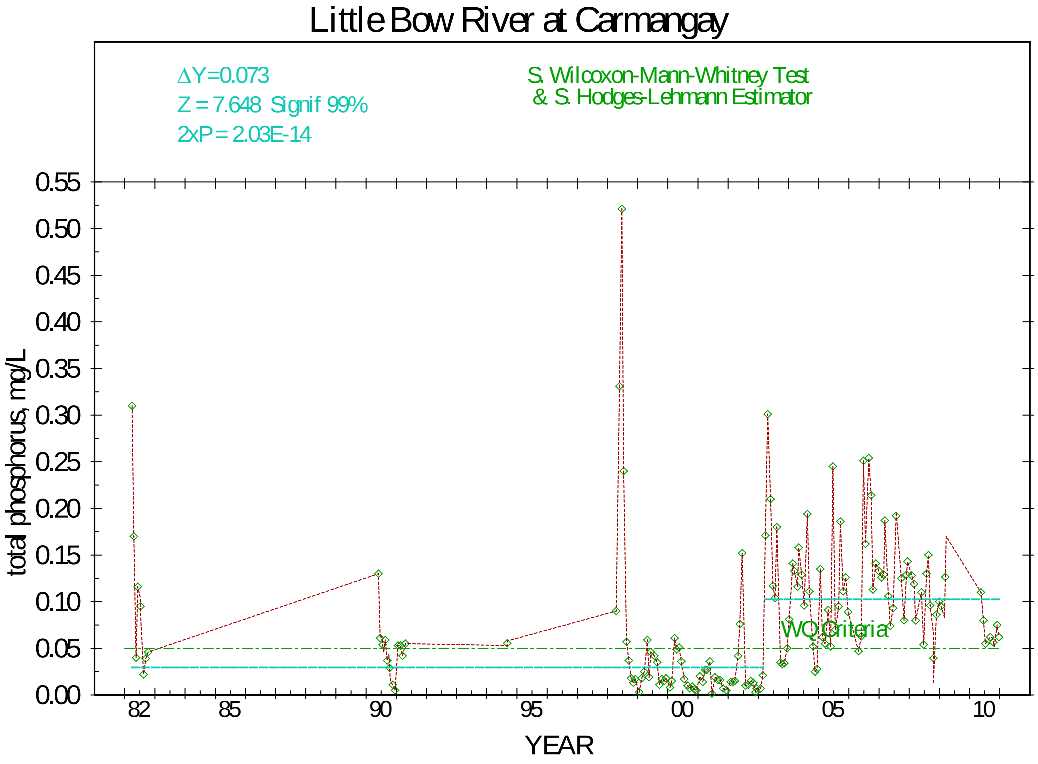


Figure 15 Total phosphorus in Little Bow River at Carmangay, 1982-2010

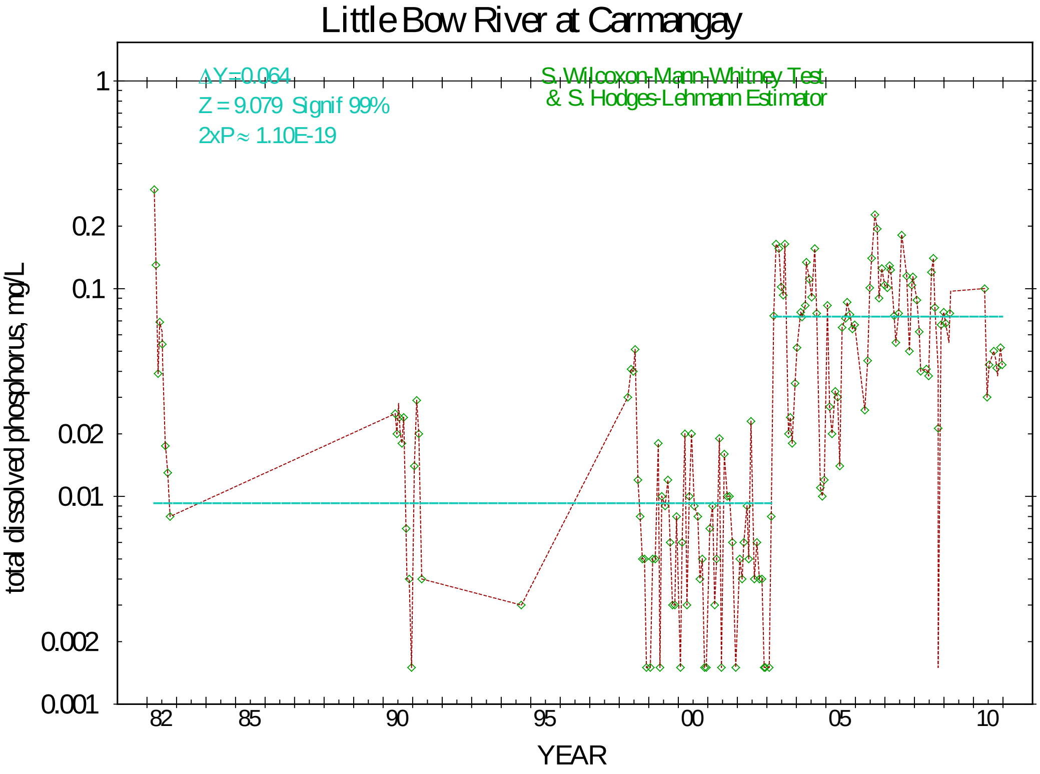


Figure 16 Total dissolved phosphorus in Little Bow River at Carmangay, 1982-2010

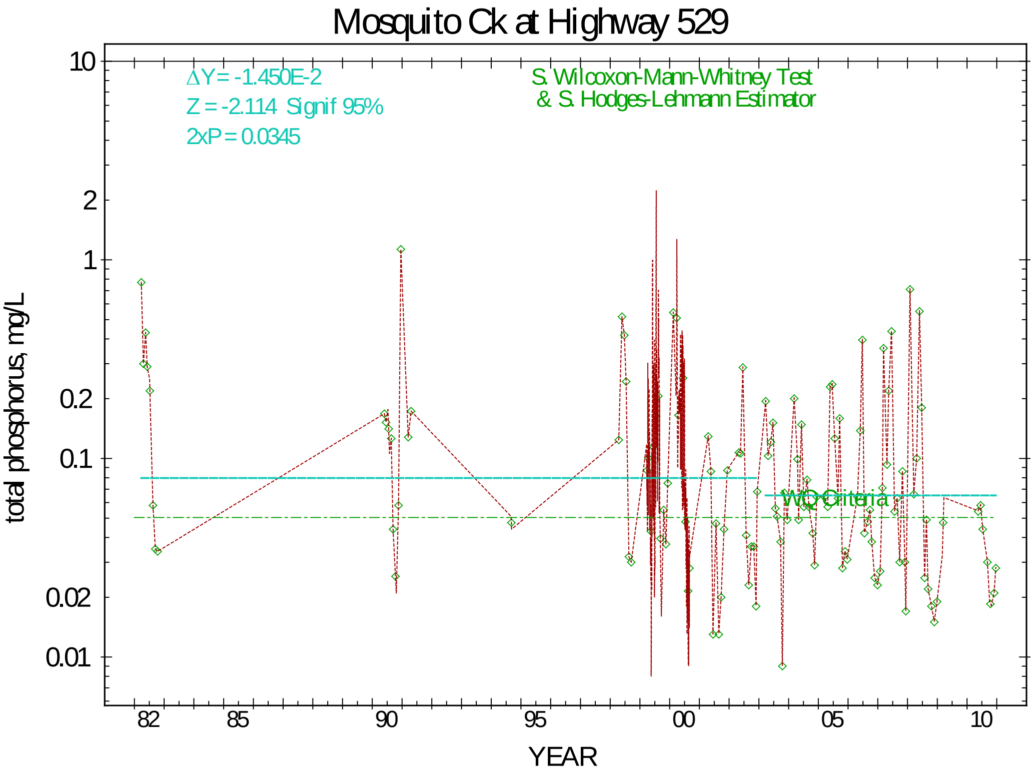


Figure 17 Total phosphorus in Mosquito Creek at Highway 529, 1982-2010

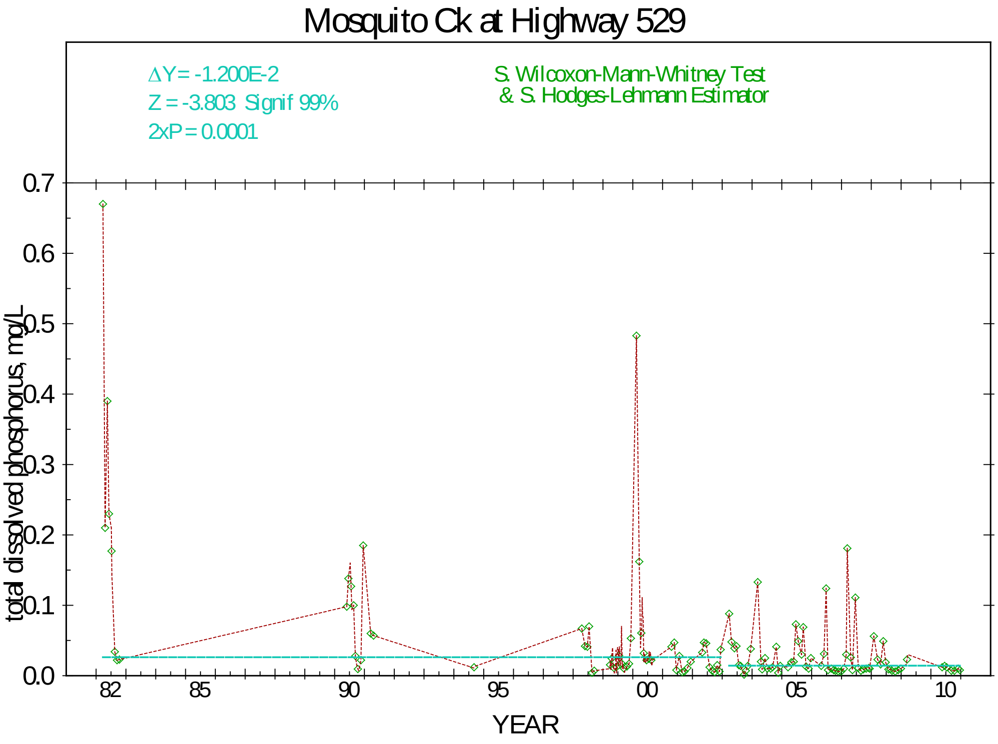


Figure 18 Total dissolved phosphorus in Mosquito Creek at Highway 529, 1982-2010

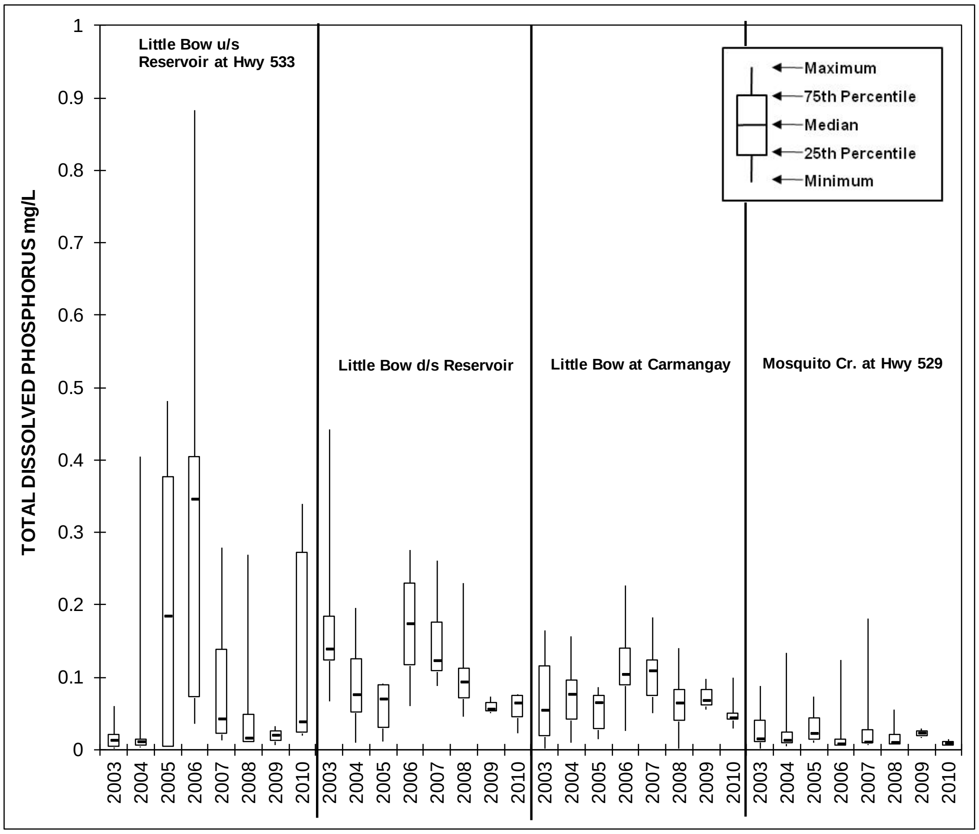


Figure 19 Total dissolved phosphorus in Twin Valley Reservoir tributaries, 2003-2010

Frank Lake discharged every year post-impoundment except 2004, when median TP levels in Little Bow River at Hwy 533, upstream from the reservoir, were at their lowest level (Figure 20). Note that only three sampling trips were completed in 2009, in the winter and early spring, as the sampling program was suspended due to budget constraints. Results in that year are likely not representative of typical water quality.

Reservoirs

All basins of Twin Valley Reservoir had very high levels of TP and TDP, well above the ASWQ guideline of 0.05 mg/L, except for 2010 in the Mosquito and Central Basin (Figure 21, 22). Peak concentrations in 2006 were highest in the West Basin, perhaps because of the influence of discharge from Frank Lake. TP and TDP levels have since declined, but even in 2010 some values were greater than the ASWQ guideline.

Clear Lake had even higher TP and TDP levels than Twin Valley Reservoir, likely because it is a terminal basin and stable constituents will concentrate over time with evaporation. Clear Lake also receives water from the Mosquito Creek diversion, which contributed very high phosphorus loadings (see mass analysis below). To place Clear Lake phosphorus concentrations in perspective, median levels there were within a range typical of the final effluent from the City of Calgary wastewater treatment plants in 1994-1995 (0.4-1.25 mg/L TP; 0.3-0.6 mg/L TDP, Sosiak 1996). TP and TDP were highest in Clear Lake in 2003, and have declined to slightly lower median concentrations.

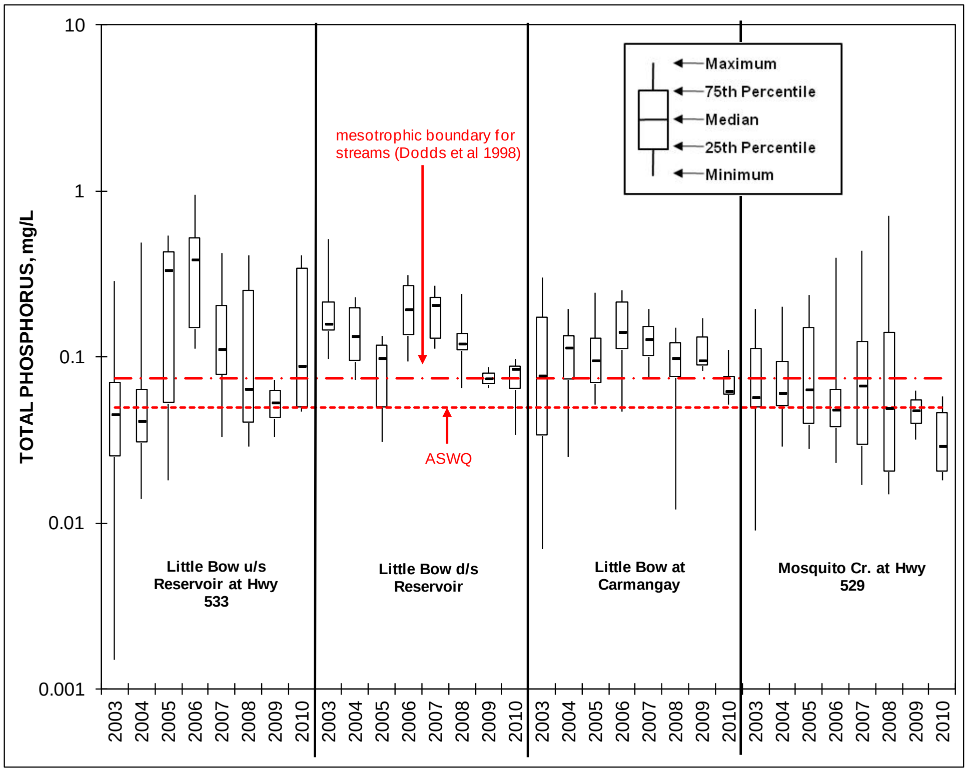


Figure 20 Total phosphorus in Twin Valley Reservoir tributaries, 2003-2010

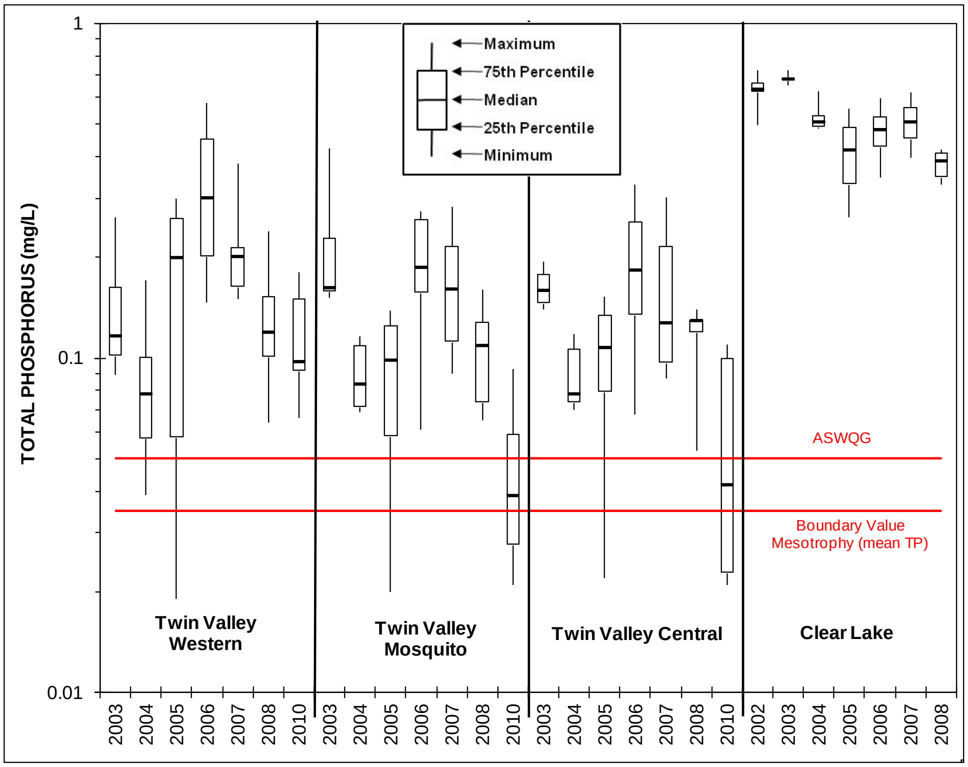


Figure 21 Total phosphorus in Twin Valley Reservoir and Clear Lake, 2002-2010

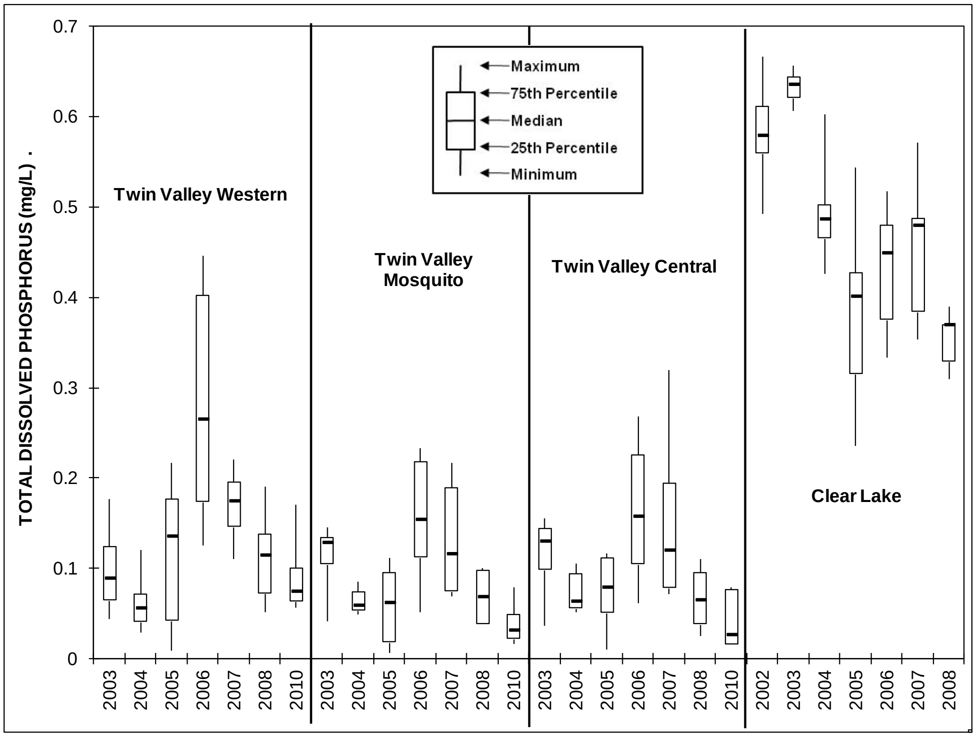


Figure 22 Total dissolved phosphorus in Twin Valley Reservoir and Clear Lake, 2002-2010

Total Phosphorus Mass

The total mass of TP throughout the Twin Valley Reservoir water column increased greatly during relatively wet years such as 2005 and 2006, but declined by 2010 to levels below those found in previous years (Figure 23, Table 2). This increase during wet years probably reflects a combination of external loading from the watershed, from Frank Lake (Figure 24), and the temporary effects of nutrient release from newly-flooded areas.

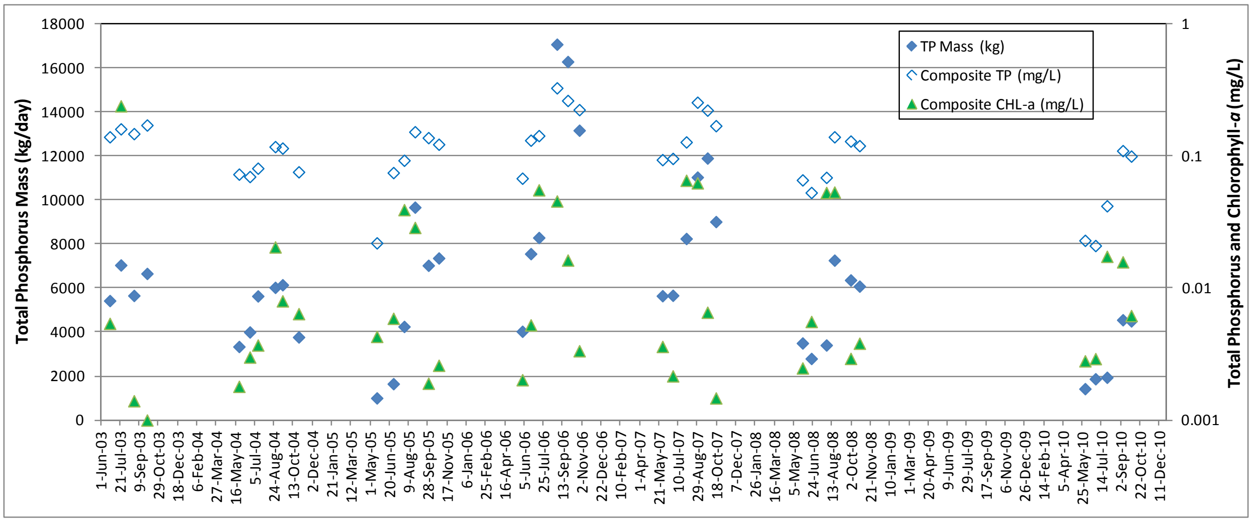


Figure 23 Total phosphorus mass on sampling days, compared to composite total phosphorus and chlorophyll-*a* in Twin Valley Reservoir, 2003-2010

Table 2 Mass balance analysis for Twin Valley Reservoir, 2004 to 2010

TWIN VALLEY RESERVOIR LAKE MASS BALANCE ANALYSIS

Sampling Interval End Date	Interval for Mass Balance	Days in Interval	Total precipitation during that sampling interval, mm[a]	TP Surface Outflow, kg	TP Input Mosquito Basin, kg	TP Input Little Bow Basin, kg	TP Atmospheric Dry and Wet Deposition, kg[b]	TP Mass in Reservoir on Sampling Day, kg	Change in TP Mass Between Sampling Trips, kg	Net internal release (+) or deposition (-), kg
2004 no Frank Lake discharge										
May 25, 2004								3343.6		
June 22, 2004	1	28	53.1	724.3	136.7	2037.4	24.7	4004.1	660.6	-813.9
July 13, 2004	2	21	50	841.7	207.1	503.4	23.2	5641.8	1637.7	1745.6
August 27, 2004	3	45	72.2	2241.4	422.4	623.5	33.5	6031.7	389.9	1551.8
September 15, 2004	4	19	16.2	1467.7	217.6	208.7	7.5	6150.7	119.0	1152.9
October 27, 2004	5	42	9.5	1779.7	140.7	361.9	4.4	3775.7	-2375.0	-1102.3
Sub-totals				7054.8	1124.5	3734.9	93.3			2534.1
2005 Frank Lake discharge sampled June 14 to September 28 (106 days)										
May 18, 2005								1004.9		
June 30, 2005	1	43	216.7	5632.3	8970.6	5632.3	100.6	1653.0	648.1	-8423.2
July 28, 2005	2	28	21.8	2715.2	3276.4	2715.2	10.1	4255.1	2602.1	-684.5
August 25, 2005	3	28	82.1	1268.2	1441.1	1268.2	38.1	9679.0	5424.0	3944.8
September 29, 2005	4	35	134.9	2431.5	2930.7	2431.5	62.6	7035.0	-2644.1	-5637.4
October 26, 2005	5	27	19.6	1440	1396.2	1440	9.1	7367.7	332.7	-1072.6
Sub-totals				13487.2	18015	13487.2	220.6			-11872.9
2006 Frank Lake discharge sampled June 8 to October 2 (116 days)										
May 31, 2006								4035.7		
June 22, 2006	1	22	155.5	6454.4	5122	4286.8	72.2	7565.2	3529.5	502.9
July 13, 2006	2	21	4.7	4223.2	2674	3660.9	2.2	8298.7	733.6	-1380.3
August 29, 2006	3	47	44.5	3620.2	2395.7	5567.5	20.7	17088.7	8789.9	4426.3
September 26, 2006	4	28	38.8	2205.4	1157.9	2914.9	18.0	16300.9	-787.8	-2673.2
October 26, 2006	5	30	19.2	1297.6	772.2	2442	8.9	13177.0	-3124.0	-5049.5
Sub-totals				17800.8	12121.8	18872.1	122.0			-4173.8
2007 Frank Lake discharge sampled April 23 to July 19 (87 days)										
May 30, 2007								5652.4		
June 26, 2007	1	27	72.8	2256	2314.6	669.2	33.8	5670.9	18.5	-743.1
July 31, 2007	2	35	26	2422.6	1448.9	1065.4	12.1	8254.1	2583.2	2479.4
August 29, 2007	3	29	29.8	2559	610.3	490.2	13.8	11046.3	2792.2	4236.9
September 24, 2007	4	26	36.3	1258.2	600.9	466.7	16.9	11910.5	864.1	1037.9
October 16, 2007	5	22	6.4	518.2	302.5	413.8	3.0	9023.0	-2887.4	-3088.5
Sub-totals				9014	5277.2	3105.3	79.6			3922.6
2008 Frank Lake discharge sampled April 22 to August 18 (118 days)										
May 28, 2008								3503.1		
June 20, 2008	1	23	68.4	2435	5134.2	1121.8	31.8	2798.9	-704.2	-4556.9
July 29, 2008	2	39	71.7	2226.2	2779.6	2601.1	33.3	3411.5	612.6	-2575.2
August 19, 2008	3	21	16	1464.8	713.5	959.2	7.4	7268.9	3857.4	3642.1
September 30, 2008	4	42	94.7	2587.1	1683.2	1889.6	44.0	6369.6	-899.3	-1929.0
October 23, 2008	5	23	7.2	1086	314.9	541	3.3	6087.0	-282.6	-55.9
Sub-totals				9799.1	10625.4	7112.7	119.8			-5474.9
2010 Frank Lake discharge sampled April 26 to September 9 (136 days)										
June 1, 2010								1426.9		
June 28, 2010	1	27	72.4	3234.7	2937.3	1204.9	33.6	1875.9	449.1	-492.0
July 28, 2010	2	30	110.7	2546.1	2165.5	1645.3	51.4	1943.3	67.4	-1248.8
September 7, 2010	3	41	15	1407.3	2175.1	1932.2	7.0	4558.9	2615.6	-91.4
September 29, 2010	4	22	9.1	635.5	1389.5	988.5	4.2	4506.5	-52.4	-1799.1
Sub-totals				7823.5	8667.4	5770.8	96.2			-3631.3
Totals				64979.4	55831.3	52083.0	731.6			-18696.2
Average (2004-2010)				10829.9	9305.2	8680.5	121.9			-3116.0

[a] based on total precipitation in each sampling interval at Environment Canada weather station at Champion

[b] atmospheric dry and wet loadings calculated with constant 0.054 mg/L TP, based on Eagle L median TP, from Bonke and Sosiak (1988)

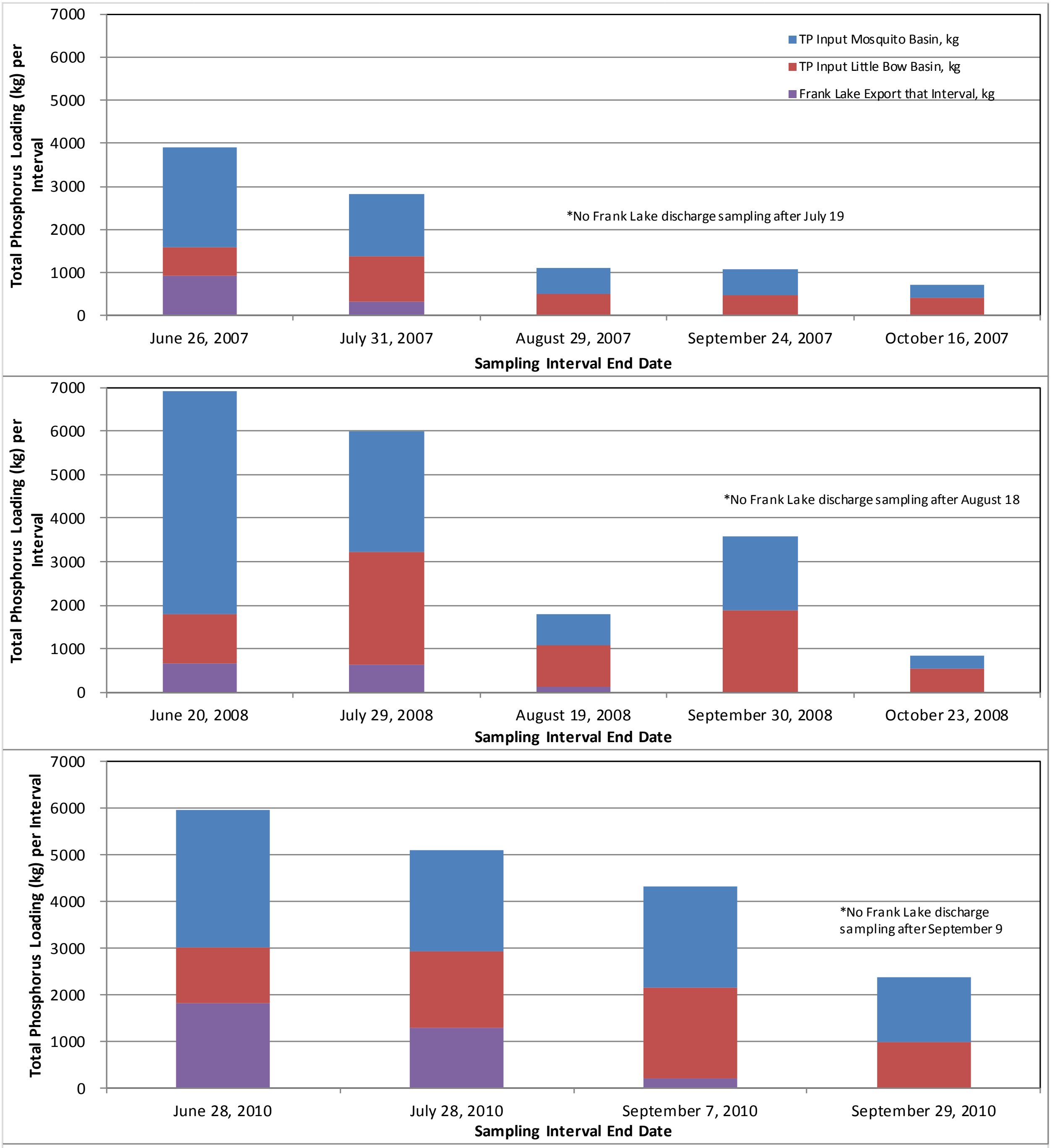


Figure 24 Total phosphorus loading from Mosquito and Little Bow basins and export from Frank Lake, 2007, 2008 and 2010

This release caused trophic upsurge, which is common in reservoirs during the first years after first filling. Some northern reservoirs can reach a stable state of productivity in about six years (Grimard and Jones 1982), while others can take as much as 20 years (Petts and Greenwood 1985). Lower phosphorus mass in 2010, seven years after first filling, could reflect declining effects of trophic upsurge, and is consistent with the six year prediction by Grimard and Jones (1982). The decline in TP mass from 2006 to 2010 occurred in spite of discharge from Frank

Lake every summer and above average precipitation in 2009 and 2010. This suggests that other sources of phosphorus had a larger impact on reservoir nutrients levels in 2010.

Mass balance during the 2004 to 2010 period suggests that Twin Valley Reservoir retained most of the TP that entered, on average a net deposition of 3116 kg per year (Table 2). Net deposition is indicated by a negative residual in the results of the mass balance analysis (Table 2). Net phosphorus retention is common in lakes and reservoirs in temperate regions.

Internal phosphorus loading was detected by the mass balance analysis (Table 2) each August except in 2010 and sometimes in July and September as well. Net phosphorus release is indicated by a positive residual in the mass balance analysis. Internal loading is common in Alberta lakes, and usually results from sediment phosphorus release under anoxic conditions. Internal phosphorus loading was also demonstrated by elevated TP concentrations at depth each summer. The years with the greatest evidence of internal loading were 2004 and 2007, which alone of the six years for which a mass balance was prepared, had a positive residual over the entire sampling season (Table 2). There was appreciable anoxia in 2004, and air and water temperatures were well above average in 2007, which could increase stratification. Lakes and reservoirs with significant internal phosphorus loading tend to respond slowly to reduced external loading due to management efforts (Marsden 1989).

In spite of a large phosphorus export from Frank Lake to the Little Bow River most years, Mosquito Creek contributed a greater TP mass in 4 of 6 years (2004 to 2010 average 9305 kg), , than the Little Bow River (average 8681 kg)(Table 2). The only exceptions with greater loadings from the Little Bow River were 2004, a dry year when Frank Lake did not discharge, and 2006, a year with above average precipitation.

In 1999, the Nanton Waste Water Treatment Plant (WWTP) effluent was by far the largest point source of dissolved phosphorus and nitrate+nitrite entering Mosquito Creek (Sosiak 2000). Frank Lake only discharged briefly in 1999, and was not a significant source of nutrients that year (Sosiak 2000). Treatment at this plant was upgraded in 2002. This resulted in an 83% drop in final effluent total phosphorus discharge from an average TP of 4.82 mg/L in January and February 2003 to an average of 0.808 mg/L TP since March 2003, based on annual reports from the Town of Nanton to AENV.

After 2003, Nanton WWTP effluent was a much smaller source of TP, at most 1.8% (193 kg) of loading from the Mosquito Creek basin to Twin Valley Reservoir during the May to October period of the mass balance in 2008. The corresponding municipal effluent loadings for 2007 and 2010 were 53.1 and 65.7 kg, respectively. It is unclear why loadings for the Nanton WWTP were so much higher in 2008. The estimate was prepared from mean monthly [TP] and total flow supplied by the Town of Nanton to AENV, and concentrations in the final effluent during the summer of 2008 were unusually high compared to other years after the treatment upgrade. The population of Nanton was only 2055 during the 2006 census (Town of Nanton 2009). Since humans typically excrete about 0.8 kg per year (Dillon et al (1986), after advanced treatment the TP loadings to Mosquito Creek from the Nanton WWTP should typically be small. Using the excretion rate from Dillon et al (1986), and assuming an 80% TP removal, roughly 137 kg TP would be released from the plant on average during the five month period of lake sampling.

In contrast, TP discharge from Frank Lake was from 20 to 58% (at most 3339 kg in 2010) of the loading from the Little Bow Basin to Twin Valley Reservoir in 2007, 2008, and 2010 (Figure 24). These exports from Frank Lake are not related to the construction or operation of Twin Valley Reservoir. The rest would be TP loading from nonpoint sources in the upper Little Bow basin. There is insufficient data to identify these individual sources in the upper Little Bow basin. The estimates of Frank Lake TP export were based on infrequent flow and quality measurements, at most five during the period of Frank Lake discharge, which tended to peak in April before the period of lake sampling. Because of this infrequent sampling, the Frank Lake TP export shown in Figure 24 should be considered rough estimates of mass export.

The Frank Lake export estimates (Figure 24) do not account for all TP discharged from Frank Lake. Additional TP export from Frank Lake occurred earlier in the season before the reservoir was sampled. A further 1656 kg was exported from Frank Lake in 2007 prior to lake sampling, which began May 30, 2007. On the other hand, the analysis was based on flow and quality samples from the Basin 3 outlet of Frank Lake, and it is not clear how much and when TP mass from Frank Lake travels the outlet stream to the Little Bow River. Over time most should reach the Little Bow River, but there could be a lag period.

Although Frank Lake remains the most important point source of nutrients the results of this mass balance study suggests that nonpoint source phosphorus from the Mosquito Creek basin is the largest source entering Twin Valley Reservoir. For every sampling interval, TP loadings from Mosquito Creek, mainly from nonpoint sources, were larger than those from Frank Lake (Table 2, Figure 24). These findings were unexpected. Because Frank Lake is very high in nitrogen and phosphorus from combined treated municipal and industrial influent (Sosiak 1994), it was anticipated that discharge from Frank Lake should contribute far more phosphorus than any other source.

Nonpoint source loadings are clearly important and contribute significant loadings to Mosquito Creek and the Little Bow River. In addition to the Nanton WWTP, there are loadings from municipal stormwater and various agricultural sources such as cow/calf wintering sites and other agricultural operations throughout the Mosquito Creek basin. These sources were documented for 1999 in Sosiak (2000) and aerial surveys. Additional sampling throughout the basin was done in 2000. There were several major feedlots in the Nanton Creek basin, a tributary of Mosquito Creek, but these were a relatively minor source of nutrients during the relatively dry condition of the study in 1999.

The mass balance was based on TP, although TDP provides a better measure of bioavailable phosphorus that can stimulate algal growth. Phosphorus budgets are typically based on TP, because there is generally not enough TDP data on all parts of the ecosystem. From March to September, 1999 TDP mass flux was 16% of the TP mass flux from the Mosquito Creek basin, and 50% of the TP flux from the Little Bow River, in each case at reservoir FSL. Accordingly, much of the phosphorus mass flux in this system is in a bioavailable form. Data from other years (Figure 19, 20) suggest that dissolved phosphorus concentrations fluctuate considerably from year to year in both basins, apparently in response to rainfall.

Twin Valley Reservoir TP was not sampled from the deepest areas in 2010, only down to 14 m of a possible 19 m over most of summer. Data is lacking from the deepest intervals in some other years, notably 2003 and 2008. Accordingly, some internal loading was likely missed for 2010, and that sampling concern may account for the apparent net deposition and absence of internal release that year. It was not possible to complete a mass balance analysis for 2003 because flow data for the Little Bow River immediately below the reservoirs was not available from either AENV or Water Survey of Canada. A mass balance during filling in 2003 might not have provided valuable insight, as TP cycling processes were just beginning to develop.

This mass balance used an area-capacity table for the entire reservoir, and applied TP measurements from a single profile from the deepest part of the reservoir to volume estimates for each depth interval over the entire reservoir. This was done because there were not separate volume estimates for each of the sub-basins, and assumes that the TP data from the deepest profile accurately represents water quality at each depth throughout the reservoir. This is a reasonable assumption because the shallower depth intervals, with the greatest volume and TP mass were in the euphotic zone and should be well mixed. The deepest intervals were all at the TP profile site that was used.

This mass balance analysis covers just the open water season, because the necessary data are typically only available during that season. In particular, TP profiles are usually only collected during the open water season.

As requested in the terms of reference for this study, data were evaluated to determine if a separate budget could be prepared for total nitrogen. Nitrogen budgets require sampling throughout the water column, to account for nitrogen from decomposition, nitrogen fixation in the euphotic zone, and sediment phosphorus release. However, nitrogen measurements throughout the reservoir water column were not routinely done during this sampling program. Accordingly, reservoir nitrogen mass could not be calculated with sufficient accuracy, and was not attempted. Experience elsewhere has generally found that inorganic nitrogen in productive lakes and reservoirs is primarily derived from atmospheric nitrogen by cyanobacteria. There are no practical options for managing this internal supply of nitrogen and the frequency of nuisance algal blooms in nitrogen-limited water bodies.

3.3.4 Nitrogen

Nitrogen is another essential nutrient for aquatic plants. Excessive nitrogen can also lead to increased growth of aquatic plants, and the same concerns associated with phosphorus. While phosphorus is most often the limiting nutrient for phytoplankton growth in north-temperate lakes, tropical and subtropical lakes are most often limited by the supply of nitrogen (Ryding and Rast 1989).

In addition, high levels of nitrate can impair drinking water quality and ammonia and nitrite may be toxic to aquatic life. Total Kjeldahl nitrogen (TKN) includes both ammonia and organic nitrogen, while total nitrogen (TN) includes TKN and nitrate+nitrite, which are often analyzed together.

Running Water

All forms of nitrogen (Table 1, Figures 25 to 28) increased significantly at the three sites on the Little Bow River and Mosquito Creek post-impoundment, except for nitrate+nitrite in the Little Bow River at Highway 533, which did not change (Table 1). Notable changes in nitrogen post-impoundment included greatly-increased levels of TKN and total ammonia in the Little Bow River below the reservoir and at Carmangay (Figure 29 to 32). For both variables, levels post-impoundment were within the historic range at the Carmangay site, which had a much longer period of record (Figure 31, 32).

TN also increased greatly at these sites (Table 1, Figure 26) and alone regularly exceeded the ASWQ guideline of 1.0 mg/L. Since this variable is the sum of TKN (mostly organic, or trivalent nitrogen) plus nitrate+nitrite, it tends to follow spatial and temporal trends in TKN concentration. There were also occasional total ammonia and nitrate+nitrite measurements over the CCME PAL guidelines (Figure 27, 28), three in total over eight years of frequent monitoring.

The TN guideline was regularly exceeded downstream from the reservoir even before impoundment (Figure 26). Accordingly, the TN guideline exceedance appears related to factors other than the creation of Twin Valley Reservoir. In any event, the CCME PAL guidelines for individual forms of nitrogen (CCME 2011a) better reflect current science than the TN guideline (from AENV 1977), and are better indicators of risk of aquatic affects. These guidelines for individual forms of nitrogen were seldom exceeded.

Levels of all these forms of nitrogen were lower in 2010 at most sites. This suggests that nitrogen concentrations have fallen since trophic upsurge. One would expect the highest levels of nitrogen, especially ammonia, at the Little Bow River sites during the elevated primary production and decomposition after first filling, and that appears to be the case. Frank Lake discharge may also have had an impact, although the wetland has been shown to remove a large percentage of the nitrogen from the combined influent (Sosiak 1994).

Different mechanisms must account for the increases in nitrogen in Mosquito Creek, and apparent decline in recent years. However, these mechanisms are not understood at this time. Detailed nitrogen chemistry was not available for the Nanton WWTP effluent. However, nitrogen discharge from the plant would be expected to gradually increase over time with population growth. Increased flow in the spring may also increase scouring of shoreline agriculture sites. The project was not expected to affect water quality in Mosquito Creek “except for a minor improvement in late spring” (NRCB/CEAA. 1998).

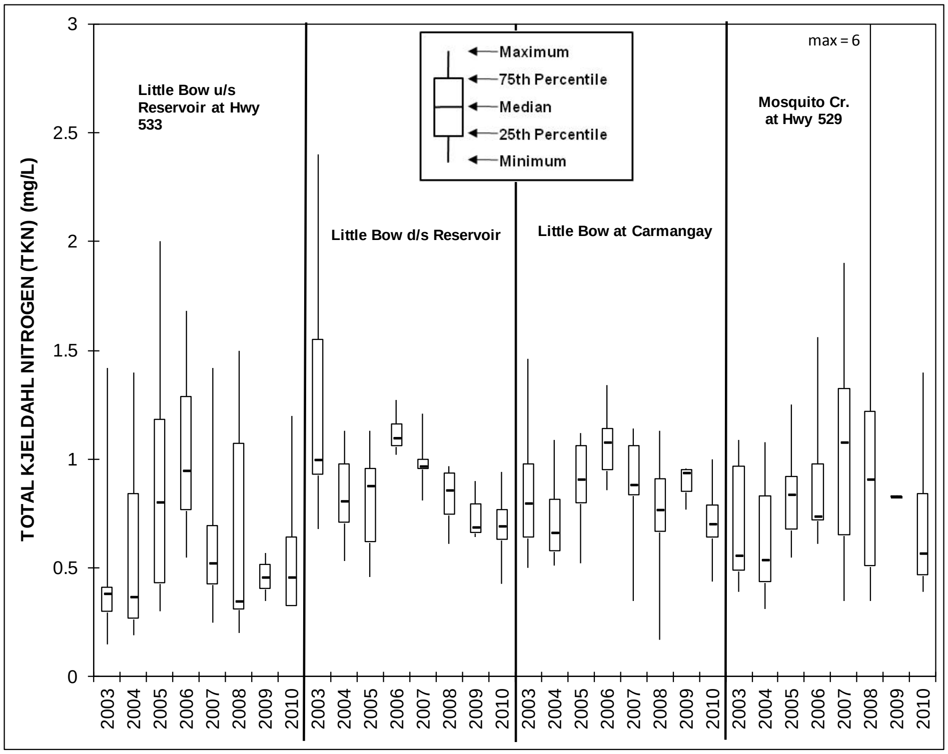


Figure 25 Total Kjeldahl nitrogen in Twin Valley Reservoir tributaries, 2003-2010

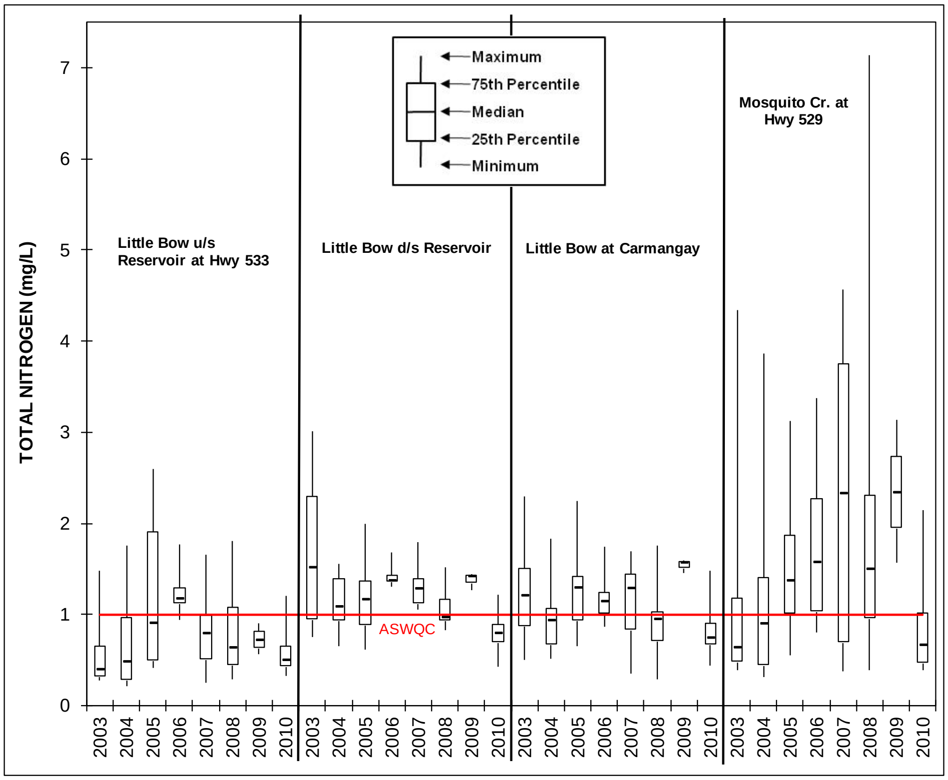


Figure 26 Total nitrogen in Twin Valley Reservoir tributaries, 2003-2010

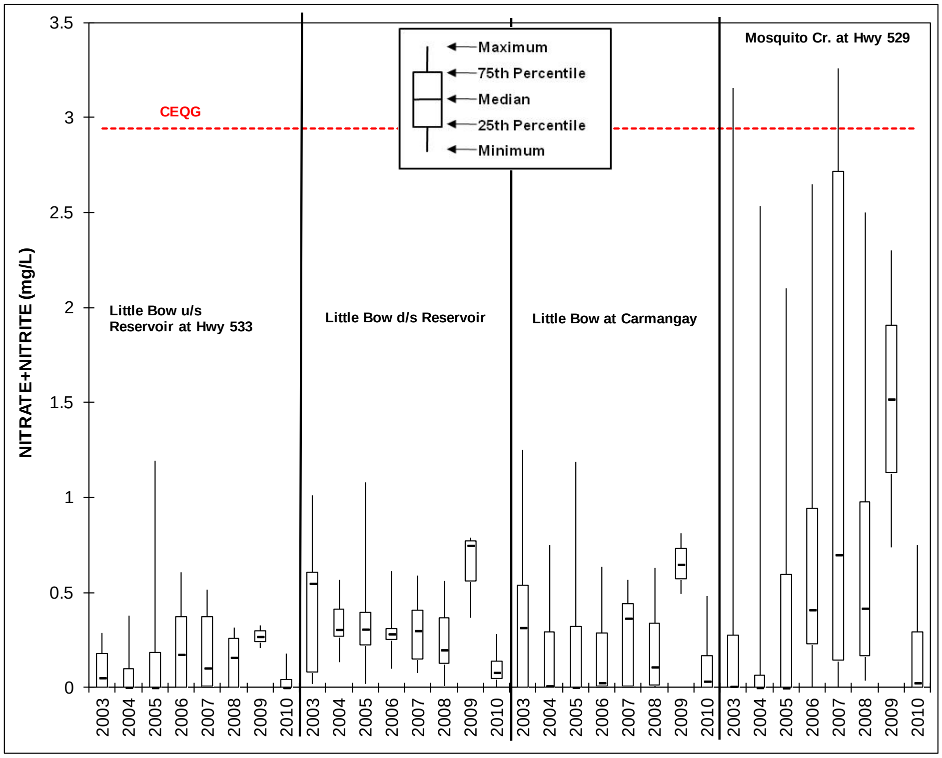


Figure 27 Nitrate+nitrite in Twin Valley Reservoir tributaries, 2003-2010

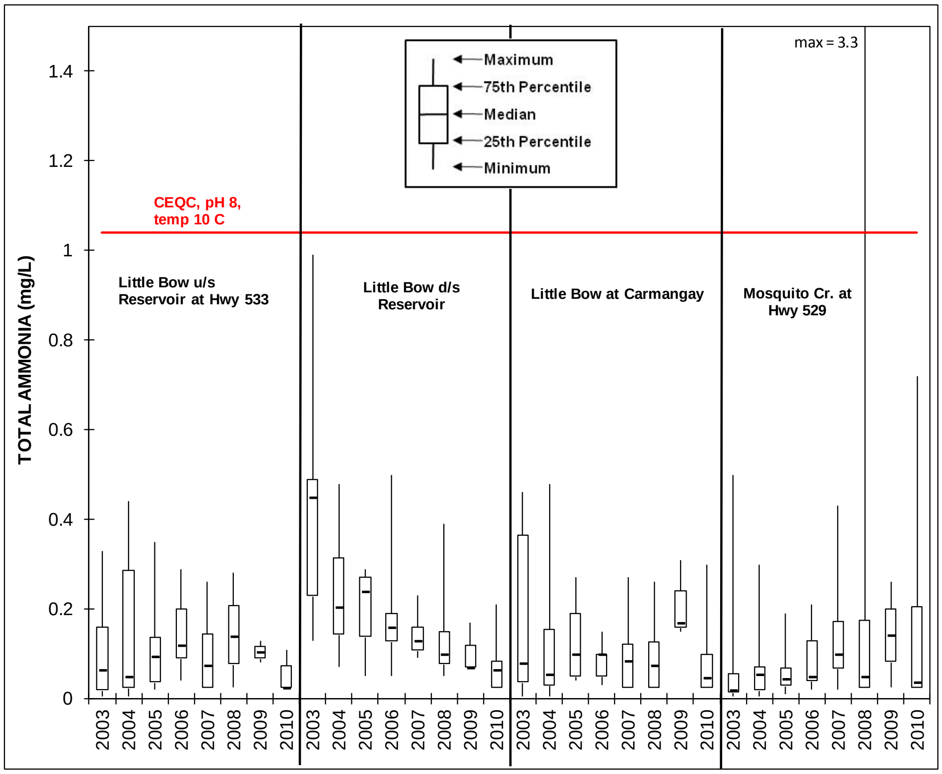


Figure 28 Total ammonia in Twin Valley Reservoir tributaries, 2003-2010

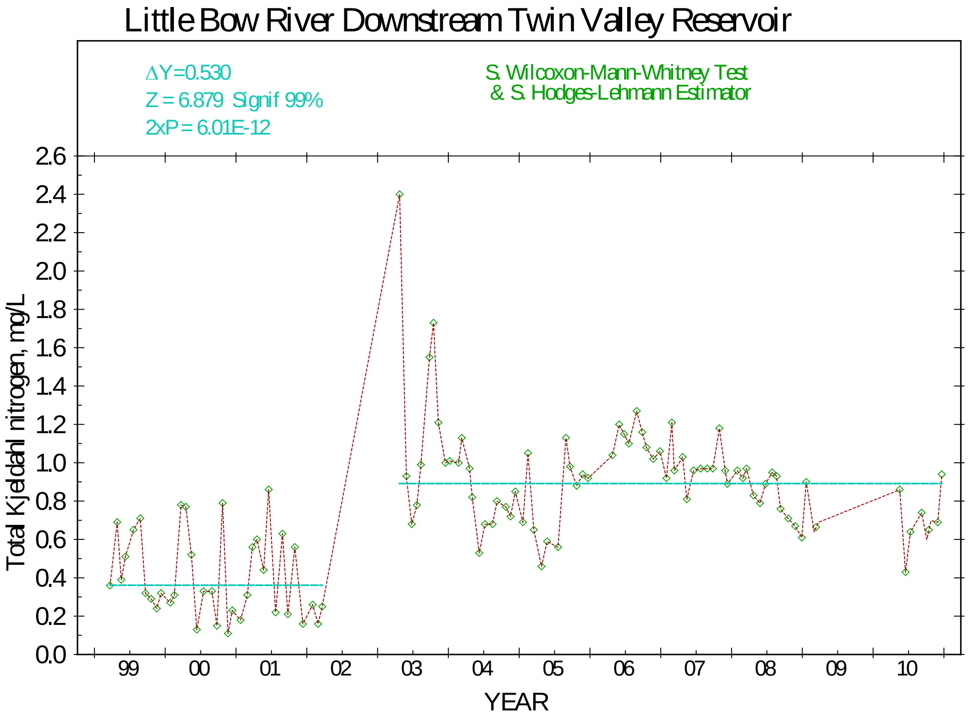


Figure 29 Total Kjeldahl nitrogen in the Little Bow River downstream from Twin Valley Reservoir, 1999-2010

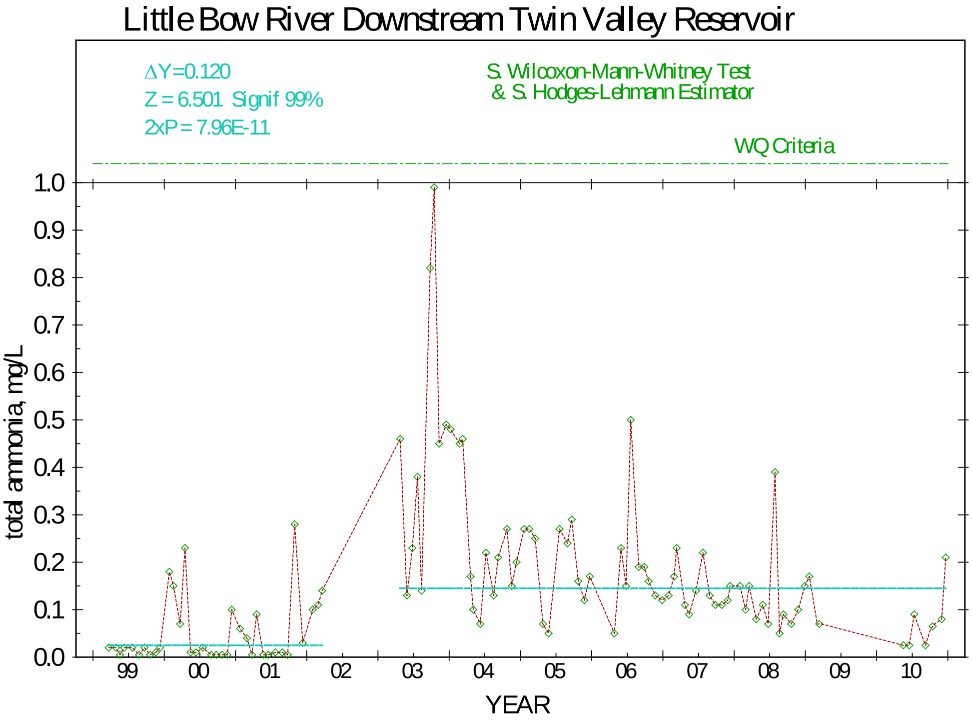


Figure 30 Total ammonia in the Little Bow River downstream from Twin Valley Reservoir, 1999-2010

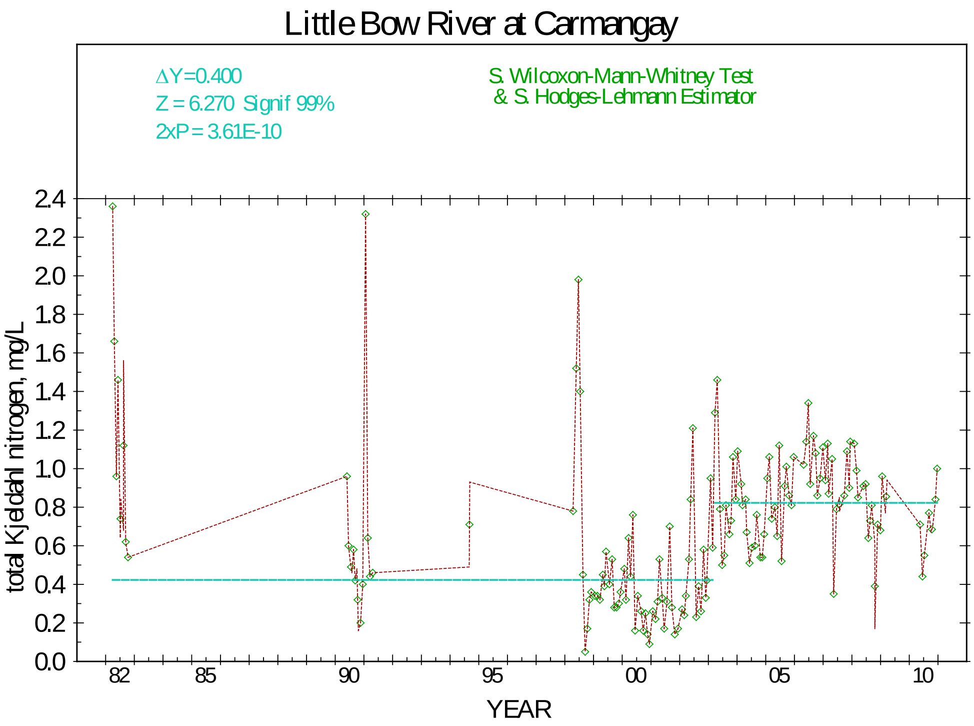


Figure 31 Total Kjeldahl nitrogen in the Little Bow River at Carmangay, 1982-2010

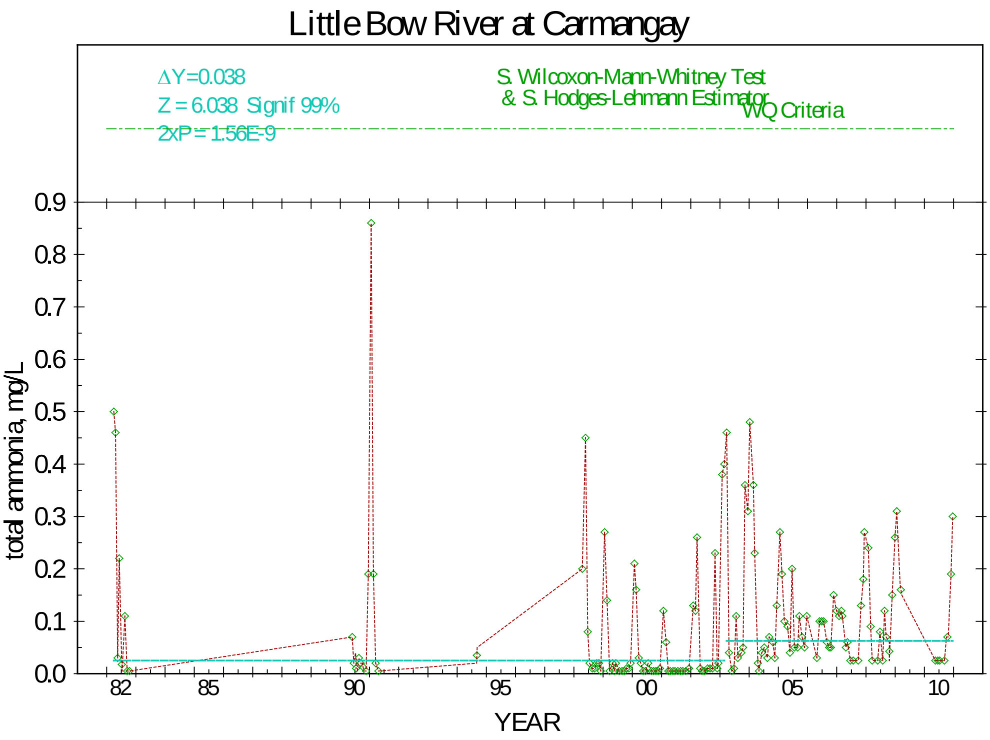


Figure 32 Total

ammonia in the Little Bow River at Carmangay, 1982-2010

Reservoirs

As with running water, TN regularly exceeded the ASWQ guideline of 1.0 mg/L in the various basin of Twin Valley Reservoir, and Clear Lake (Figure 33). However, median levels of TN were well below this guideline in Twin Valley Reservoir, in 2010. TKN generally followed patterns in TN concentration (Figure 34). Neither nitrate+nitrite, nor total ammonia exceeded the CCME PAL guideline in reservoir euphotic zone samples from either water body (Figure 35, 36). It should be noted that the plotted reservoir values were composite euphotic zone samples, and higher ammonia levels would be expected in the hypolimnion. Total ammonia ranged up to 2.4 mg/L at 18 m on August 19, 2008 in the Central Basin of Twin Valley Reservoir exceeding the CCME PAL guideline, and ranged from 0.38 to 1.36 in other monthly samples from the same hypolimnetic site, from 2003 to 2010. As with TN, total ammonia and nitrate+nitrite were highest in the reservoir soon after first filling, then declined to lowest levels in 2010.

These patterns of nitrogen concentration in Twin Valley Reservoir were consistent with elevated levels of nitrogen during first filling and trophic upsurge, decomposition, and a decline afterwards. The various forms of nitrogen did not decline over time in Clear Lake. Levels in this water body were stabilized, and it doesn’t appear to have experienced trophic upsurge as Twin Valley Reservoir did. Accordingly, nitrogen levels in Clear Lake fluctuated less from year to year.

3.3.5 Phytoplankton and Aquatic Plants

Chlorophyll *a* is the most commonly used biological indicator of phytoplankton biomass and trophic status in lakes (Cooke et al. 2005). Chlorophyll *a* was used as an indicator of phyoplankton biomass in these reservoirs and periphytic biomass in running water. Dry biomass of large aquatic plants was used to evaluate changes in macrophytes populations in running water.

Running Water

Periphyton (also known as epilithon) is a layer of algae, cyanobacteria, associated microbes, and detritus that grows attached to surfaces such as rocks or larger plants. Periphyton is a sensitive indicator of environmental change such as physical and chemical disturbances in both flowing and standing waters. At high nutrient concentrations and under appropriate light and flow, nuisance growths can form on the bottom of rivers and creeks.

Although phosphorus levels have increased in the Little Bow River, periphytic chlr *a* declined above the reservoir at Highway 533 after impoundment (Figure 37). However, there was no significant change in this variable at other sites (Table 1), including Mosquito Creek following reduced phosphorus discharge by tertiary treatment at the Nanton WWTP. Phosphorus levels in Mosquito Creek are likely still high enough for maximum growth of periphyton. On the Bow River, nuisance growth of periphyton occurred at TP of 18 µg/L (Sosiak 2002), which is much lower than TP in Mosquito Creek in recent years (Figure 20). Since Mosquito Creek is typically more turbid than the Bow River, one would expect less response from periphyton to phosphorus loading due to light inhibition.

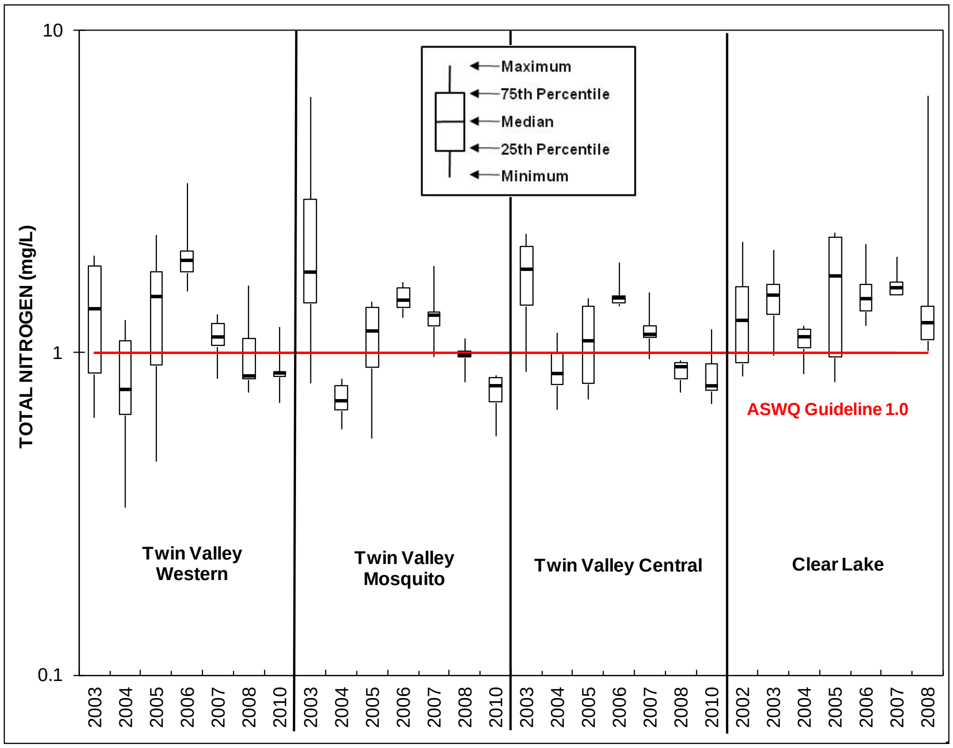


Figure 33 Total nitrogen in Twin Valley Reservoir and Clear Lake, 2002-2010

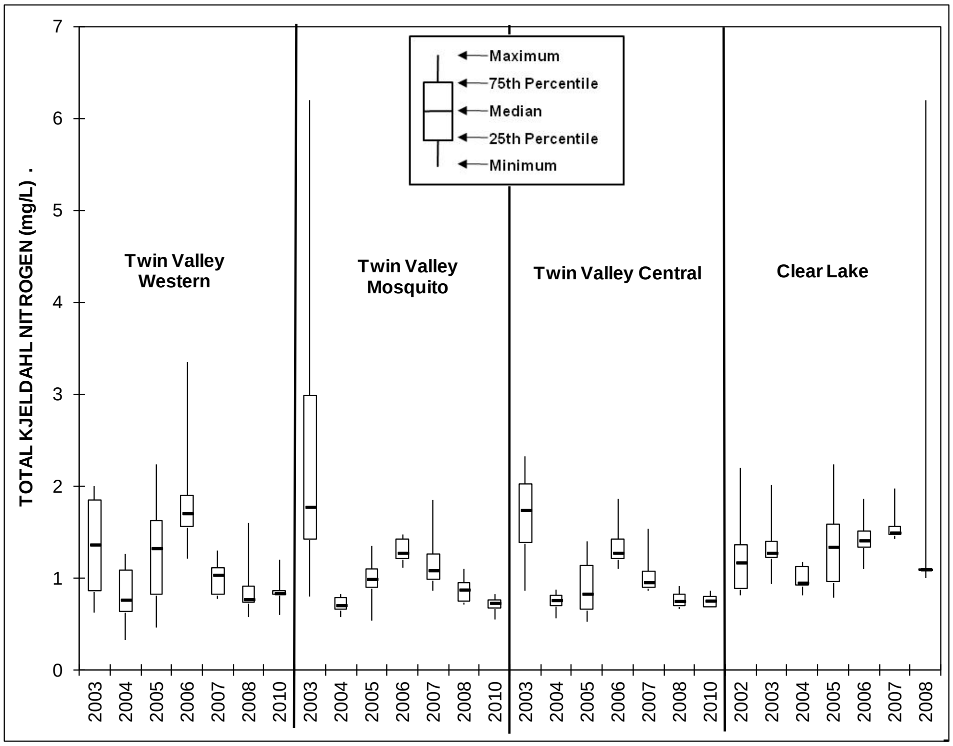


Figure 34 Total Kjeldahl nitrogen in Twin Valley Reservoir and Clear Lake, 2002-2010

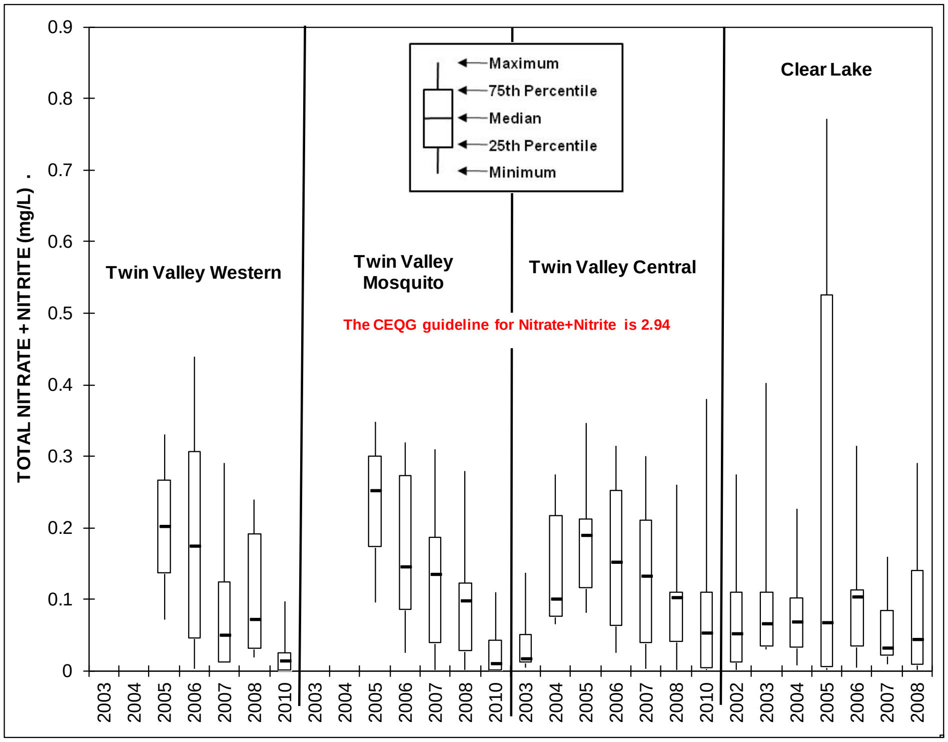


Figure 35 Nitrate+nitrite in Twin Valley Reservoir and Clear Lake, 2002-2010

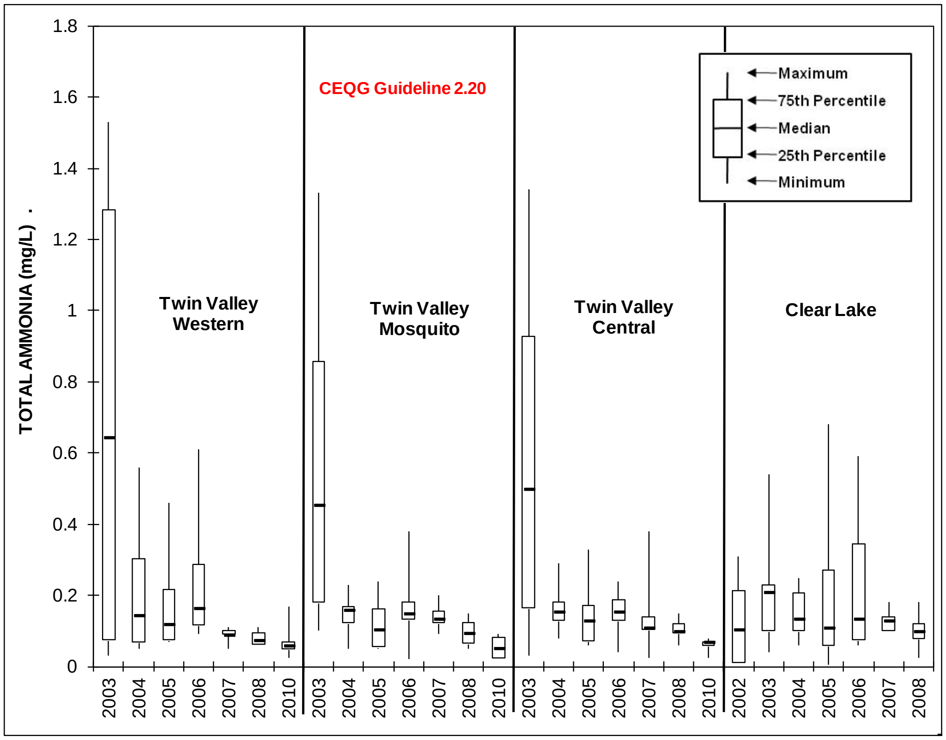


Figure 36 Total ammonia in Twin Valley Reservoir and Clear Lake, 2002-2010

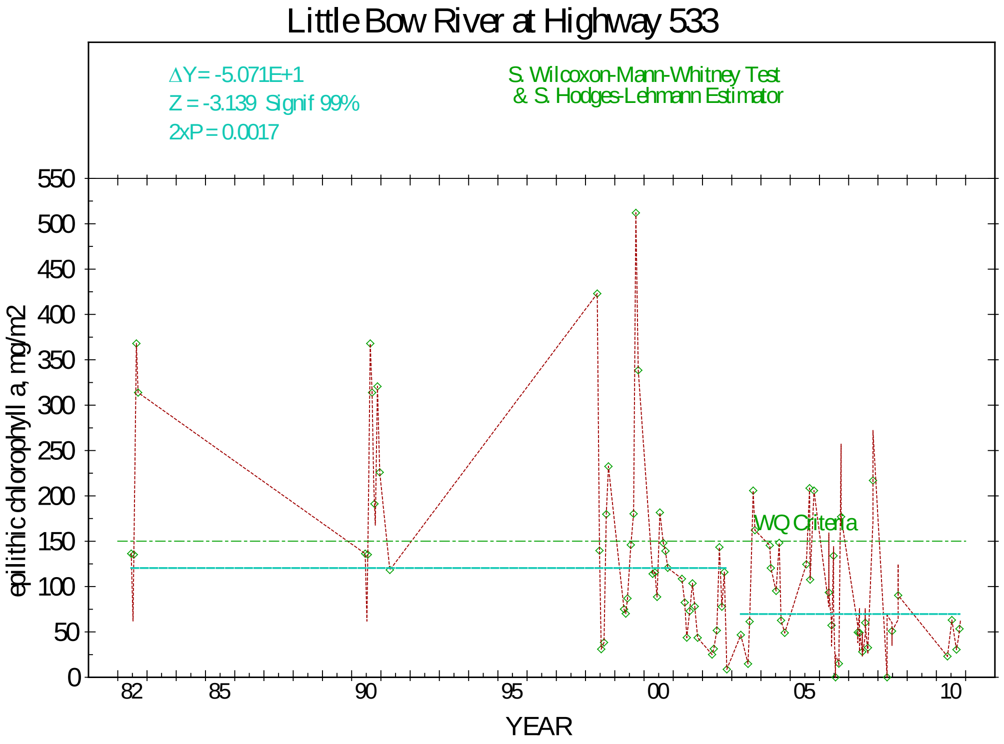


Figure 37

Periphytic chlorophyll *a* in the Little Bow River at Highway 533, 1982-2010

The decline on the Little Bow River upstream could reflect higher flows, and scouring of periphyton. In spite of the decline at this site, periphytic chlorophyll *a* exceeded the 150 mg/m^2 guideline for nuisance growth, after the impoundment of Twin Valley Reservoir at all sites (Figure 38). In terms of periphyton growth they were all relatively productive locations.

Macrophytes are large aquatic plants that grow in lakes and rivers and are either rooted emergent, rooted submergent, or entirely floating. Macrophytes are beneficial to lakes and rivers because they provide cover and spawning habitat for fish and substrate for aquatic invertebrates. They also produce oxygen and provide other benefits. However, an overabundance of macrophytes can result from high nutrient levels and may interfere with river processes, irrigation withdrawal, recreational activities (e.g., swimming, fishing, and boating), and detract from the aesthetic appeal of the system.

In spite of the increased phosphorus and nitrogen levels at these sites (Table 1), there was no significant change in macrophyte biomass (as oven-dried weight) after impoundment at any site. The most likely explanation is that this river was highly enriched both before and after impoundment. In any event, macrophytes can derive most of their nutrient requirements from sediments through their roots and may not respond to a short-term change in nutrient levels. Accordingly, physical factors such as high flows and water velocity that scour away plant material or cause bed movement, and light limitation from high turbidity, may be the most important factor controlling plant biomass at these sites. Light limitation probably accounts for the relative scarcity of macrophytes at the sampling site on Mosquito Creek (Figure 39). There were only appreciable macrophytes at this site in 2004.

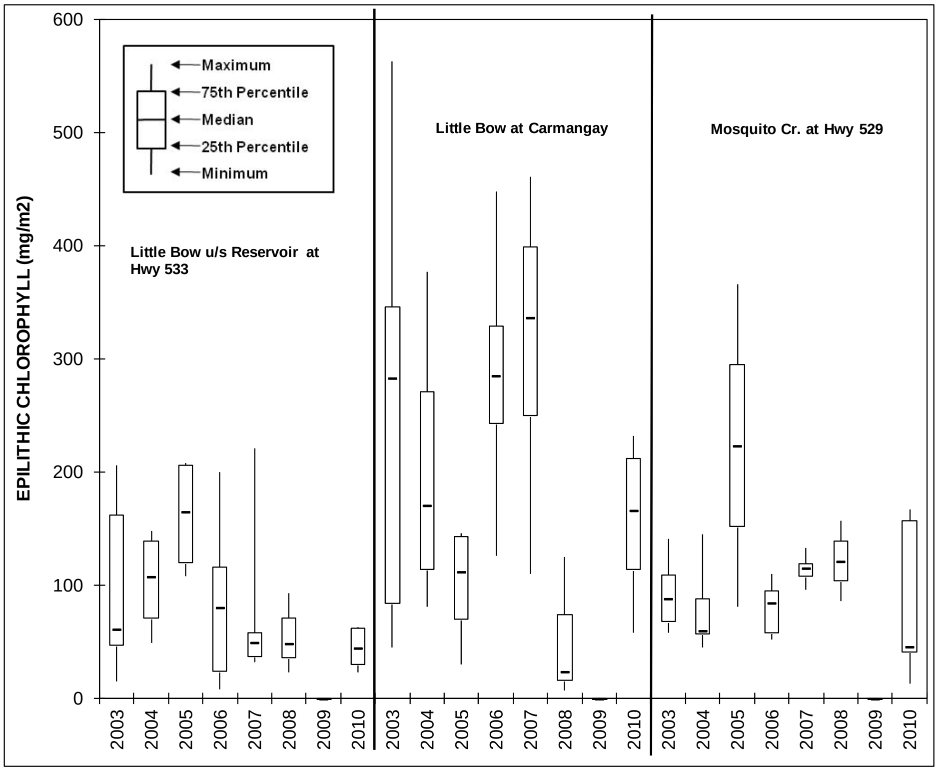


Figure 38 Periphytic chlorophyll *a* in Twin Valley Reservoir tributaries, 2003-2010

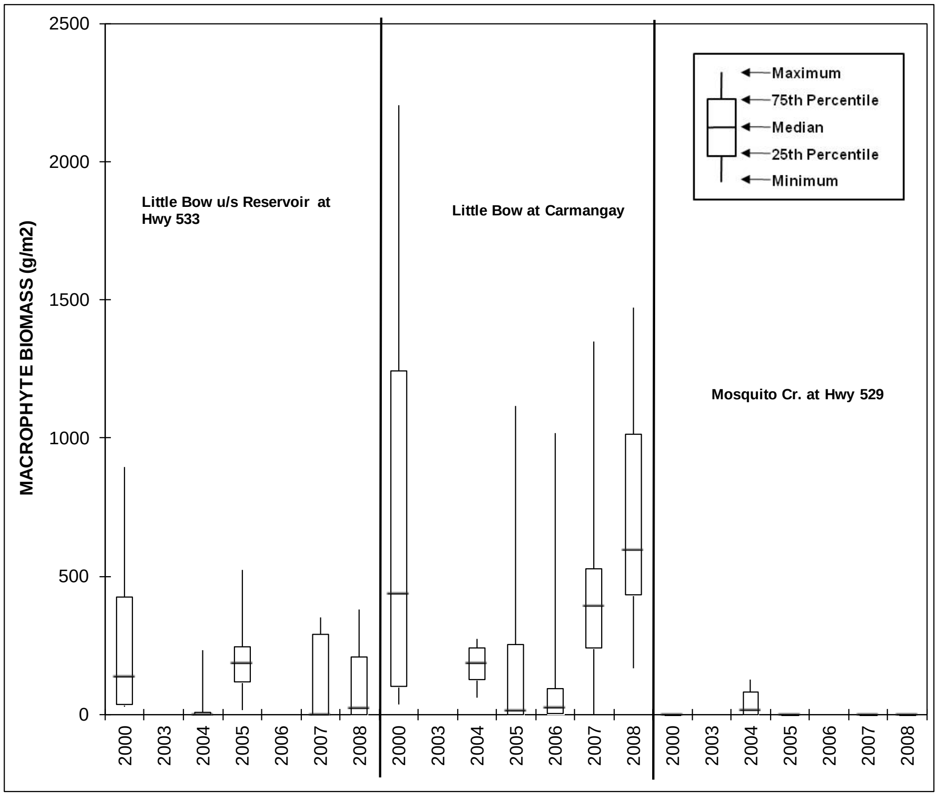


Figure 39 Dry macrophyte biomass in Twin Valley Reservoir tributaries, 2003-2010

Reservoirs

Twin Valley Reservoir and Clear Lake are productive water bodies with high phosphorus levels. Nuisance cyanobacterial blooms (Figure 40) that exceeded the maximum phytoplankton chl *a* levels (30 µg/L) predicted by modelling occurred most summers. In spite of this, median phytoplankton chl *a* levels most summers were less than the typical minimum (15 µg/L) predicted by modelling. This indicates that phytoplankton biomass was more variable than predicted, sometimes higher and sometimes lower.

Furthermore, there was appreciable spatial variation in phytoplankton chl *a*. Most years (6/7) median phytoplankton chl *a* was well below the OECD mesotrophic boundary for mean chl *a* (Figure 40) in the Central Basin of Twin Valley Reservoir, while median levels were less often below this boundary in the West and Mosquito Basins. These latter two basins are influenced by river inputs, and likely more affected by high nutrient loadings. Trophic state is evaluated using a variety of indicators, including mean phytoplankton chl *a* in section 3.3.9.

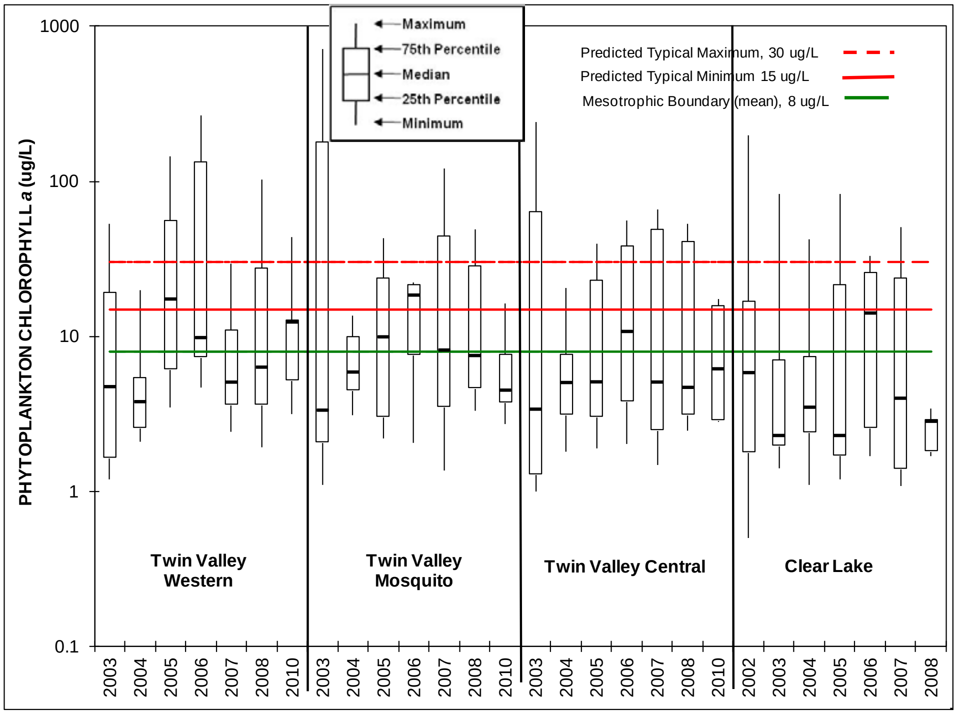


Figure 40 Phytoplankton chl *a* in Twin Valley Reservoir and Clear Lake, 2002-2010

High rainfall years such as 2006, and to a lesser extent 2005, were more productive in both reservoirs, which suggest that nutrient loading from the watershed influenced productivity. The single year when Frank Lake did not discharge, 2004, was one of the least productive years. Median phytoplankton chl *a* was lowest in the West Basin that year. This basin is most affected by loading from the Little Bow River and would be expected to respond most to loadings from Frank Lake. Median phytoplankton chl *a* in the other two basins of Twin Valley Reservoir in 2004 was within the range of the other subsequent years. Although phosphorus levels have declined in all three basins from 2006 to 2010 and maximum plankton chl *a* was lower in the

Central Basin after 2006, median phytoplankton chl *a* has not declined concurrently. Accordingly there is no evidence yet of declining phytoplankton chl *a* following initial trophic upsurge.

Years with warmer air temperatures such as 2007 and 2008 in the Central and Mosquito Basin of Twin Valley Reservoir (Figure 4, Section 3.3.1) tended to have higher maximum levels of phytoplankton chl *a*, (Figure 40), than cooler years. Although air temperatures were not especially high in 2006 (Figure 4), euphotic zone water temperatures in the Central Basin were relatively high (red shading in this basin in Figure 9). Accordingly, 2006 had the highest median phytoplankton chl *a* in the Central and Mosquito Creek basins of Twin Valley Reservoir, and Clear Lake (Figure 40). One would expect this sort of a pattern, as the cyanobacteria that occur in these water bodies (see below) are generally more tolerant of higher water temperatures than algae (Wetzel 1983). However, effects of water temperature on phytoplankton chl *a* were less consistent in the Western Basin of Twin Valley Reservoir, and Clear Lake. The warmest years (2007 and 2008) did not consistently have the highest phytoplankton chl *a* in these water bodies. Factors other than water temperature seemed to have a greater influence on phytoplankton biomass, as described elsewhere in this section.

Phytoplankton taxonomy was not done routinely due to budget constraints, but field notes suggest that blooms were often dominated by nitrogen fixing cyanobacteria such as *Aphanizomenon flos-aquae*. This taxon is quite common in productive shallow lakes and reservoirs in Alberta. A single sample collected from Twin Valley Reservoir in July 2006 was examined by Dr. Sue Watson, of the National Water Research Institute, Environment Canada and was almost entirely *A. flos-aquae*, with small amounts of *Microcystis sp.* Cyanobacterial toxins were also detected in Twin Valley Reservoir ($\leq$ 1.11 μg/L total microcystin) and Clear Lake ($\leq$ 0.83 μg/L) in 2007 and 2008. These few toxin measurements were not unusually high for a productive reservoir, and are not frequent enough to characterize toxin levels in these water bodies.

Clear Lake had much higher phosphorus levels than Twin Valley Reservoir (section 3.3.3), but lower phytoplankton chl *a*, mostly $\leq$ 4.0 μg/L. Clear Lake was less productive than forecast by modelling (Figure 40) and both water bodies are atypical in their phytoplankton response to phosphorus. When phytoplankton chl *a* for 68 Alberta lakes and reservoirs was plotted against [TP], both Twin Valley Reservoir and Clear Lake clearly produced less phytoplankton chl *a* than other Alberta lakes (Figure 41) (from Sosiak et al. 2006). This analysis used results from 2003 to 2006, but one would expect this tendency to continue, at least during trophic upsurge.

There is evidence that Clear Lake has a lower than predicted phytoplankton response to phosphorus loading because it is a nitrogen-limited water body. These are relatively uncommon in Alberta. One commonly-used method of assessing whether phosphorus or nitrogen are in short supply and limit the growth of phytoplankton, is to examine dissolved nitrogen:dissolved phosphorus ratios. Where this ratio is less than 5, lakes are often nitrogen limited, ratios in the range of 5 to 12 can by limited by either nutrient (a boundary of seven is often used), and higher ratios are typically phosphorus limited (Forsberg and Ryding (1980)(cited in Ryding and Rast 1989). During the period evaluated (2003 to 2005), this ratio was often less than 1, which indicates strong nitrogen limitation (Figure 42). Ratios for Twin Valley Reservoir were also sometimes well below 7 during parts of each year, which suggests seasonal nitrogen limitation (Figure 42). Nutrient limitation is usually assessed using multiple lines of evidence, including algal assays and N:P ratios. Although not conclusive, the extremely low dissolved N:P ratios in Clear Lake and very high TP and TDP concentrations suggest that this is a nitrogen-limited lake.

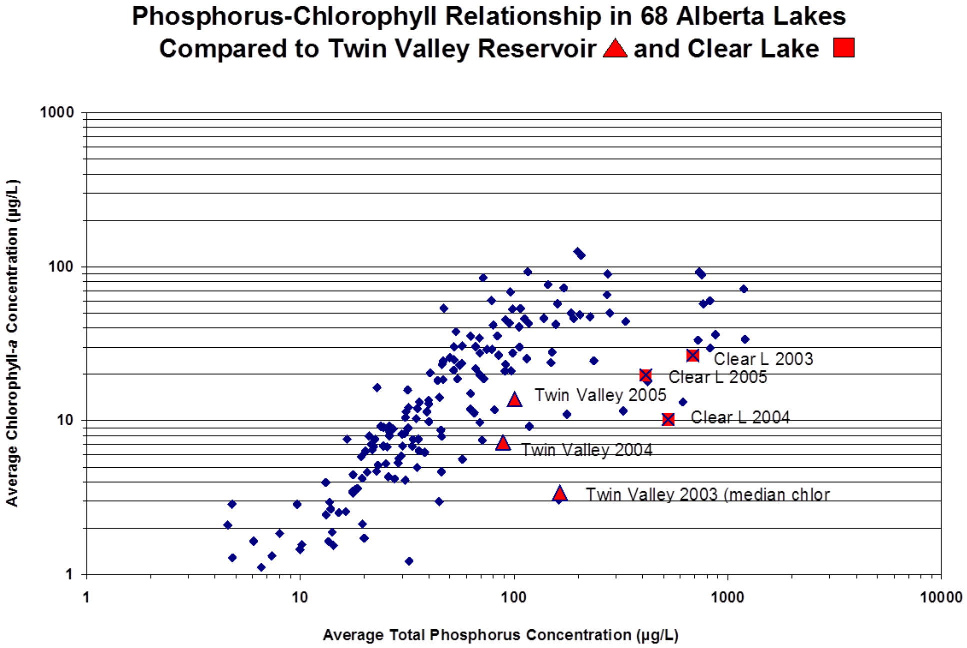


Figure 41 TP-chlorophyll relationship in Alberta lakes, compared to Twin Valley Reservoir and Clear Lake

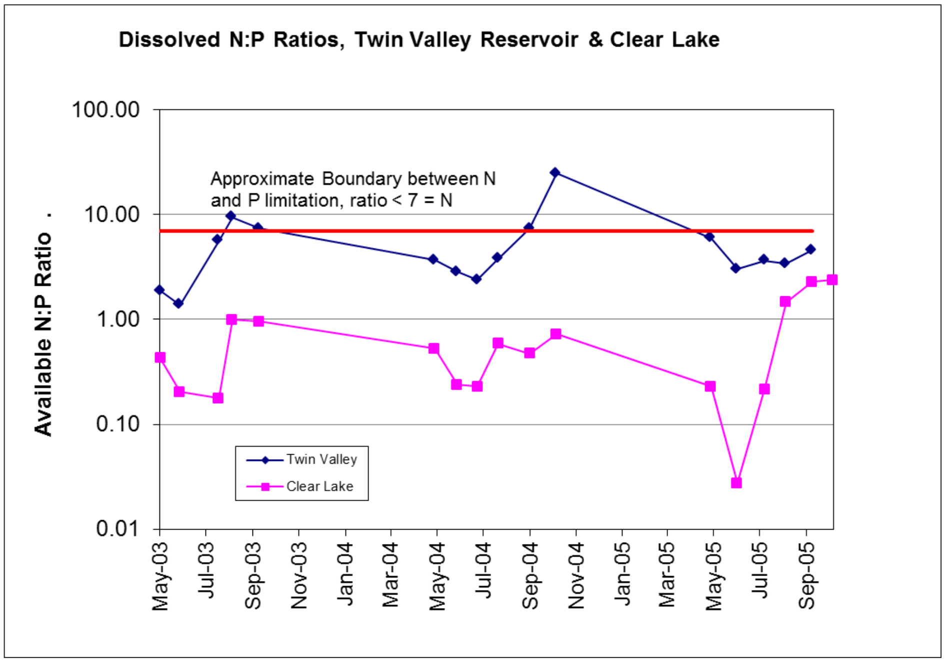


Figure 42 Dissolved N:P ratios in Twin Valley Reservoir and Clear Lake

There was also evidence of poor light penetration due to non-algal turbidity (described in Section 3.3.8) which should tend to inhibit phytoplankton biomass. High salinity is thought to be an important driver of phytoplankton community composition, and may influence species composition in Clear Lake. However, salinity did not control overall primary production patterns in one study of 19 American prairie saline lakes (Salm et al. 2009).

More extensive drinking water treatment to remove noxious tastes and odours was predicted (NRCB/CEAA 1998) if Twin Valley Reservoir remains hypertrophic. The results of this assessment (Section 3.3.9) suggest that this reservoir was less productive than forecast (eutrophic) most years, and should therefore be less prone to taste and odour concerns. However, it should be noted that taste and odour events occur in far less productive water bodies, such as Glenmore Reservoir in Calgary. No sampling for compounds such as geosmin, that cause taste and odour problems was done for this project.

3.3.6 Coliform Bacteria

Running Water

Both *E. coli* and fecal coliforms increased significantly post-impoundment in the Little Bow River at highway 533 and Carmangay, and in Mosquito Creek (Table 1, Figure 43, 44). The CCME contact recreation guideline for resampling *E. coli* was occasionally exceeded at all three locations. The CCME irrigation guideline for fecal coliforms was also sometimes exceeded at these Little Bow sites. However, this guideline was regularly exceeded at Mosquito Creek at Highway 529, and two years (2006, 2010) the median was over the guideline. The increased coliform levels at this site appear to be flow-related, as both 2006 and 2010 were unusually wet years. Under higher flows there may be more runoff and scouring of shoreline areas near agricultural sites. Loadings from the Nanton WWTP may also have increased over time, and there is little dilution in winter.

Reservoirs

There was seldom any exceedance of either the *E. coli* resampling guideline for contact recreation, or the fecal coliform irrigation guideline in samples from either Twin Valley Reservoir or Clear Lake (Figure 45, 46). The main exceptions occurred during first filling of Twin Valley Reservoir in 2003. Coliforms are seldom a concern in lakes and reservoirs of Alberta and these relatively low coliform levels are to be expected.

3.3.7 Secchi Depth and Transparency

Secchi depth is widely used as an indication of the transparency of lake water to light penetration. Secchi depth is the mean depth at which a weighted, black and white disc disappears and reappears when lowered into a lake. Low Secchi depth measurements are generally indicative of more turbid conditions usually caused by high algal biomass and other factors such as suspended solids. Because Secchi depth measurements are prone to various sources of error, underwater photometers were routinely used to determine the depth of light penetration at the profile site in each reservoir.

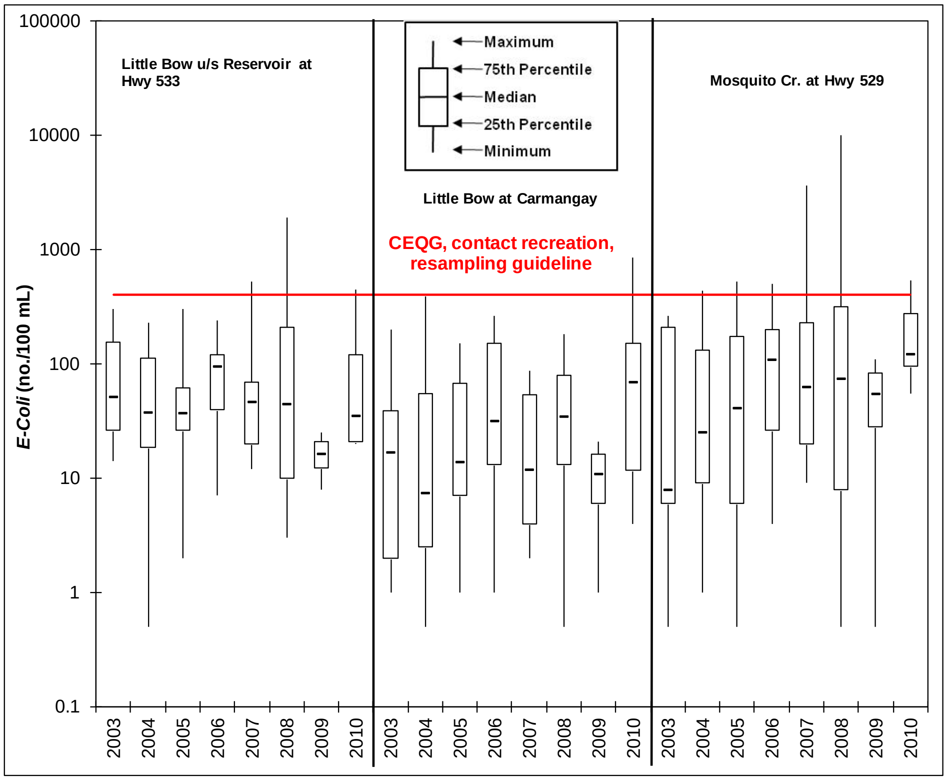


Figure 43 *E. coli* counts in Twin Valley Reservoir tributaries, 2003-2010

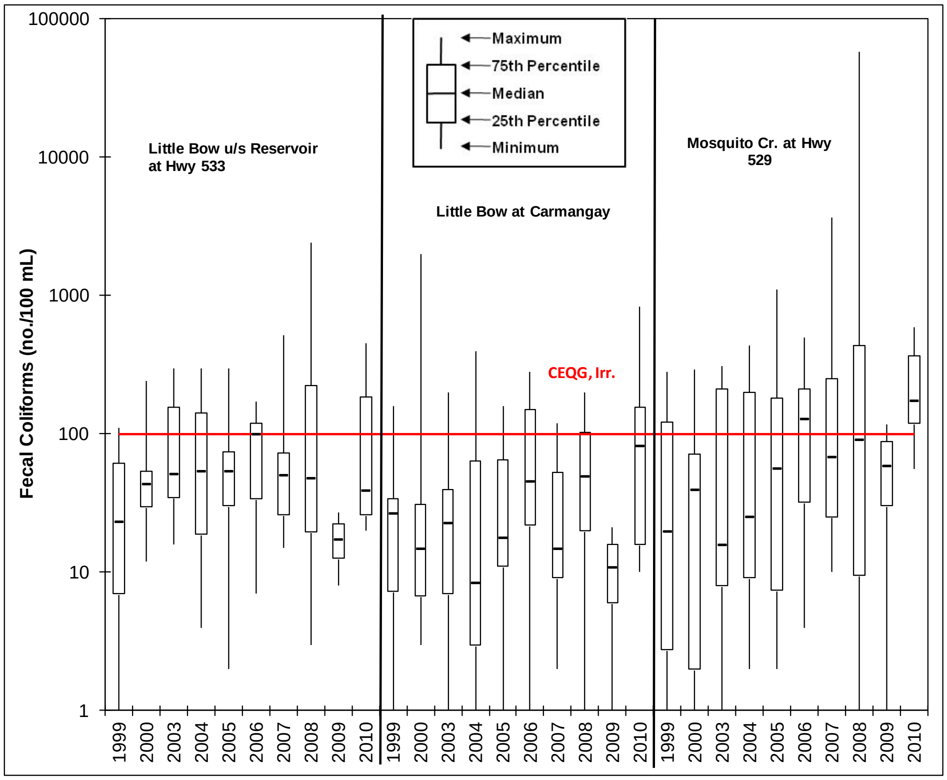


Figure 44 Fecal coliform in Twin Valley Reservoir tributaries, 1999-2010

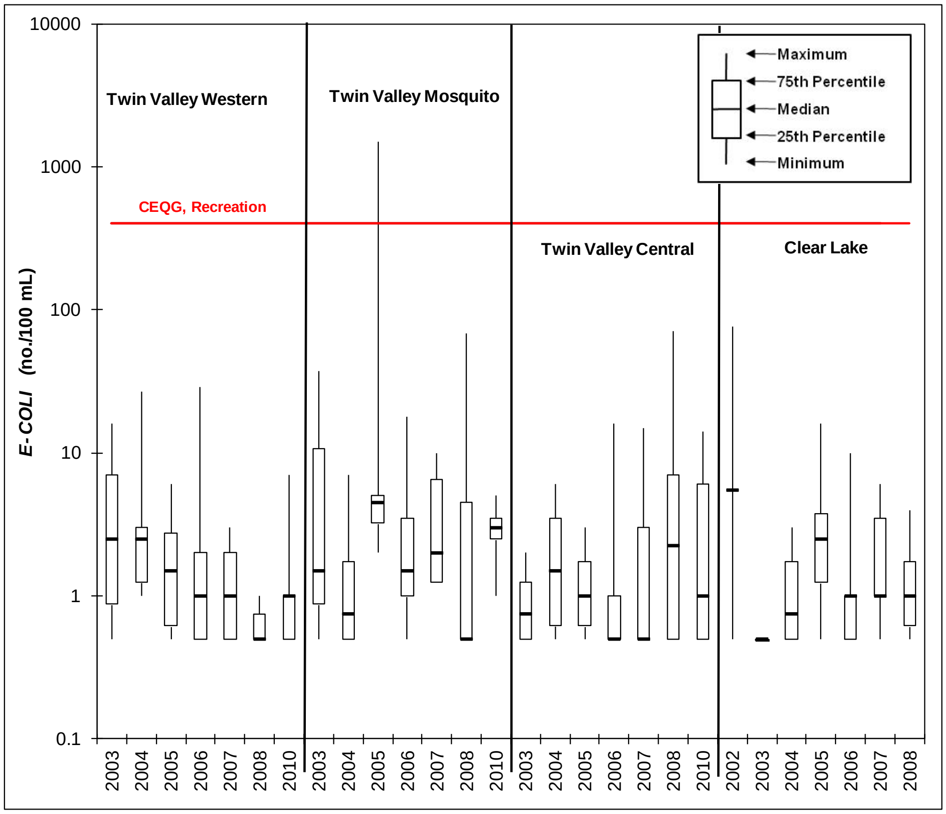


Figure 45 *E. coli* in Twin Valley Reservoir and Clear Lake, 2002-2010

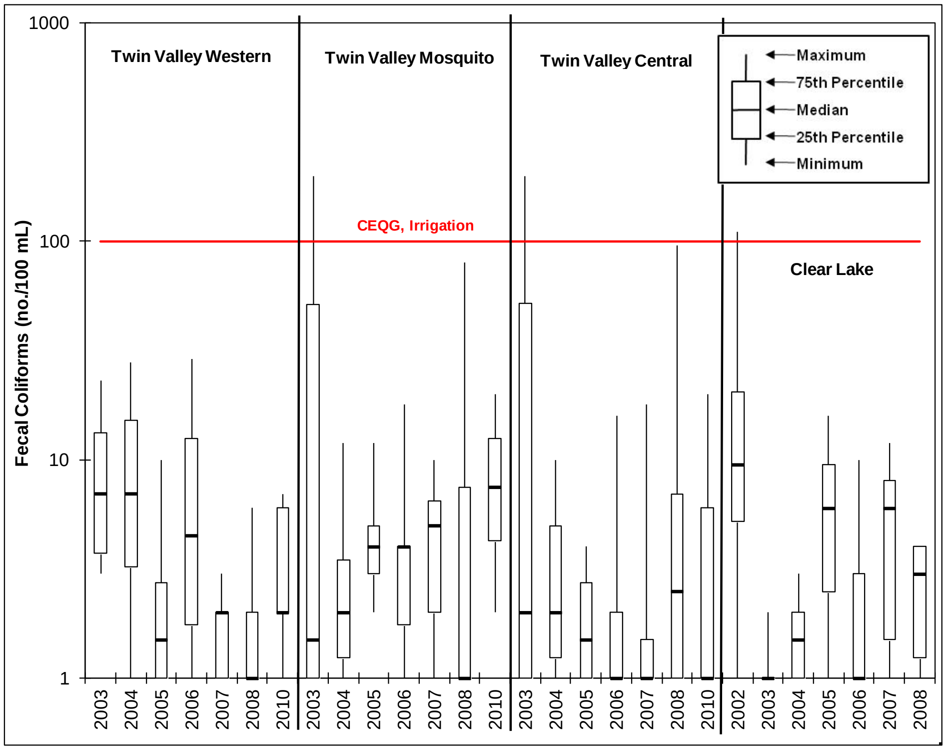


Figure 46 Fecal coliform in Twin Valley Reservoir and Clear Lake, 2002-2010

Secchi depth in Clear Lake and the Central Basin of Twin Valley Reservoir was generally below the boundary for mesotrophy and above the boundary for eutrophy, indicating less water clarity and more productive conditions typical of eutrophic lakes (Figure 47). In both water bodies median Secchi depth was more typical of eutrophic conditions (OECD boundary mean 1.5 to 3 m). However, there were some years such as 2003, 2004, and 2010 when median Secchi depth approached or exceeded the mesotrophic-eutrophic boundary in individual basins of Twin Valley Reservoir, but not in Clear Lake. This indicates higher water clarity in those years. Generally these years corresponded with relatively low phytoplankton chl *a*, which indicates less algal growth those years. Furthermore, both TP and TDP were at these lowest levels during this sampling program in the Western Basin of Twin Valley Reservoir (Section 3.3.3) in 2004 (the only year when Frank Lake did not discharge during this sampling program).

The median, 75 percentile, and maximum for Twin Valley, Central Basin, were all identical and equal to 3.5 m in 2010, because that was the Secchi depth on three consecutive sampling trips from June 1 to July 28 in 2010 (Figure 47).

It should be noted that Secchi depth can be influenced by factors other than algal biomass, such as higher levels of suspended solids and turbidity and in such cases may be a less reliable indicator of trophic state (discussed in more detail in Section 3.2.8).

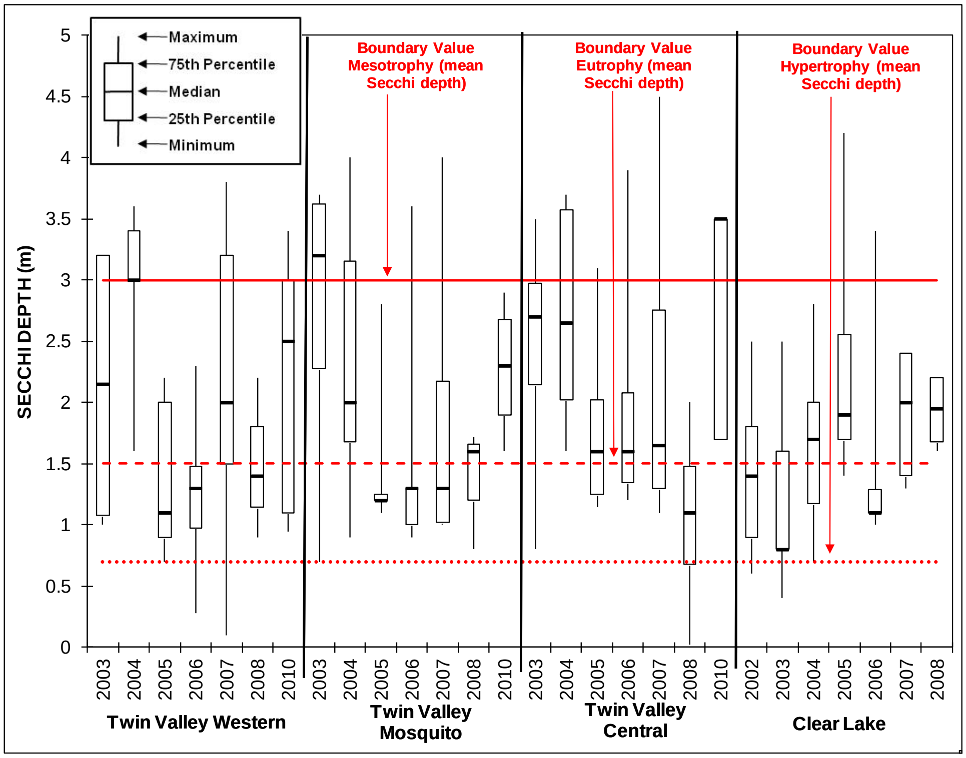


Figure 47 Secchi depth in Twin Valley Reservoir and Clear Lake, 2002-2010

3.3.8 Suspended Solids and Turbidity

Total suspended solids is a measure of the total amount of suspended particles such as fine silt and clay, organic matter and small organisms in water. It is typically measured as non-filterable residue (NFR), the amount of dry material retained on a glass-fibre filter. Suspended solids can carry nutrients and contaminants, are sometimes aesthetically undesirable, can clog water treatment filters and irrigation pumps, and can kill aquatic life when they settle on a stream bottom. Turbidity is an indirect measure of suspended solids and clarity. Turbidity meters measure the degree to which light is scattered and absorbed as it passes through a sample.

Running Water

Turbidity and suspended sediments (as NFR) have increased significantly following impoundment in the Little Bow at Highway 533 and Mosquito Creek at Highway 529 (Figure 48 to 51, Table 1), but only turbidity increased downstream at Carmangay (Table 1, Figure 52). These variables exceeded guidelines at both locations post-impoundment (Figure 53, 54). A few scattered measurements during the winter months of 2009 have been included. Some of these values did not exceed the guidelines, because NFR and turbidity are typically much lower during the winter months. The CCME guidelines varied from site to site, because they were expressed as an increase compared to historic baseline concentrations at each site.

An increase in turbidity was predicted due to the higher flows and scouring of the upstream channel of the Little Bow River. The EIA predicted no change in water quality in Mosquito Creek under higher diversion flows in the spring and early summer (NRCB/CEAA 1998). However, suspended solids and turbidity have clearly increased and remained elevated above the guidelines to 2010. Previous work (Sosiak 2000), found that Women's Coulee, which drains into Mosquito Creek, contributed more suspended solids to Mosquito Creek than any other source. When flows were first diverted from the Highwood River down Women's Coulee, they followed a seasonal runoff channel, rather than a canal or well-developed stream channel. Increased flow would be expected to cut deeper into this existing seasonal channel and increase sediment transport down Women's Coulee.

To evaluate sources of phosphorus and suspended solids along Women's Coulee, four sites from below Women's Coulee Reservoir to 690 Avenue were sampled monthly five times each year during the open water season from May 13, 2003 to September 28, 2006. Median concentrations for the three variables sampled are tabulated below (Table 3). These results suggest that sources from the vicinity of Old Women's Buffalo Jump to 658 Avenue likely contribute the bulk of suspended sediments entering Women's Coulee. There is extensive bank erosion in this reach. Photographs of this erosion are available in Sosiak (2000). There is also some bank erosion downstream of 690 Avenue, which is the site closest to the mouth of Women's Coulee. However, erosion is more extensive near the Buffalo Jump. The pattern of TP and TDP increase along Women's Coulee is more gradual, and suggests diffuse inputs from agricultural operations along the coulee rather than loading from a reach with extensive erosion, like NFR.

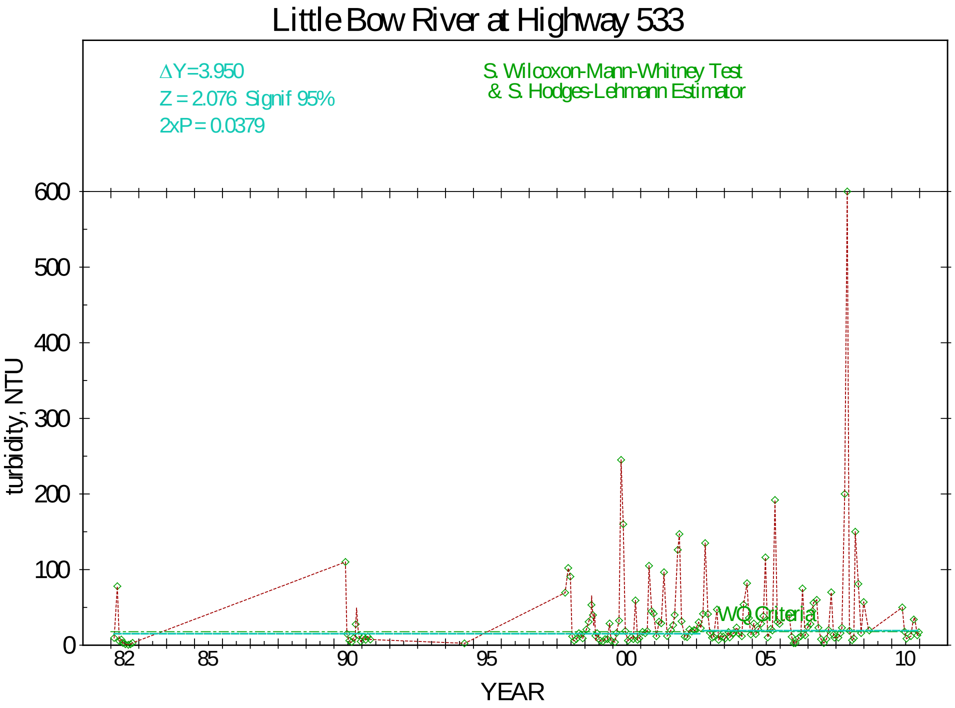


Figure 48 Turbidity in the Little Bow River at Highway 533, 1982-2010

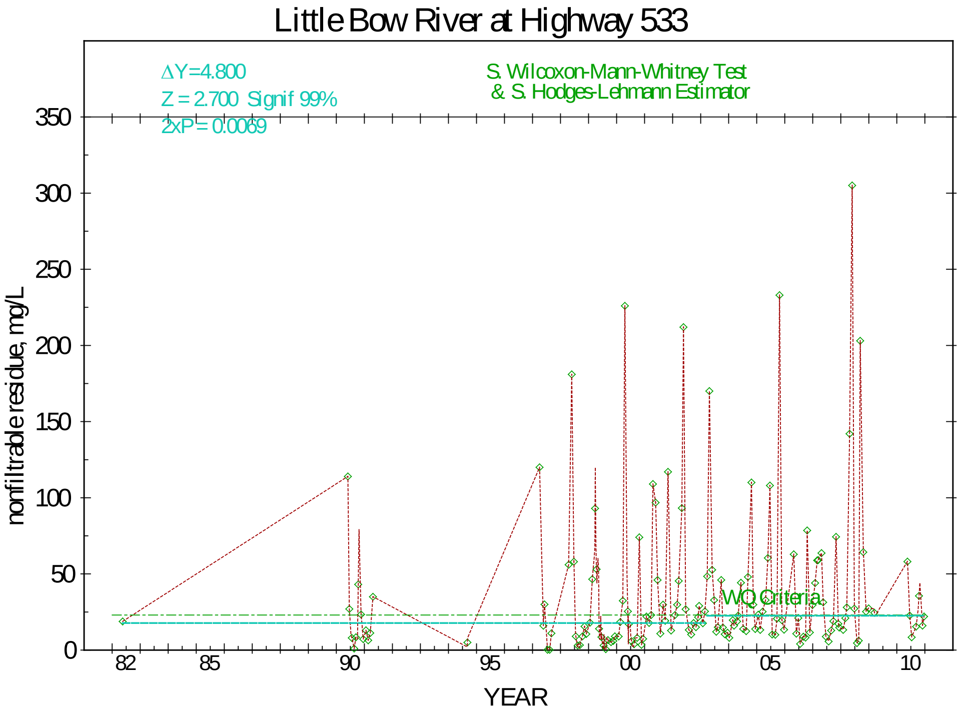


Figure 49 NFR in

the Little Bow River at Highway 533, 1982-2010

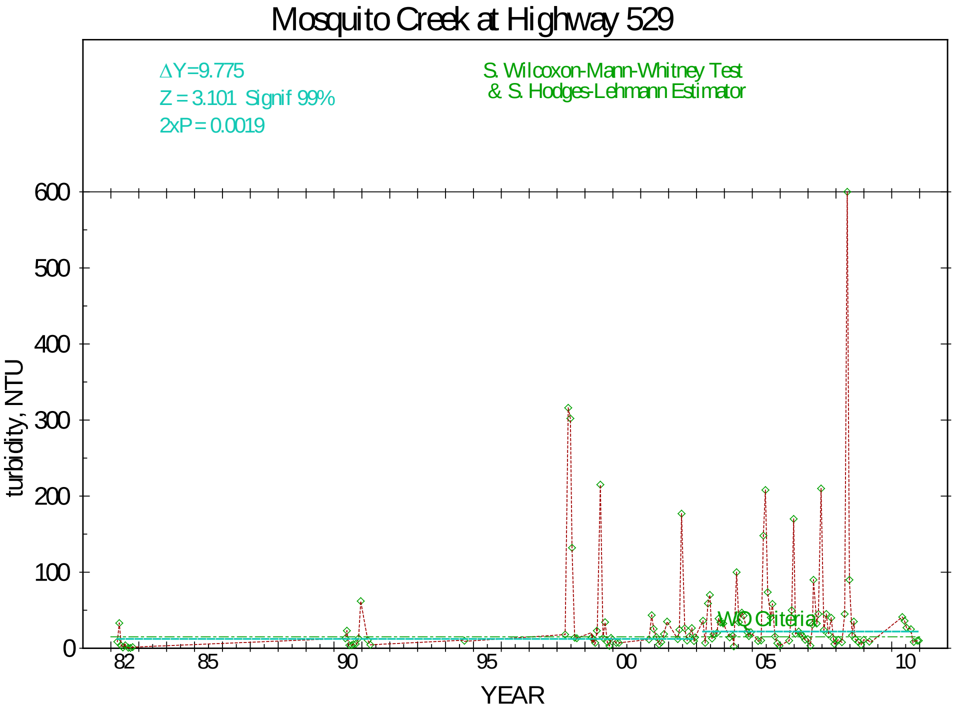


Figure 50 Turbidity in Mosquito Creek at Highway 529, 1982-2010

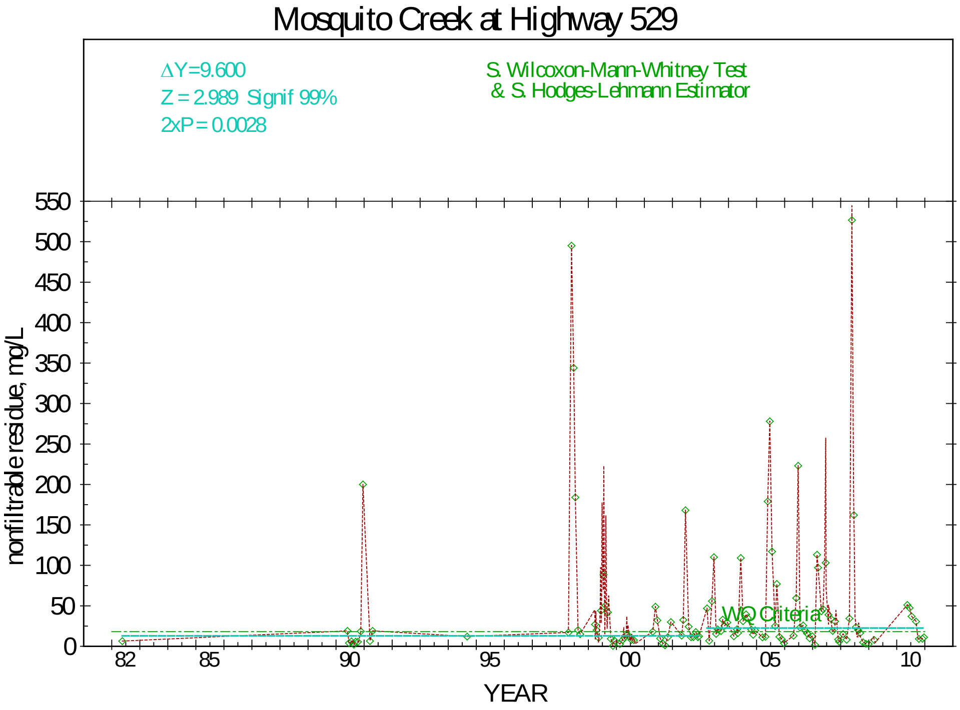


Figure 51 NFR in Mosquito Creek at Highway 529, 1982-2010

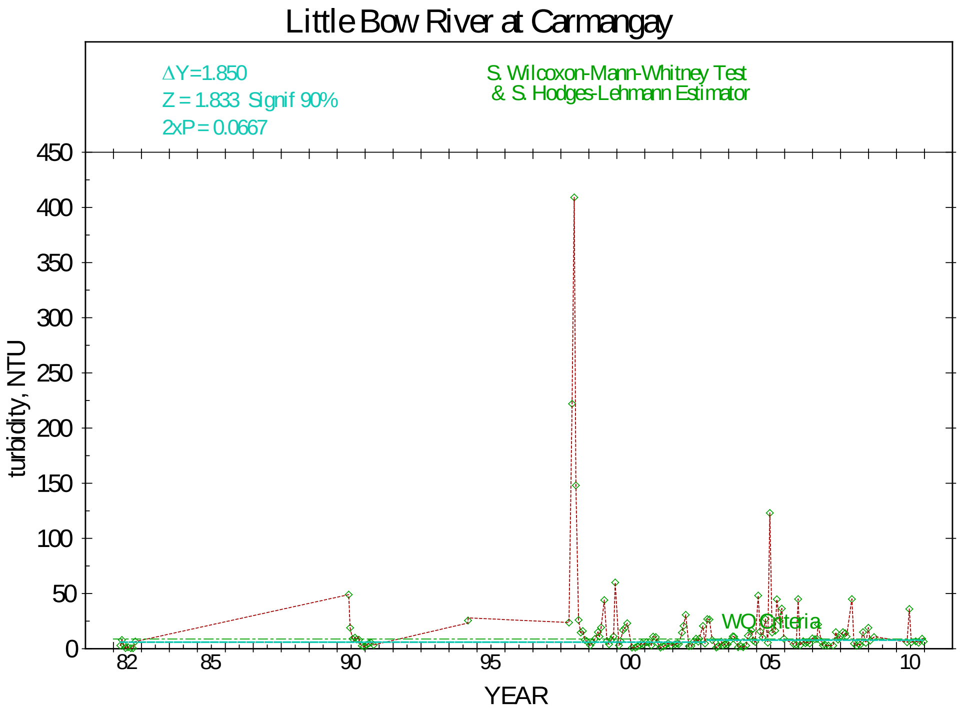


Figure 52 Turbidity in the Little Bow River at Carmangay, 1982-2010

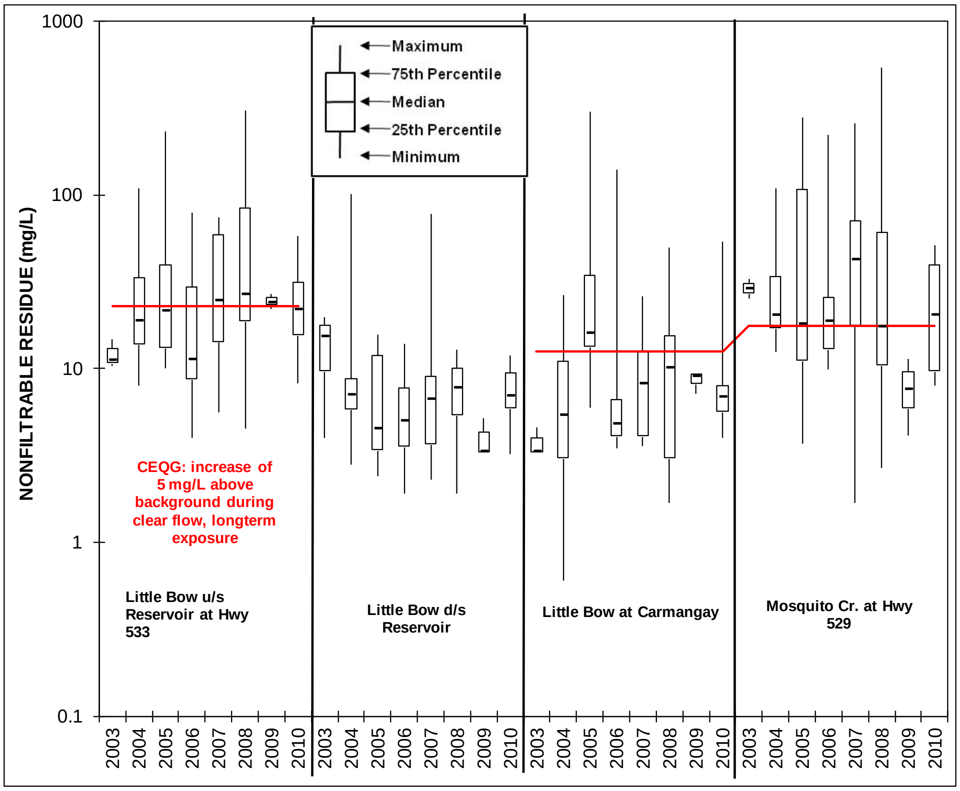


Figure 53 NFR in Twin Valley Reservoir tributaries 2003-2010

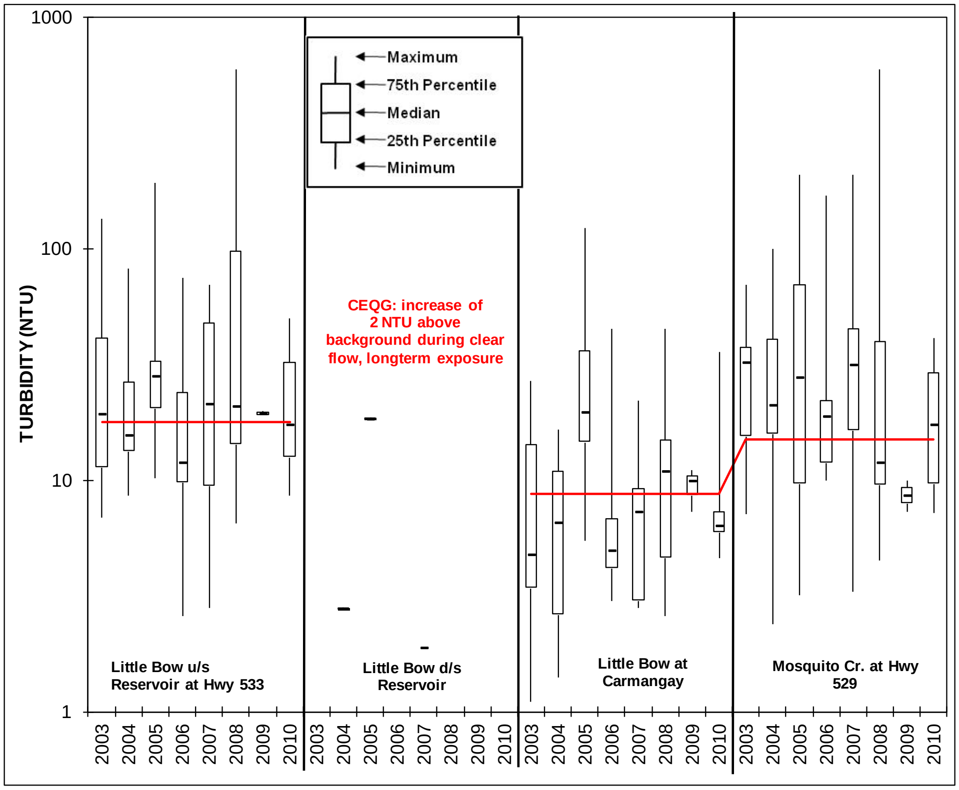


Figure 54 Turbidity in Twin Valley Reservoir tributaries 2003-2010

Table 3 Median concentration of phosphorus and suspended solids, as nonfiltrable residue (NFR), along Women's Coulee (WC) from May 13, 2003 to September 28, 2006

Sites	TP, mg/L	TDP, mg/L	NFR, mg/L
WC downstream reservoir	0.019	0.004	9.40
WC near Highway 540[a]	0.021	0.007	12.45
WC at 658 Ave.	0.042	0.006	34.45
WC at 690 Ave.	0.080	0.006	37.65

[a] site AB05AC1330, which is upstream from an area of erosion near the Old Women's Buffalo Jump, described in Sosiak (2000)

Reservoirs

These water bodies have moderately high levels of suspended solids (Figure 55) and turbidity (Figure 56), perhaps related to wind-induced re-suspension of sediments, bank erosion (photo, Figure 57), or loading of increasingly-turbid water from tributaries, described above. Clear Lake in particular had an obvious chalky colour perhaps caused by fine suspended inorganic material (photo, Figure 58).

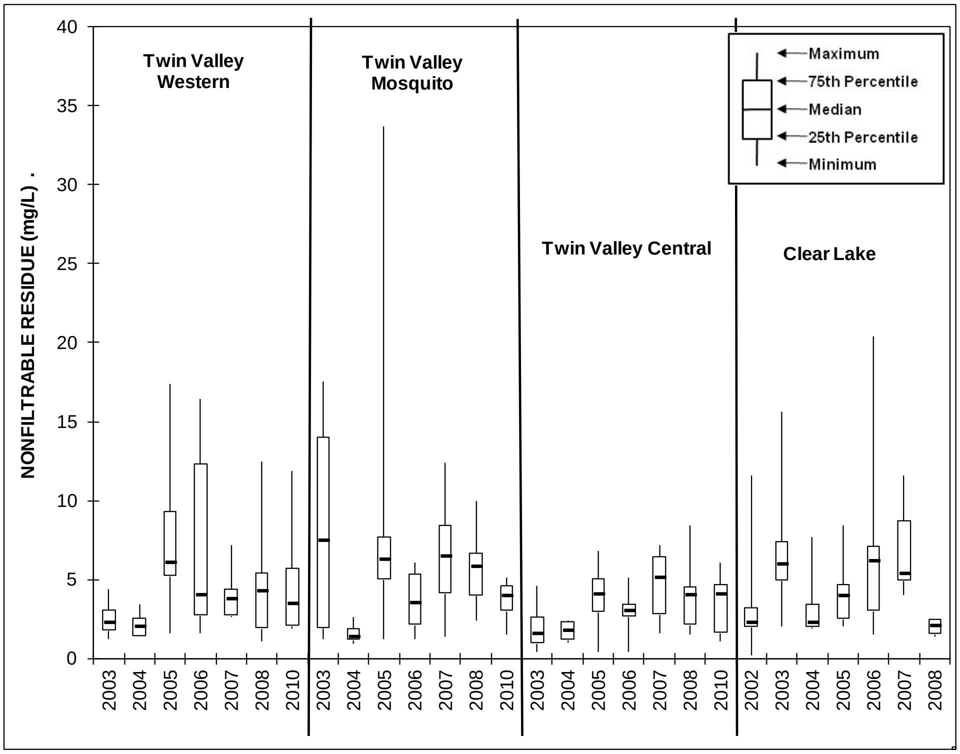


Figure 55 NFR in Twin Valley Reservoir and Clear Lake 2002-2010

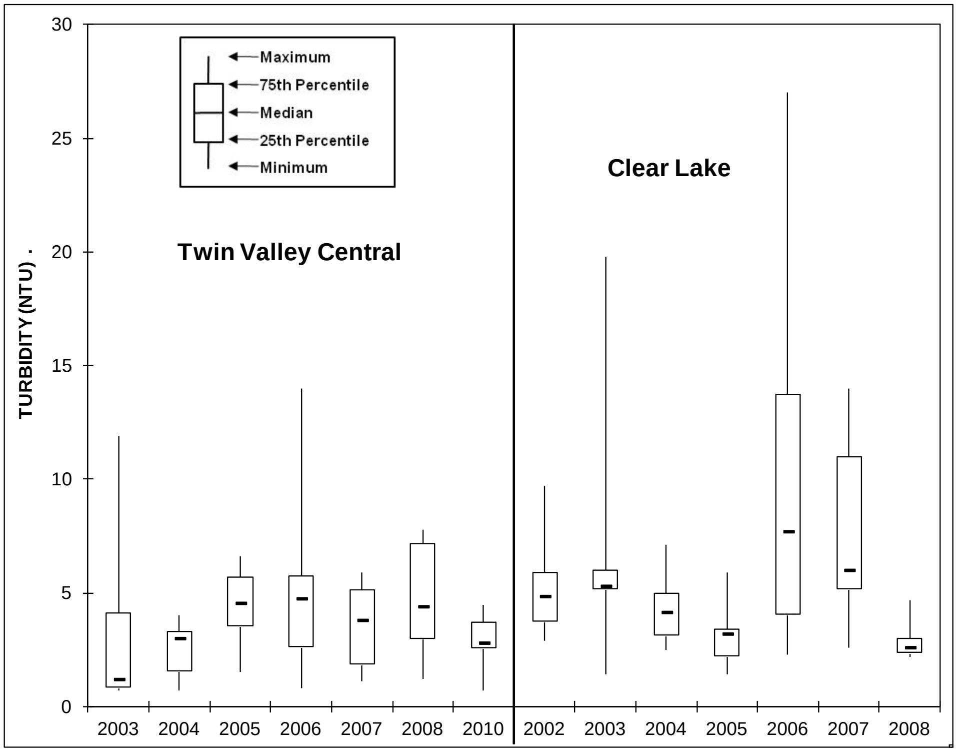


Figure 56 Turbidity in Twin Valley Reservoir and Clear Lake 2002-2010

Figure 57 Bank erosion at Twin Valley Reservoir

Figure 58 Water colour of Clear Lake

Non-algal turbidity in both these reservoirs inhibits phytoplankton biomass, as indicated by phytoplankton chl *a*. Phytoplankton chl *a* was regressed against light extinction to evaluate the contribution of non-algal turbidity (Sosiak et al. 2006). The Y-intercept of the linear regression lines in Figure 59 and 60 indicates the amount of light extinction that is due to factors others than chlorophyll, at 0 µg/L of phytoplankton chl *a*. Since the Y-intercept was greater for Clear Lake than Twin Valley Reservoir, non-algal turbidity appears more evident and the influence on phytoplankton biomass in Clear Lake more likely.

Suspended solids were especially high in the Mosquito Basin of Twin Valley Reservoir, and during wet years such as 2005, as expected with increased runoff related to precipitation (Figure 55). Suspended solids and turbidity appeared to increase over time in the Central Basin of Twin Valley Reservoir. However, this apparent trend was not tested statistically as there was a relatively short period of record. Otherwise there was no obvious temporal trend in these two variables in Clear Lake or in other basins.

Elevated turbidity is relatively common in slightly saline to saline Alberta lakes, which averaged 12 NTU in one study, much higher than the 3 NTU average for freshwater lakes (Mitchell and Prepas 1990). Although TDS levels were higher in Clear Lake, both water bodies are well below 1000 mg/L (Figure 67a) and would not typically be classified as saline. Above that level they would be considered slightly saline.

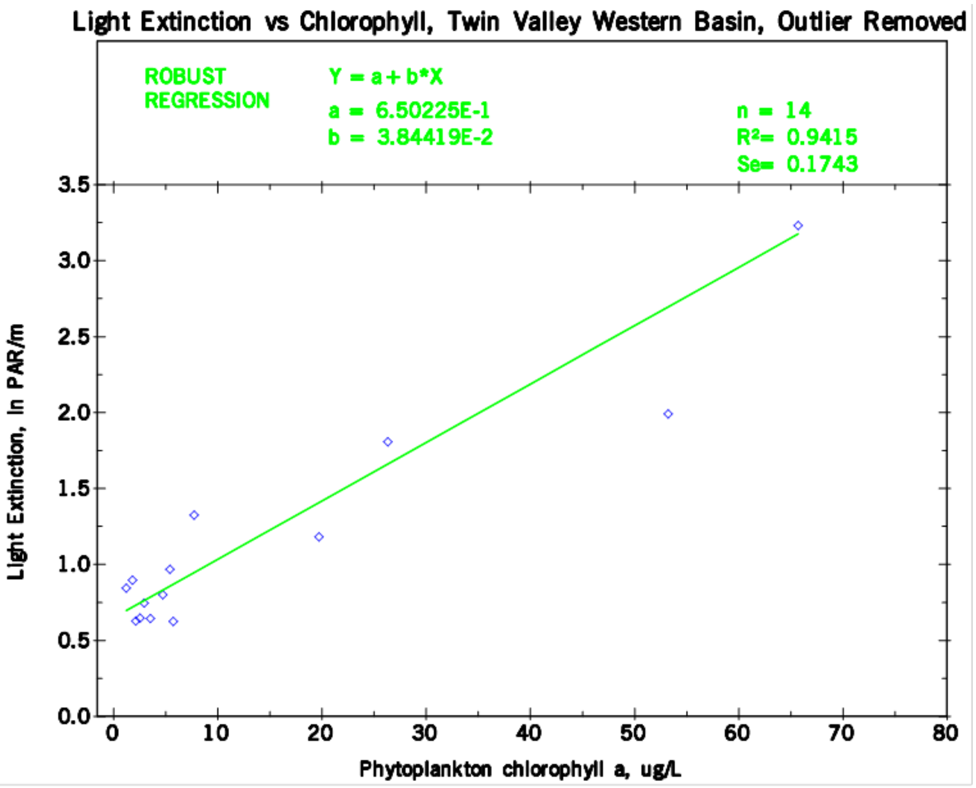


Figure 59 Light extinction regressed against chlorophyll *a*, Twin Valley Reservoir

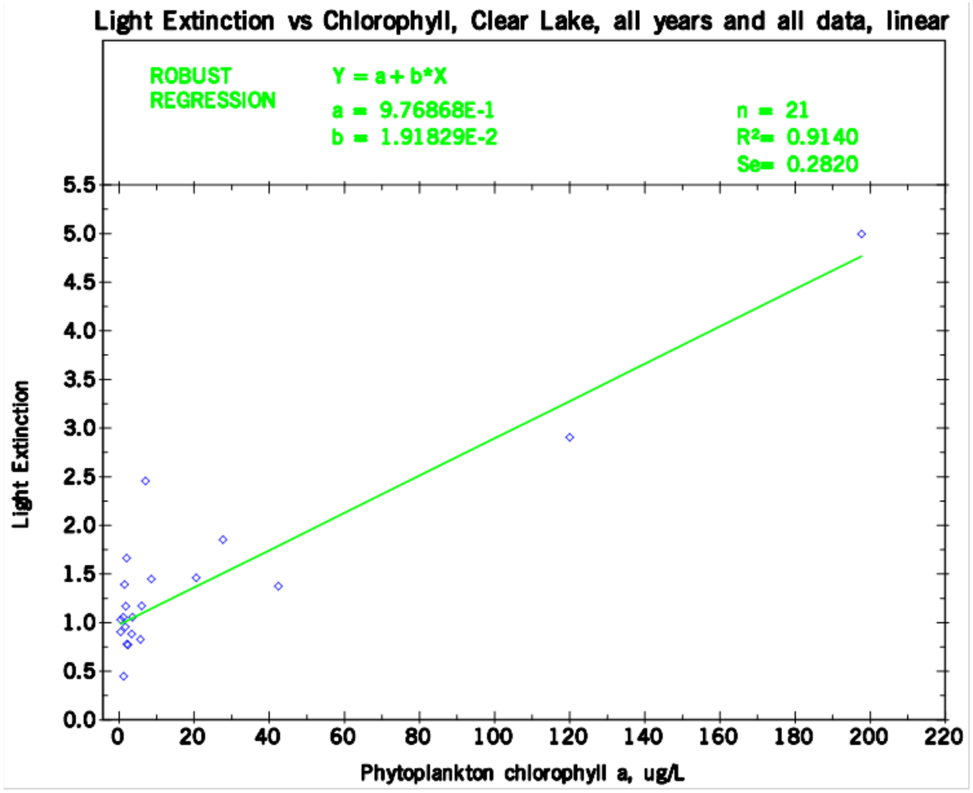


Figure 60 Light extinction regressed against chlorophyll *a*, Clear Lake

3.3.9 Trophic State Assessment

The trophic state of a lake is a system of classification based on the level of phytoplankton production in a lake. These are commonly used to classify lakes as oligotrophic (low), mesotrophic (middle), eutrophic (high), or hypertrophic – which denotes very high levels of phytoplankton production.

This classification system is based on commonly-measured indicators in a large set of lakes in a given region. This report used the fixed boundary system for TP, phytoplankton chl *a*, and Secchi depth, developed by the OECD (1982) which is based on an extensive study of European lakes and reservoirs and is most often used by AEW to classify lakes. The other commonly used system in North America, the Carlson TSI index is mainly based on American lakes and reservoirs, and may perform poorly in lakes and reservoirs that are nitrogen-limited or turbid (Brezonik 1984). As described above, at least Clear Lake appears to be nitrogen-limited. Accordingly, the Carlson TSI index may not be appropriate.

Trophic state is important for this project because the joint panel of the NRCB/CEAA (1998) made a specific recommendation in their decision report, that the trophic state of the new reservoir should be reduced through a series of recommendations from the predicted hypertrophic state to mesotrophy.

All the years of data for Twin Valley Reservoir and Clear Lake were compared to the OECD fixed boundaries, and the predominant trophic state for these indicators most years is summarized in Table 4.

Table 4 Predominant trophic state in Twin Valley Reservoir (TV) and Clear Lake during 2002-2010

Water Body/Basin	**Predominant Trophic State (in Bold Font) Based on OECD Fixed Boundary System**				
	Mean TP	Mean Chl *a*	Max. Chl *a*	Mean Secchi	Min. Secchi
Clear Lake	Hypertrophic	**Eutrophic**	Eutrophic/ Hypertrophic	**Eutrophic**	**Eutrophic**
TV, Western	Hypertrophic	Eutrophic/ Hypertrophic	Eutrophic/ Hypertrophic	**Eutrophic**	**Eutrophic**
TV, Mosquito	Hypertrophic	**Eutrophic**	Mesotrophic	**Eutrophic**	**Eutrophic**
TV, Central	Hypertrophic	**Eutrophic**	**Eutrophic**	**Eutrophic**	**Eutrophic**

Productivity can vary greatly from one year to the next in some productive water bodies, and that was the case with these reservoirs. Classification was more complex than usual for Alberta lakes, with a large amount of spatial and temporal variation and evidence of nitrogen and perhaps light limitation in both water bodies. The latter factors would tend to reduce the impact of high phosphorus loading to a reservoir. Also, these trophic classification systems are from other regions of the world and may not fully capture regional differences in algal productivity in western Canada.

In some ways, a measure of algal biomass such as phytoplankton chl *a* is the best way to evaluate trophic state, as this is a direct measure of the algae that is produced. Based on mean phytoplankton chl *a* all basins of Twin Valley Reservoir, and Clear Lake, would be classified as eutrophic and sometimes hypertrophic (Table 4).

Results based on maximum phytoplankton chl *a* were more variable, but again most water bodies were either eutrophic or hypertrophic most years. For example, in the Central Basin of Twin Valley, both the 75 percentile and maximum phytoplankton chl *a* were within the 25-75 µg/L eutrophic range four of the seven sampling years. This more variable classification likely reflects infrequent but dense cyanobacterial blooms that occurred most years. Most years, maximum phytoplankton chl *a* also exceeded the maximum levels predicted by modelling for the EIA in 1995. This may reflect the model configuration, which was based on the incorrect assumption that Frank Lake would seldom discharge. However, measured minimum phytoplankton chl *a* was well below that predicted by the modelling.

The Mosquito Basin of Twin Valley Reservoir was rated mesotrophic based on this measure in three years, and either eutrophic or hypertrophic the other four years. Increasing turbidity levels and light limitation, perhaps flow-dependant, in this basin may suppress primary production some years. In 2004, when no discharge from Frank Lake occurred, all three basins of Twin Valley Reservoir were rated mesotrophic based on mean phytoplankton chl *a*. It is also noteworthy that TP and phytoplankton chl *a* levels were much lower and Secchi depth was higher, in the Mosquito Basin in 2010.

The OECD classification is based on mean phytoplankton chl *a*, while median values have been plotted in the box and whisker plots. This statistic displays the data more accurately. Mean phytoplankton chl *a* was on average about 4.6 times greater than median values, because the data were skewed by infrequent large blooms. This means that a trophic ranking based on means tends to be higher than median concentrations would indicate. For example, 6 of 7 chlorophyll means for Clear Lake were eutrophic or greater, but only 1 of the 7 chlorophyll medians were in that range. Most medians were below the mesotrophic boundary, which suggests a less productive condition.

Based on the available data and the OECD classification system, both Clear Lake and the Central Basin of Twin Valley Reservoir were eutrophic most of the sampling years.

3.3.10 Major Ions, Salinity, and SAR

Total dissolved solids (TDS) is the amount of inorganic salts and other dissolved materials in fresh water, and is a measure of the degree of salinity of a water supply. Constraints on the types of crops that can be irrigated occur at high levels of salinity. Water bodies with TDS $\leq$ 1000 mg/L are considered fresh, or non-saline. The salinity of lakes is highly variable and depends on the underlying geology and weathering of rocks, atmospheric deposition and evaporation-precipitation processes.

TDS includes the major ions. The major anions include carbonates, bicarbonates, chlorides, and sulphates. Major cations include calcium, magnesium, sodium, and potassium. Some ions such as chloride are known as conservative substances and their concentration is little affected by biotic processes. Others such as calcium are more reactive, are influenced greatly by metabolism, and can exhibit marked seasonal and spatial dynamics (Wetzel 1983). Fluoride will be discussed here along with chloride, another major halide.

The Sodium Adsorption Ratio (SAR) is used to evaluate the suitability of waters used for irrigation, and is an estimate of the degree to which sodium will be adsorbed from water by soil (CCREM 1987). SAR is used to assess the potential for soil infiltration problems due to sodium imbalance in irrigation water. SAR is no longer part of the CCME guidelines, but is still used by certain Alberta government departments (AENV 2000, 2002) and accordingly was calculated for this project.

Running Water

Total dissolved solids (Figure 61) in the Little Bow River upstream from Twin Valley Reservoir at Highway 533 and downstream at Carmangay increased significantly after impoundment to peak levels in 2006 (Figure 62a). This was followed by some decline. TDS at Carmangay was generally above the 500 mg/L irrigation guideline for sensitive crops grown in Alberta (such as raspberries, strawberries, beans or carrots) starting in 2006. TDS remained within a range acceptable for more salinity-tolerant local crops (such as wheat, alfalfa), which can tolerate salinity in the range of 500 to 800 mg/L TDS. A complete list of crops and their salinity tolerance is available in AENV (1999). This increase in dissolved solids concentration in the Little Bow basin could be a result of release of these constituents from newly-flooded soils, and discharge of saline water from Frank Lake, where outflow water was frequently over irrigation guidelines in 1990-93 (Sosiak 1994).

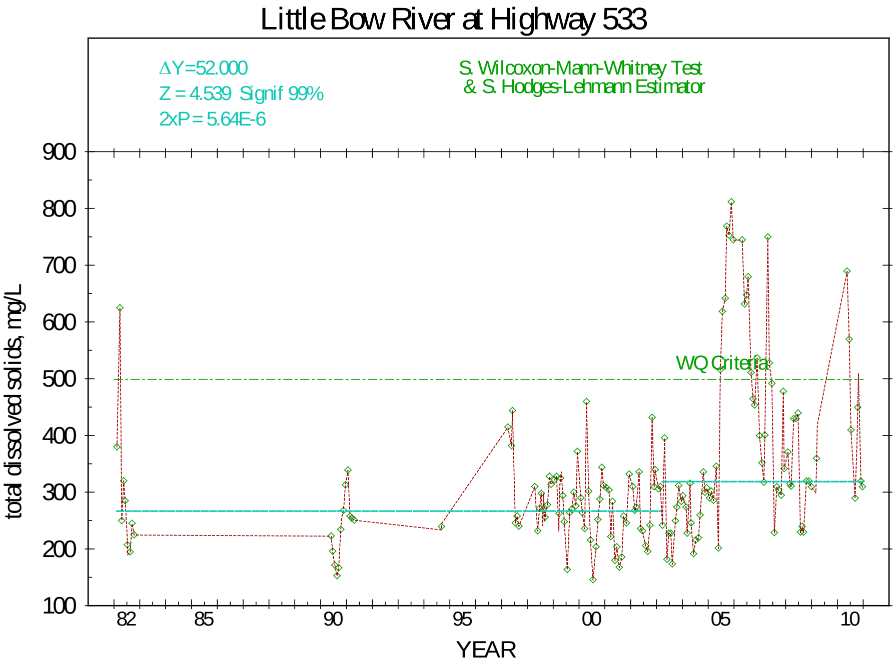


Figure 61 TDS in the Little Bow River at Highway 533, 1982-2010

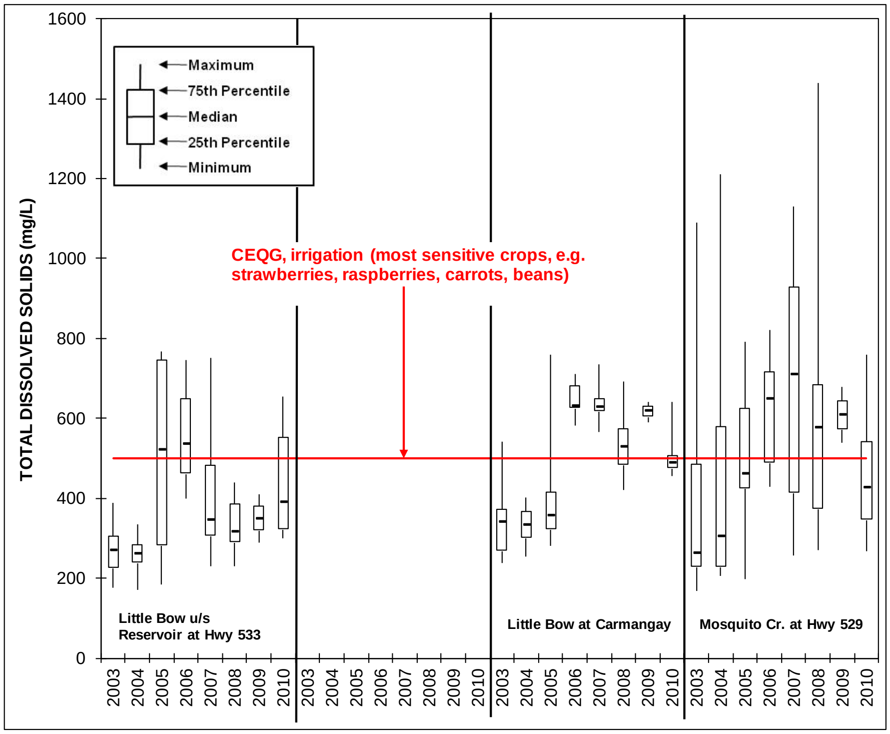


Figure 62a TDS in Twin Valley Reservoir tributaries, 2003-2010

Total dissolved solids have also increased significantly post-impoundment in Mosquito Creek at Highway 529 (Table 1, Figure 62a). TDS was typically lowest during the peak irrigation months from May to August, but some years remained higher than the CCME guideline for irrigation of sensitive crops in spring, and was generally higher than in the Little Bow River. TDS levels were lower in 2010 at all sites, but still at times over the 500 mg/L guideline for the most sensitive crops. Reasons for this increase in Mosquito Creek are not known, but could include increased salt loadings over time from the Town of Nanton with population growth, or temporary salt release from flooded soils due to higher flows post-impoundment. Since the post-impoundment years were wetter than average, there may have been more groundwater recharge during periods of high rainfall, and later release of groundwater more saline than receiving streams. Many of the highest TDS measurements for Mosquito Creek were from the winter months, when there is little dilution of the Nanton WWTP effluent. The population of the Town of Nanton grew by 11.6% from 2001 to 2006 period (Town of Nanton 2009), and by about 25% since 1981. Mosquito Creek does not receive any discharge from Frank Lake.

SAR peaked in the Little Bow River at Highway 533 in 2005, and at Carmangay in 2006, but has since generally declined (Figure 62b). In contrast median SAR increased over time post-impoundment to a later peak during 2007-2008, and was much lower in 2010. SAR was always below the 4 unit guideline at all sites on running water.

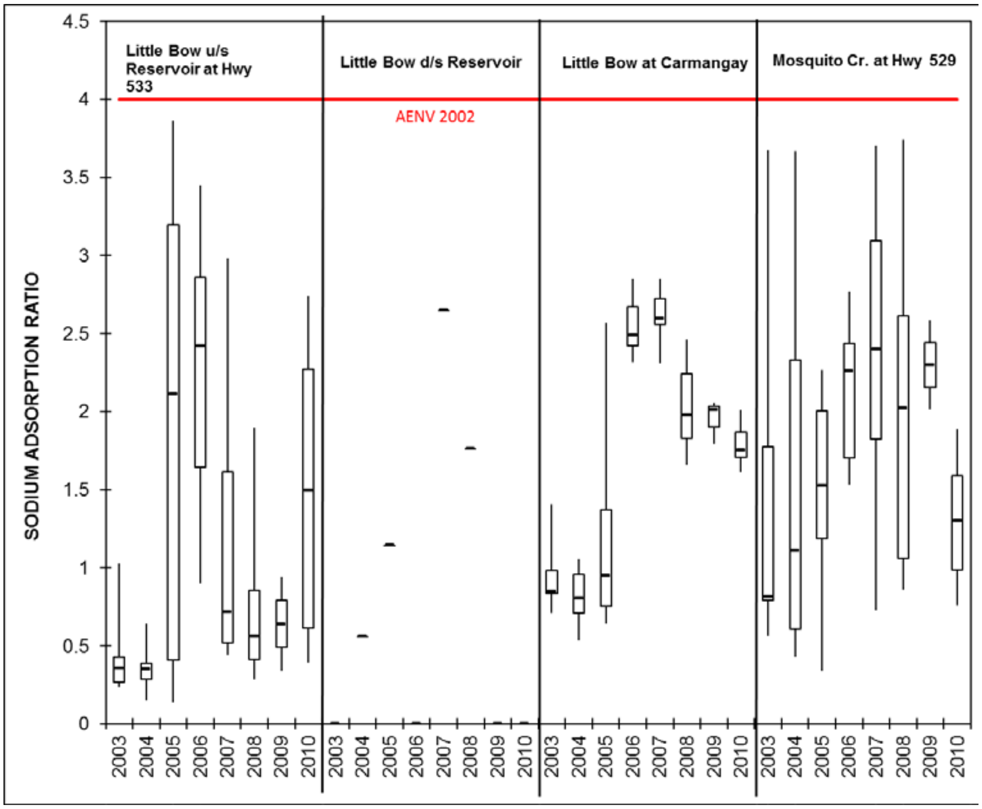


Figure 62b SAR in the Little Bow River and Mosquito Creek, 2003-2010

Of the major cations and anions, sodium and sulphate increased significantly post-impoundment at all sites on running water, while chloride only increased in the Little Bow River at Highway 533, and in Mosquito Creek (Table 1). None of these individual ions were above corresponding water quality guidelines at these sites during this sampling program (Figure 63, 64). This includes the recently released CCME PAL guideline for chloride of 120 mg/L (CCME 2011b).

In contrast, fluoride levels have declined slightly (0.02 mg/L) at the Little Bow River at Highway 533 (Figure 65), and Carmangay (Figure 66) since impoundment. Fluoride was above the CCME PAL guideline both before and after 2003 (Figure 65). This guideline is naturally exceeded in surface waters in southern Alberta. Fluoride would decline at these sites with higher flows, if much of the fluoride was loading from groundwater. Groundwater in Alberta is sometimes naturally high in fluoride.

Reservoirs

TDS in Clear Lake was above the 500 mg/L water quality guideline to protect sensitive crops before filling in 2002 (Figure 67a). This variable was not at levels that would impact common local crops that are more salinity-tolerant like alfalfa and wheat. After lake stabilization, TDS briefly fell below the guideline in 2004 and 2005, then again increased above the guideline in 2006 to 2008. Due to budget constraints there was no sampling of Clear Lake in 2010. Based on the available data, there may be constraints to the use of Clear Lake water for the irrigation of sensitive crops. This should be confirmed by further sampling.

Salinity in Clear Lake was predicted in the Little Bow EIA to remain elevated until 5-6 years after stabilization, due to the release of salts from sediments and buried salt layers. It was still high after six years in 2008. The reason for elevated salinity in Clear Lake is not clear. It may reflect increased salt concentration from evaporation, without sufficient withdrawal for irrigation and other uses. Salinity was also above this guideline in Twin Valley reservoir in 2006 and 2007, and then fell below this guideline in 2008 and 2010.

SAR was occasionally above the 4 unit guideline in Clear Lake before lake stabilization in 2002, but remained well below this guideline in Twin Valley Reservoir and Clear Lake after impoundment (Figure 67b). This suggests that irrigation problems related to soil infiltration are unlikely for supplies drawn from these water bodies.

As one would expect, sodium, sulphate, and chloride demonstrated the same pattern in Clear Lake and Twin Valley Reservoir as TDS, initial decline followed by an increase in concentration (Figure 68 to 70). None of these variables exceeded a water quality guideline. In contrast, fluoride, was generally over the CCME PAL guideline even before Clear Lake stabilization, and increased in Clear Lake over time, but not Twin Valley Reservoir (Figure 71).

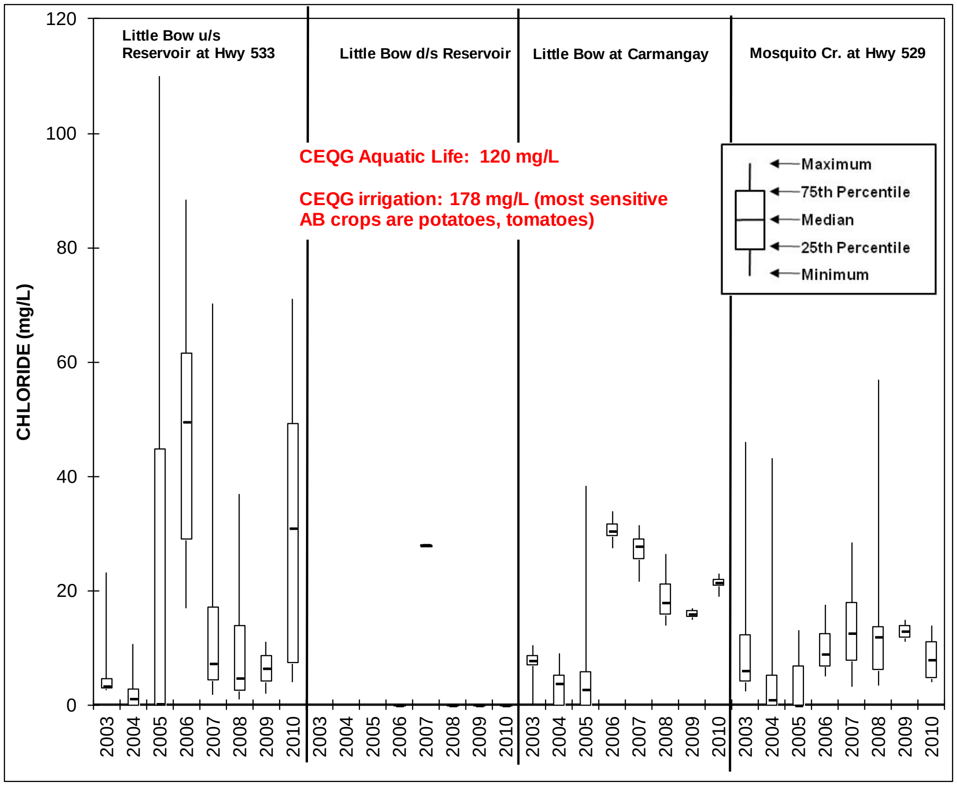


Figure 63 Chloride in Twin Valley Reservoir tributaries, 2003-2010

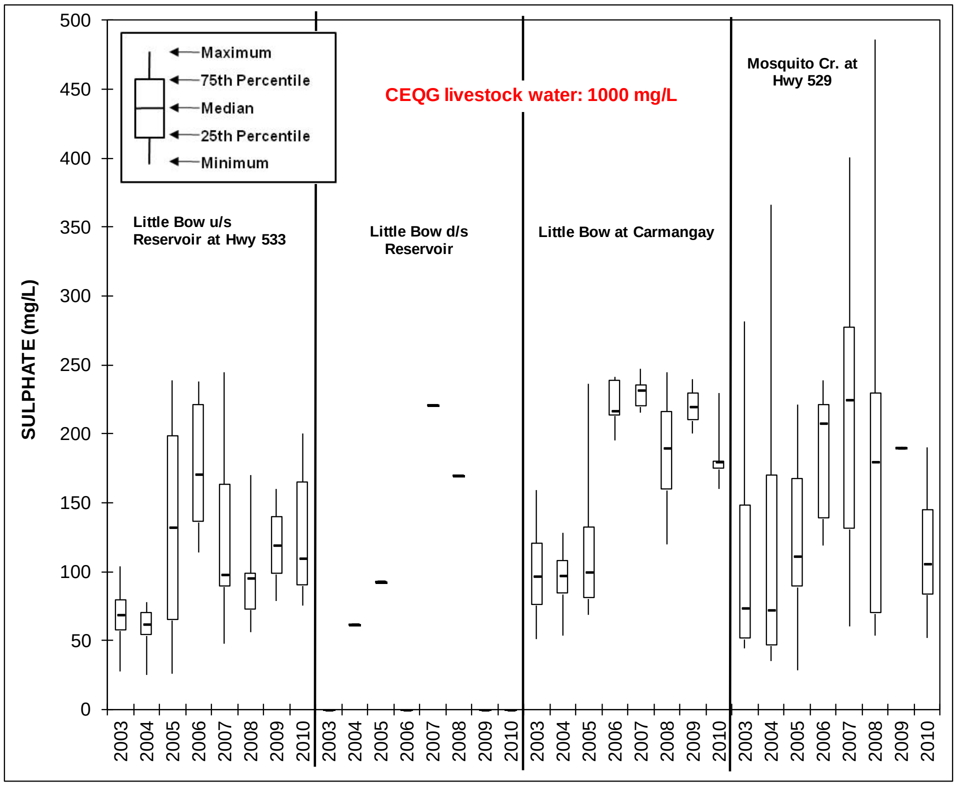


Figure 64 Sulphate in Twin Valley Reservoir tributaries, 2003-2010

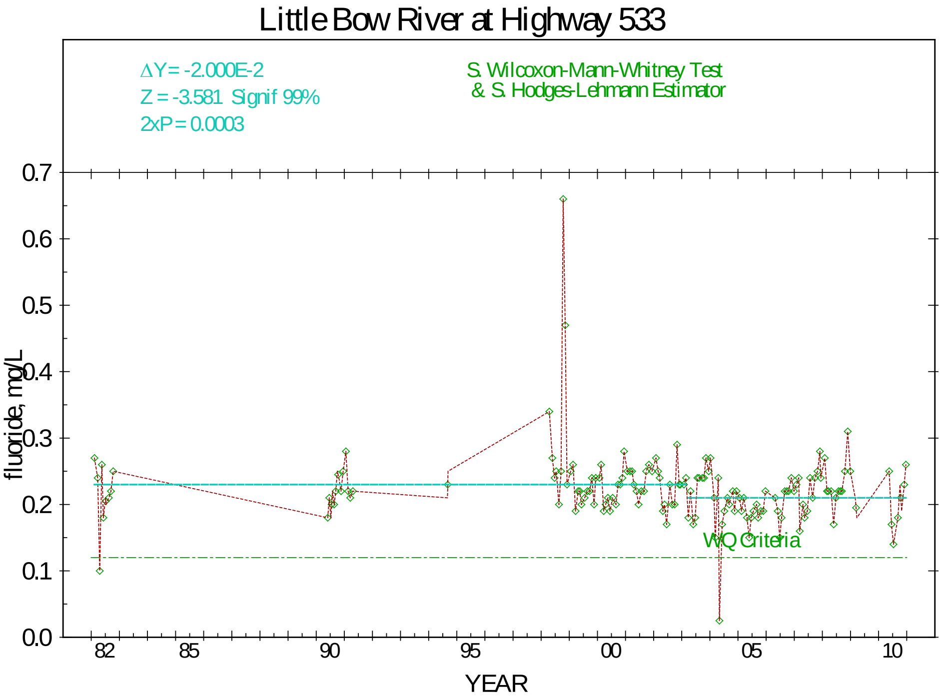


Figure 65 Fluoride in the Little Bow River at Highway 533, 1982-2010

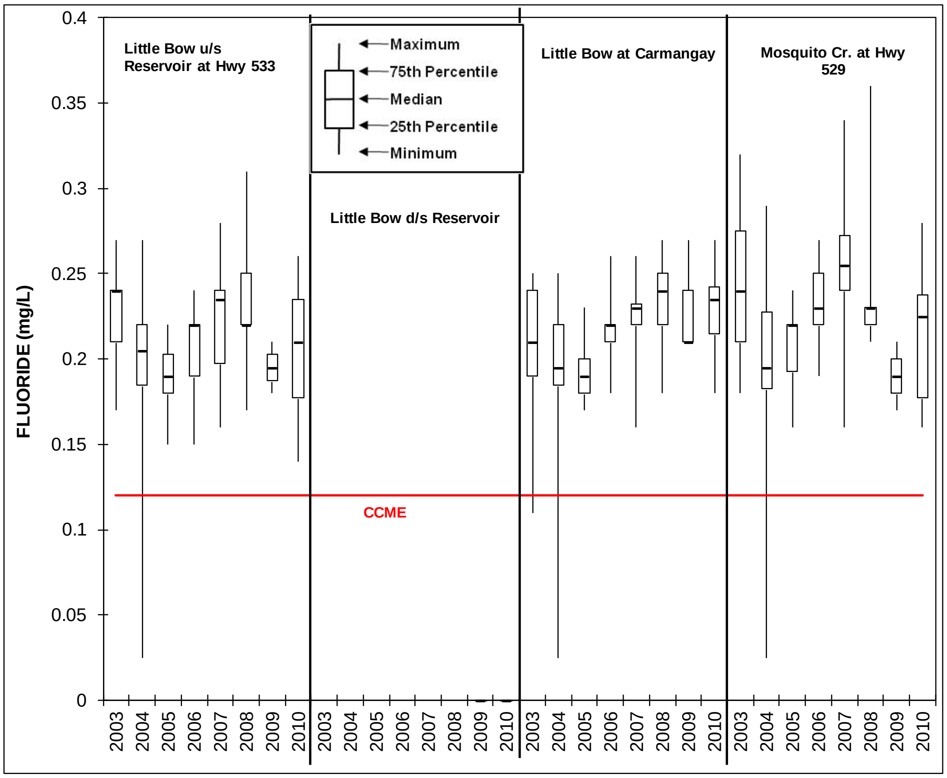


Figure 66 Fluoride in Twin Valley Reservoir tributaries, 2003-2010

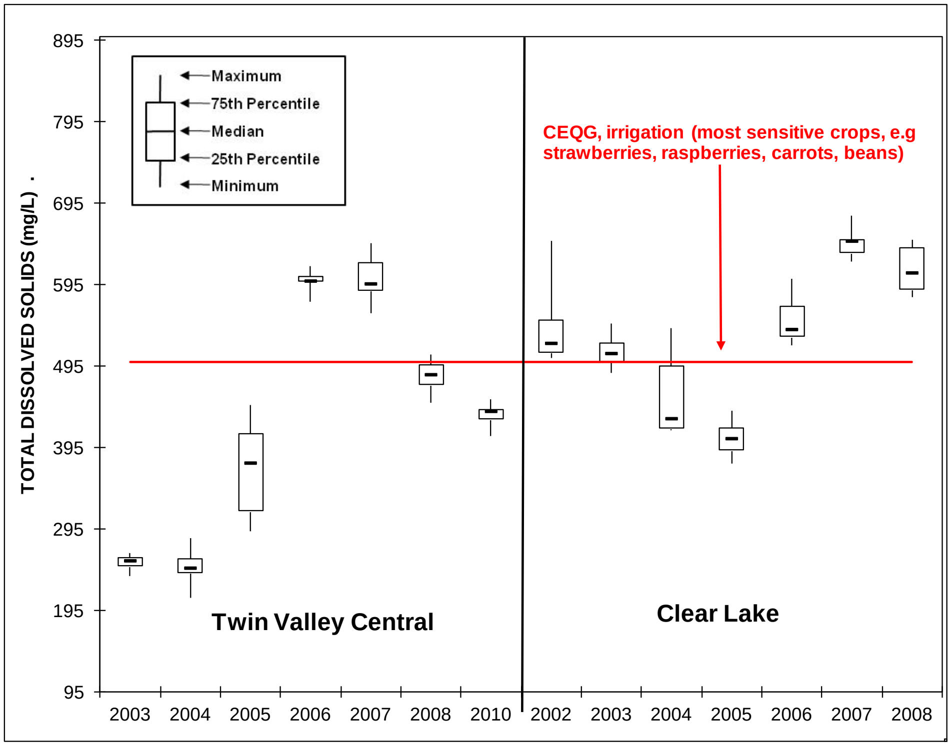


Figure 67a TDS in Twin Valley Reservoir and Clear Lake, 2002-2010

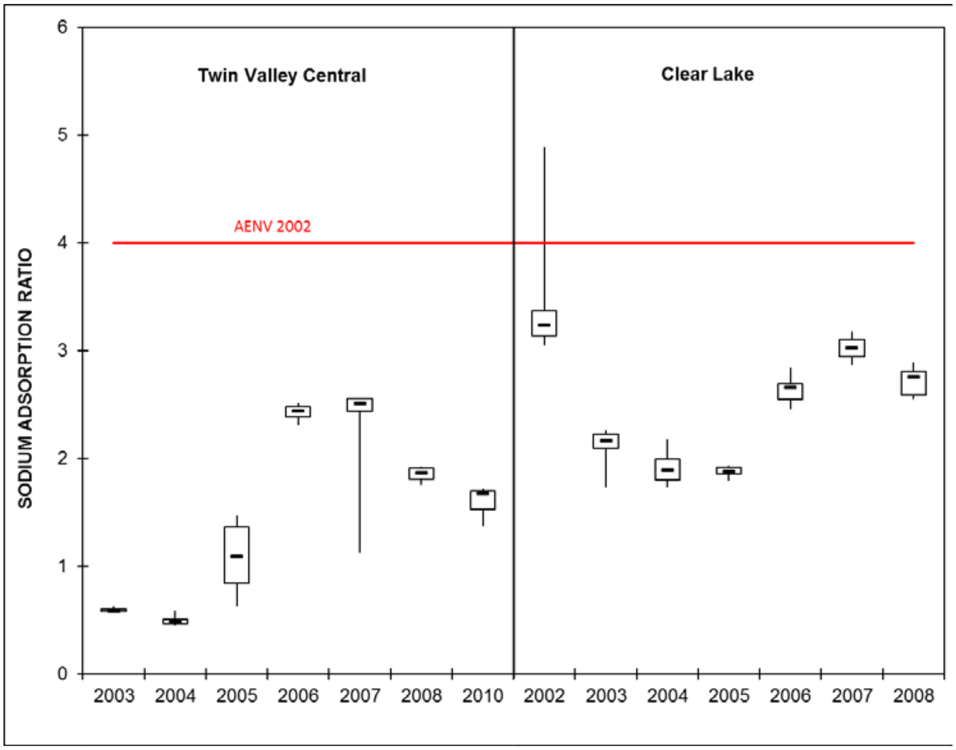


Figure 67b SAR in Twin Valley Reservoir and Clear Lake, 2002-2010

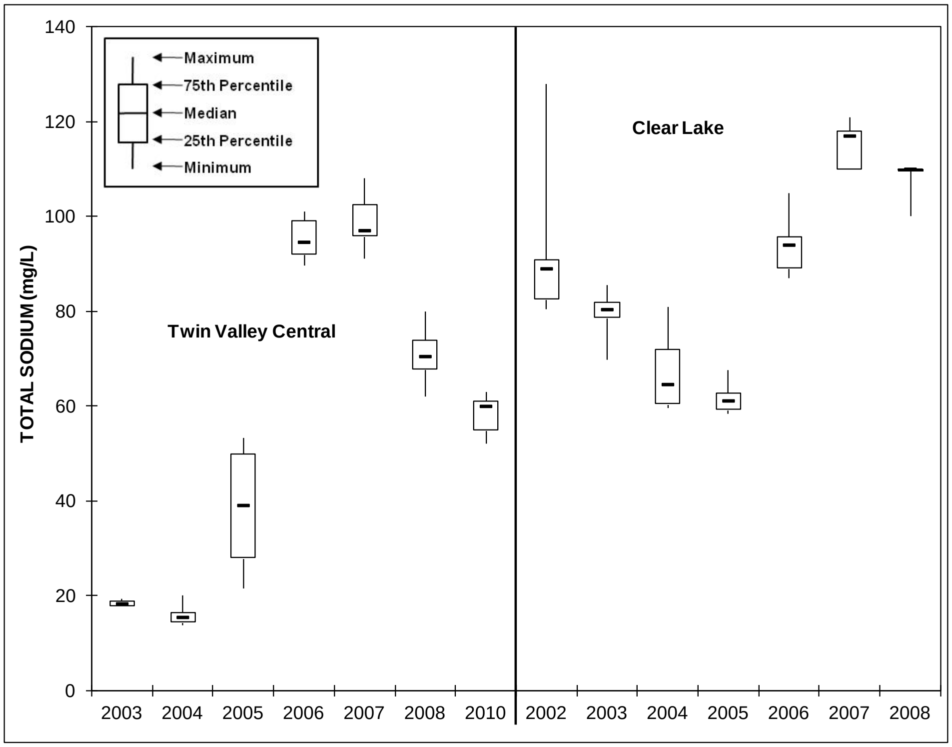


Figure 68 Sodium in Twin Valley Reservoir and Clear Lake, 2002-2010

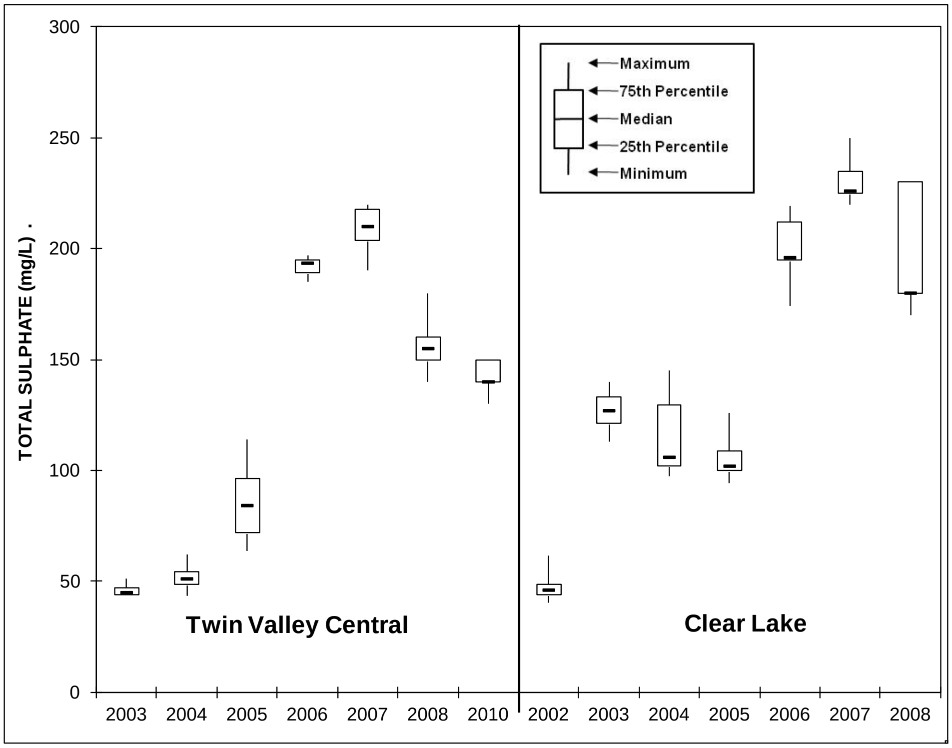


Figure 69 Sulphate in Twin Valley Reservoir and Clear Lake, 2002-2010

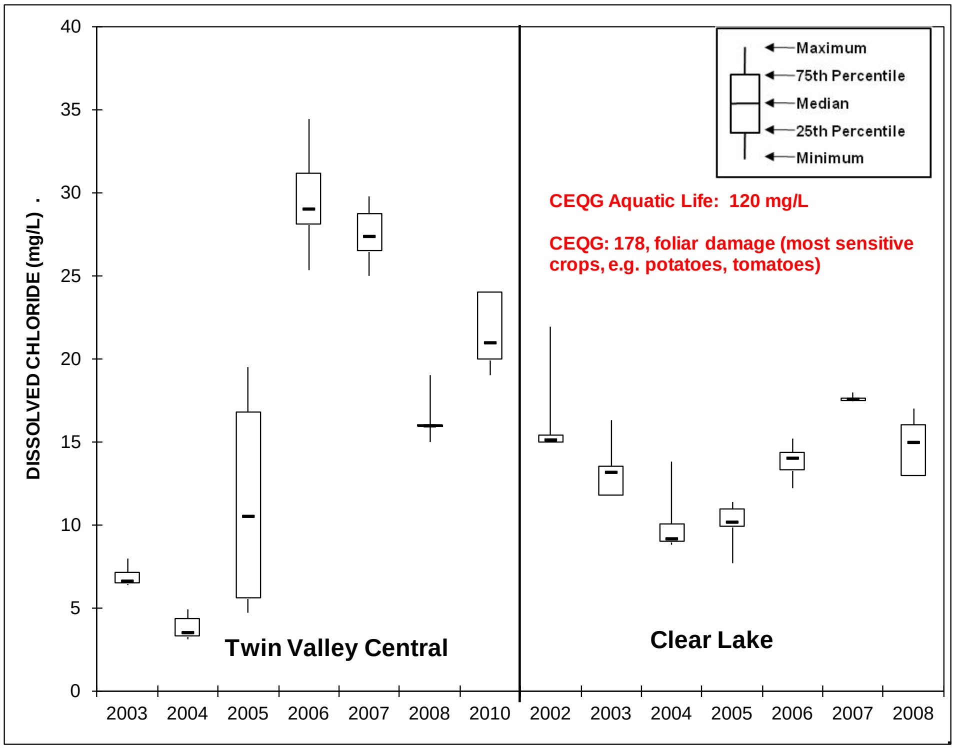


Figure 70 Chloride in Twin Valley Reservoir and Clear Lake, 2002-2010

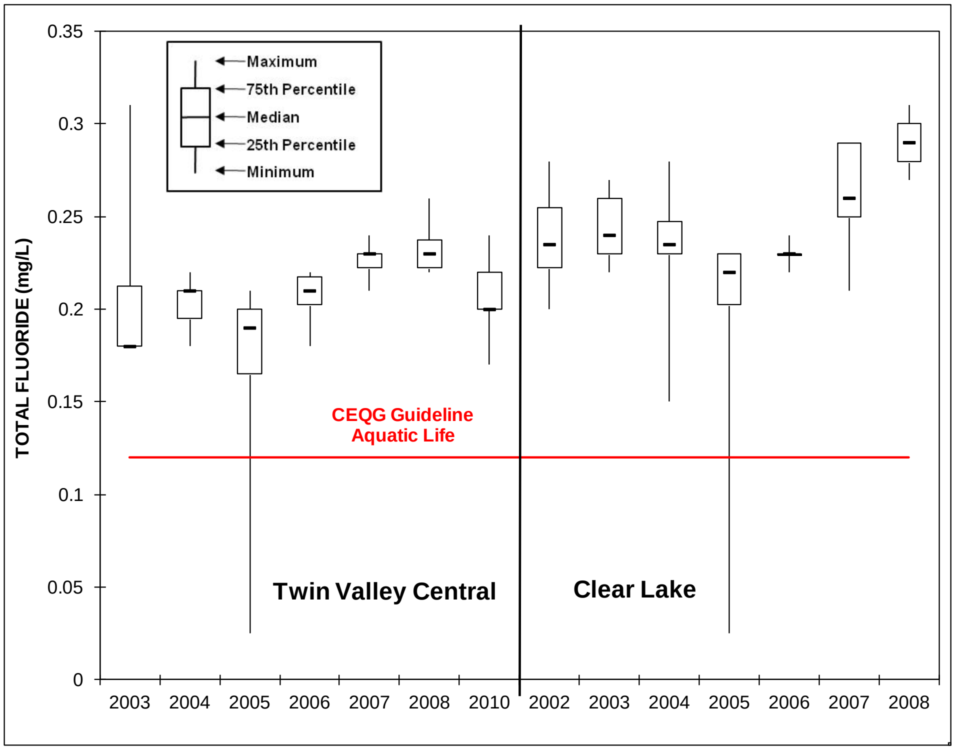


Figure 71 Fluoride in Twin Valley Reservoir and Clear Lake, 2002-2010

3.3.11 Conductivity and pH

Conductivity, or specific conductance, is a measure of the ability of water to conduct an electrical current. Because the presence of dissolved ions increases the ability of water to conduct an electrical current, this variable provides an indication of total dissolved solids or ionic concentration of the water.

pH is a measure of the degree of acidity or alkalinity of a water body. Highly acidic (pH 4.5) or highly alkaline conditions (pH 9.5) can be lethal to some aquatic organisms.

Conductivity

Running Water

Hourly conductivity and pH was recorded during the summer pre and post-impoundment by datasondes installed in the Little Bow River at Highway 533, just downstream from Twin Valley Reservoir, and in Mosquito Creek at Highway 529. Conductivity increased dramatically in the Little Bow at Highway 533 in 2005 and 2006 (Appendix II), and remained above 800 µS/cm through most of the summer (Figure 72). Prior to these two years and after, conductivity was typically half this level, around 400 to 600 µS/cm. A similar increase in conductivity occurred at the site on the Little Bow River downstream from the reservoir and Carmangay (Figure 73, 74). As with the reservoir, the increase in conductivity continued into 2007. Conductivity also increased temporarily in Mosquito Creek in 2005 and 2006 to levels above 700 µS/cm, and subsequently declined to around 500 µS/cm, which was still higher than conditions prior to 2005 (Figure 75). All these increases after impoundment were statistically significant (Table 1).

The fact that both the Little Bow River above Twin Valley Reservoir and Mosquito Creek exhibited an increase in conductivity suggests that this was due to increased watershed loadings of salts, perhaps related to the unusually high precipitation in 2005 and 2006, or regular Frank Lake discharge, causing elevated salinity (Sosiak 1994). Once loaded to the reservoir, these salts remained and affected conductivity at the downstream site for another year. Increased salinity and conductivity was predicted by modelling of Clear Lake and off-stream wetlands (NRCB/CEAA 1998, APWSS 1995) due to release of salts from sediments and evaporation, but not for the upper Little Bow, Mosquito Creek, or Twin Valley Reservoir.

Reservoirs

The conductivity isopleths for all three basins of Twin Valley Reservoir (Figure 76) also demonstrate a temporary increase in conductivity from around 400 to 800-1000 µS/cm starting in bottom water in 2005, spreading throughout the water column and continuing into 2007, followed by a decline to about 600 µS/cm in subsequent years. As described above, since this increase in conductivity also occurred in the two inflowing tributaries, the increase in the reservoir likely reflected temporarily increased loadings of salt from the upstream watershed, including Frank Lake, during wetter years, and any release from newly flooded soils. Some release from soils may be shown by higher conductivity at depth in the isopleths. Plunging of cooler inflow water with higher conductivity in the riverine zone would also cause that effect, and is a well-documented phenomenon in reservoirs.

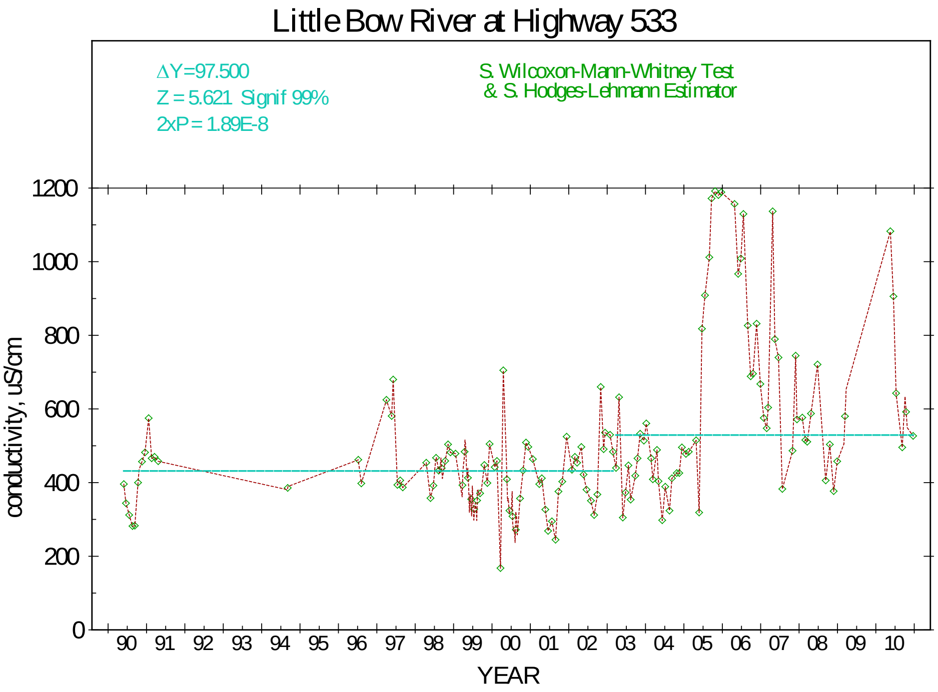


Figure 72 Conductivity in the Little Bow River at Highway 533, 1990-2010

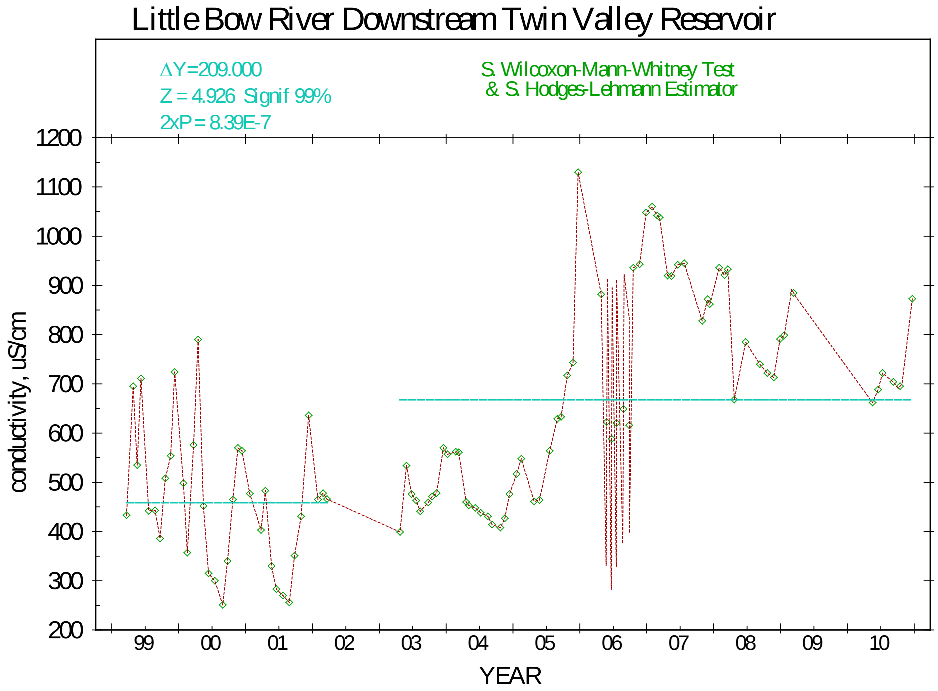


Figure 73 Conductivity in the Little Bow River downstream from Twin Valley Reservoir, 1999-2010

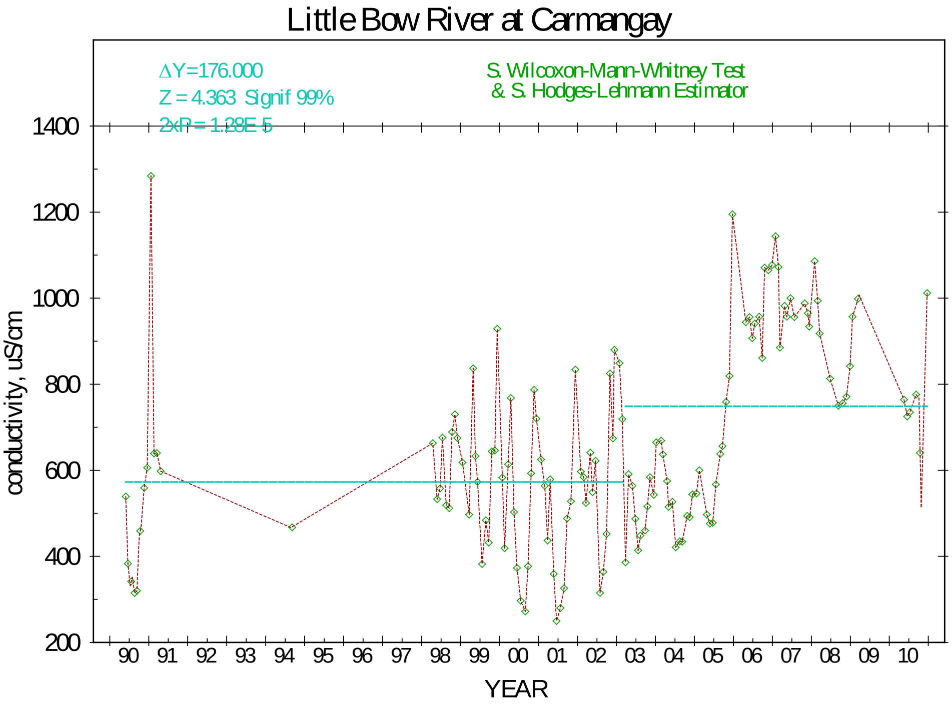


Figure 74 Conductivity in the Little Bow River at Carmangay, 1990-2010

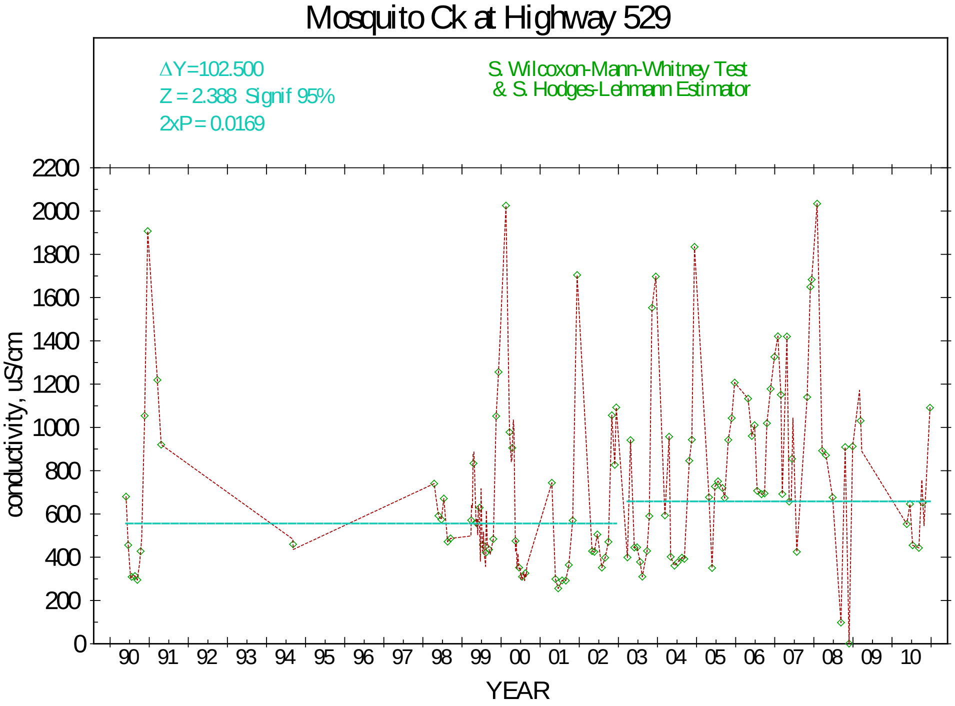


Figure 75

Conductivity in Mosquito Creek at Highway 529, 1982-2010

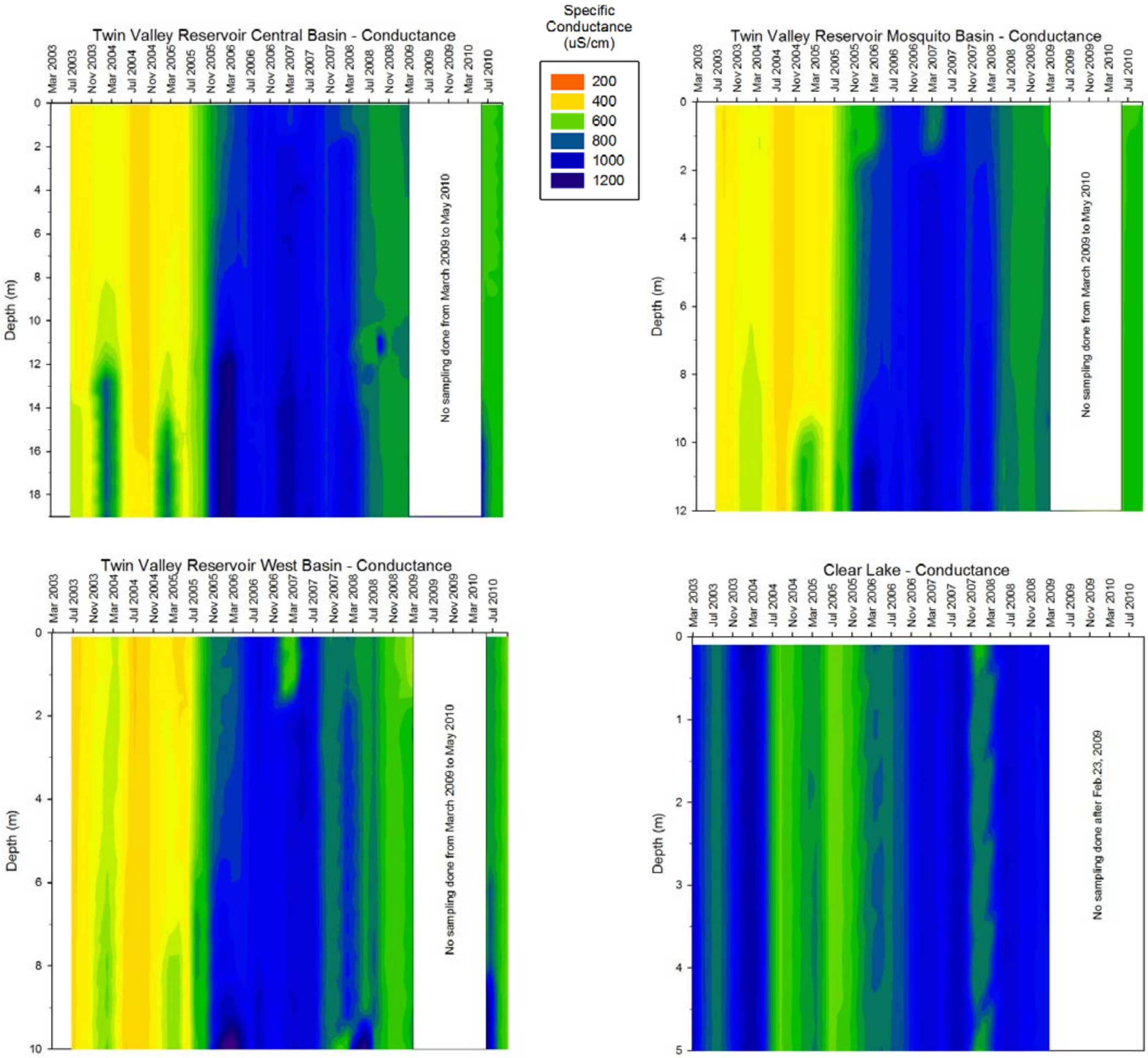


Figure 76 Specific conductance profiles for Clear Lake and Twin Valley Reservoir sites, 2003-2010

The pattern for conductivity in Clear Lake was opposite that found in Twin Valley Reservoir (Figure 76). Conductivity declined with the stabilization of lake level to a median of 652 µS/cm in 2005, then increased above the 750 µS/cm that was predicted to occur 5-6 years after refilling the lake, and remained around 1000 µS/cm for the last two available years of sampling, in 2007 and 2008. These would be years 5 and 6 after the stabilization of Clear Lake in 2002. Accordingly, Clear Lake shows no sign yet of the predicted reduction in conductivity and salinity.

pH

Running Water

pH declined after impoundment at the datasonde site downstream from the reservoir (Appendix II). While sometimes over the 9 pH unit guideline before 2003, it did not exceed this guideline during the main period of trophic upsurge from 2003 to 2008. This variable again exceeded the guideline at this site in 2010. The decline in pH at this site during trophic upsurge likely reflected effects of the reservoir, where pH was consistently below the guideline.

A similar decline in pH occurred at the datasonde site on Mosquito Creek at Highway 529. While often at or near the pH 9 guideline before 2003, pH was well below this guideline after 2003 (Appendix II). The decline in pH at this site may reflect effects of increasing turbidity, such as suppression of primary production. There was no evidence of a change in pH in the Little Bow River at Highway 533 after the impoundment of Twin Valley Reservoir (Appendix II). The pH 9 guideline was greatly exceeded both before (1999, 2000, 2001) and after impoundment (2007, 2008, 2010).

None of these changes in pH in running water after impoundment were statistically significant, based on testing of monthly sampling (Table 1), except at Carmangay, where there was a modest increase in pH (Figure 77).

Reservoirs

pH slowly increased over time in Twin Valley Reservoir, but remained well below the CCME guideline of 9.0 (Figure 78, 79). More neutral pH occurred in bottom water of all three basins in the years after first flooding, down to 7.05 in March 2006 in the Central. This may be related to decomposition or some other characteristic of newly-flooded land. pH became more alkaline over time, and typical of productive surface waters in southern Alberta.

Clear Lake remained alkaline after stabilization, with more alkaline values in the open water season. Three times over the seven years sampled, pH exceeded the CCME guideline, with values up to 9.17 recorded. No values over this guideline were measured in the last two years sampled, in 2007 and 2008.

The original CCME guideline for pH is intended to protect freshwater fish from high pH. CCREM (1989) states that pH of 9 to 9.5 is likely to be harmful to salmonid fish and perch if present for a considerable length of time. Sampling was done at most monthly. Accordingly the duration of high pH is not known. However, this guideline was only exceeded on three sampling days over seven years of monthly sampling, which is infrequent.

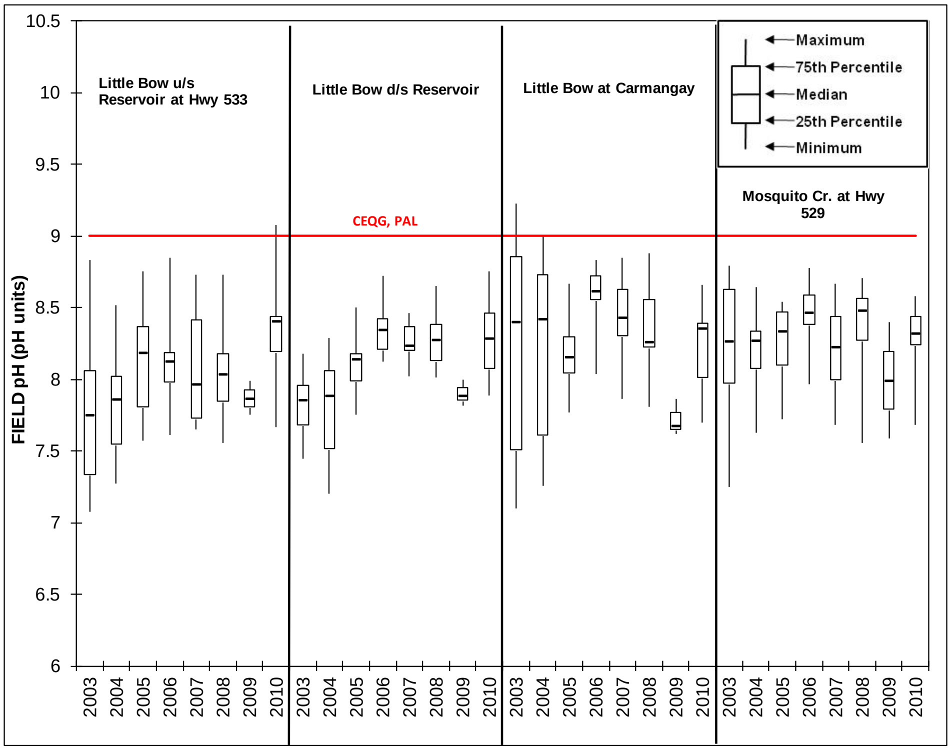


Figure 77 pH in Twin Valley Reservoir tributaries, 2003-2010

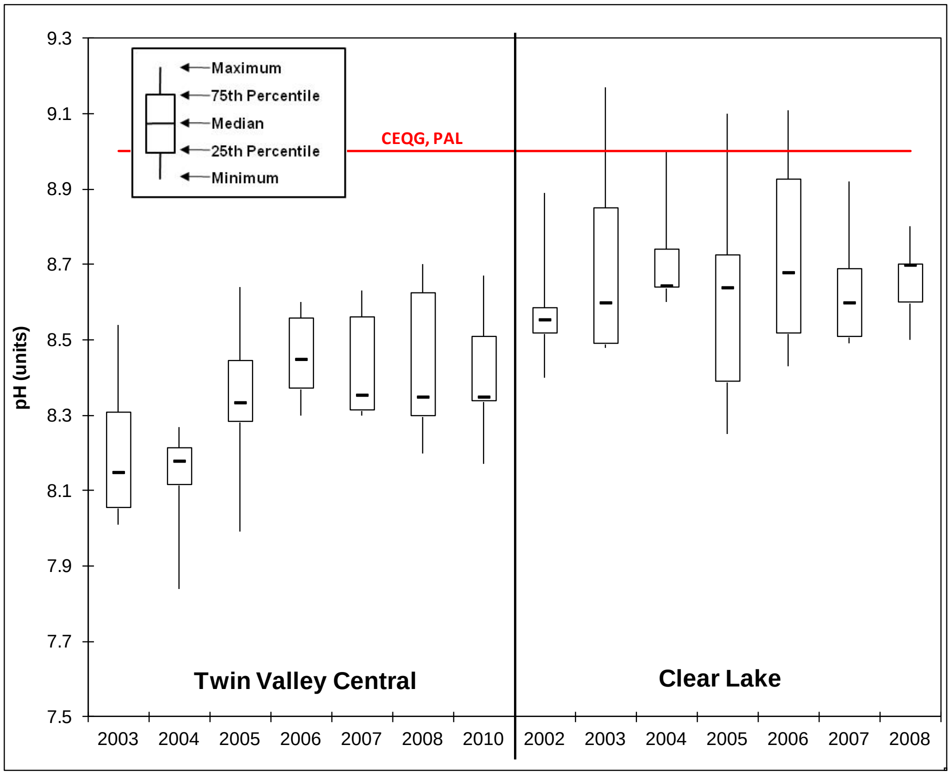


Figure 78 pH in Twin Valley Reservoir and Clear Lake, 2003-2010

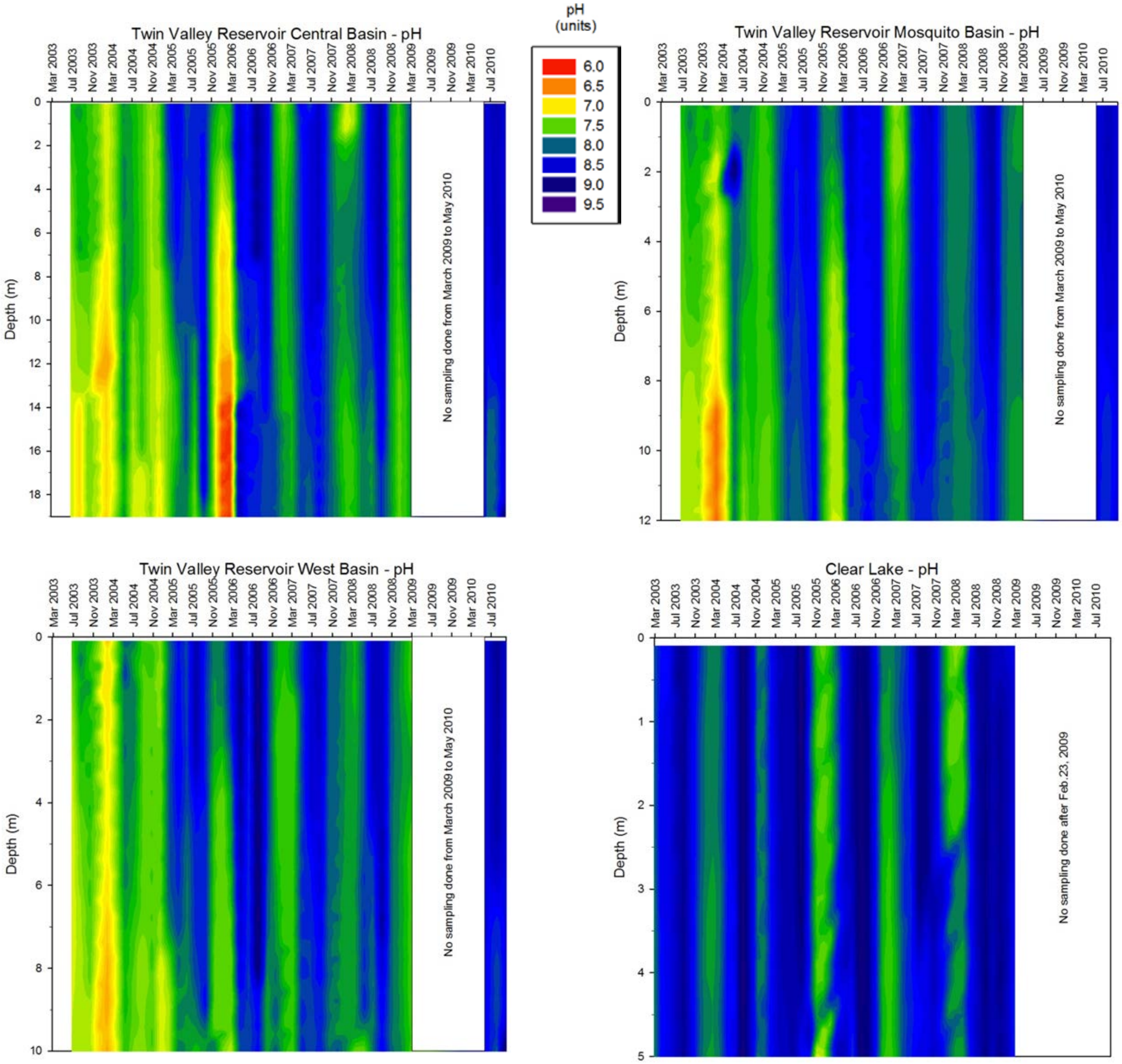


Figure 79 pH profiles for Clear Lake and Twin Valley Reservoir sites, 2003-2010

3.3.12 Metals

Running Water

Total selenium has also increased significantly in the Little Bow River at Highway 533 and Carmangay (Table 1), and sometimes exceeded the 0.001 mg/L CCME aquatic life guideline post-impoundment until 2007, both upstream and downstream of the reservoir (Figure 80 to 82). In 2008 and 2010, total selenium remained below this guideline. Similarly, total selenium has increased significantly after 2003 and exceeded this guideline in Mosquito Creek at Highway

529 until 2008, but was well below the guideline in 2010 (Figure 83). Total selenium remained slightly above pre-impoundment levels during 2008 to 2010 at all these sites. These plots included a few selenium measurements during the winter of 2009, but nothing from the open water season that year. Results to 2010 suggest that the increase in selenium may be temporary, since it declined at most locations after 2007. Further monitoring is warranted.

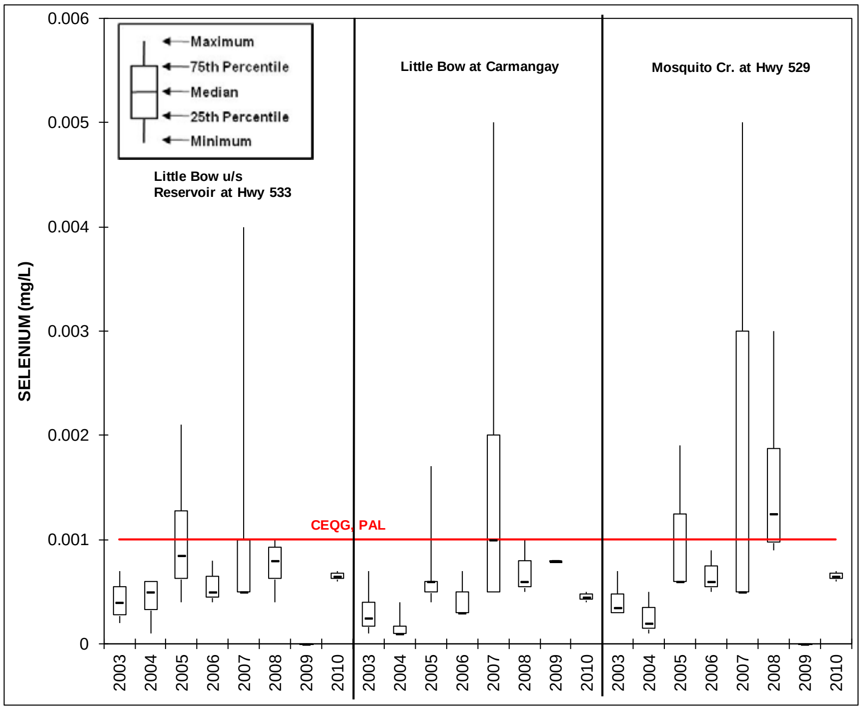


Figure 80 Total selenium in Twin Valley Reservoir tributaries, 2003-2010

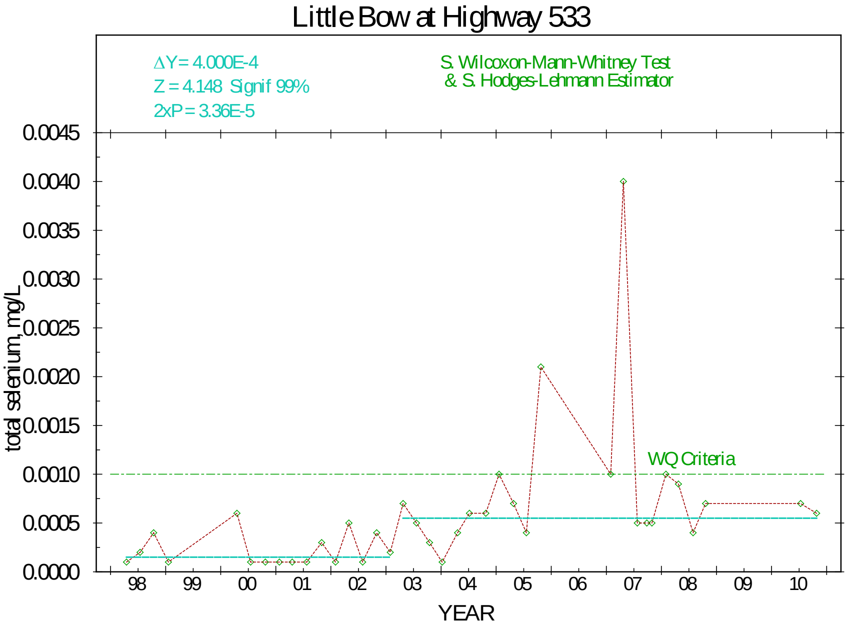


Figure 81 Total selenium in Little Bow River at Highway 533, 1998-2010

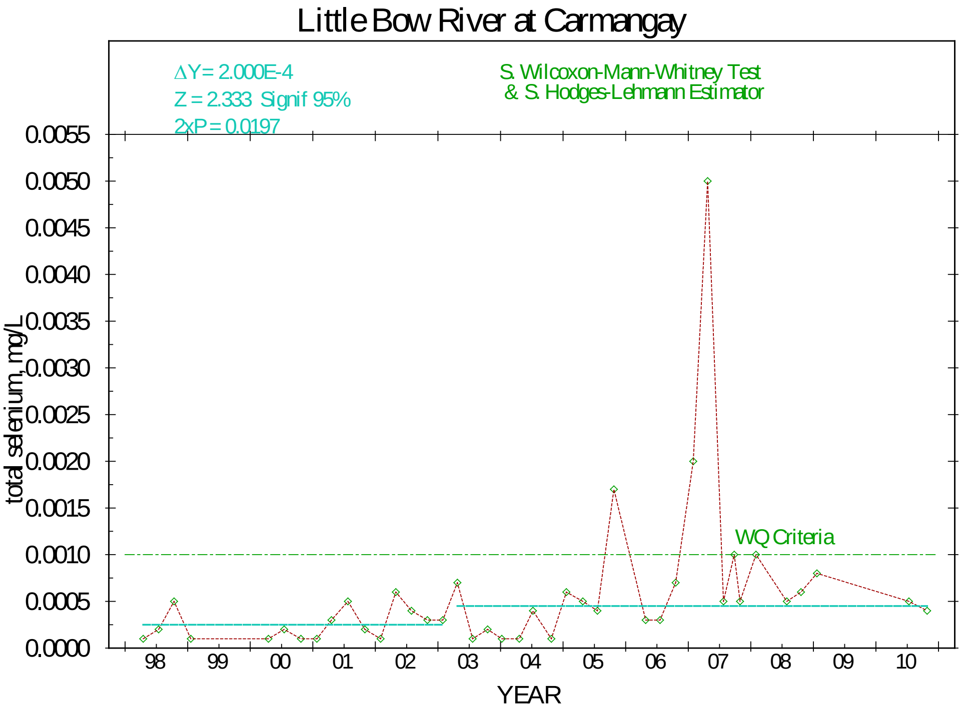


Figure 82 Total selenium in Little Bow River at Carmangay, 1998-2010

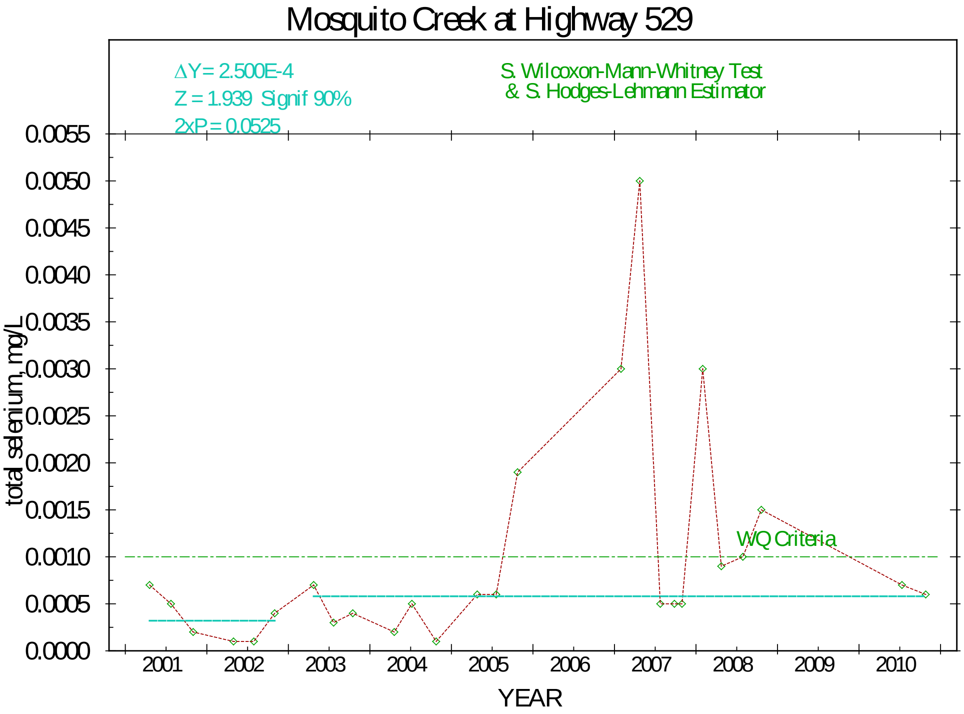


Figure 83 Total

selenium in Mosquito Creek at Highway 529, 2001-2010

Total aluminum levels also increased significantly after impoundment in the Little Bow River at Carmangay and in Mosquito Creek at Highway 529 (Table 1). Total aluminum and total iron at times exceeded the CCME PAL guidelines at all sites both before and after impoundment (Figures 84 to 88). Elevated levels of these metals have occurred in sampling since the 1980's. Total metals have been plotted to allow comparisons with CCME guidelines, which are mostly based on total metals. Sampling over previous decades was generally analyzed as extractable metals. Although relatively high levels of total aluminum up to 5 mg/L were reported, this likely reflects particulate metals. Aluminum is far less toxic under the alkaline conditions that are prevalent in these basins, than under acidic conditions.

Total mercury levels were sometimes above the CCME PAL guideline for inorganic mercury (26 ng/L) until 2008 at all sites on running water (Figure 89). They were also above draft Alberta guidelines (5 ng/L chronic, 13 ng/L acute) but below both these relatively conservative guidelines thereafter. The Alberta guidelines have been in draft format since 1998 (AEP 1998). It appears that the routine detection limit for total mercury was reduced in 2010 (from 50 to 2 ng/L), which may have artificially increased the number of values below the lower detection limit. These changes in concentration in running water after impoundment were not statistically significant (Table 1). Historical data from the 1980s included some relatively high values and changing detection limits.

These data appear to reflect the increased release of mercury and bioaccumulation that was forecast to occur in the Little Bow River upstream and downstream from the new reservoir. This was forecast to be a moderate long-term negative impact of the project in the Little Bow River (NRCB/CEAA Joint Panel 1998). Total mercury analysis detects all forms of mercury, and increased mercury methylation was forecast. Mercury was also detected in the influent and effluent from Frank Lake (Sosiak 1994). Since, total mercury concentrations fell below the guideline in 2010 and the winter of 2009, there is reason for some optimism that levels will continue to decline. However, that is not guaranteed and further monitoring is warranted.

Arsenic is a toxic metalloid, with intermediate characteristics between metals and non-metals. Total arsenic levels increased significantly in the Little Bow River at Highway 533 and at Carmangay (Figure 90, 91). However, at both locations total arsenic remained below the CCME PAL guideline except for one measurement in 2003 (Figure 92). Silver also increased following first filling and sometimes exceeded the CCME PAL guideline (Figure 93). However, it was always below guidelines at all sites after 2006. Elevated levels of selenium, aluminum, iron, arsenic, and silver post-impoundment likely reflected channel scouring during higher flows post-impoundment upstream of Twin Valley Reservoir or runoff during wet years such as 2005.

Other metals that were evaluated did not exceed guidelines, and no other concerns in running water were identified. Median concentrations during years before and after impoundment are summarized in Appendix I.

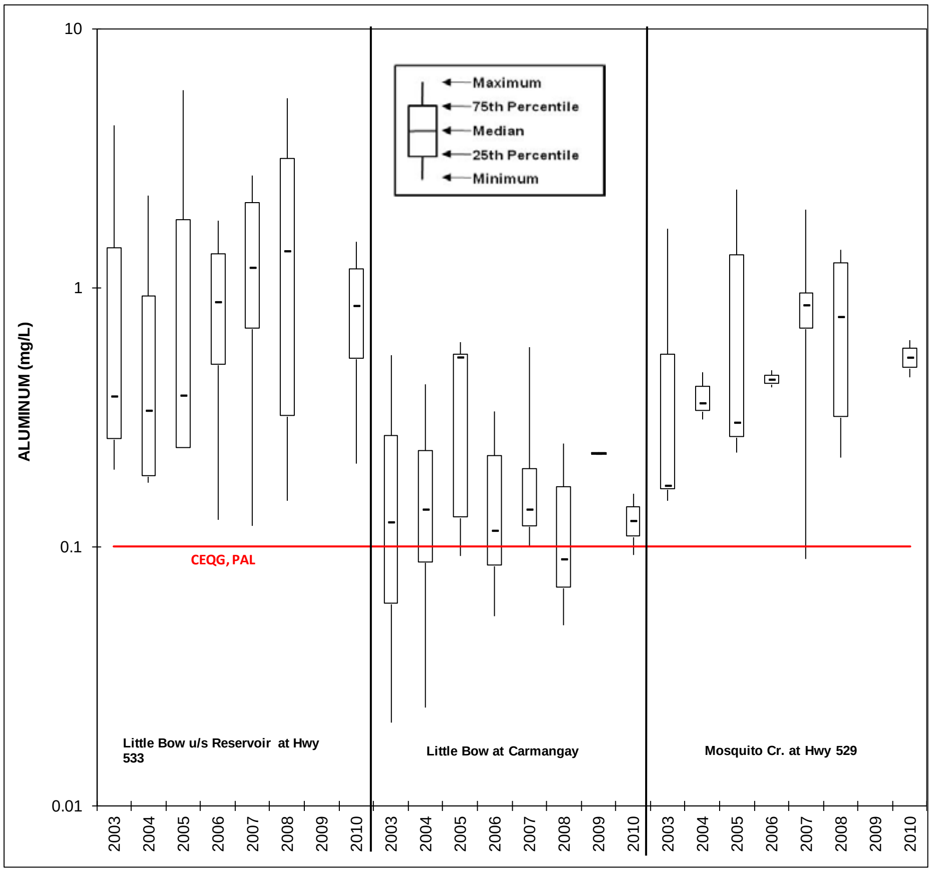


Figure 84 Total aluminum in Twin Valley Reservoir tributaries, 2003-2010

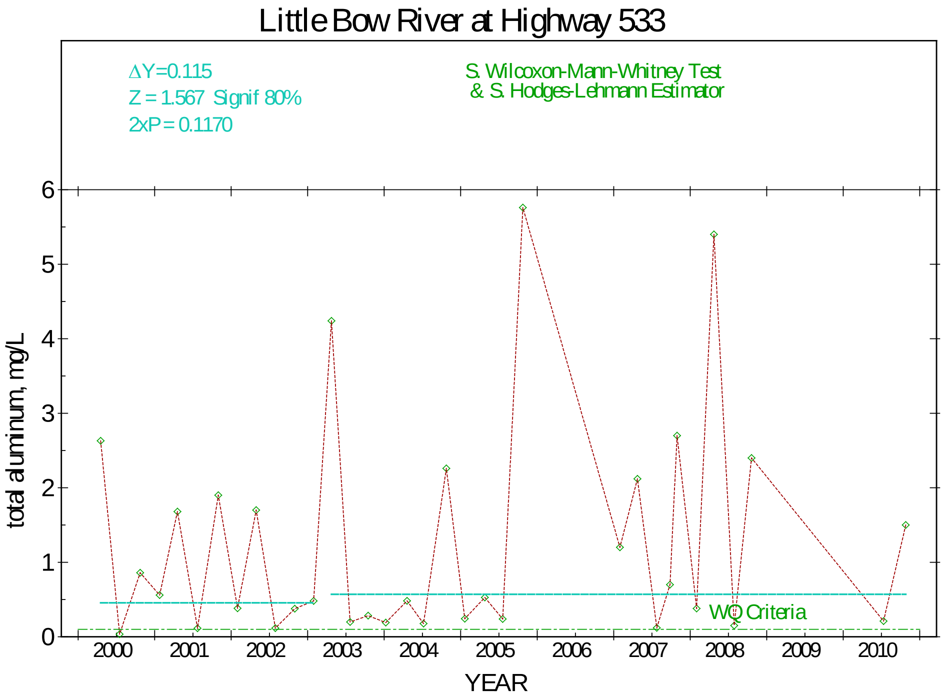


Figure 85 Total aluminum in Little Bow River at Highway 533, 2000-2010

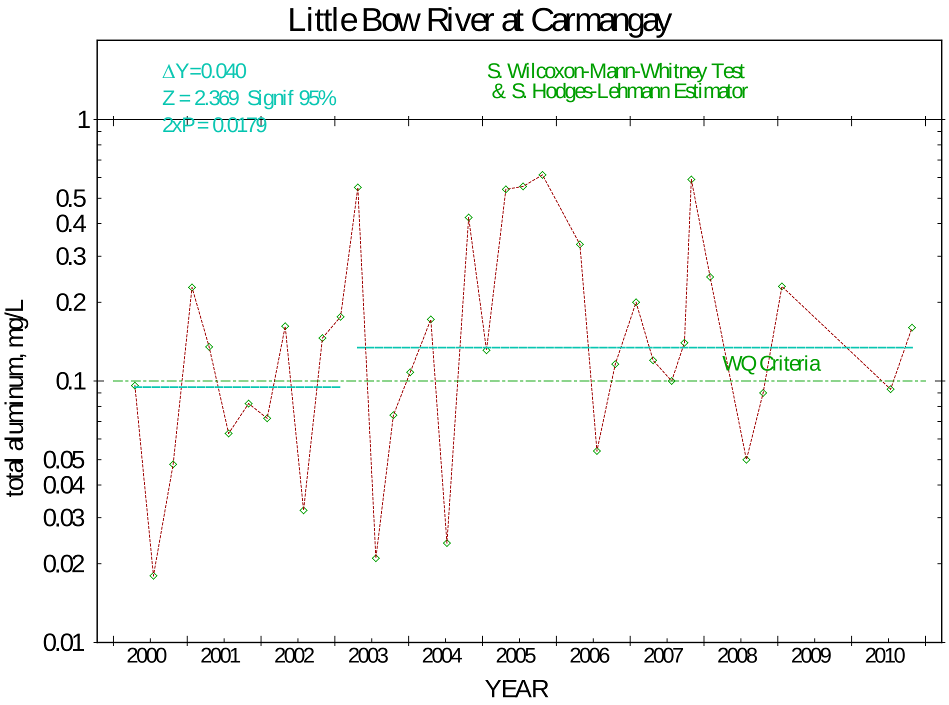


Figure 86 Total aluminum in Little Bow River at Carmangay, 2000-2010

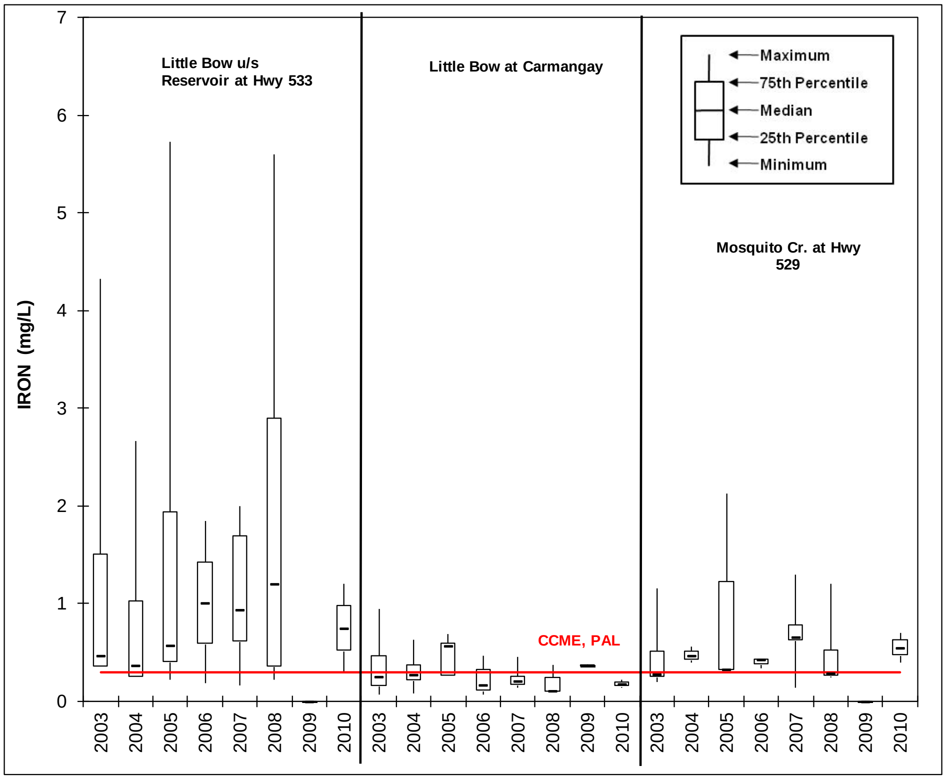


Figure 87 Total iron in Twin Valley Reservoir tributaries, 2003-2010

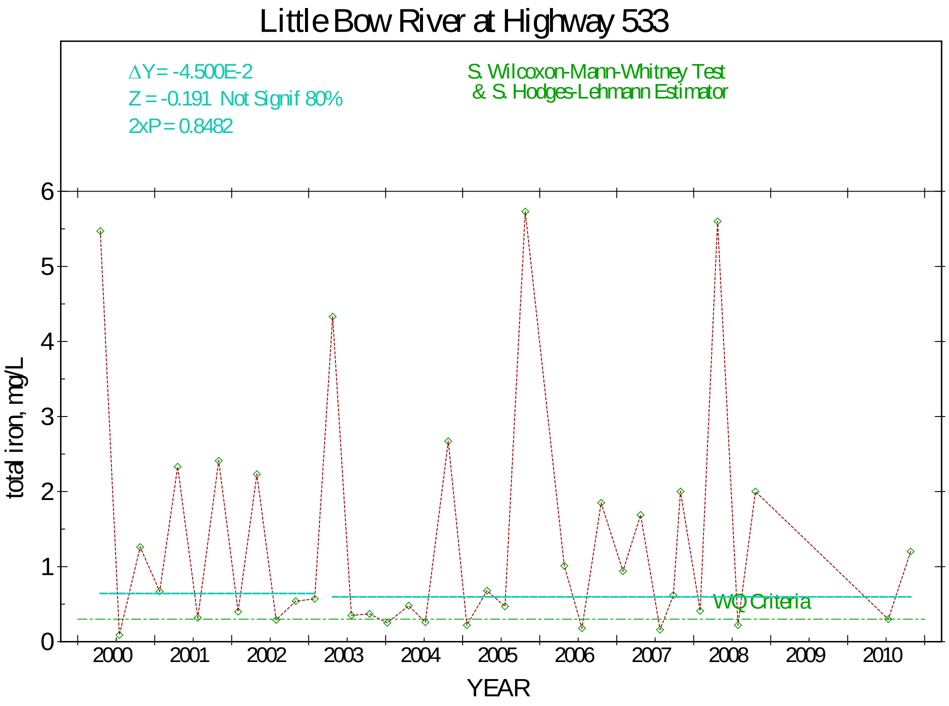


Figure 88 Total iron in Little Bow River at Highway 533, 2000-2010.

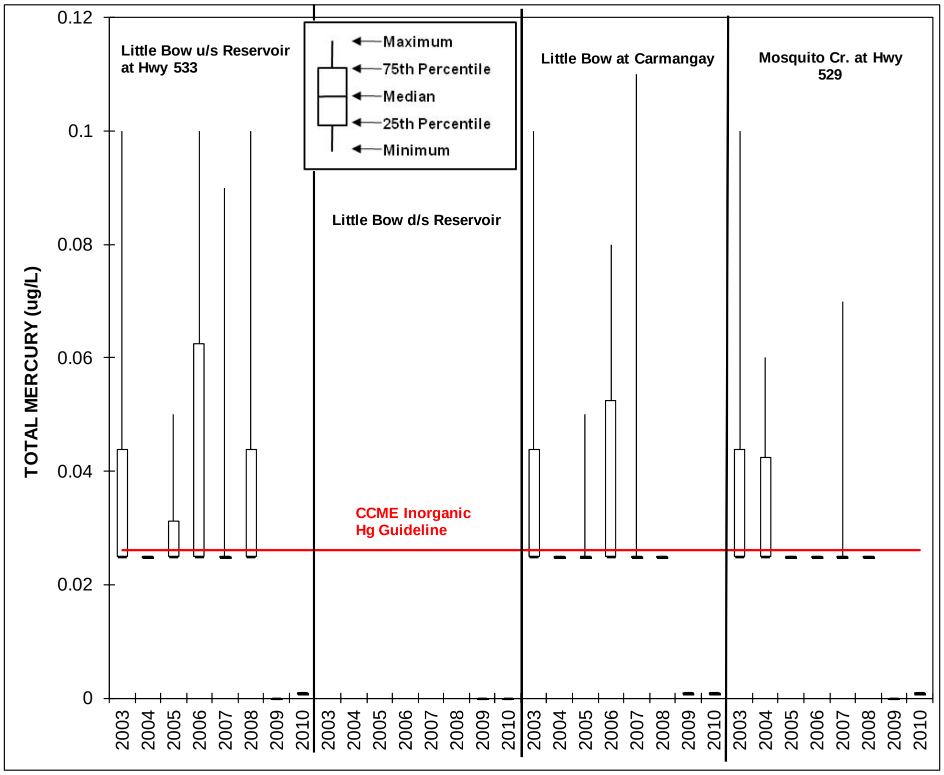


Figure 89 Total mercury in Twin Valley Reservoir tributaries, 2003-2010

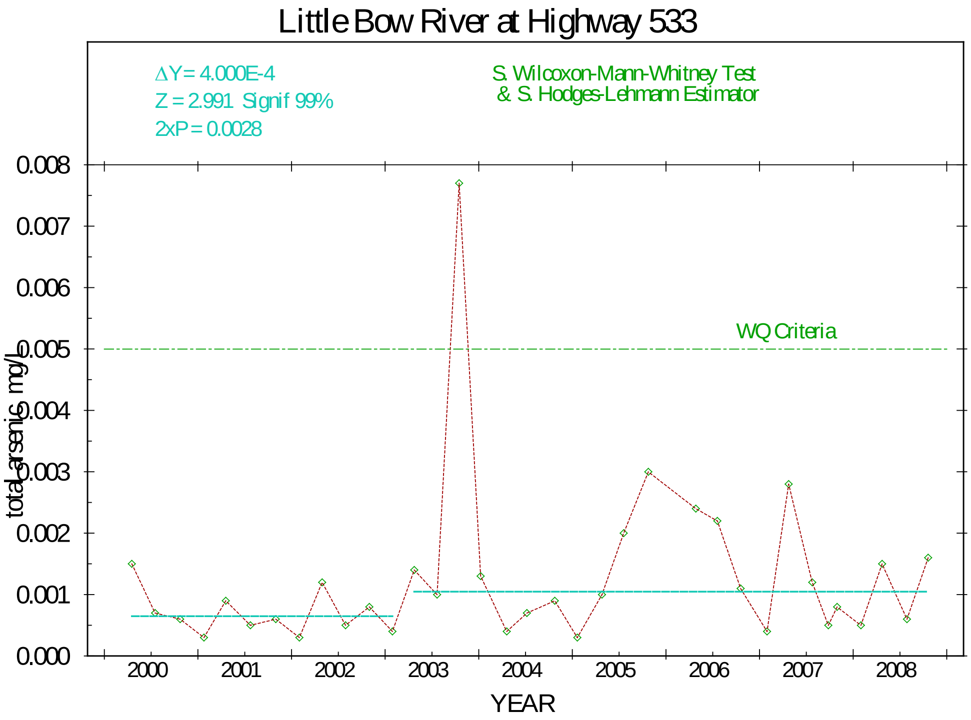


Figure 90 Total arsenic in Little Bow River at Highway 533, 2000-2010

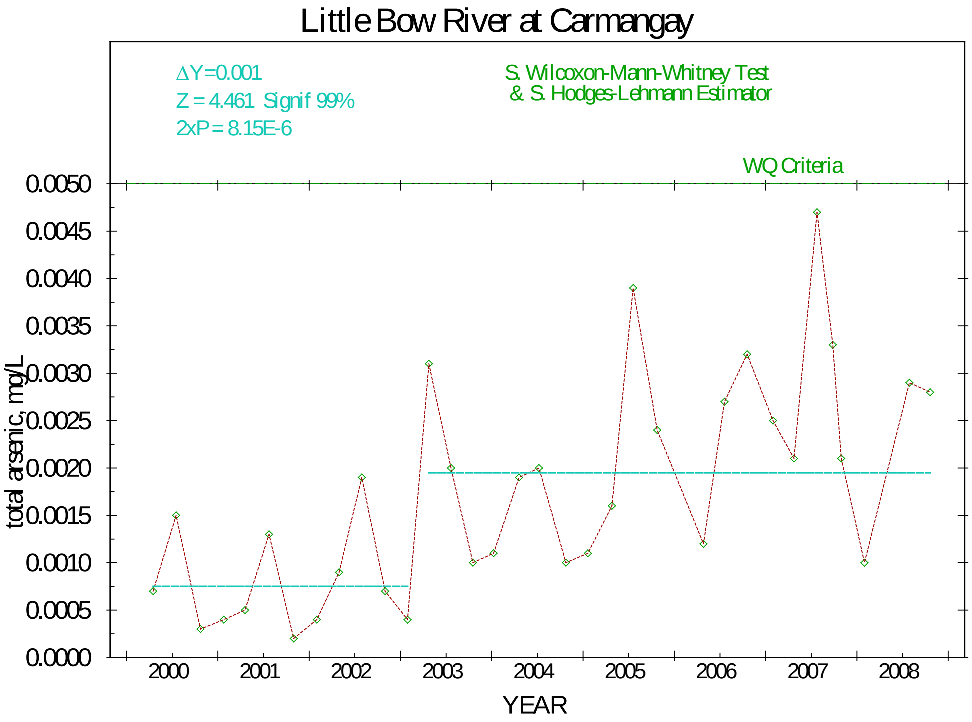


Figure 91 Total arsenic in Little Bow River at Carmangay, 2000-2010

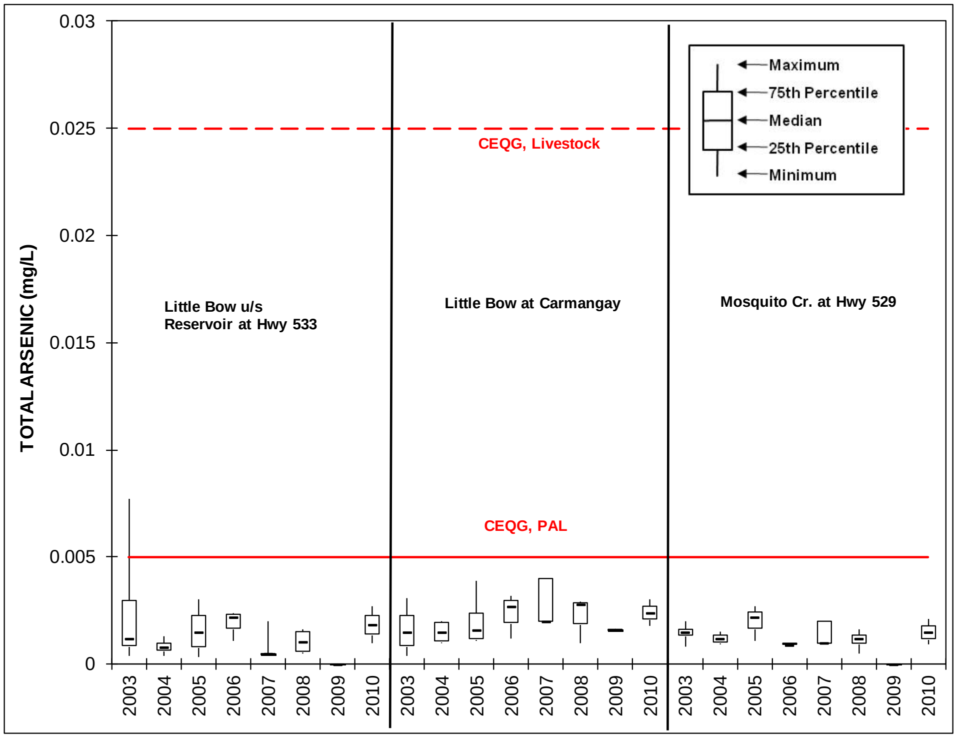


Figure 92 Total arsenic in Twin Valley Reservoir tributaries, 2003-2010

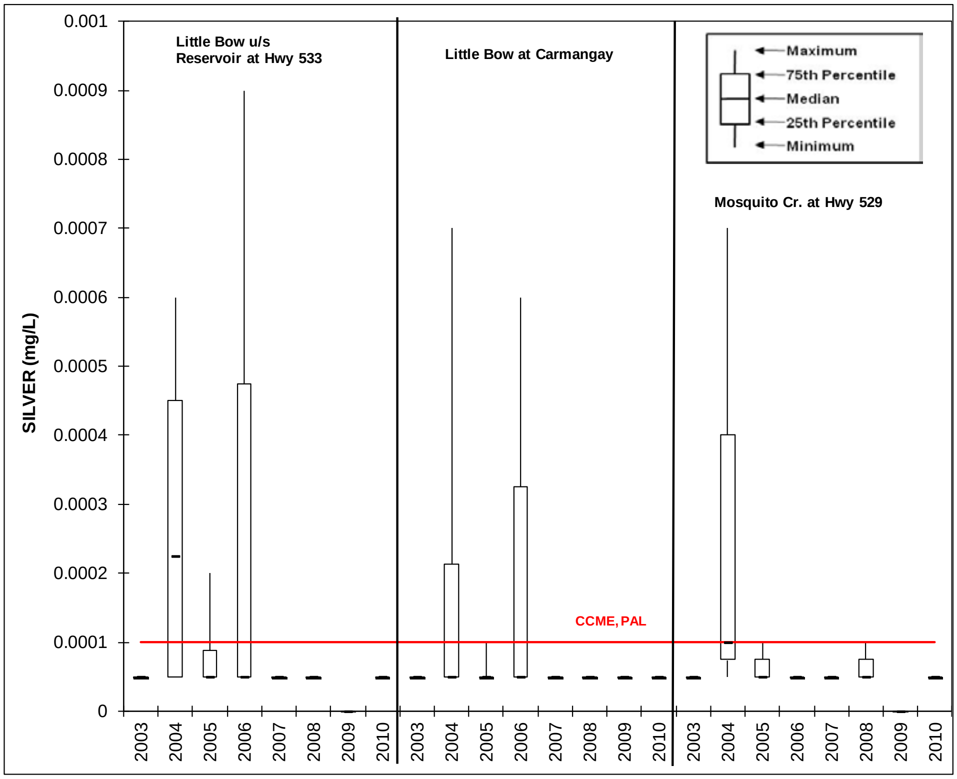


Figure 93 Total silver in Twin Valley Reservoir tributaries, 2003-2010

Reservoirs

Total selenium often exceeded the CCME PAL guideline during first filling of Twin Valley Reservoir in 2003 (Figure 94). However, this metal was always below this guideline thereafter in Twin Valley Reservoir, and in all sampling years in Clear Lake. The temporary increase in 2003 was likely due to release of this metal from newly-flooded soils.

Except for a single sample from the Central Basin in 2006, total arsenic has remained below the CCME PAL guideline in Twin Valley Reservoir (Figure 95). However, nearly all samples from Clear Lake both before and after lake stabilization greatly exceeded the CCME PAL guideline, but not the CCME livestock guideline. Total arsenic levels in Clear Lake declined somewhat after 2004, but remained well above the guideline.

Although arsenic levels in Clear Lake were high compared to other Alberta lakes, they were still well below levels that are known to cause acute and chronic toxic effects on aquatic life in controlled laboratory studies. CCME (2001) reviewed the available literature in developing the arsenic guideline and the lowest observed effects on freshwater aquatic life were at 0.05 mg/L for *Scenedesmus obliquus* (growth reduction), 0.550 mg/L for rainbow trout (*Oncorhynchus mykiss*)(LC_{50}), and 0.320 mg/L for one copepod invertebrate (growth reduction). Effects on aquatic life in Clear Lake are unlikely, in spite of guideline exceedance, while concentrations remain below these aquatic effects thresholds. Since Clear Lake is a terminal basin, it likely concentrates stable substances such as arsenic through evaporation. There is some evidence of a decline in arsenic levels in Clear Lake from 2003 to 2008. This was not tested statistically, as there were not enough years of data to establish a reliable trend. It is unclear whether this apparent trend to declining arsenic concentrations in Clear Lake will continue.

Total mercury levels were sometimes above the CCME PAL guideline for inorganic mercury (26 ng/L) until 2008 in the Central Basin of Twin Valley Reservoir and until 2006 in Clear Lake (Figure 96). They were also above the draft Alberta guidelines (5 ng/L chronic, 13 ng/L acute) but below these relatively conservative guidelines thereafter.

These data appear to reflect the increased rate of mercury release that was forecast to occur in Twin Valley Reservoir. This was forecast to be a major long-term negative impact of the project in the Little Bow River (NRCB/CEAA Joint Panel 1998). Consumption advisories that recommend limiting consumption of northern pike from the Little Bow River and Twin Valley Reservoir, based on elevated mercury levels, have been issued (Government of Alberta 2009). Since total mercury concentrations fell below the guideline in 2010, there is reason for some optimism that levels will continue to decline. However, that is not guaranteed and further monitoring is warranted.

Total aluminum also frequently exceeded the CCME PAL guideline in both water bodies, and total iron exceeded the guideline only in Clear Lake (Figure 97 and 98). Total lead and silver also exceeded the CCME PAL guideline on isolated individual days in both water bodies (Figure 99 and 100). These guideline exceedances likely reflect the high levels of suspended matter in both water bodies, both wind-induced re-suspension of sediments in shallow areas, and external loading.

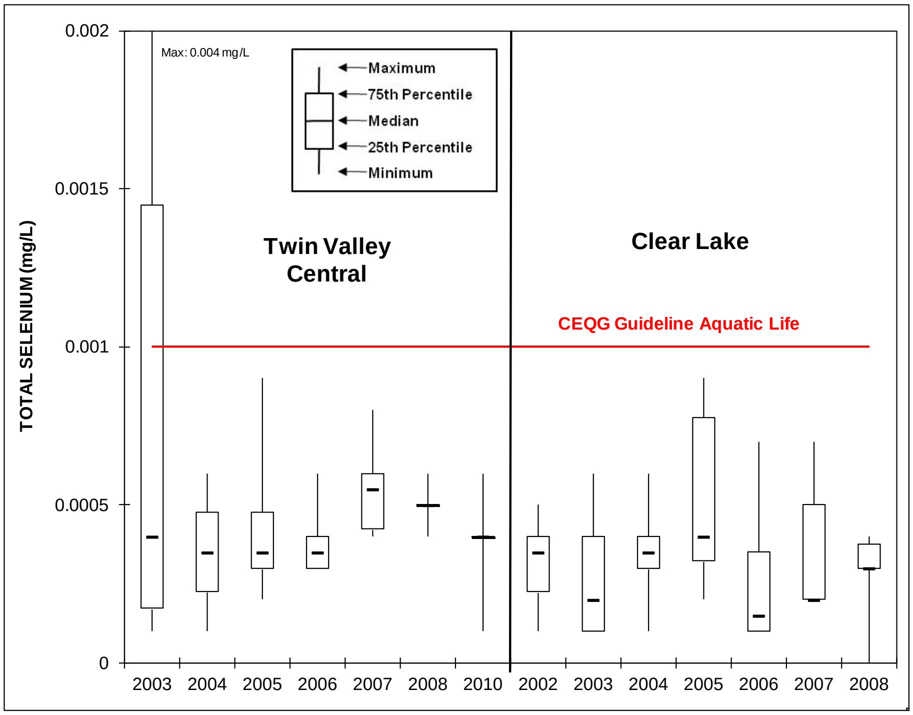


Figure 94 Total selenium in Twin Valley Reservoir and Clear Lake, 2002-2010

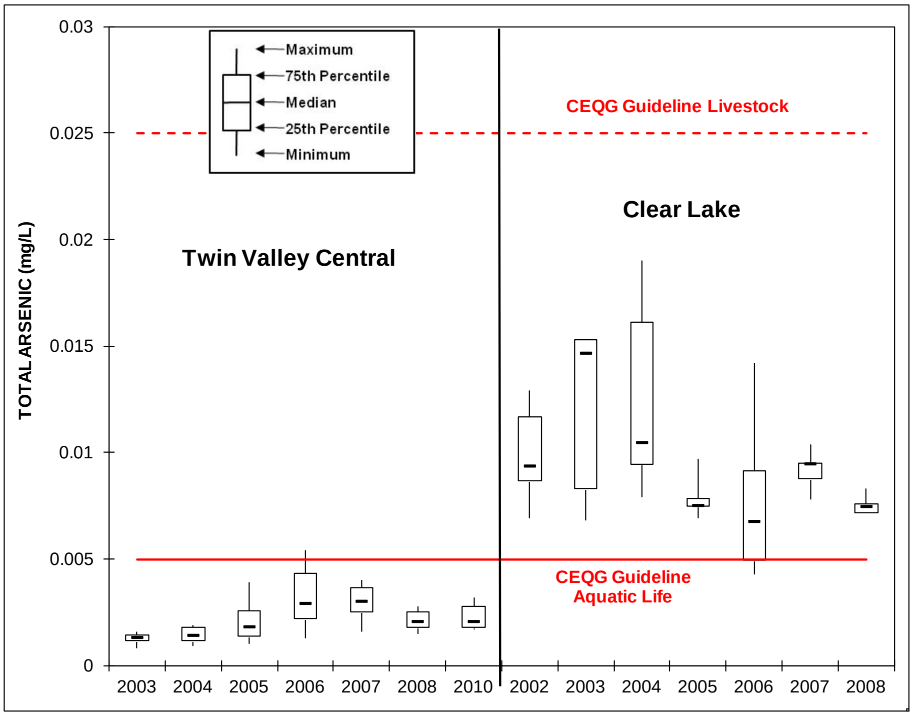


Figure 95 Total arsenic in Twin Valley Reservoir and Clear Lake, 2002-2010

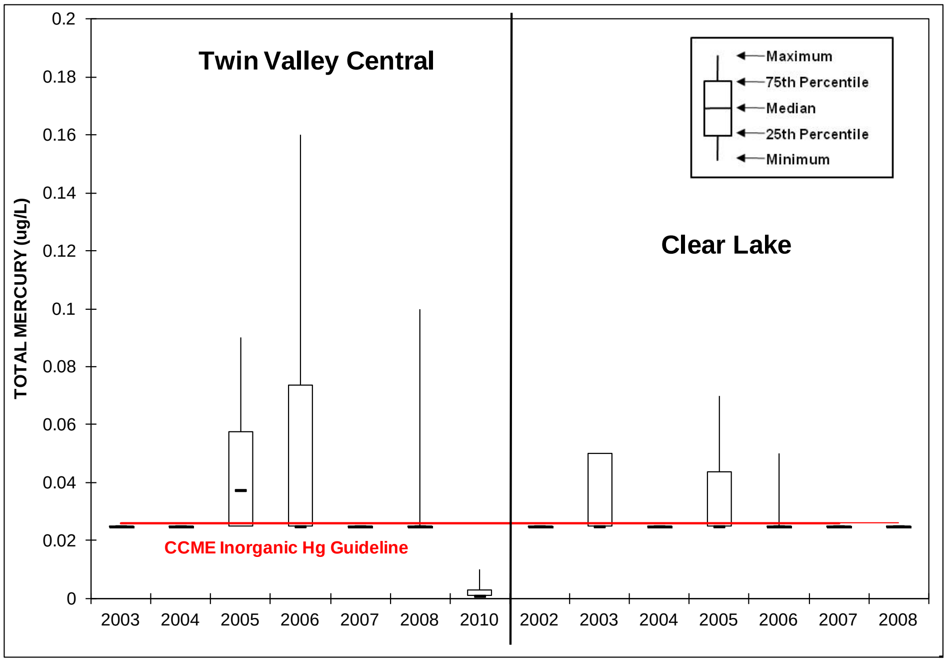


Figure 96 Total mercury in Twin Valley Reservoir and Clear Lake, 2002-2010

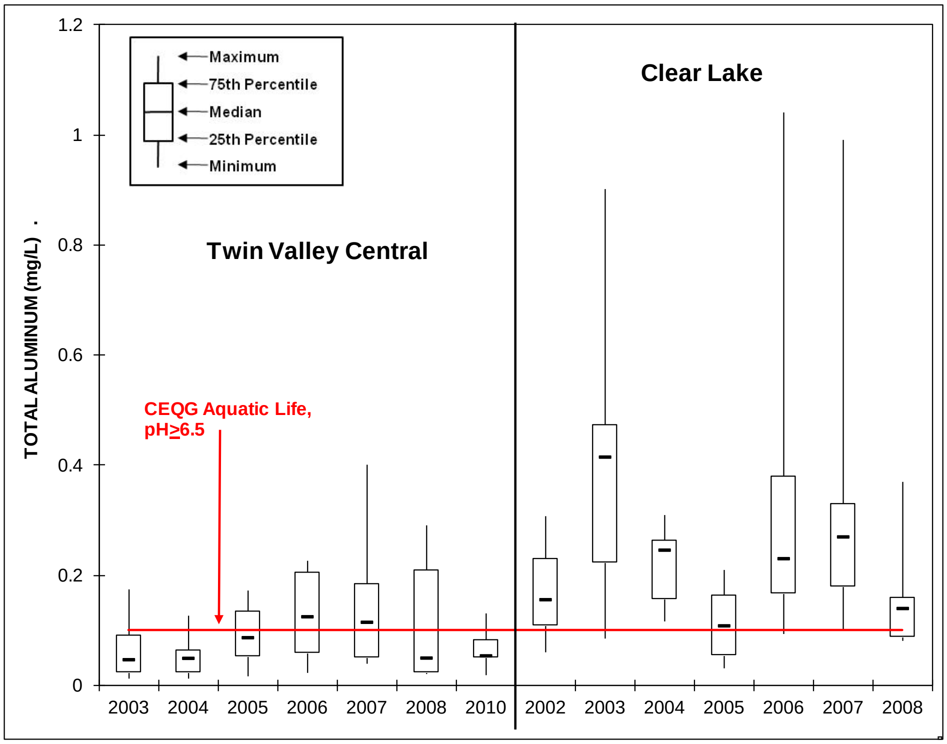


Figure 97 Total aluminum in Twin Valley Reservoir and Clear Lake, 2002-2010

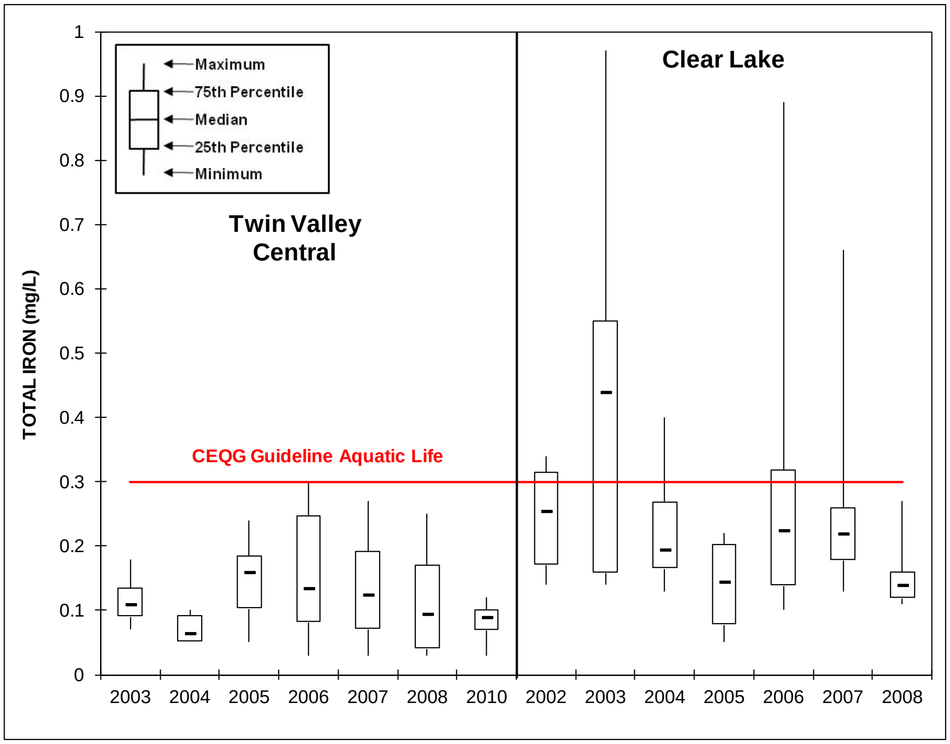


Figure 98 Total iron in Twin Valley Reservoir and Clear Lake, 2002-2010

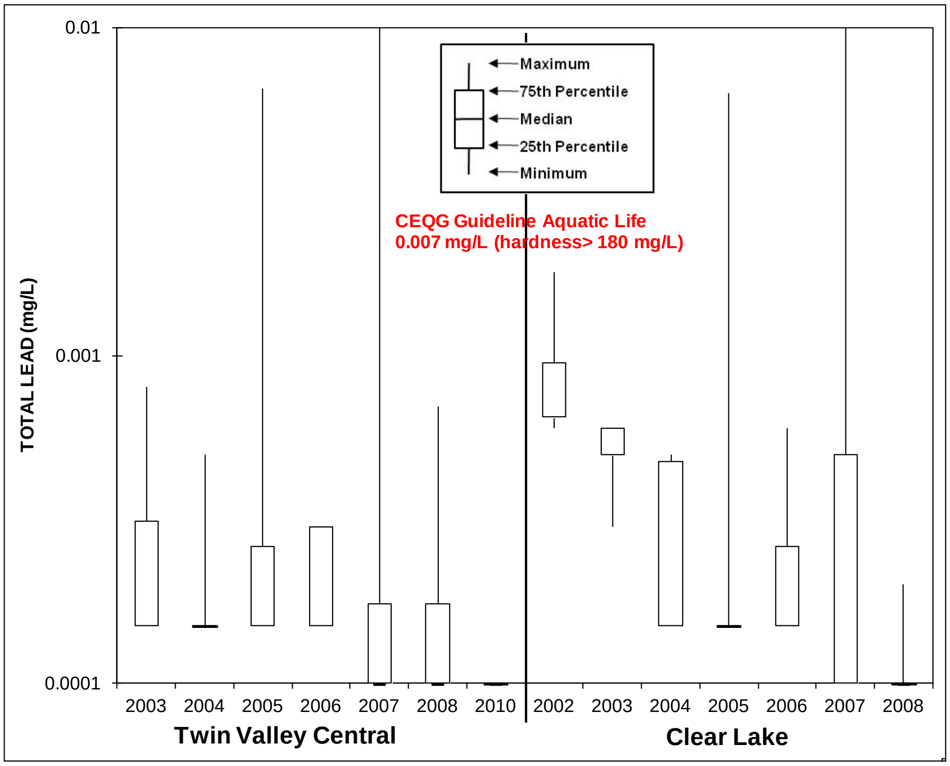


Figure 99 Total lead in Twin Valley Reservoir and Clear Lake, 2002-2010

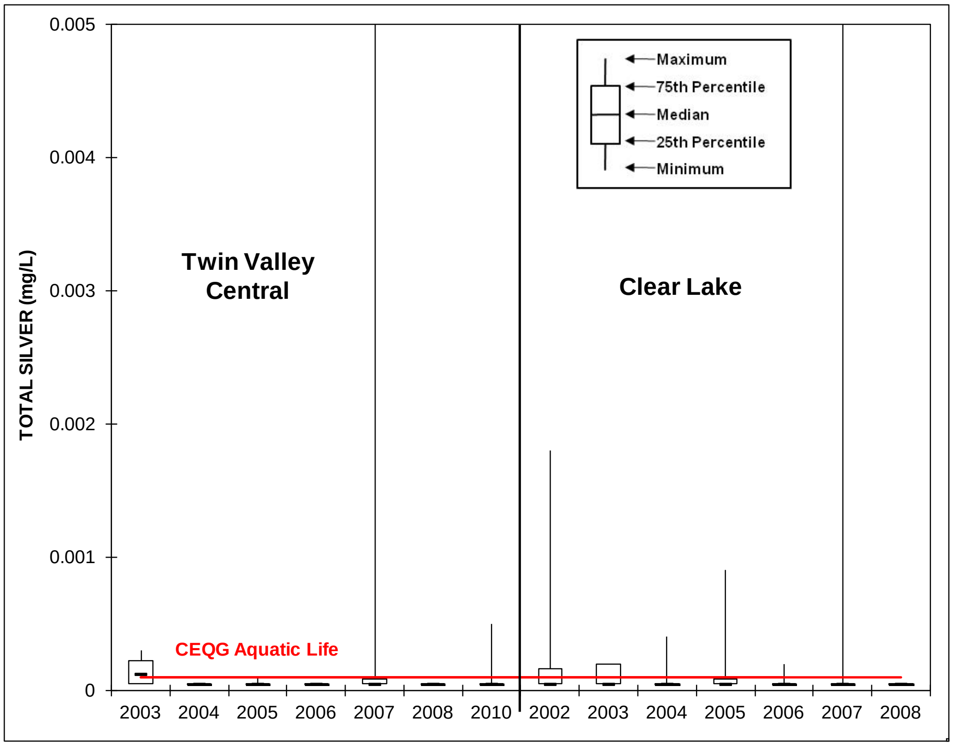


Figure 100 Total silver in Twin Valley Reservoir and Clear Lake, 2002-2010

Other metals that were evaluated did not exceed guidelines, and no other concerns in reservoirs were identified. Median concentrations over all years sampled are summarized in Appendix I.

3.3.13 Organic Carbon

Running Water

Total and dissolved organic carbon (Figure 101 and 102) doubled in the lower Little Bow River at Carmangay following the impoundment of Twin Valley Reservoir, and this increase was statistically significant (Table 1). DOC and TOC levels at Carmangay peaked around 12 mg/L in 2006-2007, with scattered higher outliers, and declined somewhat in 2010, but remained well above the BRBC objective of 5 mg/L and pre-impoundment levels. There was a smaller but still significant increase in median DOC and TOC at the Little Bow at Highway 533 (Table 1, Figure 103, 104). Concentrations at this site were generally lower than at Carmangay except during the high runoff years of 2005 and 2006, when these variables again both peaked around 12 mg/L. TOC and DOC levels in Mosquito Creek were similar to those at Carmangay, but these variables were not significantly higher in Mosquito Creek after 2003 (Table 1, Figure 105, 106), compared to pre-impoundment levels.

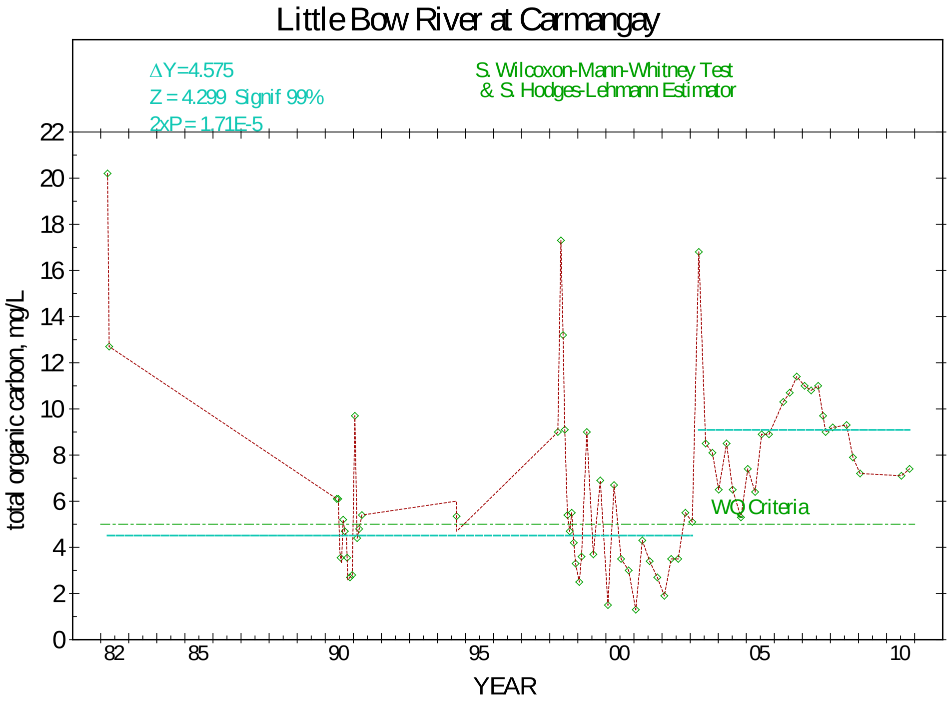


Figure 101 Total organic carbon in the Little Bow River at Carmangay, 1982-2010

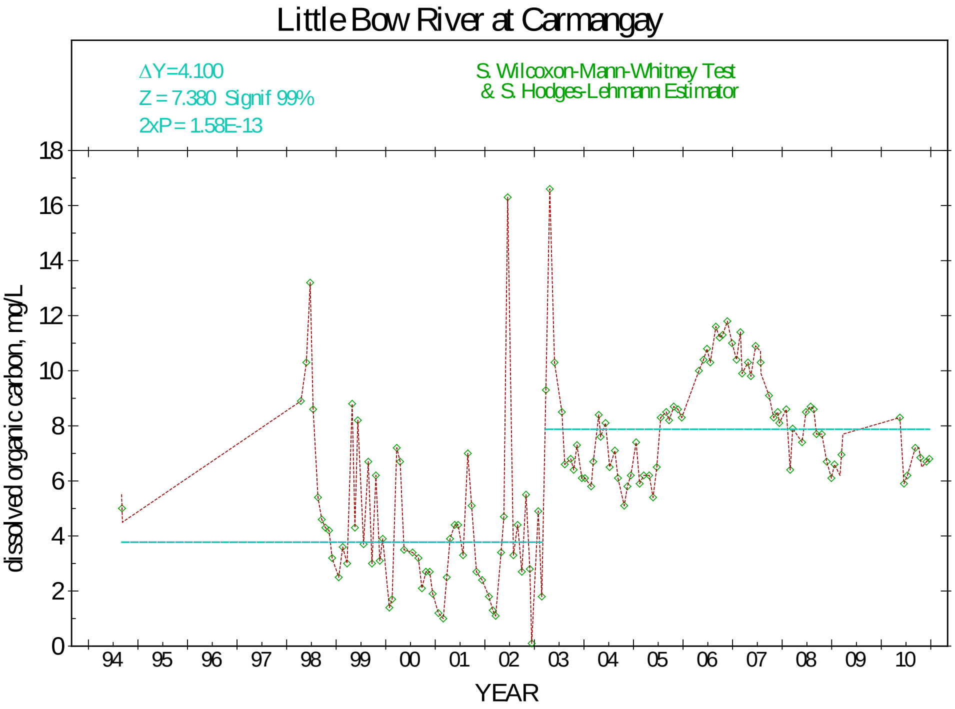


Figure 102 Dissolved organic carbon in the Little Bow River at Carmangay, 1994-2010

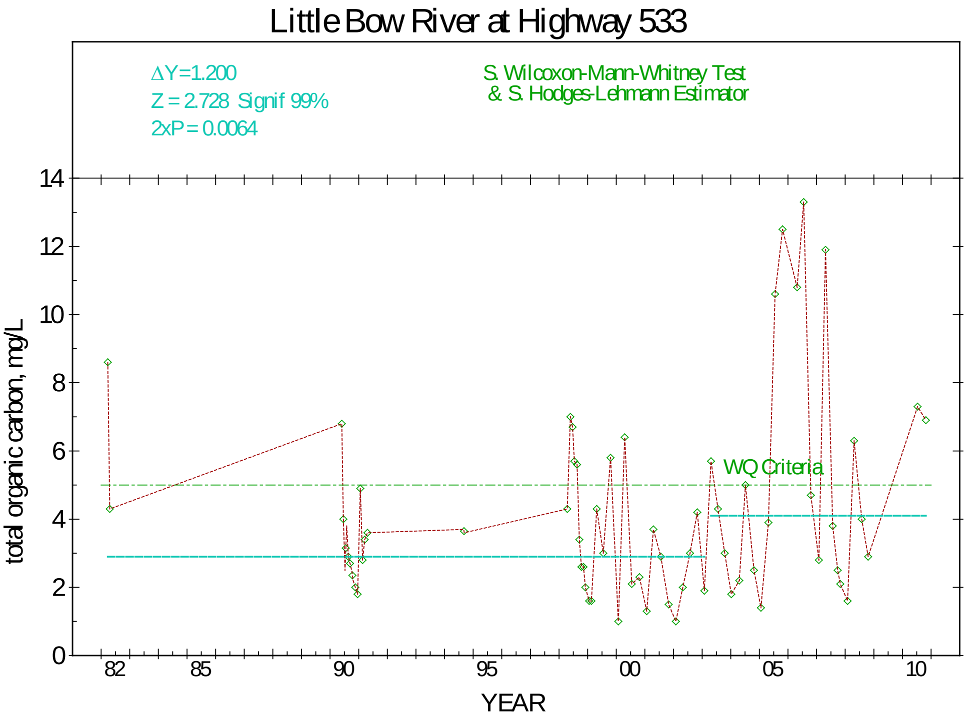


Figure 103 Total organic carbon in the Little Bow River at Highway 533, 1982-2010

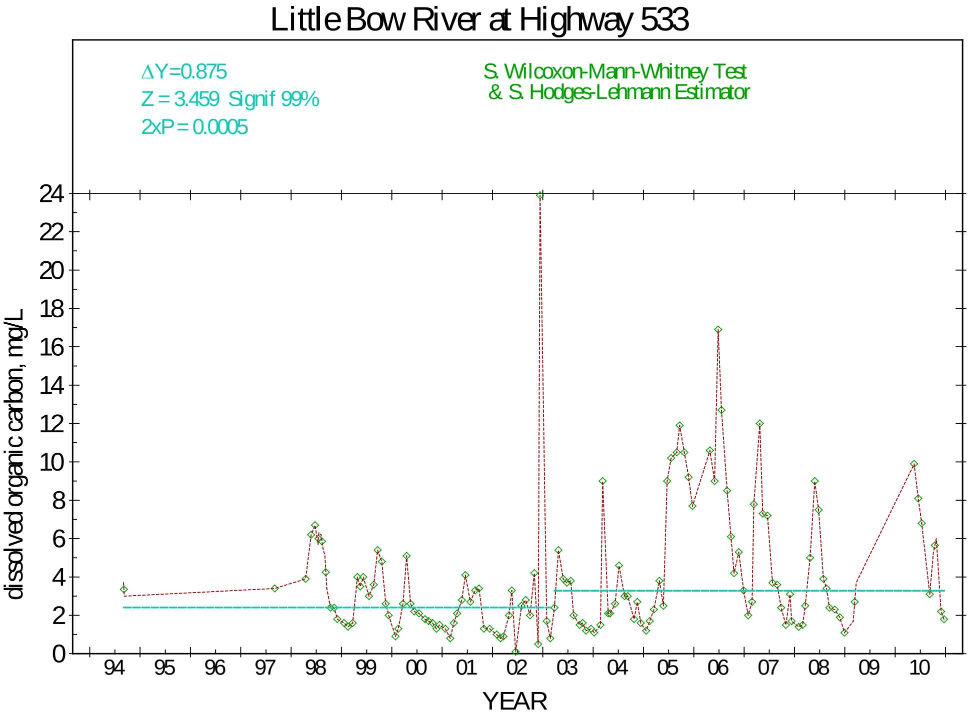


Figure 104 Dissolved organic carbon in the Little Bow River at Highway 533, 1994-2010

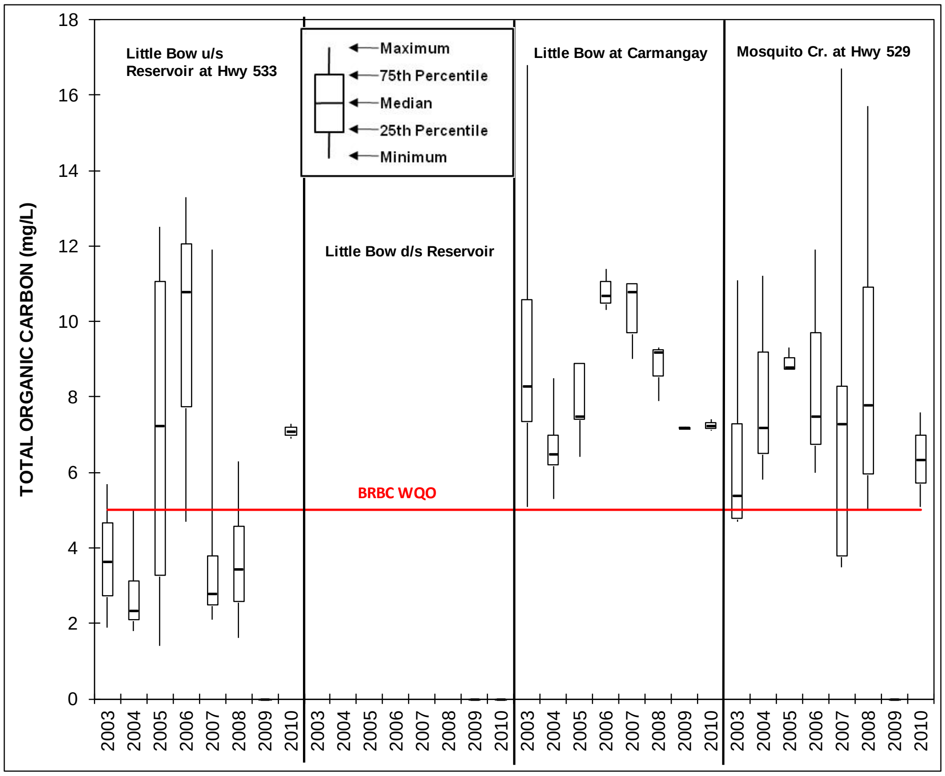


Figure 105 Total organic carbon in Twin Valley Reservoir tributaries, 2003-2010

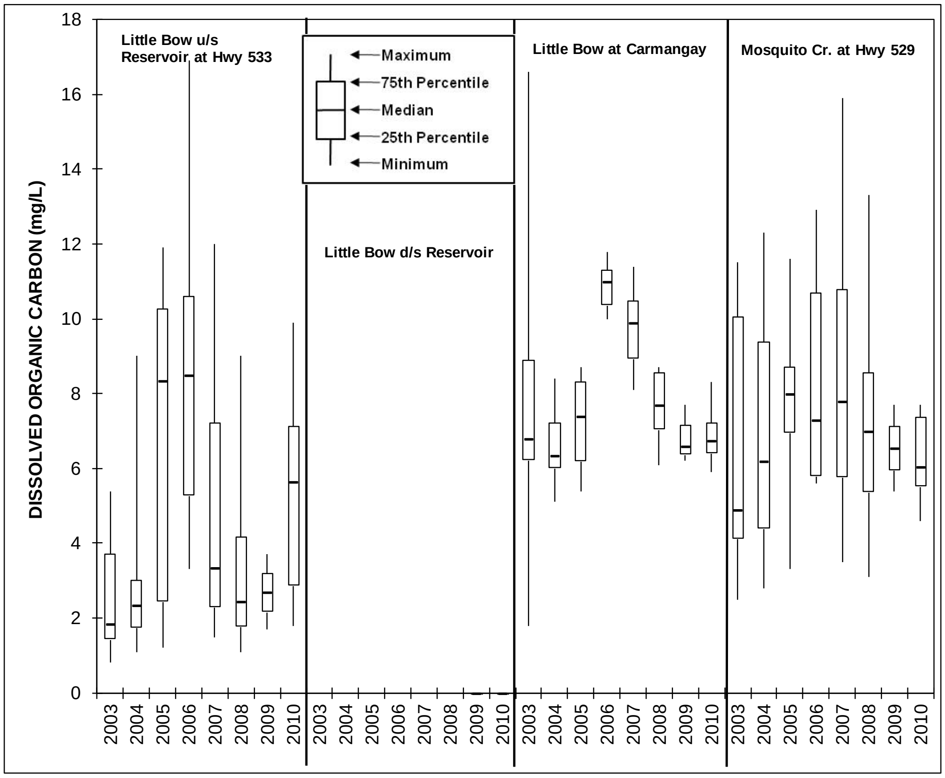


Figure 106 Dissolved organic carbon in Twin Valley Reservoir tributaries, 2003-2010

These findings suggest a potential risk to human health related to increased organic carbon levels in the Little Bow River. There has been an increase in disinfection byproducts in finished drinking water in communities downstream from Twin Valley reservoir (Personal communication, D. Lok, AENV, Lethbridge). These compounds are produced during chlorination of raw water supplies high in organic carbon, and are recognized as potential carcinogens.

Reservoirs

Median DOC levels in Twin Valley Reservoir peaked around 12 mg/L in 2006, when phytoplankton chl *a* levels were highest (Figure 107), then declined somewhat. However, DOC in this reservoir remained well above 2-3 mg/L levels typical of the Little Bow River at Highway 533 before impoundment. Accordingly some of the organic carbon could be from primary production within the reservoir. TOC was not measured in the reservoirs, but since TOC was typically at or above DOC concentrations in running water and includes particulate forms of carbon, TOC in Twin Valley Reservoir likely would have been well above the BRBC TOC objective of 5 mg/L throughout the sampling period. DOC was even higher in Clear Lake than in Twin Valley Reservoir and would have likely also exceeded the BRBC objective. High DOC levels are not surprising as Clear Lake is a terminal basin, which traps all external loadings. There is no municipal water withdrawal from Clear Lake thus impacts on human health are less of a concern.

Increased organic carbon at these sites could be due to discharge from Frank Lake, or increased algal production in Twin Valley Reservoir and the downstream Little Bow River. It is not possible to estimate the exact contribution of organic carbon from the various sources from the available data. In particular there are no organic carbon data from profiles, so internal loading of organic carbon cannot be estimated. However, the fact that peak levels of both DOC and TOC where measured peaked at around 12 mg/L, both upstream and downstream from the reservoir, suggests that the bulk of the organic carbon was from a source upstream from Highway 533 on the Little Bow River. DOC was not routinely measured upstream from Highway 533 post-impoundment. However, Frank Lake Basin 1 discharge had very high median DOC levels in 1990-92 of 19.3 mg/L (Sosiak 1994), compared to typically low levels of 2.15 mg/L in the Little Bow River well upstream at the Highwood Control Structure during 1999-2000. DOC and TOC were also lowest at sites on running water and reservoirs in 2004, when Frank Lake was not discharging (notably tributary TOC, Figure 105, and reservoir DOC, Figure 107). Accordingly, Frank Lake seems like a plausible source of high loadings of organic carbon to the Little Bow River upstream from Highway 533. Another possibility is that the high TOC levels upstream were caused by high runoff from sources throughout the upper watershed during the wet period in 2006.

If primary production in Twin Valley Reservoir continues to decline as noted in 2010, there could be some decrease in TOC downstream over time. However, since Frank Lake appears to be an important source, elevated TOC levels (above the BRBC objective), and water treatment issues could continue as long as Frank Lake continues to discharge. There are few recent data available for the Little Bow River upstream from Frank Lake. Analysis to determine other upstream sources of TOC based on the available data might be misleading.

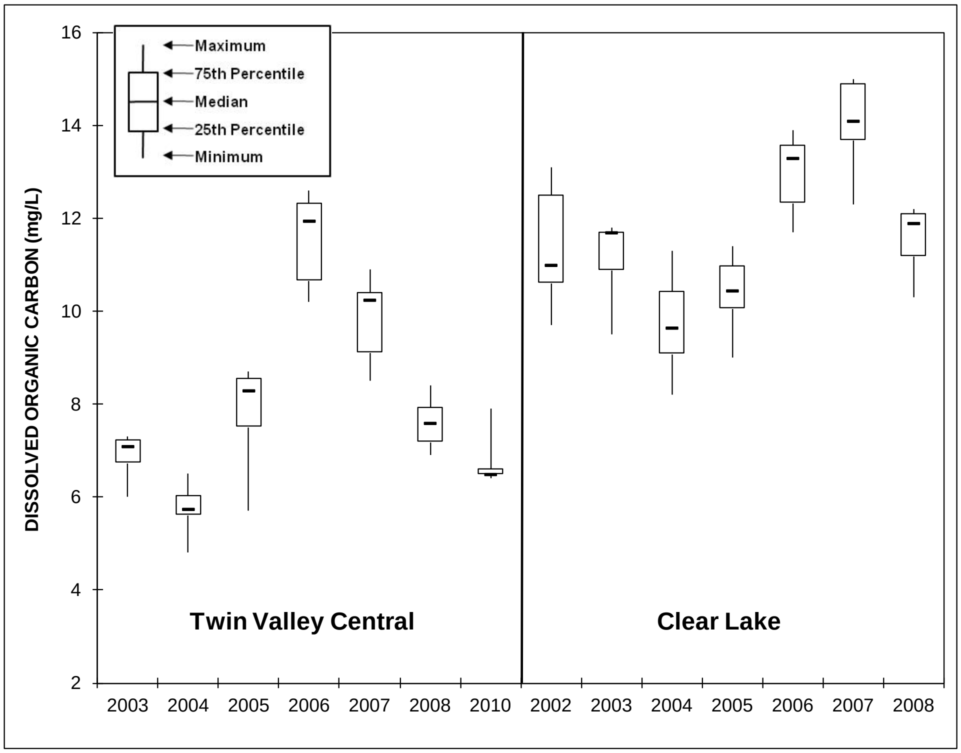


Figure 107 Dissolved organic carbon in Twin Valley Reservoir and Clear Lake, 2003-2010

3.4 Comparison of Changes in Water Quality to Modelling Predictions

Overall, modelling predictions were generally correct in four of the 19 cases (21%) summarized in Table 5. A further 9 predictions (47%) were not correct, but water quality was actually better than forecast. Notable predictions in this category included lower productivity in both Twin Valley Reservoir and Clear Lake than forecast, less extensive winter anoxia, no evidence of toxic levels of ammonia downstream, and no increase in the growth of aquatic plants in the Little Bow River upstream from the reservoir. Some of these cases reflect the fact that Twin Valley Reservoir and Clear Lake do not respond to external loading of phosphorus in a typical fashion.

Six of the water quality predictions (32%) were incorrect, and actual conditions involved a deterioration of water quality. These cases included a deterioration of three water quality variables in Mosquito Creek (coliforms, salinity, suspended solids), when no change was predicted except an improvement in spring, increased salinity in Clear Lake, and fish mercury levels that exceeded consumption guidelines in Twin Valley Reservoir.

Table 5 Summary of water quality predictions identified by NRCB and actual outcomes

Concern	Section in NRCB Report	Predictions in EIA (ratings Table 5.8)	Actual Outcomes
Little Bow Reservoir, Clear Lake and Lower Little Bow River			
Hg levels in reservoir fish	Sect. 8.7.2	° “the potential for accumulation of mercury in fish is low”, and mercury methylation potential is moderate. ° “Tissue concentrations in most predatory fish would not likely exceed 0.5 mg/kg, except in large individuals. ° Some consumption restrictions might be necessary”. ° Negative, major, long term	**Incorrect Prediction of Fish Hg.** ° Hg detected at levels above one guideline in composite water samples in Twin Valley and Clear Lake, and in Little Bow River upstream and downstream until 2008; ° Most reservoir pike exceeded 0.5 mg/kg. Mean total Hg in 2005: 0.68, 2006: 0.56 (Govt. of Alberta 2009). 23/30 fish in 2005 over GL. Fewer over GL in 2004 (4/30). ° Consumption restrictions required. ° Some indication of declining Hg in water samples. Fish Hg may decline over time.
Downstream temperature in Little Bow	Sect. 8.7.3	° Downstream temperatures decrease by up to 4 C ° Regain equilibrium within 40-50 km. ° Positive, minor, long term	**Correct Prediction of Downstream Temp.** ° Peak temperatures just below reservoir were ~3 to 4 C lower than before. ° Always below 22 C in post-impoundment monitoring, but not the case before (peaks up to 26 C before)
Downstream metals	Sect. 8.7.2, Table 5.8	° Modest increase in downstream metals in summer predicted, including Hg ° Described as a negative, minor, long term concern ° Negative, minor, long term	**Correct prediction of increase in some metals** ° Selenium, aluminum, iron, silver, mercury, arsenic have increased downstream ° For some metals, could be short-term increase, as some evidence of decline in selenium and mercury in recent years
Downstream oxygen	p. 5-19	° “dissolved oxygen levels (immediately downstream) would be low during periods of reservoir stratification” ° Minor, negative	**Downstream DO Prediction Correct For Some Years.** ° DO very low immediately downstream in 2003 and 2007 alone, and unsuitable for most fish species. ° DO above guideline during rest of post-impoundment years, even when reservoir weakly-stratified.
Downstream ammonia	Table 5.8	° increased ammonia above downstream objectives, and could be toxic in release water ° Negative, minor, long term	**Change in downstream ammonia not as severe as forecast.** ° Ammonia increased significantly by median 0.12 mg/L immediately downstream ° Still below lowest guideline for ambient pH and temperatures, and well below acute thresholds.
Downstream aquatic plants and algae	Table 5.8	° Marginal reduction in aquatic plant biomass and significant reduction in benthic algae ° Positive, minor, long term	**No significant change in macrophytes or periphyton downstream, contrary to prediction**. River sediments likely highly enriched with nutrients before and after impoundment, and sufficient for aquatic macrophytes.
Downstream suspended solids	Sect. 8.7.2, Table 5.8	° Sediment settling in reservoir; implies suspended solids should be lower than at present. ° Positive, minor, long term	**No decline in TSS downstream to date.** No significant change in TSS at the Carmangay site, but turbidity has increased significantly there.
Downstream bacteria	Sect. 8.7.2, Table 5.8	° Significantly lower bacteria levels ° Positive, minor, long term	**Significantly <u>higher</u> coliform levels all sites** ° Affects all sites, including Mosquito Creek, which was not anticipated. ° Sometimes above various guidelines, and appears to be flow-related.
Twin Valley Trophic State	Table 5.8	° Twin Valley Reservoir predicted to be hypertrophic ° “Algal biomass as measured by chlorophyll a is predicted to be typically in the 15 to 30 µg/L range” ° Negative, major, long term	**Twin Valley Reservoir not as productive as forecast, and without widespread winter anoxia.** ° Based on all indicators, Twin Valley Reservoir was eutrophic most years. TP suggested hypertrophy but other indicators suggest lower productivity. ° Evidence of seasonal nitrogen limitation and poor light penetration due to non-algal turbidity that may reduce response of Twin Valley phytoplankton to phosphorus loading ° Phytoplankton chl a was more variable than predicted, with nuisance blooms that exceeded predicted maxima and medians typically below predicted minimum.

Clear Lake trophic state	Table 5.8, p. 5-21	° "would stabilize at eutrophic with irrigation withdrawals" ° Nutrient withdrawal viewed as positive, minor, long term ° "hypertrophic without irrigation withdrawal"	**Clear Lake not as productive as forecast** ° Extremely high TP levels, but not nearly as productive as forecast (eutrophic rather than hypertrophic), likely because it appears to be a nitrogen-limited water body ° Nitrogen limitation is rare in Alberta, and could not have been reasonably predicted.
Twin Valley DO	Table 5.8	° Periodic hypolimnetic anoxia giving rise to both winter and summer fish kills ° Negative, major, long term	**No evidence of winter anoxia after 2006, and less extensive hypolimnetic anoxia in summer in recent years**. ° Winter anoxia and negative redox in bottom waters of Twin Valley Reservoir to 2006, but less extensive anoxia thereafter. ° Anoxia that did occur was not throughout the water column or in all basins, and fish could escape. Would appear unlikely to cause winter mortality. Apparently no reports of fish kills to date.
Clear Lake salinity impacts on irrigation	Table 5.8	° 1. Gradual reduction in total dissolved solids, compared to historical levels ° 2. Predicted to remain elevated until 5-6 years after first filling. ° Reduction described as positive major, long term	**TDS remains above guideline.** ° TDS dropped below guideline initially then increased and above guideline for last 3 years of sampling (six years after filling in 2008) ° May reflect evaporation in terminal basin, and less irrigation withdrawal than anticipated.
Upper Little Bow River and Mosquito Creek			
Upstream water temperature in Little Bow.	p. 5-15	° With proposed project flows, summer temperatures in Little Bow River upstream… would increase to the extent they could inhibit a warm water fishery ° Neutral, short term until implementation of revised operating plan	**Change in upstream temperature not as severe as forecast**. ° Peak hourly water temperature 1.9 C higher (peak 27.4 C) in 2003, 2004, 2007 post-impoundment, but little difference apparent other years. ° Values over 22 C guideline before and after impoundment, much cooler in wet 2005 season. ° Datasonde record did not exceed the 29 C acute maximum for walleye recommended by Taylor and Barton (1992).
Upstream Little Bow DO	p. 5-15	° Lower summer flows in the LBR upstream from the proposed reservoir would result in dissolved oxygen levels lower than acceptable to support a warm-water ecosystem ° Increased frequency and duration of critical conditions. ° Negative, major, short term	**Incorrect Prediction of Upstream DO**. ° No apparent decline in upstream DO over 7 years post-impoundment ° DO fell below guideline every year before impoundment (1999-2001), and during monitoring from 2005-2010, but not in 2003 or 2004.
Elevated suspended solids upstream on Little Bow	Table 5.8	° Elevated suspended solids during freshet, during formation of enlarged channel to convey increased flows ° Negative, minor, seasonal	**Correct Prediction of Increased Turbidity, but Has Lasted Longer than Anticipated** ° NFR has increased significantly by 4.8 mg/L in Little Bow at Highway 533, and has remained above guideline throughout 7 years of sampling. ° Turbidity also increased significantly by 4.0 NTU
Aquatic plants and periphyton upstream on Little Bow	Table 5.8	° Increase biomass due to nutrient loading from Frank Lake ° Negative, major, short term	**Incorrect predictions. Periphyton Biomass Has Declined** ° Significant decline in periphyton upstream. Likely reflects scouring or turbidity. ° No significant change in macrophyte biomass upstream from reservoir on Little Bow.
All effects on water quality in Mosquito Creek	p. 5-20	The project would not affect water quality in Mosquito Creek, except for a minor improvement in late spring.	**Water quality in Mosquito Creek has deteriorated under new flow regime** ° Irrigation guideline for fecal coliforms regularly exceeded after 2003 ° Increased nitrogen levels ° Increased TDS, guideline exceeded. May be declining

The intent of this analysis is to compare predictions to what actually occurred, for the benefit of future projects. This kind of analysis has rarely been done following such a major project. The consultants that completed impact predictions for the EIA conscientiously used the best data and resources that were available at the time.

Some important water quality changes that occurred were not predicted or evaluated in the EIA, and accordingly they are not included in the summary table. For example, the production of carcinogens in chlorinated drinking was mentioned as a potential impact of Frank Lake discharge and a hypertrophic reservoir, but the summary Table 5.8, in the NRCB/CEAA (1998) report mentioned only treatment to remove noxious taste and odours, not the impact of elevated TOC on disinfection by-products.

Overall, 13 (68%) of the water quality predictions summarized in the NRCB/CEAA (1998) proved to be accurate, or the actual outcome was better than forecast. The 9 cases (47%) where outcomes were better than expected need to be evaluated, as the results suggest that assumptions were too conservative and the model configuration did not accurately represent conditions in these water bodies. The six predictions (32%) that were incorrect are a concern and need to be evaluated to determine causes for this lack of success.

4.0 CONCLUSIONS

4.1 Physical, Chemical and Biological Characteristics

1. Temperature and DO in Running Water. As predicted by modelling, water temperature was slightly higher in the upstream Little Bow River some summers, three of the seven years post-impoundment, compared to prep-impoundment, with elevated temperatures ranging up to 27.4^{o}C, compared to highs of 25.8^{o}C before impoundment. Peak water temperatures were roughly 3 to 4^{o}C lower downstream of Twin Valley Reservoir following impoundment, and always below the temperature guideline. DO levels fell below the 5 mg/L Alberta guideline both before and after impoundment in the Little Bow River at Highway 533, but did so less frequently after impoundment. DO levels at the site on the Little Bow River downstream from the reservoir were extremely low after impoundment in 2003 and 2007, but were otherwise over the guideline. Declines in DO likely reflected oxygen demand from newly flooded soils, and decomposition of plant material.

2. Reservoirs Temperature and DO. The Central Basin of Twin Valley Reservoir had weak thermal stratification most summers. In contrast, relatively shallow Clear Lake displayed no evidence of thermal stratification, and very little anoxia. Much of the water column of the Central Basin of Twin Valley Reservoir was anoxic during the summer of 2003, after first filling due to oxygen demand from newly-flooded soils. Periods of anoxia in summer decreased over time, and after 2006, there was no evidence of prolonged anoxia in winter, which was predicted to have the potential to cause fish kills.

3. Phosphorus in Running water. Both total and dissolved phosphorus increased significantly post-impoundment in the Little Bow River upstream and downstream from

Twin Valley Reservoir to peak levels in 2006. This increase was likely a result of release of these constituents from newly flooded soils, and discharge from Frank Lake, which occurred every summer but 2004. In contrast total and dissolved phosphorus levels in Mosquito Creek declined post-impoundment, because of improved wastewater treatment at the Nanton WWTP.

Results of the mass balance indicate that Mosquito Creek contributed a greater TP mass during 2004 to 2010 (on average 9305 kg) in 4/6 years than the Little Bow River (average 8681 kg). Most of this came from nonpoint sources in this basin such as erosion on Women's Coulee and elsewhere, municipal stormwater and various agricultural sources. Although the Nanton WWTP was by far the largest point source of dissolved phosphorus historically, following implementation of tertiary treatment and an 83% drop in TP discharge, the plant was a relatively minor point source of TP loading. Frank Lake remains the most important point source of nutrients, accounting for 20 to 58% of the loading in summer from the Little Bow Basin to Twin Valley Reservoir, in three years with sufficient data to account for various sources.

4. <u>Phosphorus in Reservoirs</u>. All basins of Twin Valley Reservoir had very high levels of TP and TDP, well above the AWWQ guideline, except for 2010, due to temporary phosphorus release from newly-flooded soils and discharge from Frank Lake. Phosphorus concentrations and mass peaked in 2006, and have since declined, perhaps because trophic upsurge has ended. Results from a mass balance using 2004 to 2010 data, indicated that Twin Valley Reservoir retained most of the TP that entered, on average a net deposition of 3116 kg per year. These results also indicate that internal phosphorus loading occurred every summer except 2010, and that exception could reflect sampling methods rather than lack of internal loading.

   Clear Lake had even higher TP and TDP levels than Twin Valley Reservoir, from Mosquito Creek phosphorus loadings, and because it is a terminal basin and constituents should tend to concentrate over time with evaporation.

   There was not sufficient data to develop a nitrogen budget for Twin Valley Reservoir.

5. <u>Nitrogen in Running Water</u>. All forms of nitrogen increased significantly in the Little Bow River and Mosquito Creek post-impoundment, but declined in 2010 at most sites. In spite of the increase, guidelines for the protection of aquatic life were seldom exceeded for any form of nitrogen, except for TN. The TN guideline was also exceeded before 2003 and must have been caused by factors other than impoundment. The period of elevated nitrogen in the Little Bow River from 2003 to 2008 likely reflect decomposition during trophic upsurge. Reasons for increased nitrogen levels in Mosquito Creek are not understood at this time.

6. <u>Nitrogen in Reservoirs</u>. Neither total ammonia nor nitrate+nitrite exceeded guidelines for the protection of aquatic life in the euphotic zone of Twin Valley Reservoir or Clear Lake. Levels of various forms of nitrogen were highest after first filling then declined to lowest levels in 2010. This suggests that the temporary increase in nitrogen was due to

trophic upsurge. Nitrogen levels have not declined to the same extent in recent years in Clear Lake, presumably because this water body did not undergo the same process of trophic upsurge after lake levels were stabilized.

7. Aquatic Plants in Running Water. Periphytic algae declined above the reservoir at Highway 533 after impoundment, probably as a result of higher flows and scouring. There was no significant change in this variable at other sites, or the abundance of aquatic macrophytes. Excessive nutrients and suitable habitat likely provided ideal conditions for growth, and there was high periphytic and macrophyte biomass before and after impoundment.

8. Phytoplankton and Trophic State in Reservoirs. Twin Valley Reservoir and Clear Lake are productive water bodies, with high phosphorus levels supporting high phytoplankton biomass and periodic nuisance cyanobacterial blooms that sometimes exceeded the maximum phytoplankton chl *a* levels (30 μg/L) predicted by modelling. In spite of these nuisance blooms, both Clear Lake and the Central Basin of Twin Valley Reservoir would be described as eutrophic most sampling years, rather than the hypertrophic conditions that were predicted.

9. Coliforms in Running Water. Both *E. coli* and fecal coliforms increased significantly post-impoundment at sites on the Little Bow River and in Mosquito Creek, and there was exceedance of contact recreation and irrigation guidelines at various sites, most often on Mosquito Creek. Higher coliform counts appeared to be related to precipitation, as the highest counts in this creek occurred in two of the wettest years (2006, 2009). These increases may reflect scouring of shoreline areas near agricultural sites or increased loadings from the Nanton WWTP over time. Coliform counts were generally not a concern in the reservoirs.

10. Secchi Depth and Transparency in Reservoirs. Secchi depth in Clear Lake and the Central Basin of Twin Valley Reservoir was generally within a range typical of eutrophic lakes. However, there were individual years of much higher clarity in separate basins of Twin Valley Reservoir, but never Clear Lake which had reduced clarity due to fine suspended inorganic material.

11. Suspended Solids and Turbidity in Running Water. Turbidity and suspended sediments have increased significantly and exceeded guidelines following impoundment in the Little Bow at Highway 533 as predicted due to the higher flows and scouring of the upstream channel of the Little Bow River. These variables also increased and exceeded guidelines in Mosquito Creek at Highway 529, although no change in water quality there was predicted. Previous work in 1999 determined that sources along Women’s Coulee contributed more suspended sediment than any other source along Mosquito Creek. Surveys during 2003 to 2006 suggest that erosion near the buffalo jump on Women’s Coulee contribute the bulk of the suspended sediment from that coulee.

12. Suspended Solids in Reservoirs. Both Twin Valley Reservoir and Clear Lake have moderately high levels of suspended solids and turbidity, perhaps related to wind-

induced resuspension of sediments, bank erosion, or loading of increasingly-turbid water from tributaries. Non-algal turbidity in these reservoirs inhibits phytoplankton biomass and this effect is strongest in Clear Lake.

13. Salinity in Running Water. Salinity (as TDS) increased significantly after impoundment at sites on the Little Bow River upstream and downstream from Twin Valley Reservoir at Carmangay. This may reflect release of salts from newly-flooded soils, and discharge of saline water from Frank Lake. TDS has also increased after impoundment in Mosquito Creek, and levels were higher than in the Little Bow River. Of the major cations and anions, sodium, sulphate and conductivity increased significantly post-impoundment at most sites on running water, while chloride only increased in the Little Bow River at Highway 533, and in Mosquito Creek. TDS levels were somewhat lower in 2010 at all sites, but still at times over the irrigation guideline.

    TDS at all these locations exceeded guidelines for the irrigation of sensitive crops (e.g., raspberries, strawberries, beans or carrots) but remains within a range acceptable for more salinity-tolerant crops (e.g., wheat and other grains). Suitability of water from these sites for irrigation should be evaluated based on the salinity-tolerance of individual crops.

    Salinity in Reservoirs TDS in Clear Lake was above the 500 mg/L water quality guideline to protect sensitive crops before filling in 2002, briefly fell below the guideline, then again increased above the guideline in 2006 to 2008. Individual ions and conductivity followed the same pattern as TDS in Clear Lake. This increase may reflect increased salt concentration from evaporation, without sufficient withdrawal for irrigation and other uses.

    In 2008, TDS in Clear Lake was not at levels that would impact more salinity tolerant crops like alfalfa and wheat. Clear Lake was not sampled in 2010. The suitability of this source for irrigation of sensitive crops should be confirmed by further sampling. Suitability of water from Clear Lake for irrigation should be evaluated based on the salinity-tolerance of individual crops.

14. Metals in Running Water and Reservoirs. Total selenium increased significantly in the Little Bow River upstream and downstream from Twin Valley Reservoir, and in Mosquito Creek after impoundment, and sometimes exceeded the aquatic life guideline until 2007-2008, but remained below this guideline thereafter. Results to 2010 suggest that the increase in selenium may be temporary.

    Similarly, total mercury levels were sometimes above the guideline for inorganic mercury until 2008 at all sites on running water, but not thereafter. These mercury results appear to reflect the predicted mobilization of mercury from newly-flooded soils. Total arsenic increased significantly in the Little Bow River upstream and downstream from Twin Valley Reservoir. However, at both locations total arsenic generally remained below the water quality guideline. Other metals such as aluminium and iron also exceeded guidelines at various locations both before and after impoundment.

Total selenium and mercury also temporarily increased above guidelines after first filling of Twin Valley Reservoir, and stabilization of Clear Lake. This likely reflects release of these metals from newly-flooded soils.

Nearly all arsenic results from Clear Lake exceeded the aquatic life guideline, but not the CCME livestock guideline. Total arsenic levels in Clear Lake declined somewhat after 2004, but remained well above the guideline. Although arsenic exceeded the aquatic life guideline, it remained below levels known to cause acute and chronic toxic effects on aquatic life.

15. Organic Carbon and Water Treatment Concerns. Total and dissolved organic carbon doubled in the lower Little Bow at Carmangay following the impoundment of Twin Valley Reservoir and this increase was statistically significant. Levels of these variables declined somewhat in 2010, but remained well above one water quality objective at this location. Levels also increased in the Little Bow River upstream after impoundment, but there was not a significant increase in Mosquito Creek.

    DOC levels in Twin Valley Reservoir were also relatively high and peaked around 12 mg/L in 2006. DOC levels were higher still in Clear Lake. Increased organic carbon at these sites could be due to discharge from Frank Lake, increased cyanobacterial production in Twin Valley Reservoir, and the downstream Little Bow River, or be related to runoff during wet years. If primary production in Twin Valley Reservoir continues to decline as noted in 2010, there could be some decrease in TOC downstream over time. However, since Frank Lake appears to be an important source, water treatment issues could continue as long as Frank Lake continues to discharge.

4.2 Predictions from Impact Assessment

1. Modelling predictions were correct in four of the 19 cases (21%). Notable cases where conditions were better than forecast (47% of cases evaluated) included lower productivity in both Twin Valley Reservoir and Clear Lake than forecast, less extensive winter anoxia, no evidence of toxic levels of ammonia downstream, and no increase in the growth of aquatic plants in the Little Bow River upstream from the reservoir.

2. Cases where water quality was worse than predicted (32% of cases evaluated) included a deterioration of three water quality variables in Mosquito Creek (coliforms, salinity, suspended solids), when no deterioration was predicted, increased salinity in Clear Lake, and fish mercury levels that exceeded consumption guidelines in Twin Valley Reservoir.

4.3 Recommendations

1. Continued monitoring that targets specific sites and concerns is warranted. Specific concerns that need to be evaluated by monitoring over the long term include: (1) arsenic and the effects of irrigation expansion on salinity in Clear Lake, (2) increasing levels of coliforms, salinity, and suspended sediments in Mosquito Creek, (3) effects of increased organic carbon and reservoir productivity on drinking water supplies from Twin Valley Reservoir and downstream, and (4) temporal trends in mercury and selenium and other metals in Twin Valley Reservoir and the Little Bow River.

2. Future efforts to reduce phosphorus loading to Twin Valley Reservoir should target nonpoint sources on Mosquito Creek and control of discharge from Frank Lake.

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Appendix Ia Median values for samples collected during the open-water season from Clear Lake (2001-2010) and sites on the Twin Valley Reservoir, 2003-2010

VARIABLE	UNITS	2001	2002	2003	2004	2005	2006	2007	2008	*2009*	2003	2004	2005	2006	2007	2008	*2009*	2010
		CLEAR LAKE - AC0380									**TWIN VALLEY RESERVOIR MOSQUITO BASIN - AC2080**							
No. Of Samples:		**6**	**7**	**5**	**6**	**6**	**6**	**6**	**6**	**1**	**4**	**6**	**6**	**4**	**6**	**6**	**1**	**4**
TP	mg/L	0.7765	0.625	0.685	0.51	0.4205	0.455	0.536	0.385	--	0.163	0.084	0.099	0.217	0.1615	0.1095	--	0.039
TDP	mg/L	0.6485	0.563	0.636	0.487	0.4015	0.434	0.484	0.355	--	0.129	0.0595	0.0625	0.1685	0.1165	0.069	--	0.032
PO$_4$, Diss. Ortho	mg/L	0.6155	0.555	0.611	0.4595	0.3665	0.384	0.4625	0.315	--	--	--	--	--	0.046	--	--	--
TKN	mg/L	1.115	1.3	1.28	0.955	1.345	1.43	1.49	1.1	--	1.78	0.71	0.995	1.395	1.09	0.88	--	0.735
NH$_3$, Tot.	mg/L	0.08	0.02	0.21	0.135	0.11	0.18	0.115	0.1	--	0.455	0.16	0.105	0.165	0.135	0.095	--	0.0525
NO$_2$+NO$_3$-N	mg/L	0.052	0.045	0.067	0.0695	0.0685	0.107	0.0315	0.027	--	--	--	0.253	0.1465	0.136	0.099	--	0.01125
NO$_2$	mg/L	0.00725	0.00825	0.0015	0.007	0.0185	0.011	0.004	0.00225	--	--	--	0.016	0.01	0.0015	0.00325	--	0.0015
NO$_3$	mg/L	0.044	0.059	0.067	0.068	0.0295	0.104	0.029	0.0205	--	--	--	0.235	0.1365	0.1335	0.096	--	0.01125
TN, Calc.	mg/L	1.167	1.345	1.347	1.0245	1.4135	1.537	1.5215	1.127	--			1.248	1.5415	1.226	0.979	--	0.74625
Silica Reactive	mg/L	8.095	5.4	9.55	7.005	5.46	6.94	10.485	7.4	--	--	--	--	--	5.6	--	--	--
DOC	mg/L	12.4	10.7	11.7	9.65	10.45	13.5	14.5	11.6	--	--	--	--	--	10.7	--	--	--
CHL-a	mg/m3	4.3	6	2.3	3.5	2.3	4.64	9.7	2.88	--	3.35	5.9	9.95	18.9	8.18	7.54	--	4.51
Conductance, Lab	uS/cm	991	835	783	695	651.5	823	1000	970	--	--	--	--	--	870	--	--	--
TDS, Calc.	mg/L	666	518	511	431	406.5	538	650	625	--	--	--	--	--	594	--	--	--
NFR	mg/L	5.35	2.6	6	2.3	4	6	7.05	2.3	--	7.5	1.4	6.3	3.55	6.5	5.85	--	4
FR	mg/L	690	572	538	458	411.5	580	607	665	--	--	--	--	--	596	--	--	--
Turbidity	NTU	11.65	4.2	5.3	4.15	3.2	5.4	6.55	2.8	--	--	--	--	--	17	--	--	--
Total Alkalinity	mg/L	321.5	304	293	275	229.5	249	285	290	--	--	--	--	--	253	--	--	--
PP Alkalinity	mg/L	21.85	14	11.8	13.9	11.55	11.2	15.6	18	--	--	--	--	--	10.9	--	--	--
pH, Lab	units	8.57	8.54	8.6	8.645	8.64	8.63	8.645	8.7	--	--	--	--	--	8.61	--	--	--
Hardness	mg/L	255	250	270	220	200	240	270	285	--	--	--	--	--	290	--	--	--
Sodium, Diss. Filt.	mg/L	125.5	88	80.4	64.6	61.15	93	116	105	--	--	--	--	--	93	--	--	--
Sodium, Tot.	mg/L	125.5	90	83	63.55	62.05	101	117.5	110	--	--	--	--	--	93.3	--	--	--
Calcium, Diss. Filt.	mg/L	50.4	52.8	58.1	44.95	39.5	46.2	52.35	50.5	--	--	--	--	--	59	--	--	--
Calcium, Tot.	mg/L	53.5	52.9	58.6	45.25	39.45	48.8	54.2	51.5	--	--	--	--	--	52	--	--	--
Magnesium, Diss.	mg/L	30.75	27.4	30.1	27.4	24.75	29.2	34.5	37.5	--	--	--	--	--	36	--	--	--
Magnesium, Tot.	mg/L	31	28.5	30.7	27.75	24.15	31	36.85	39	--	--	--	--	--	33.5	--	--	--
Potassium, Diss. Filt.	mg/L	19.2	13.9	16.1	12.2	12.15	14.7	17.65	15	--	--	--	--	--	8	--	--	--
Potassium, Tot.	mg/L	19.35	14.7	16.5	12.05	11.85	15.8	18.65	15.5	--	--	--	--	--	8.3	--	--	--
Chloride, Diss.	mg/L	25.05	15	13.2	9.2	10.2	14.1	17.6	15.5	--	--	--	--	--	26.9	--	--	--
Sulphate, Diss.	mg/L	201	131	127	106	102	196	226.5	205	--	--	--	--	--	214	--	--	--
Sulphur, Diss.	mg/L	68.3	45.1	43.2	32.3	32.9	59.1	72.45	65	--	--	--	--	--	66	--	--	--
Sulphur, Tot.	mg/L	68.75	45.3	43.9	33.4	31.8	64.5	78.9	70	--	--	--	--	--	62.6	--	--	--
Fluoride, Diss.	mg/L	0.25	0.23	0.24	0.235	0.22	0.23	0.265	0.285	--	--	--	--	--	0.24	--	--	--
Bicarbonate	mg/L	332	324	323	302	267	283	308.5	320	--	--	--	--	--	282	--	--	--
Carbonate	mg/L	26.25	16.8	14.2	16.7	13.85	13.5	18.5	21	--	--	--	--	--	13.1	--	--	--
Secchi Depth	m	0.75	1.4	0.8	1.7	1.9	1.1	2	1.9	--	3.2	2	1.2	1.3	1.3	1.45	--	2.3
True Colour	rel. units	20	20	15	20	16.5	21	17	11	--	--	--	--	--	15	--	--	--
Cyanide, Tot.	mg/L	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.001	--	--	--	--	--	--	--	--	--
Fecal Coliforms	no./100 mL	5	9	1	1	4	1	6	3	1	1.5	2	3.5	4	5	1	1	7.5
Escherichia Coliforms	no./100 mL	2	2	0.5	0.5	2	1	1	1	0.5	1.5	0.5	4	1	2	0.5	0.5	3
Microcystin, Tot.	ug/L	--	--	--	--	--	--	0.83	0.035	--	--	--	--	--	--	--	--	--
Diss. Oxygen,	mg/L	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Air Temperature	deg C	--	--	--	18	--	12	--	--	--	18.5	23.5	--	21.5	--	--	--	--
Euphotic Depth	m	--	--	--	--	--	--	--	4.3	--	--	--	--	--	--	4.1	--	6.2
Total Water Depth	m	--	--	--	--	--	--	--	4.435	--	--	--	--	--	--	11.2	--	9.75
Al, Diss.	mg/L	0.015	0.01	0.066	0.0735	0.011	0.041	0.15	0.072	--	--	--	--	--	0.2	--	--	--
Al, Tot.	mg/L	0.4305	0.131	0.415	0.246	0.1085	0.283	0.3	0.13	--	--	--	--	--	0.04	--	--	--
Sb, Diss.	mg/L	0.0006	0.0002	0.0001	0.0004	0.0004	0.0002	0.0003	0.00045	--	--	--	--	--	0.0001	--	--	--
Sb, Tot.	mg/L	0.0006	0.0004	0.0001	0.0006	0.0005	0.0001	0.0002	0.0006	--	--	--	--	--	0.0001	--	--	--
As, Diss.	mg/L	0.012	0.0083	0.0106	0.00925	0.00485	0.0053	0.0086	0.00925	--	--	--	--	--	0.0023	--	--	--
As, Tot.	mg/L	0.01375	0.0092	0.0147	0.0105	0.00755	0.0078	0.00995	0.00755	--	--	--	--	--	0.003	--	--	--
Ba, Diss.	mg/L	0.06905	0.0706	0.0718	0.07065	0.0652	0.0868	0.1	0.055	--	--	--	--	--	0.05	--	--	--
Ba, Tot.	mg/L	0.0774	0.0921	0.0747	0.0861	0.0728	0.101	0.1	0.07	--	--	--	--	--	0.09	--	--	--
Be, Diss.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005	--	--	--	--	--	0.0005	--	--	--
Be, Tot.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005	--	--	--	--	--	0.0005	--	--	--
B, Diss.	mg/L	0.055	0.04	0.06	0.05	0.055	0.06	0.06	0.06	--	--	--	--	--	0.1	--	--	--
B, Tot.	mg/L	0.08	0.07	0.07	0.055	0.05	0.06	0.07	0.065	--	--	--	--	--	0.05	--	--	--
Cd, Diss.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	--	--	--	--	0.0001	--	--	--
Cd, Tot.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	--	--	--	--	0.0001	--	--	--
Cr, Diss.	mg/L	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.005	0.0005	--	--	--	--	--	0.05	--	--	--
Cr, Tot.	mg/L	0.0025	0.004	0.002	0.001	0.00075	0.001	0.005	0.0005	--	--	--	--	--	0.005	--	--	--
Co, Diss.	mg/L	0.00035	0.0003	0.0004	0.00023	0.00035	0.0004	0.0009	0.00015	--	--	--	--	--	0.0007	--	--	--
Co, Tot.	mg/L	0.0005	0.0004	0.0005	0.00045	0.00045	0.0005	0.0012	0.00023	--	--	--	--	--	0.0008	--	--	--
Cu, Diss.	mg/L	0.00215	0.0017	0.0019	0.00165	0.0011	0.002	0.0041	0.0015	--	--	--	--	--	0.002	--	--	--
Cu, Tot.	mg/L	0.00265	0.0032	0.002	0.00255	0.0013	0.0025	0.00525	0.0014	--	--	--	--	--	0.0024	--	--	--
Fe, Diss.	mg/L	0.0125	0.04	0.06	0.115	0.03	0.005	0.13	0.065	--	--	--	--	--	0.3	--	--	--
Fe, Tot.	mg/L	0.72	0.21	0.44	0.195	0.145	0.25	0.24	0.15	--	--	--	--	--	0.06	--	--	--
Pb, Diss.	mg/L	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.0001	0.0001	--	--	--	--	--	0.0001	--	--	--
Pb, Tot.	mg/L	0.0007	0.0008	0.0006	0.00028	0.00015	0.00015	0.0004	0.0001	--	--	--	--	--	0.0001	--	--	--
Li, Diss.	mg/L	0.0135	0.006	0.006	0.0065	0.01	0.012	0.01	0.01	--	--	--	--	--	0.1	--	--	--
Li, Tot.	mg/L	0.0135	0.006	0.011	0.008	0.011	0.013	0.01	0.01	--	--	--	--	--	0.01	--	--	--
Mn, Diss.	mg/L	0.002	0.004	0.017	0.003	0.0035	0.002	0.0245	0.008	--	--	--	--	--	0.02	--	--	--
Mn, Tot.	mg/L	0.0235	0.014	0.026	0.014	0.0155	0.023	0.039	0.0165	--	--	--	--	--	0.019	--	--	--
Hg, Diss.	ug/L	--	0.025	0.025	--	--	0.025	0.025	0.025	--	--	--	--	--	0.025	--	--	--
Hg, Tot.	ug/L	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	--	--	--	--	--	0.025	--	--	--
Mo, Diss.	mg/L	0.0032	0.0023	0.0023	0.0026	0.0018	0.0027	0.003	0.003	--	--	--	--	--	0.0019	--	--	--
Mo, Tot.	mg/L	0.00345	0.0026	0.0023	0.00255	0.00225	0.0028	0.0032	0.00315	--	--	--	--	--	0.002	--	--	--
Ni, Diss.	mg/L	0.00535	0.0018	0.002	0.0022	0.00285	0.003	0.00615	0.0016	--	--	--	--	--	0.0043	--	--	--
Ni, Tot.	mg/L	0.00595	0.0029	0.0023	0.0026	0.0053	0.0036	0.00745	0.0016	--	--	--	--	--	0.0048	--	--	--
Se, Diss.	mg/L	0.00015	0.0001	0.0002	0.0002	0.00025	0.0001	0.0001	0.0004	--	--	--	--	--	0.001	--	--	--
Se, Tot.	mg/L	0.00025	0.0003	0.0002	0.00035	0.0004	0.0001	0.0002	0.0003	--	--	--	--	--	0.0005	--	--	--

VARIABLE	UNITS	2001	2002	2003	2004	2005	2006	2007	2008	*2009*	2003	2004	2005	2006	2007	2008	*2009*	2010
		CLEAR LAKE - AC0380									TWIN VALLEY RESERVOIR MOSQUITO BASIN - AC2080							
No. Of Samples:		6	7	5	6	6	6	6	6	1	4	6	6	4	6	6	1	4
Ag, Diss.	mg/L	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	--	--	--	--	--	0.00005	--	--	--
Ag, Tot.	mg/L	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	--	--	--	--	--	0.00005	--	--	--
Sr, Diss.	mg/L	0.329	0.338	0.368	0.3395	0.279	--	0.39	0.415	--	--	--	--	--	0.5	--	--	--
Sr, Tot.	mg/L	0.377	0.402	0.384	0.3735	0.2935	0.325	0.395	0.44	--	--	--	--	--	0.46	--	--	--
Tl, Diss.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	--	--	--	--	0.0001	--	--	--
Tl, Tot.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	--	--	--	--	0.0001	--	--	--
Sn, Diss.	mg/L	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	--	--	--	--	--	0.0005	--	--	--
Sn, Tot.	mg/L	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	--	--	--	--	--	0.0005	--	--	--
Ti, Diss.	mg/L	0.005	0.0005	0.004	0.006	0.0025	0.006	0.009	0.003	--	--	--	--	--	0.002	--	--	--
Ti, Tot.	mg/L	0.0175	0.003	0.007	0.009	0.0045	0.014	0.0175	0.0035	--	--	--	--	--	0.003	--	--	--
U, Diss.	mg/L	0.0024	0.0016	0.0015	0.00215	0.0014	0.0018	0.00205	0.0021	--	--	--	--	--	0.0023	--	--	--
U, Tot.	mg/L	0.00255	0.002	0.0017	0.00225	0.00165	0.0019	0.00185	0.00195	--	--	--	--	--	0.0019	--	--	--
V, Diss.	mg/L	0.005	0.003	0.005	0.0055	0.003	0.004	0.005	0.004	--	--	--	--	--	0.002	--	--	--
V, Tot.	mg/L	0.007	0.004	0.005	0.0055	0.004	0.004	0.0055	0.004	--	--	--	--	--	0.002	--	--	--
Zn, Diss.	mg/L	0.0032	0.0016	0.0026	0.0014	0.00525	0.0079	0.0085	0.007	--	--	--	--	--	0.02	--	--	--
Zn, Tot.	mg/L	0.02345	0.0251	0.0097	0.0105	0.0109	0.0234	0.0135	0.00225	--	--	--	--	--	0.005	--	--	--
Zr, Diss.	mg/L	0.00055	0.001	0.0012	0.00055	0.0003	0.0005	--	--	--	--	--	--	--	--	--	--	--
Zr, Tot.	mg/L	0.0012	0.0037	0.0015	0.00175	0.0009	0.0016	--	--	--	--	--	--	--	--	--	--	--

Notes:
'--' = no data
All coliform data collected at 'Profile' sites and may contain extra samples
2009 sample contains only coliform data collected at the 'Profile' sites for one February date

VARIABLE	UNITS	2003	2004	2005	2006	2007	2008	*2009*	2010	2003	2004	2005	2006	2007	2008	*2009*	2010
		TWIN VALLEY RESERVOIR CENTRAL BASIN - AC2100								**TWIN VALLEY RESERVOIR WEST BASIN - AC2120**							
No. Of Samples:		**4**	**6**	**6**	**6**	**6**	**6**	**1**	**5**	**4**	**6**	**6**	**5**	**5**	**6**	**1**	**5**
TP	mg/L	0.1544	0.0785	0.108	0.184	0.149	0.0945	--	0.042	0.117	0.0785	0.2005	0.36	0.202	0.12	--	0.098
TDP	mg/L	0.1305	0.064	0.0795	0.158	0.1205	0.0655	--	0.027	0.0895	0.0565	0.136	0.306	0.175	0.115	--	0.075
PO_4, Diss. Ortho	mg/L	0.102	0.0505	0.036	0.1275	0.112	0.09	--	0.015	--	--	--	--	--	--	--	--
TKN	mg/L	1.745	0.765	0.835	1.28	0.96	0.755	--	0.76	1.37	0.77	1.33	1.76	1.03	0.775	--	0.84
NH_3, Tot.	mg/L	0.5	0.155	0.13	0.155	0.11	0.105	--	0.07	0.645	0.145	0.12	0.19	0.1	0.075	--	0.06
NO_2+NO_3-N	mg/L	0.018	0.1015	0.1905	0.153	0.1335	0.1035	--	0.054	--	--	0.203	0.158	0.124	0.073	--	0.015
NO_2	mg/L	0.006	0.011	0.0105	0.0085	0.0015	0.00225	--	0.0015	--	--	0.018	0.006	0.0015	0.0055	--	0.0015
NO_3	mg/L	0.0145	0.088	0.1815	0.1415	0.1305	0.0985	--	0.054	--	--	0.183	0.152	0.124	0.0695	--	0.015
TN, Calc.	mg/L	1.763	0.8665	1.0255	1.433	1.0935	0.8585	--	0.814			1.533	1.918	1.154	0.848	--	0.855
Silica Reactive	mg/L	6.18	3.32	7.78	8.185	6.31	5.7	--	0.45	--	--	--	--	--	--	--	--
DOC	mg/L	7.1	5.75	8.3	11.95	10.25	7.6	--	6.5	--	--	--	--	--	--	--	--
CHL-a	mg/m3	3.4	5.05	5.1	10.78	5.085	4.7	--	6.19	4.75	3.8	17.45	8.82	3.64	6.345	--	12.4
Conductance, Lab	uS/cm	433	446.5	630.5	944.5	892.5	765	--	700	--	--	--	--	--	--	--	--
TDS, Calc.	mg/L	256.5	247.5	376.5	600	596.5	485	--	440	--	--	--	--	--	--	--	--
NFR	mg/L	1.6	1.8	4.1	3.05	5.15	4.05	--	4.1	2.3	2.05	6.1	3.3	3.8	4.3	--	3.5
FR	mg/L	268	260	403.5	618	572	495	--	440	--	--	--	--	--	--	--	--
Turbidity	NTU	1.2	3	4.55	4.75	3.8	4.4	--	2.8	--	--	--	--	--	--	--	--
Total Alkalinity	mg/L	179	175	244	285	258.5	230	--	210	--	--	--	--	--	--	--	--
PP Alkalinity	mg/L	0.25	0.25	2.05	7.6	3.15	2.075	--	2.1	--	--	--	--	--	--	--	--
pH, Lab	units	8.15	8.18	8.335	8.45	8.355	8.35	--	8.35	--	--	--	--	--	--	--	--
Hardness	mg/L	185	195	235	290	300	260	--	240	--	--	--	--	--	--	--	--
Sodium, Diss. Filt.	mg/L	18.35	15.5	39.1	94.6	97.6	69.5	--	60	--	--	--	--	--	--	--	--
Sodium, Tot.	mg/L	19.3	15.55	38.95	96.9	97.05	70.5	--	60	--	--	--	--	--	--	--	--
Calcium, Diss. Filt.	mg/L	48.55	51.2	54.6	60.4	60.55	55	--	54	--	--	--	--	--	--	--	--
Calcium, Tot.	mg/L	49.8	51	55.5	61.35	54.4	53	--	53	--	--	--	--	--	--	--	--
Magnesium, Diss.	mg/L	15.85	15.95	25.3	33.9	35.25	29.5	--	27	--	--	--	--	--	--	--	--
Magnesium, Tot.	mg/L	16.3	15.5	24.7	34.85	33.8	29.5	--	26	--	--	--	--	--	--	--	--
Potassium, Diss. Filt.	mg/L	4.1	3.35	6.4	9.8	8.45	6.2	--	6	--	--	--	--	--	--	--	--
Potassium, Tot.	mg/L	4.3	3.25	6.35	9.85	8.5	6.25	--	6	--	--	--	--	--	--	--	--
Chloride, Diss.	mg/L	6.65	3.55	10.55	29.05	27.4	16	--	21	--	--	--	--	--	--	--	--
Sulphate, Diss.	mg/L	45	51.2	84.25	193.5	210	155	--	140	--	--	--	--	--	--	--	--
Sulphur, Diss.	mg/L	14.55	16.2	26.25	58.6	61.1	51.5	--	44	--	--	--	--	--	--	--	--
Sulphur, Tot.	mg/L	15.1	16.05	25.55	58.6	61.35	50.5	--	44	--	--	--	--	--	--	--	--
Fluoride, Diss.	mg/L	0.18	0.21	0.19	0.21	0.23	0.23	--	0.2	--	--	--	--	--	--	--	--
Bicarbonate	mg/L	218	213.5	275.5	328.5	308.5	280	--	240	--	--	--	--	--	--	--	--
Carbonate	mg/L	0.25	0.25	2.5	9.1	3.8	2.475	--	2.5	--	--	--	--	--	--	--	--
Secchi Depth	m	2.7	2.65	1.6	1.6	1.65	2	--	3.5	2.15	3	1.1	1.4	2	1.4	--	2.5
True Colour	rel. units	25	20	19.3	22.5	15	11	--	10	--	--	--	--	--	--	--	--
Cyanide, Tot.	mg/L	0.001	0.001	0.001	0.002	0.001	0.001	--	0.001	--	--	--	--	--	--	--	--
Fecal Coliforms	no./100 mL	2	2	1	1	1	1	1	1	7	7	1	1	2	1	1	2
Escherichia Coliforms	no./100 mL	0.75	1	1	0.5	0.5	0.5	0.5	1	2.5	2	1	1	1	0.5	1	1
Microcystin, Tot.	ug/L	--	--	--	--	0.035	0.66		--	--	--	--	--	--	--	--	--
Diss. Oxygen,	mg/L	0.99	--	--	--	--	--		--	--	--	--	--	--	--	--	--
Air Temperature	deg C	12	21.5	--	19.5	--	--		--	19	21.5	--	22.5	--	--	--	--
Euphotic Depth	m	--	--	--	--	--	4.4		4.6	--	--	--	--	--	3.75	--	5.1
Total Water Depth	m	--	--	--	--	--	16.85		14.8	--	--	--	--	--	10.2	--	8.1
Al, Diss.	mg/L	0.007	0.0025	0.008	0.01	0.02	0.015		0.011	--	--	--	--	--	--	--	--
Al, Tot.	mg/L	0.047	0.0495	0.087	0.125	0.115	0.0505		0.054	--	--	--	--	--	--	--	--
Sb, Diss.	mg/L	0.0002	0.0002	0.00015	0.0001	0.00015	0.0003		0.0001	--	--	--	--	--	--	--	--
Sb, Tot.	mg/L	0.00015	0.00035	0.0001	0.0001	0.00015	0.00055		0.0003	--	--	--	--	--	--	--	--
As, Diss.	mg/L	0.0011	0.0011	0.00125	0.00145	0.0039	0.00245		0.0025	--	--	--	--	--	--	--	--
As, Tot.	mg/L	0.00135	0.00145	0.00185	0.00295	0.0035	0.0021		0.0021	--	--	--	--	--	--	--	--
Ba, Diss.	mg/L	0.0921	0.1009	0.11	0.118	0.11	0.11		0.09	--	--	--	--	--	--	--	--
Ba, Tot.	mg/L	0.0946	0.1075	0.116	0.124	0.12	0.105		0.09	--	--	--	--	--	--	--	--
Be, Diss.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005		0.0005	--	--	--	--	--	--	--	--
Be, Tot.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005		0.0005	--	--	--	--	--	--	--	--
B, Diss.	mg/L	0.015	0.02	0.035	0.04	0.035	0.025		0.03	--	--	--	--	--	--	--	--
B, Tot.	mg/L	0.025	0.03	0.03	0.04	0.04	0.035		0.03	--	--	--	--	--	--	--	--
Cd, Diss.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001		0	--	--	--	--	--	--	--	--
Cd, Tot.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001		0	--	--	--	--	--	--	--	--
Cr, Diss.	mg/L	0.0005	0.0005	0.0005	0.0005	0.005	0.0005		0.0005	--	--	--	--	--	--	--	--
Cr, Tot.	mg/L	0.0025	0.001	0.00075	0.001	0.005	0.0005		0.0005	--	--	--	--	--	--	--	--
Co, Diss.	mg/L	0.00015	0.00015	0.00023	0.00035	0.00095	0.00015		0.00015	--	--	--	--	--	--	--	--
Co, Tot.	mg/L	0.00028	0.00023	0.0004	0.0005	0.00115	0.00015		0.00015	--	--	--	--	--	--	--	--
Cu, Diss.	mg/L	0.00075	0.00055	0.00135	0.00175	0.00335	0.00095		0.0007	--	--	--	--	--	--	--	--
Cu, Tot.	mg/L	0.0014	0.001	0.00155	0.00205	0.00475	0.00095		0.0011	--	--	--	--	--	--	--	--
Fe, Diss.	mg/L	0.06	0.02	0.03	0.0075	0.03	0.03		0.03	--	--	--	--	--	--	--	--
Fe, Tot.	mg/L	0.11	0.065	0.16	0.135	0.125	0.095		0.09	--	--	--	--	--	--	--	--
Pb, Diss.	mg/L	0.00015	0.00015	0.00015	0.00015	0.0001	0.0001		0.0001	--	--	--	--	--	--	--	--
Pb, Tot.	mg/L	0.00015	0.00015	0.00015	0.00023	0.0001	0.0001		0.0001	--	--	--	--	--	--	--	--
Li, Diss.	mg/L	0.002	0.002	0.0105	0.0125	0.01	0.01		0.01	--	--	--	--	--	--	--	--
Li, Tot.	mg/L	0.002	0.002	0.0095	0.016	0.01	0.01		0.01	--	--	--	--	--	--	--	--
Mn, Diss.	mg/L	0.089	0.002	0.0055	0.002	0.0045	0.003		0.002	--	--	--	--	--	--	--	--
Mn, Tot.	mg/L	0.108	0.0525	0.0335	0.0265	0.023	0.01		0.014	--	--	--	--	--	--	--	--
Hg, Diss.	ug/L	0.025	--	--	0.025	0.025	0.025		0.003	--	--	--	--	0.025	--	--	--
Hg, Tot.	ug/L	0.025	0.025	0.0375	0.025	0.025	0.025		0.001	--	--	--	--	0.025	--	--	--
Mo, Diss.	mg/L	0.00095	0.0012	0.0019	0.0021	0.0021	0.0023		0.0018	--	--	--	--	--	--	--	--
Mo, Tot.	mg/L	0.0011	0.00125	0.002	0.00215	0.0023	0.0024		0.002	--	--	--	--	--	--	--	--
Ni, Diss.	mg/L	0.00048	0.0013	0.0025	0.00275	0.0056	0.00115		0.0011	--	--	--	--	--	--	--	--
Ni, Tot.	mg/L	0.0017	0.0013	0.0042	0.0035	0.00735	0.00125		0.0013	--	--	--	--	--	--	--	--
Se, Diss.	mg/L	0.0002	0.0002	0.0001	0.0001	0.00035	0.0006		0.0006	--	--	--	--	--	--	--	--
Se, Tot.	mg/L	0.0004	0.00035	0.00035	0.00035	0.00055	0.0005		0.0004	--	--	--	--	--	--	--	--

VARIABLE	UNITS	2003	2004	2005	2006	2007	2008	*2009*	2010	2003	2004	2005	2006	2007	2008	*2009*	2010
		TWIN VALLEY RESERVOIR CENTRAL BASIN - AC2100								**TWIN VALLEY RESERVOIR WEST BASIN - AC2120**							
	No. Of Samples:	**4**	**6**	**6**	**6**	**6**	**6**	**1**	**5**	**4**	**6**	**6**	**5**	**5**	**6**	**1**	**5**
Ag, Diss.	mg/L	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005		0.00005	--	--	--	--	--	--	--	--
Ag, Tot.	mg/L	0.00013	0.00005	0.00005	0.00005	0.00005	0.00005		0.00005	--	--	--	--	--	--	--	--
Sr, Diss.	mg/L	0.248	0.297	0.3835	--	0.495	0.455		0.4	--	--	--	--	--	--	--	--
Sr, Tot.	mg/L	0.2785	0.298	0.3975	0.509	0.47	0.44		0.41	--	--	--	--	--	--	--	--
Tl, Diss.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001		0.0001	--	--	--	--	--	--	--	--
Tl, Tot.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001		0.0001	--	--	--	--	--	--	--	--
Sn, Diss.	mg/L	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005		0.0005	--	--	--	--	--	--	--	--
Sn, Tot.	mg/L	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005		0.0005	--	--	--	--	--	--	--	--
Ti, Diss.	mg/L	0.0005	0.003	0.002	0.002	0.0045	0.00075		0.0005	--	--	--	--	--	--	--	--
Ti, Tot.	mg/L	0.00125	0.004	0.0035	0.003	0.009	0.00075		0.002	--	--	--	--	--	--	--	--
U, Diss.	mg/L	0.00065	0.0008	0.00175	0.00255	0.0024	0.00225		0.0016	--	--	--	--	--	--	--	--
U, Tot.	mg/L	0.00065	0.0008	0.0019	0.0027	0.0022	0.00215		0.0017	--	--	--	--	--	--	--	--
V, Diss.	mg/L	0.0005	0.0005	0.001	0.002	0.002	0.001		0.0005	--	--	--	--	--	--	--	--
V, Tot.	mg/L	0.0005	0.0005	0.002	0.002	0.002	0.001		0.002	--	--	--	--	--	--	--	--
Zn, Diss.	mg/L	0.00255	0.002	0.00835	0.01195	0.01	0.0045		0.004	--	--	--	--	--	--	--	--
Zn, Tot.	mg/L	0.02375	0.0072	0.01975	0.01315	0.009	0.007		0.005	--	--	--	--	--	--	--	--
Zr, Diss.	mg/L	0.0003	0.00055	0.0003	0.00075	--	--		--	--	--	--	--	--	--	--	--
Zr, Tot.	mg/L	0.0019	0.0012	0.0006	0.001	--	--		--	--	--	--	--	--	--	--	--

Notes:

'--' = no data
All coliform data collected at 'Profile' sites and may contain extra samples
2009 sample contains only coliform data collected at the 'Profile' sites for one February date

Appendix Ib Median values for samples collected during the open-water season from sites on the Little Bow River and Mosquito Creek, 2003-2010

VARIABLE	UNITS	2003	2004	2005	2006	2007	2008	2009	2010	2003	2004	2005	2006	2007	2008	2009	2010
		LITTLE BOW RIVER AT HWY 533 EAST OF NANTON								MOSQUITO CREEK AT HWY 529 EAST OF PARKLAND							
No. Of Samples:		**12**	**13**	**13**	**13**	**13**	**13**	**2**	**8**	**10**	**11**	**11**	**13**	**18**	**17**	**2**	**8**
TP	mg/L	0.045	0.041	0.3325	0.441	0.111	0.064	0.053	0.088	0.0615	0.0605	0.0635	0.0515	0.067	0.049	0.0475	0.029
TDP	mg/L	0.013	0.011	0.1845	0.3875	0.0425	0.016	0.02	0.0385	0.0265	0.013	0.0225	0.012	0.0105	0.01	0.023	0.009
PO_4, Diss. Ortho	mg/L	0.01	0.0095	0.1685	0.3635	0.0375	0.0175	0.0205	0.035	0.018	0.0085	0.016	0.0015	0.0045	0.013	0.0195	0.005
TKN	mg/L	0.385	0.37	0.805	0.945	0.525	0.35	0.46	0.46	0.62	0.54	0.84	0.82	1.08	0.91	0.83	0.57
NH_3, Tot.	mg/L	0.065	0.05	0.095	0.135	0.075	0.14	0.105	0.025	0.025	0.055	0.045	0.095	0.1	0.05	0.1425	0.0375
NO_2+NO_3-N	mg/L	0.0465	0.0895	0.1935	0.317	0.1045	0.16	0.27	0.0015	0.006	0.083	0.651	0.846	0.7005	0.419	1.52	0.0265
NO_2	mg/L	0.0015	0.0015	0.003	0.0075	0.0015	0.00225	0.00225	0.0015	0.00325	0.00325	0.0055	0.015	0.013	0.01	0.0015	0.0015
NO_3	mg/L	0.031	0.07	0.192	0.309	0.1045	0.16	0.27	0.0015	0.00375	0.083	0.6415	0.8295	0.6805	0.411	1.52	0.0265
TN, Calc.	mg/L	0.4315	0.4595	0.9985	1.262	0.6295	0.51	0.73	0.4615	0.626	0.623	1.491	1.666	1.7805	1.329	2.35	0.5965
Silica Reactive	mg/L	3.29	2.76	2.54	2.73	2.95	3	--	1.63	0.36	0.18	3.43	0.235	1.43	0.0925	--	0.245
DOC	mg/L	1.85	2.35	8.35	7.55	3.35	2.45	2.7	5.65	5	6.2	8	7.2	7.8	7	6.55	6.05
TOC	mg/L	3.65	2.35	7.25	8.9	2.8	3.45	--	7.1	6	7.2	8.8	7.4	7.3	7.8	--	6.35
CHL-a	mg/m3	3.2	2	3.35	4.015	2.925	2.995	1.53	3.105	13.65	4.1	6.2	8.305	6.97	3.72	3.925	3.94
Conductance, Field	uS/cm	456.5	419	909	899.5	574	507.5	580.5	635	445.5	497.5	727	1014.5	1043	892	1030.5	553
Conductance, Lab	uS/cm	434	441.5	863.5	985.5	574	511.5	565	645	509.5	521.5	734	1050	1120	894	985	715
TDS, Calc.	mg/L	271	262.5	522.5	626.5	347	317.5	350	391.5	312	306	462.5	690.5	711	578	610	428
NFR	mg/L	21.5	19.2	21.9	23.75	25.1	27.25	24.45	22.3	27.3	20.7	18.4	14.45	43.2	17.75	7.75	20.75
FR	mg/L	262	267	567.5	623.5	354	306	360	400	303	302	459	714.5	719	532	655	445
Turbidity	NTU	19.45	15.75	28.35	18.5	21.5	21	19.5	17.5	33.2	21.25	28	14	31.75	12	8.65	17.5
Total Alkalinity	mg/L	167	178	246.5	243.5	204.5	182	180	205	198	201.5	334	384	356.5	320	340	290
PP Alkalinity	mg/L	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	3.4	2.65	10.2	8.7	0.525	5.3	3.625	5.2
pH, Field	units	7.755	7.865	8.19	8.12	8.08	8.105	7.87	8.41	8.27	8.275	8.34	8.395	8.28	8.48	7.995	8.325
pH, Lab	units	8.095	8.1	8.26	8.29	8.205	8.2	8.03	8.29	8.405	8.37	8.5	8.435	8.305	8.4	8.235	8.43
Hardness	mg/L	205	215	265	280	245	240	250	241	200	205	310	355	340	310	315	279.5
Sodium, Diss. Filt.	mg/L	12.05	11.55	79.3	103	25.65	18.5	23.5	51.5	36.85	35.45	60.05	101.4	111	92	92	50
Sodium, Tot.	mg/L	18.75	12.8	55.9	113.5	20	19.5	--	64	48.7	88.9	56.7	104.5	130	123.5	--	45
Calcium, Diss. Filt.	mg/L	55	58.4	65.65	68.5	64.55	63.1	66	62.5	47.05	42.15	65.9	61.95	62.5	58	60	53
Calcium, Tot.	mg/L	71.2	65.95	66.95	72.4	66	85.5	--	59.5	43.3	40.4	66.3	57.55	59	74	--	49
Magnesium, Diss. Filt.	mg/L	17.95	16.05	24.25	27.85	20.15	19.05	20.5	22.5	21.45	22.05	37.95	48.75	47.3	36.3	40	35.5
Magnesium, Tot.	mg/L	20.95	18.15	23.5	29.8	19.2	21.5	--	24	22.5	43.1	38.5	52.7	57	58.5	--	34.5
Potassium, Diss. Filt.	mg/L	1.4	1.2	9.65	10.9	2.7	1.95	2.1	6.5	2.55	4.45	5.75	5.6	6.1	5.4	6	4.2
Potassium, Tot.	mg/L	2.15	1.4	6.25	13.2	2	2.25	--	8.05	3.1	6.3	5.9	5.8	7.2	6.9	--	3.7
Chloride, Diss.	mg/L	3.4	2.85	53.15	61.3	7.35	4.8	6.5	31	6.9	5.75	7.9	11.1	12.65	12	13	8
Sulphate, Diss.	mg/L	69.05	62.2	132.5	172	98.2	95.65	119.5	110	79.15	72.5	111.5	216.5	225	180	190	106
Sulphur, Diss.	mg/L	27.75	22.45	33.55	54.35	26	35.5	--	43.5	39.6	49.8	30.1	66.35	74	117	--	27.5
Sulphure, Tot.	mg/L	29.2	23.45	32.9	53.8	27	31	--	40.5	40	53	30	64.45	81.9	85	--	29
Fluoride, Diss.	mg/L	0.24	0.205	0.19	0.215	0.235	0.22	0.195	0.21	0.24	0.195	0.22	0.23	0.255	0.23	0.19	0.225
Bicarbonate	mg/L	202	217	279	295.5	237.5	227	220	250	231.5	245.5	391	436.5	420	370	400	335
Carbonate	mg/L	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	4.1	3.15	12.25	10.45	0.625	6.4	4.375	6.2
True Colour	rel. units	5	10	12	11	4.25	3	5.5	8	10	20	15.35	11.5	10.5	11	14.5	10
Cyanide, Tot.	mg/L	0.001	0.001	0.001	0.001	0.001	0.001	--	0.001	0.001	0.001	0.001	0.001	0.001	0.001	--	0.001
Fecal Coliforms	no./100 mL	52	54.5	54.5	85	51	48.5	17.5	39.5	16	25.5	57	97	69	92	59.5	176
Escherichia Coliforms	no./100 mL	52	38	37.5	66	47	45	16.5	35.5	8	25.5	41.5	86	63.5	73	55.25	123
Macrophyte Biomass	g/m2	--	39.71	215.09	222.2	123.63	117.61	--	--	--	40.03	0	43.04	0	0	--	--
Epilithon CHL-a	mg/m2	61.416	107.8202	165.1592	80.56667	49.66667	48.7	--	44.76667	88.38783	60.04467	223.422	84.63333	115.3667	103.6668	--	45.93333
Phaeophytin	mg/m2	--	--	18.53333	10.18	9.066667	6.376667	--	8.283333	--	--	16.03017	13	17.86667	17.36667	--	10.21
Algae Cover	%	--	--	--	--	70	0	0	40	--	--	--	--	0	0	0	40
Macrophyte Cover	%	--	--	--	--	5	0	0	80	--	--	--	--	0	0	0	0
Diss. Oxygen, Field	mg/L	9.46	10.21	9.89	9.825	10.615	8.88	9.625	9.91	9.93	10.645	9.81	10.41	10.49	8.1	11.61	9.17
Diss. Oxygen, Winkler	mg/L	10.32	9.52	10.19	7.42	12.22	10.93	--	9.93	9.675	9.36	--	9.16	10.85	8.31	--	8.925
Air Temperature	deg C	14	10.5	13.5	12	12.5	5	0	9	18.5	11	15	12.5	14	9.5	0	8
Water Temperature	deg C	8.59	5.19	11.72	6.2	5.27	3.515	0.01	12.32	14.31	12.46	12.71	7.165	8.55	4.34	-0.025	11.89
Al, Diss.	mg/L	0.0065	0.0235	0.0175	0.0065	0.2	0.245	--	0.276	0.01	0.054	0.006	0.0065	0.07	0.115	--	0.115
Al, Tot.	mg/L	0.3825	0.337	0.3855	1.102	1.2	1.39	--	0.855	0.173	0.36	0.303	0.428	0.86	0.775	--	0.54
Sb, Diss.	mg/L	0.0001	0.0003	0.00015	0.0001	0.0001	0.0001	--	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	--	0.0001
Sb, Tot.	mg/L	0.0001	0.0003	0.0002	0.0001	0.0002	0.0001	--	0.0002	0.0003	0.0004	0.0002	0.00015	0.0001	0.0001	--	0.00015
As, Diss.	mg/L	0.00055	0.00045	0.00095	0.001	0.0005	0.0007	--	0.00155	0.0011	0.0009	0.0012	0.0003	0.0011	0.0014	--	0.00125
As, Tot.	mg/L	0.0012	0.0008	0.0015	0.00215	0.0005	0.00105	--	0.00185	0.0015	0.0012	0.0022	0.0009	0.0012	0.0012	--	0.0015
Ba, Diss.	mg/L	0.1054	0.10595	0.112	0.09345	0.1	0.125	--	0.095	0.0997	0.103	0.109	0.0943	0.11	0.135	--	0.09
Ba, Tot.	mg/L	0.123	0.117	0.125	0.112	0.12	0.145	--	0.095	0.107	0.117	0.119	0.109	0.12	0.125	--	0.11
Be, Diss.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005	--	0.0005	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005	--	0.0005
Be, Tot.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005	--	0.0005	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005	--	0.0005
B, Diss.	mg/L	0.01	0.015	0.025	0.03	0.01	0.02	--	0.015	0.02	0.06	0.05	0.05	0.06	0.095	--	0.03
B, Tot.	mg/L	0.02	0.02	0.025	0.035	0.02	0.015	--	0.015	0.03	0.07	0.05	0.05	0.06	0.07	--	0.03
Cd, Diss.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	0
Cd, Tot.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	0
Cr, Diss.	mg/L	0.00175	0.00075	0.0005	0.0005	0.005	0.005	--	0.00275	0.0005	0.001	0.0005	0.0005	0.005	0.005	--	0.00275
Cr, Tot.	mg/L	0.004	0.002	0.0015	0.0025	0.005	0.005	--	0.00275	0.002	0.001	0.001	0.002	0.005	0.005	--	0.003
Co, Diss.	mg/L	0.00015	0.00015	0.00035	0.00015	0.0009	0.00015	--	0.00015	0.00015	0.00015	0.0003	0.00015	0.0011	0.00015	--	0.00015
Co, Tot.	mg/L	0.00015	0.0004	0.00055	0.00065	0.0012	0.00015	--	0.000275	0.0004	0.0004	0.0005	0.0004	0.0012	0.0003	--	0.000275
Cu, Diss.	mg/L	0.00075	0.00065	0.00095	0.0014	0.0027	0.0005	--	0.0004	0.0014	0.0013	0.0013	0.002	0.0036	0.0017	--	0.00065
Cu, Tot.	mg/L	0.00145	0.00095	0.0032	0.00295	0.0037	0.0013	--	0.0012	0.0026	0.002	0.0018	0.0034	0.004	0.0017	--	0.00165
Fe, Diss.	mg/L	0.03	0.04	0.025	0.03	0.03	0.16	0.17	0.09	0.025	0.045	0.02	0.04	0.055	0.11	0.2	0.14
Fe, Tot.	mg/L	0.47	0.37	0.575	1.1	0.94	1.205	--	0.75	0.29	0.47	0.33	0.385	0.66	0.29	--	0.55
Pb, Diss.	mg/L	0.00015	0.00015	0.00015	0.00015	0.0001	0.0001	--	0.0001	0.00015	0.00015	0.00015	0.00015	0.0001	0.0001	--	0.0001
Pb, Tot.	mg/L	0.00045	0.0008	0.001	0.0009	0.0007	0.001	--	0.0005	0.00015	0.0006	0.0003	0.00045	0.0004	0.0002	--	0.00045
Li, Diss.	mg/L	0.002	0.002	0.009	0.015	0.01	0.01	--	0.01	0.002	0.012	0.006	0.021	0.02	0.025	--	0.01
Li, Tot.	mg/L	0.002	0.002	0.0125	0.015	0.01	0.01	--	0.01	0.002	0.014	0.006	0.022	0.02	0.025	--	0.01
Mn, Diss.	mg/L	0.007	0.004	0.009	0.013	0.024	0.0175	0.0345	0.0185	0.002	0.002	0.002	0.007	0.0105	0.005	0.0105	0.0085
Mn, Tot.	mg/L	0.0285	0.026	0.0425	0.066	0.07	0.1015	--	0.029	0.048	0.024	0.055	0.0205	0.037	0.063	--	0.0225
Hg, Diss.	ug/L	0.025	0.025	--	0.025	0.025	0.025	--	0.0015	0.025	--	--	0.025	0.025	0.025	--	0.002
Hg, Tot.	ug/L	0.025	0.025	0.025	0.0525	0.025	0.025	--	0.001	0.025	0.025	0.025	0.025	0.025	0.025	--	0.001

VARIABLE	UNITS	2003	2004	2005	2006	2007	2008	2009	2010	2003	2004	2005	2006	2007	2008	2009	2010
		LITTLE BOW RIVER AT HWY 533 EAST OF NANTON								MOSQUITO CREEK AT HWY 529 EAST OF PARKLAND							
No. Of Samples:		**12**	**13**	**13**	**13**	**13**	**13**	**2**	**8**	**10**	**11**	**11**	**13**	**18**	**17**	**2**	**8**
Mo, Diss.	mg/L	0.00125	0.00105	0.001	0.00105	0.0011	0.0009	--	0.001	0.0026	0.0027	0.0021	0.00255	0.0029	0.0022	--	0.00205
Mo, Tot.	mg/L	0.00125	0.00115	0.00115	0.0012	0.0013	0.0011	--	0.0011	0.0028	0.0027	0.0022	0.00265	0.0029	0.0033	--	0.0021
Ni, Diss.	mg/L	0.00115	0.00345	0.0024	0.0028	0.0064	0.0007	--	0.00095	0.001	0.0017	0.0032	0.00305	0.0063	0.0011	--	0.00095
Ni, Tot.	mg/L	0.0026	0.005	0.0038	0.00395	0.011	0.0014	--	0.00155	0.0021	0.0022	0.0056	0.00345	0.011	0.0013	--	0.0015
Se, Diss.	mg/L	0.0002	0.00025	0.00055	0.00015	0.0005	0.0011	--	0.00085	0.0002	0.0001	0.0001	0.00055	0.0004	0.00145	--	0.001
Se, Tot.	mg/L	0.0004	0.0005	0.00085	0.00045	0.0004	0.0008	--	0.00065	0.0004	0.0002	0.0006	0.00075	0.0005	0.00125	--	0.00065
Ag, Diss.	mg/L	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	--	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	--	0.00005
Ag, Tot.	mg/L	0.00005	0.000225	0.00005	0.00005	0.00005	0.00005	--	0.00005	0.00005	0.0001	0.00005	0.00005	0.00005	0.00005	--	0.00005
Sr, Diss.	mg/L	0.3745	0.341	0.363	0.443	0.38	0.48	--	0.375	0.379	0.548	0.621	0.892	0.76	1.045	--	0.535
Sr, Tot.	mg/L	0.38	0.35	0.384	0.44	0.4	0.48	--	0.35	0.399	0.55	0.641	0.7555	0.85	0.885	--	0.535
Tl, Diss.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	0.0001
Tl, Tot.	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	--	0.0001
Sn, Diss.	mg/L	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	--	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	--	0.0005
Sn, Tot.	mg/L	0.001	0.00075	0.0005	0.0005	0.0005	0.0005	--	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	--	0.0005
Ti, Diss.	mg/L	0.0005	0.002	0.00175	0.002	0.004	0.001	--	0.0025	0.0005	0.004	0.001	0.0005	0.007	0.005	--	0.0055
Ti, Tot.	mg/L	0.006	0.004	0.0065	0.0175	0.019	0.008	--	0.011	0.002	0.006	0.003	0.005	0.011	0.004	--	0.0095
U, Diss.	mg/L	0.001	0.001	0.00095	0.0013	0.001	0.0008	--	0.00095	0.0017	0.0033	0.003	0.004	0.0053	0.0022	--	0.0019
U, Tot.	mg/L	0.0011	0.00105	0.00105	0.00145	0.0012	0.001	--	0.00105	0.0018	0.0033	0.0033	0.00435	0.0049	0.0035	--	0.00245
V, Diss.	mg/L	0.00075	0.0015	0.00075	0.00075	0.001	0.0005	--	0.0005	0.0005	0.002	0.001	0.001	0.002	0.0005	--	0.0005
V, Tot.	mg/L	0.002	0.0015	0.002	0.003	0.002	0.001	--	0.0035	0.002	0.002	0.002	0.002	0.003	0.002	--	0.004
Zn, Diss.	mg/L	0.00285	0.0007	0.0119	0.0034	0.008	0.006	--	0.00375	0.0027	0.0013	0.0011	0.00645	0.005	0.004	--	0.0015
Zn, Tot.	mg/L	0.0138	0.01015	0.0267	0.0177	0.011	0.005	--	0.017	0.0089	0.0088	0.012	0.0144	0.006	0.006	--	0.00825
Zr, Diss.	mg/L	0.00175	0.00035	0.0003	0.00055	--	--	--	--	0.0011	0.0007	0.0003	0.0004	--	--	--	--
Zr, Tot.	mg/L	0.00405	0.00145	0.0007	0.00185	--	--	--	--	0.0021	0.0011	0.0007	0.0011	--	--	--	--

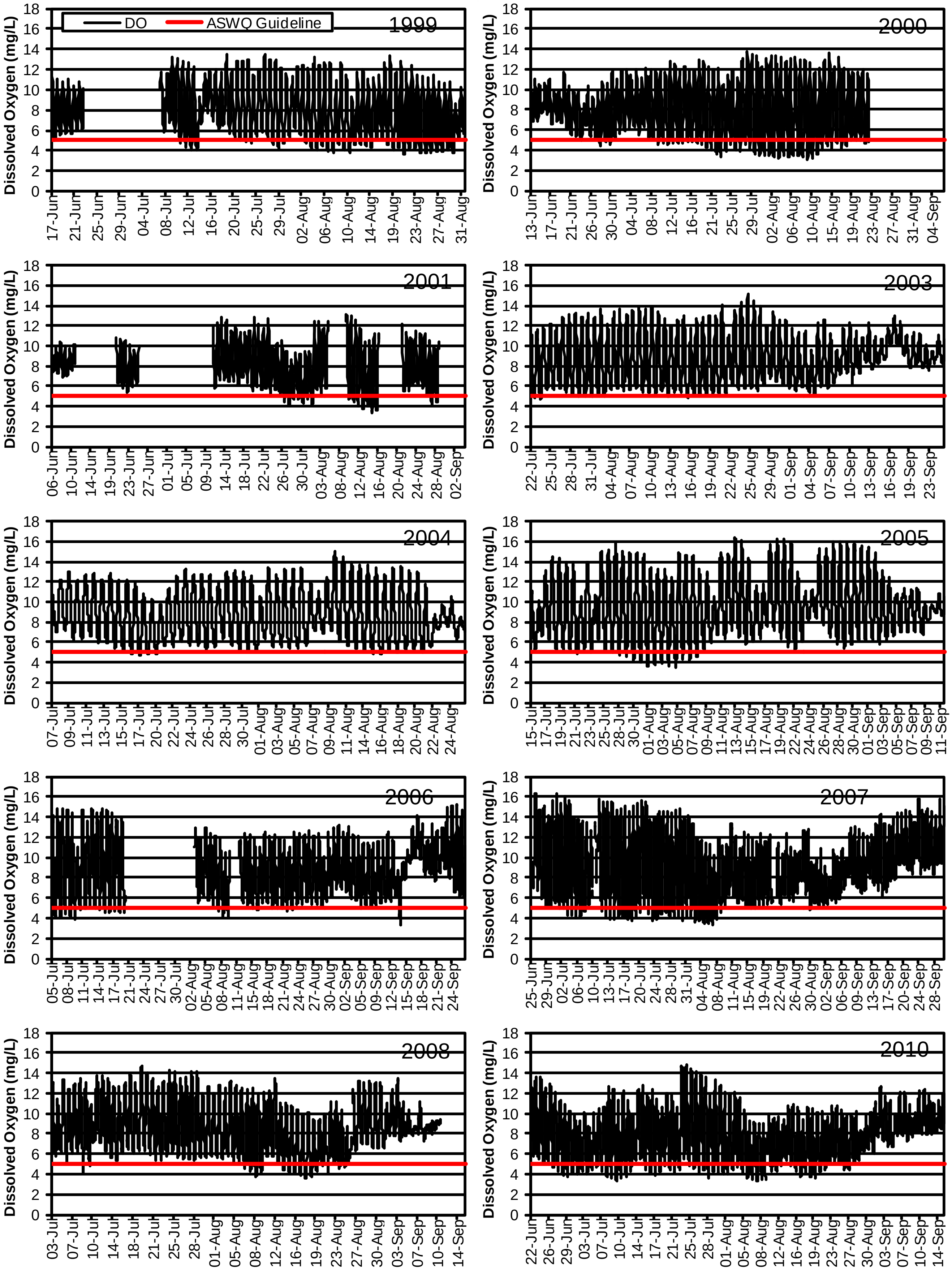
Note: '--' = no data

VARIABLE	UNITS	2003	2004	2005	2006	2007	2008	2009	2010	2003	2004	2005	2006	2007	2008	2009	2010
		LITTLE BOW RIVER D/S OF NEW RESERVOIR								**LITTLE BOW RIVER AT CARMANGAY**							
No. Of Samples:		**9**	**12**	**11**	**12**	**12**	**12**	**3**	**8**	**12**	**13**	**13**	**13**	**13**	**13**	**3**	**8**
TP	mg/L	0.158	0.133	0.098	0.149	0.1775	0.12	0.074	0.0845	0.077	0.1135	0.093	0.1285	0.1275	0.1	0.095	0.062
TDP	mg/L	0.139	0.076	0.07	0.123	0.121	0.0935	0.056	0.0645	0.0545	0.0765	0.0645	0.0955	0.109	0.067	0.068	0.044
PO_4, Diss. Ortho	mg/L	--	0.033	0.077	--	0.235	--	--	--	0.031	0.067	0.0325	0.078	0.0805	0.065	0.063	0.033
TKN	mg/L	1	0.81	0.88	1.07	0.965	0.86	0.69	0.695	0.8	0.665	0.885	0.985	0.885	0.81	0.94	0.705
NH_3, Tot.	mg/L	0.45	0.205	0.24	0.155	0.13	0.1	0.07	0.065	0.08	0.055	0.095	0.07	0.085	0.08	0.17	0.0475
NO_2+NO_3-N	mg/L	0.527	0.287	0.285	0.2985	0.344	0.2	0.75	0.081	0.334	0.245	0.262	0.162	0.3665	0.1	0.65	0.035
NO_2	mg/L	0.023	0.0195	0.01	0.012	0.0035	0.005	0.0015	0.0015	0.01	0.0065	0.0075	0.0055	0.003	0.004	0.0015	0.0015
NO_3	mg/L	0.504	0.2735	0.261	0.2895	0.3405	0.195	0.75	0.081	0.2835	0.225	0.2415	0.156	0.3645	0.096	0.64	0.035
TN, Calc.	mg/L	1.527	1.097	1.165	1.3685	1.309	1.06	1.44	0.776	1.134	0.91	1.147	1.147	1.2515	0.91	1.59	0.74
Silica Reactive	mg/L	--	--	--	--	--	--	--	--	1	1.81	6.06	2.11	1.98	1.2	7.7	0.61
DOC	mg/L	--	5.9	8.1	--	10	--	--	--	6.8	6.35	7.8	10.6	9.9	7.7	6.6	6.75
TOC	mg/L	--	--	--	--	--	--	--	--	8.3	6.5	8.15	10.5	10.8	9.2	7.2	7.25
CHL-a	mg/m3	--	--	--	--	--	--	--	--	1.95	3.5	4.55	4.415	4.38	3.17	2.74	2.62
Conductance, Field	uS/cm	471	450.5	596.5	918.5	923	770	878	700	529.5	521	600	956.5	966	801	990	764
Conductance, Lab	uS/cm	--	467	627	--	969	--	--	--	559	544.5	624.5	1020.5	968	810	980	775
TDS, Calc.	mg/L	--	268	397	--	641	--	--	--	342	334.5	380.5	659.5	629.5	530	620	490
NFR	mg/L	4.2	7.2	4.6	4.55	6.2	7.9	3.4	7.1	4.1	5.5	16.65	5.85	8.35	7.7	9.2	7
FR	mg/L	--	282	405	--	620	--	--	--	362	343	392.5	669	633	540	650	485
Turbidity	NTU	--	2.8	18.5	--	1.9	--	--	--	4.8	6.6	20.95	6.35	7.35	11	10	6.4
Total Alkalinity	mg/L	--	181	262	--	284	--	--	--	183	192.5	230	294.5	273	250	310	210
PP Alkalinity	mg/L	--	2.8	8.7	--	0.25	--	--	--	4.1	2.475	4.3	11	8.05	4.1	0.25	3.425
pH, Field	units	7.86	7.89	8.145	8.23	8.265	8.325	7.89	8.29	8.405	8.425	8.16	8.58	8.55	8.37	7.68	8.36
pH, Lab	units	--	8.38	8.54	--	8.24	--	--	--	8.44	8.375	8.38	8.525	8.475	8.4	8.05	8.37
Hardness	mg/L	--	200	260	--	310	--	--	--	210	230	255	330	295	270	330	265
Sodium, Diss. Filt.	mg/L	--	18.2	42.6	--	108	66	--	--	30.8	29.65	36	103.5	105	73	86	65
Sodium, Tot.	mg/L	--	--	--	--	--	--	--	--	37.75	30.4	28.7	100.95	108	72	93	63.5
Calcium, Diss. Filt.	mg/L	--	53.2	59.1	--	66.8	55	--	--	51.1	57.6	57.6	65.7	60.15	58	70	58
Calcium, Tot.	mg/L	--	--	--	--	--	--	--	--	51.3	57.35	55.95	64.85	63.6	53	75	56
Magnesium, Diss. Filt.	mg/L	--	16.3	27.7	--	35.8	31	--	--	20.2	21.2	25.15	38.15	36.05	31	39	29.5
Magnesium, Tot.	mg/L	--	--	--	--	--	--	--	--	20.15	21.55	21.55	37.3	38.4	32	45	29
Potassium, Diss. Filt.	mg/L	--	3.9	6	--	8.9	5	--	--	4.5	3.9	5.65	9.1	8.75	6	6.2	5.9
Potassium, Tot.	mg/L	--	--	--	--	--	--	--	--	5.2	4.4	5.45	8.35	9.5	6	6.8	5.7
Chloride, Diss.	mg/L	--	4.3	9.1	--	28.1	--	--	--	7.9	4.55	5.9	31.5	27.85	18	16	21.5
Sulphate, Diss.	mg/L	--	62.2	93.3	--	221	170	--	--	97	97.45	102	221	232	190	220	180
Sulphur, Diss.	mg/L	--	--	--	--	--	50	--	--	34.35	32.15	30	68.6	71.2	82	--	53
Sulphure, Tot.	mg/L	--	--	--	--	--	--	--	--	35.05	32.9	27.65	66.8	75	54	77	52.5
Fluoride, Diss.	mg/L	--	0.2	0.2	--	0.24	--	--	--	0.21	0.195	0.195	0.215	0.23	0.24	0.21	0.235
Bicarbonate	mg/L	--	215	298	--	347	--	--	--	205	222.5	279.5	326.5	313	280	370	245
Carbonate	mg/L	--	3.3	10.5	--	0.25	--	--	--	4.9	2.975	5.15	13.2	9.65	4.9	0.25	4.075
True Colour	rel. units	--	15	18.9	--	17	--	--	--	20	20	16	18.5	16.5	12	10	10
Cyanide, Tot.	mg/L	--	--	--	--	--	--	--	--	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Fecal Coliforms	no./100 mL	--	--	--	--	--	--	--	--	23	8.5	22	31	15	50	11	83
Escherichia Coliforms	no./100 mL	--	--	--	--	--	--	--	--	17	7.5	14	17.5	12	35	11	70
Macrophyte Biomass	g/m2	--	--	--	--	--	--	--	--	--	178.45	199.26	134.39	433.35	747.18	--	--
Epilithon CHL-a	mg/m2	--	--	--	--	--	--	--	--	283.2607	170.8152	112.1442	285.3333	336.6667	124.6333	--	166.3333
Phaeophytin	mg/m2	--	--	--	--	--	--	--	--	--	--	15.6685	69.93333	86.66667	11.28333	--	29.93333
Algae Cover	%	--	--	--	--	0	0	0	10	--	--	--	--	100	0	0	90
Macrophyte Cover	%	--	--	--	--	0	0	0	30	--	--	--	--	20	0	0	75
Diss. Oxygen, Field	mg/L	9.93	11.92	12.12	12.43	13.15	12.985	12.14	10.77	12.105	13.415	11.33	12.39	11.145	9.155	7.9	8.865
Diss. Oxygen, Winkler	mg/L	9.05	10.64	8.8	10.29	12.64	11.8	12.805	9.7	11.1	10.915	--	--	--	10.455	--	8.59
Air Temperature	deg C	23	11	13.5	13.5	12.5	2	-2	8	19.5	11.5	15.5	14	9	7.5	-4	8.5
Water Temperature	deg C	12.25	8.755	9.15	8.925	6.265	6.565	2.45	12.01	10.95	7.89	12.42	8.175	6.58	5.79	-0.02	12.34
Al, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0045	0.0195	0.013	0.005	0.02	0.02	--	0.096
Al, Tot.	mg/L	--	--	--	--	--	--	--	--	0.125	0.14	0.548	0.101	0.14	0.09	0.23	0.1265
Sb, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001
Sb, Tot.	mg/L	--	--	--	--	--	--	--	--	0.00015	0.00015	0.0002	0.0001	0.0001	0.0005	0.0003	0.0001
As, Diss.	mg/L	--	--	--	--	--	--	--	--	0.00135	0.00135	0.00135	0.0008	0.0021	0.0022	0.0016	0.00215
As, Tot.	mg/L	--	--	--	--	--	--	--	--	0.0015	0.0015	0.002	0.00195	0.0025	0.0028	0.0016	0.0024
Ba, Diss.	mg/L	--	--	--	--	--	0.1	--	--	0.0871	0.1036	0.1095	0.1125	0.11	0.13	--	0.09
Ba, Tot.	mg/L	--	--	--	--	--	--	--	--	0.09955	0.10915	0.1245	0.1255	0.12	0.09	0.14	0.095
Be, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005	0.0005	0.0005
Be, Tot.	mg/L	--	--	--	--	--	--	--	--	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005	0.0005	0.0005
B, Diss.	mg/L	--	--	--	--	--	0.1	--	--	0.025	0.025	0.025	0.04	0.04	0.05	--	0.03
B, Tot.	mg/L	--	--	--	--	--	--	--	--	0.035	0.025	0.025	0.04	0.04	0.04	0.05	0.03
Cd, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0
Cd, Tot.	mg/L	--	--	--	--	--	--	--	--	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0
Cr, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0005	0.0005	0.0005	0.0005	0.005	0.005	--	0.00275
Cr, Tot.	mg/L	--	--	--	--	--	--	--	--	0.002	0.0015	0.0015	0.00125	0.005	0.005	0.005	0.00275
Co, Diss.	mg/L	--	--	--	--	--	--	--	--	0.00015	0.00035	0.0003	0.00035	0.0011	0.0003	0.00015	0.00015
Co, Tot.	mg/L	--	--	--	--	--	--	--	--	0.000225	0.00045	0.0006	0.00045	0.0013	0.00015	0.00015	0.00015
Cu, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0007	0.00065	0.001	0.0025	0.002	0.0009	0.0006	0.00045
Cu, Tot.	mg/L	--	--	--	--	--	--	--	--	0.00125	0.00115	0.0018	0.00305	0.0028	0.0009	0.0012	0.0011
Fe, Diss.	mg/L	--	0.02	0.01	--	0.02	0.3	--	--	0.05	0.035	0.025	0.025	0.03	0.04	0.18	0.07
Fe, Tot.	mg/L	--	--	--	--	--	--	--	--	0.255	0.275	0.585	0.265	0.21	0.11	0.37	0.18
Pb, Diss.	mg/L	--	--	--	--	--	--	--	--	0.00015	0.00015	0.00015	0.00015	0.0001	0.0001	0.0001	0.0001
Pb, Tot.	mg/L	--	--	--	--	--	--	--	--	0.00015	0.000275	0.00045	0.00015	0.0001	0.0003	0.0003	0.0001
Li, Diss.	mg/L	--	--	--	--	--	0.1	--	--	0.004	0.002	0.0075	0.0185	0.01	0.01	--	0.01
Li, Tot.	mg/L	--	--	--	--	--	--	--	--	0.004	0.002	0.0075	0.0185	0.01	0.01	0.01	0.01
Mn, Diss.	mg/L	--	0.009	0.006	--	0.008	0.07	--	--	0.004	0.008	0.0045	0.007	0.0145	0.014	0.057	0.01
Mn, Tot.	mg/L	--	--	--	--	--	--	--	--	0.0375	0.108	0.085	0.037	0.043	0.015	0.096	0.02
Hg, Diss.	ug/L	--	--	--	--	--	--	--	--	0.025	0.025	--	0.025	0.025	0.025	0.0005	0.0015
Hg, Tot.	ug/L	--	--	--	--	--	--	--	--	0.025	0.025	0.025	0.025	0.025	0.025	0.001	0.001

VARIABLE	UNITS	2003	2004	2005	2006	2007	2008	2009	2010	2003	2004	2005	2006	2007	2008	2009	2010
		LITTLE BOW RIVER D/S OF NEW RESERVOIR								LITTLE BOW RIVER AT CARMANGAY							
	No. Of Samples:	**9**	**12**	**11**	**12**	**12**	**12**	**3**	**8**	**12**	**13**	**13**	**13**	**13**	**13**	**3**	**8**
Mo, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0015	0.00145	0.00155	0.00205	0.0021	0.0023	0.0027	0.00185
Mo, Tot.	mg/L	--	--	--	--	--	--	--	--	0.00155	0.00155	0.0016	0.00235	0.0025	0.0023	0.0028	0.00215
Ni, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0019	0.00305	0.0026	0.0036	0.0068	0.0015	0.0014	0.0012
Ni, Tot.	mg/L	--	--	--	--	--	--	--	--	0.0023	0.00345	0.0046	0.00345	0.01	0.0013	0.0018	0.00145
Se, Diss.	mg/L	--	--	--	--	--	--	--	--	0.00015	0.00015	0.0003	0.0003	0.0002	0.0008	0.001	0.00065
Se, Tot.	mg/L	--	--	--	--	--	--	--	--	0.00025	0.0001	0.00055	0.0005	0.0005	0.0006	0.0008	0.00045
Ag, Diss.	mg/L	--	--	--	--	--	--	--	--	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005
Ag, Tot.	mg/L	--	--	--	--	--	--	--	--	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005
Sr, Diss.	mg/L	--	--	--	--	--	0.5	--	--	0.308	0.3585	0.339	0.648	0.52	0.59	--	0.445
Sr, Tot.	mg/L	--	--	--	--	--	--	--	--	0.315	0.353	0.3515	0.6025	0.55	0.46	0.67	0.425
Tl, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Tl, Tot.	mg/L	--	--	--	--	--	--	--	--	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Sn, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Sn, Tot.	mg/L	--	--	--	--	--	--	--	--	0.0005	0.0005	0.0005	0.00075	0.0005	0.0005	0.0005	0.0005
Ti, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0005	0.001	0.0005	0.001	0.004	0.001	0.0005	0.00125
Ti, Tot.	mg/L	--	--	--	--	--	--	--	--	0.002	0.0025	0.0095	0.0025	0.005	0.005	0.003	0.002
U, Diss.	mg/L	--	--	--	--	--	--	--	--	0.0013	0.0014	0.0014	0.0026	0.0028	0.0021	0.0029	0.00175
U, Tot.	mg/L	--	--	--	--	--	--	--	--	0.0014	0.0014	0.0015	0.00285	0.0025	0.0021	0.003	0.00215
V, Diss.	mg/L	--	--	--	--	--	--	--	--	0.00075	0.00075	0.0005	0.0015	0.002	0.0005	0.0005	0.0005
V, Tot.	mg/L	--	--	--	--	--	--	--	--	0.00075	0.0015	0.002	0.002	0.002	0.0005	0.001	0.0035
Zn, Diss.	mg/L	--	--	--	--	--	--	--	--	0.00235	0.0019	0.00375	0.00375	0.004	0.004	0.007	0.00275
Zn, Tot.	mg/L	--	--	--	--	--	--	--	--	0.00865	0.0079	0.01445	0.0187	0.006	0.005	0.005	0.00475
Zr, Diss.	mg/L	--	--	--	--	--	--	--	--	0.00075	0.0006	0.00025	0.00035	--	--	--	--
Zr, Tot.	mg/L	--	--	--	--	--	--	--	--	0.00215	0.00145	0.00075	0.0028	--	--	--	--

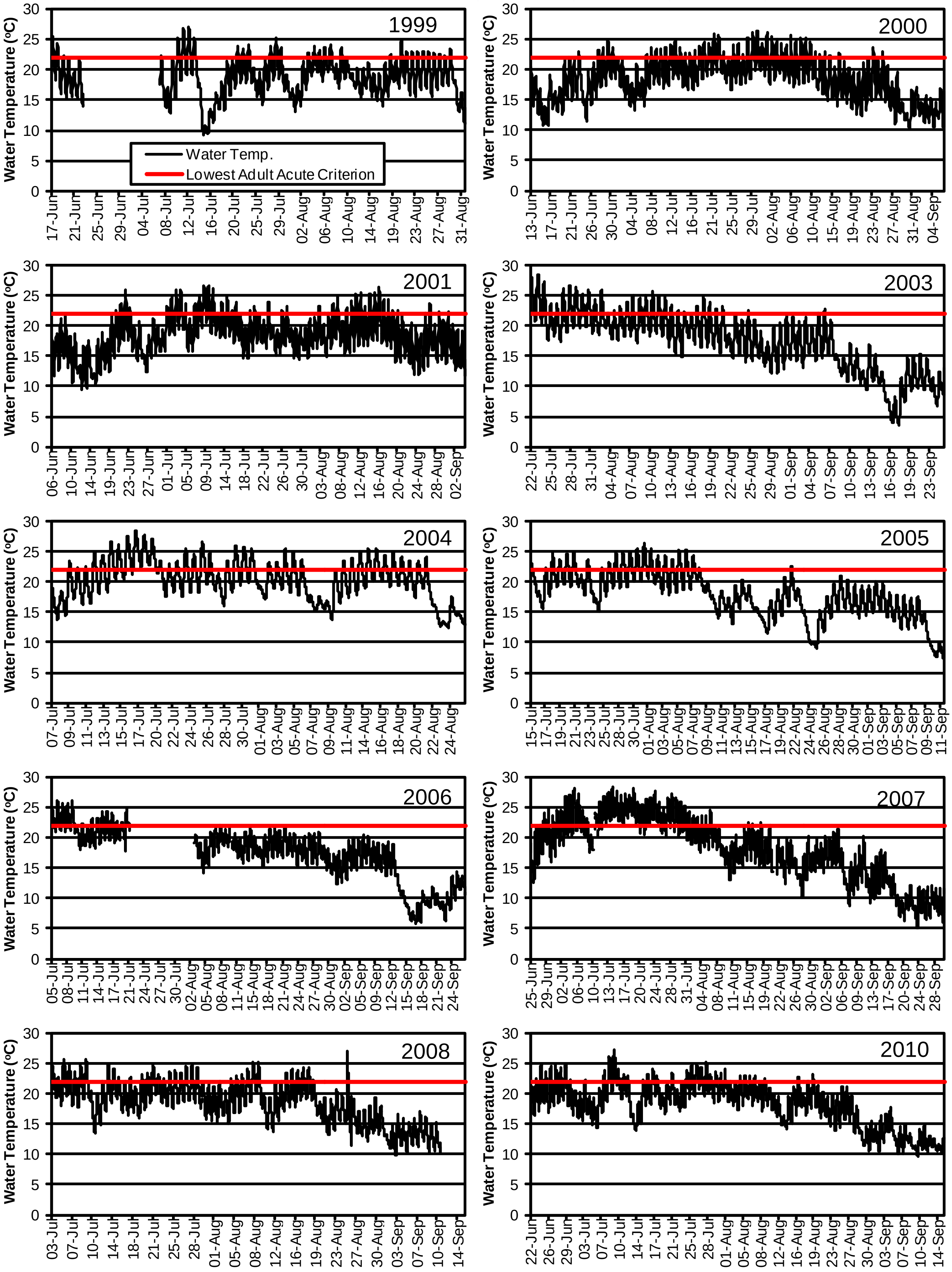
Note: '--' = no data

Appendix II Hourly recording of DO, water temperature, pH, and conductivity in the Little Bow River at Highway 533, Little Bow River downstream from Twin Valley Reservoir, and Mosquito Creek at Highway 529, 1999 to 2010



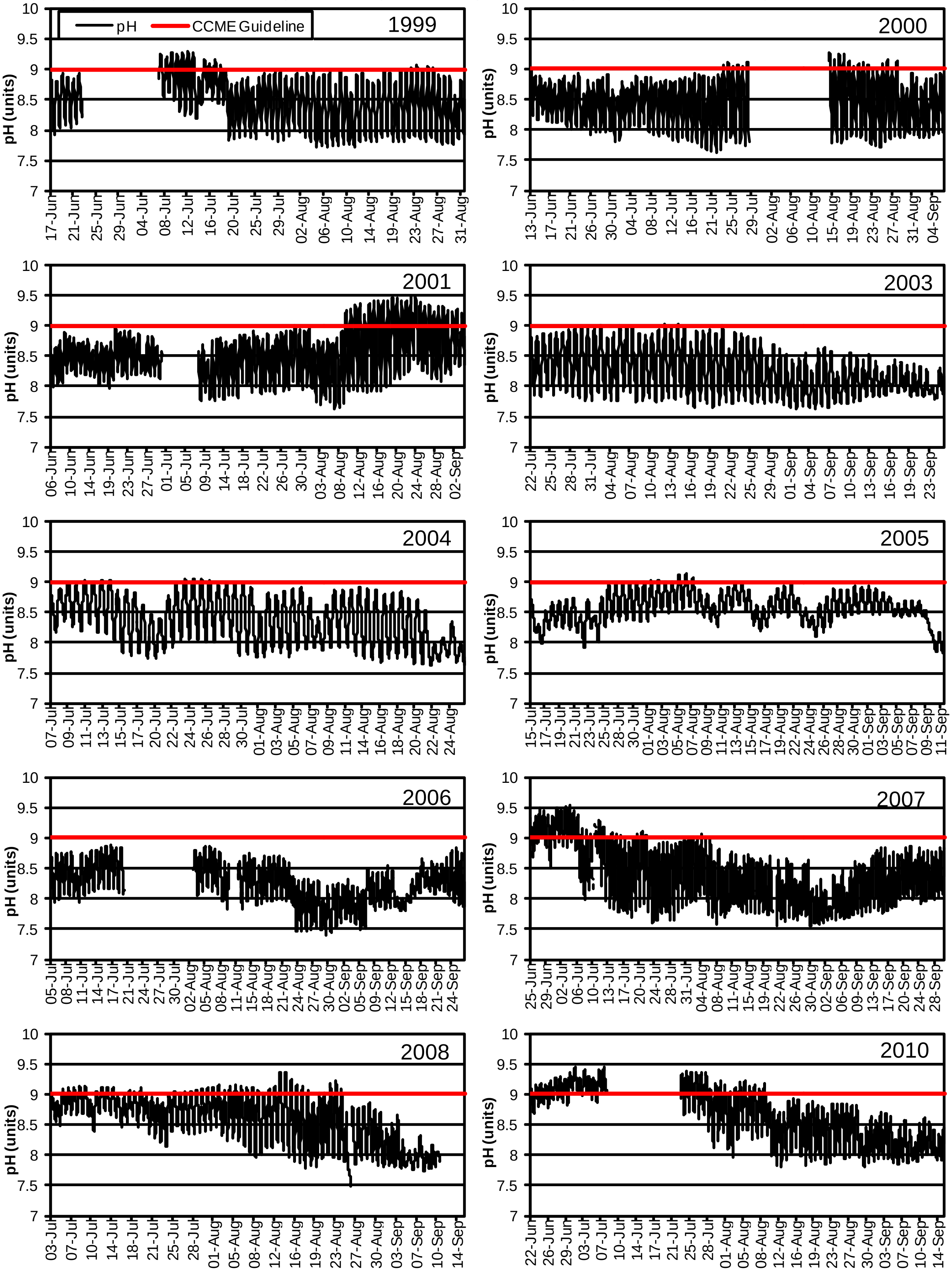
* Note: no data for 2002 and 2009

Summary dissolved oxygen (≤ hourly) in Little Bow River at Highway 533, 1999-2010



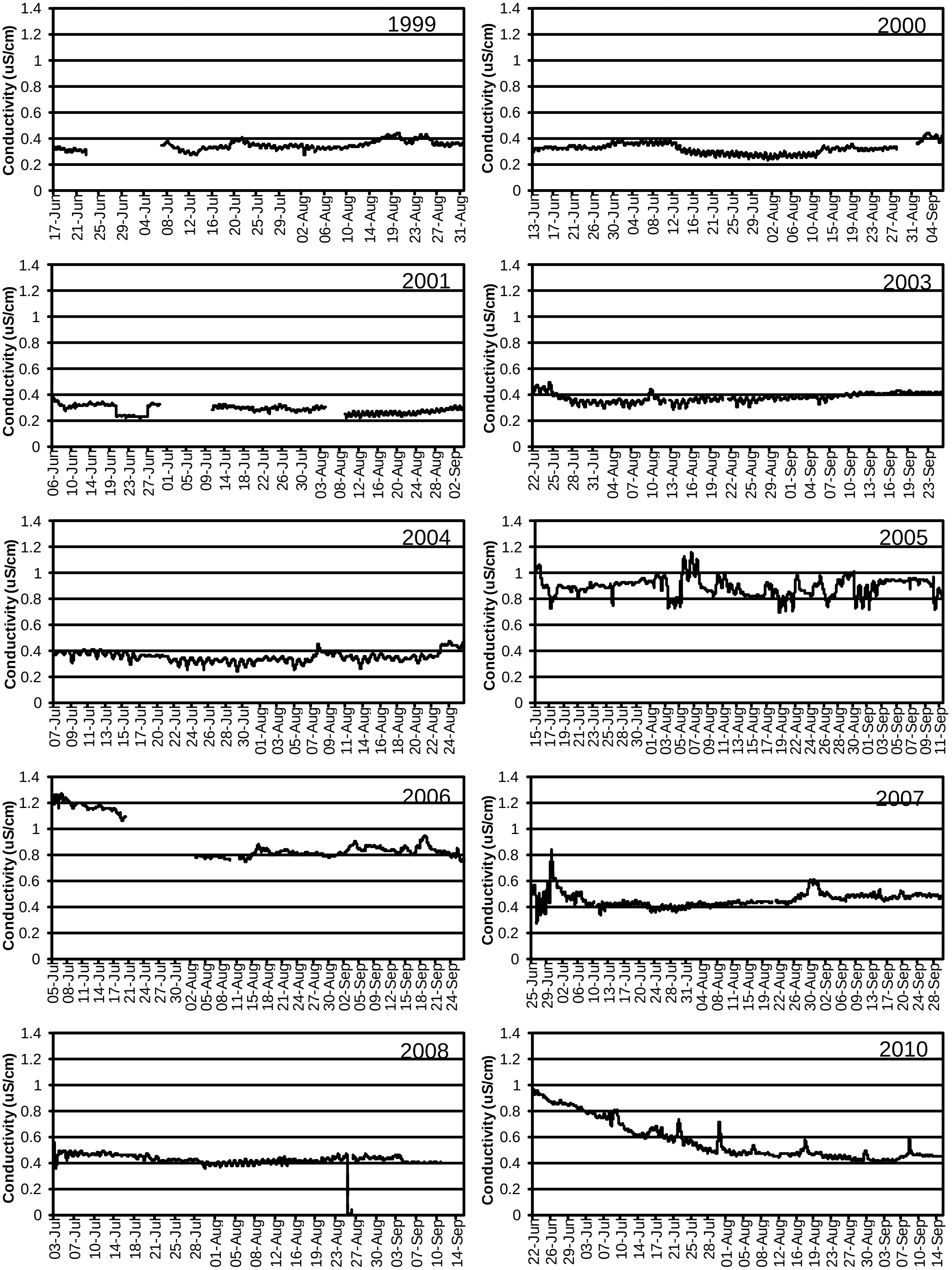
* Note: no data for 2002 and 2009

Summer water temperature (≤ hourly) in Little Bow River at Highway 533, 1999-2010



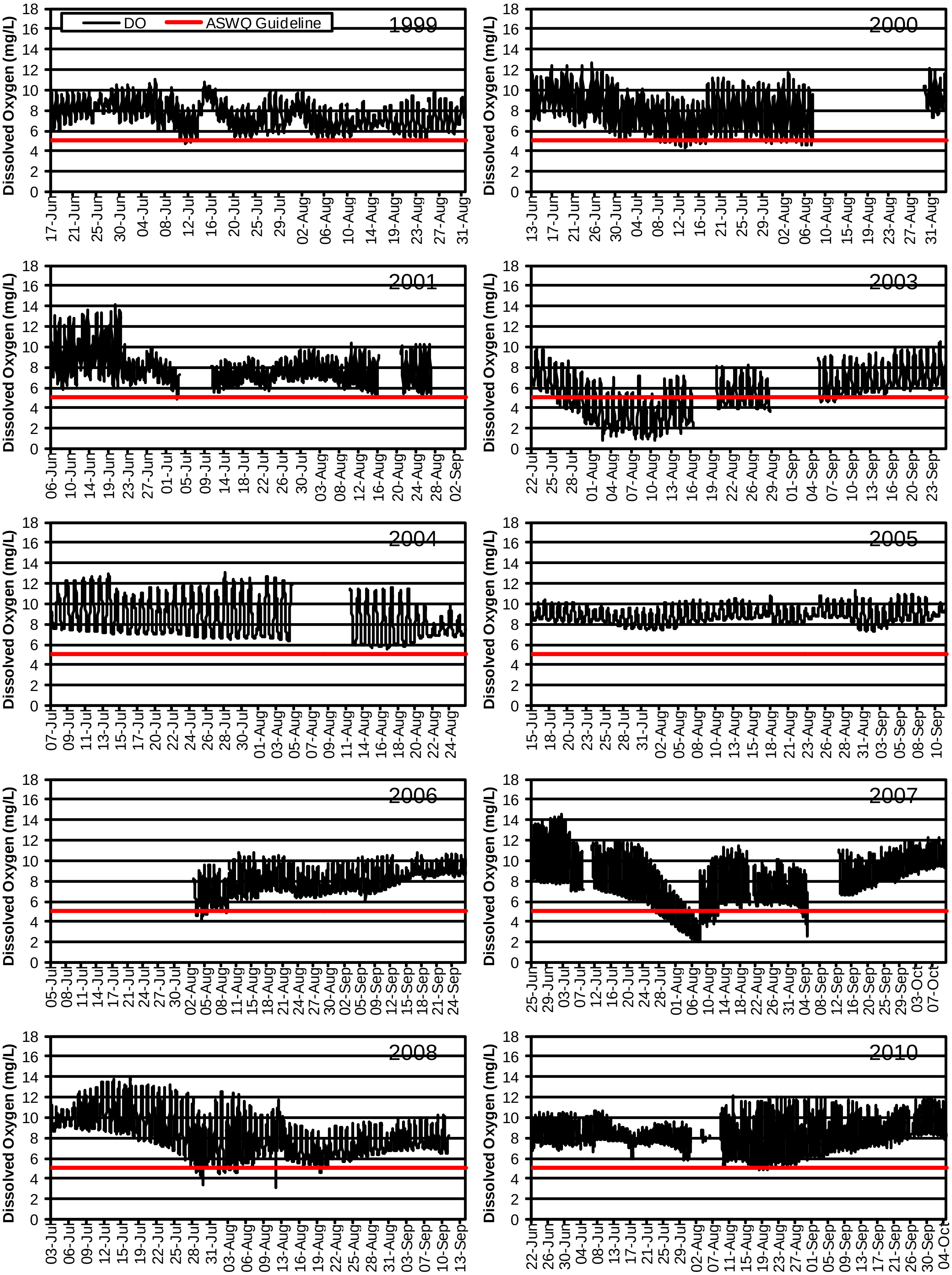
* Note: no data for 2002 and 2009

Summer pH (≤ hourly) in Little Bow River at Highway 533, 1999-2010



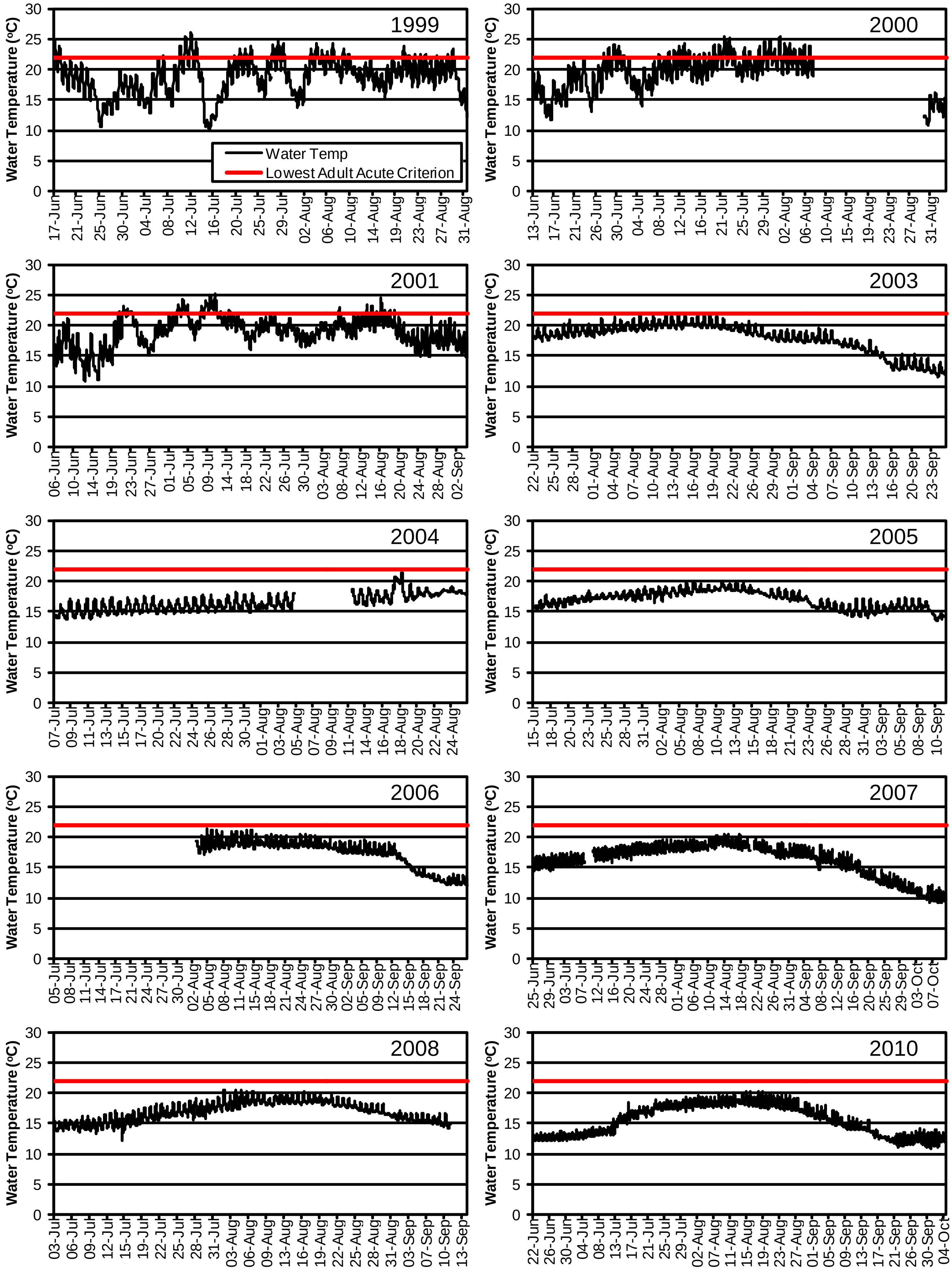
* Note: no data for 2002 and 2009

Summary conductivity (≤ hourly) in Little Bow River at Highway 533, 1999-2010



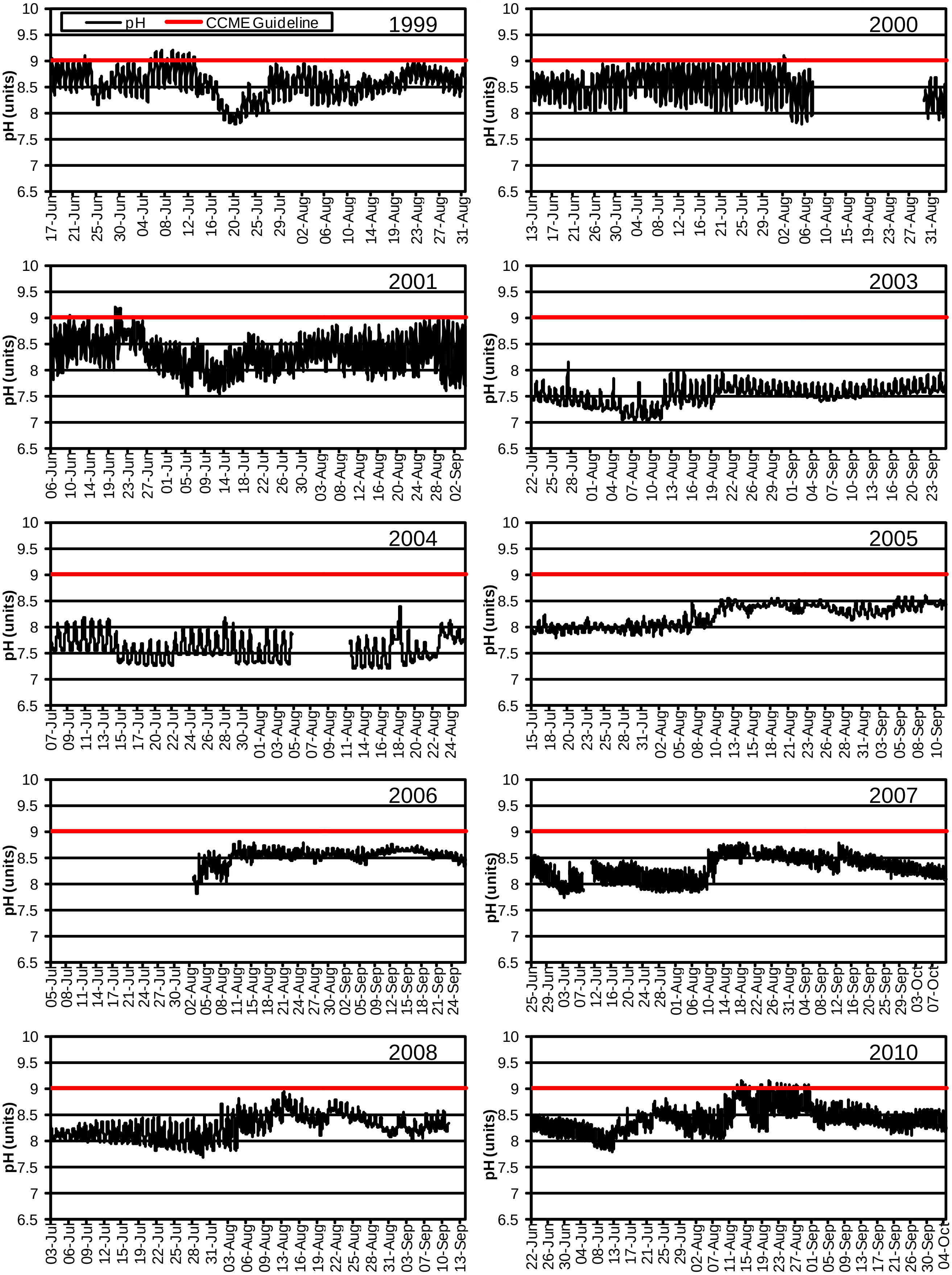
* Note: no data for 2002 and 2009

Summer dissolved oxygen (≤ hourly) in the Little Bow River d/s Twin Valley Reservoir, 1999-2010



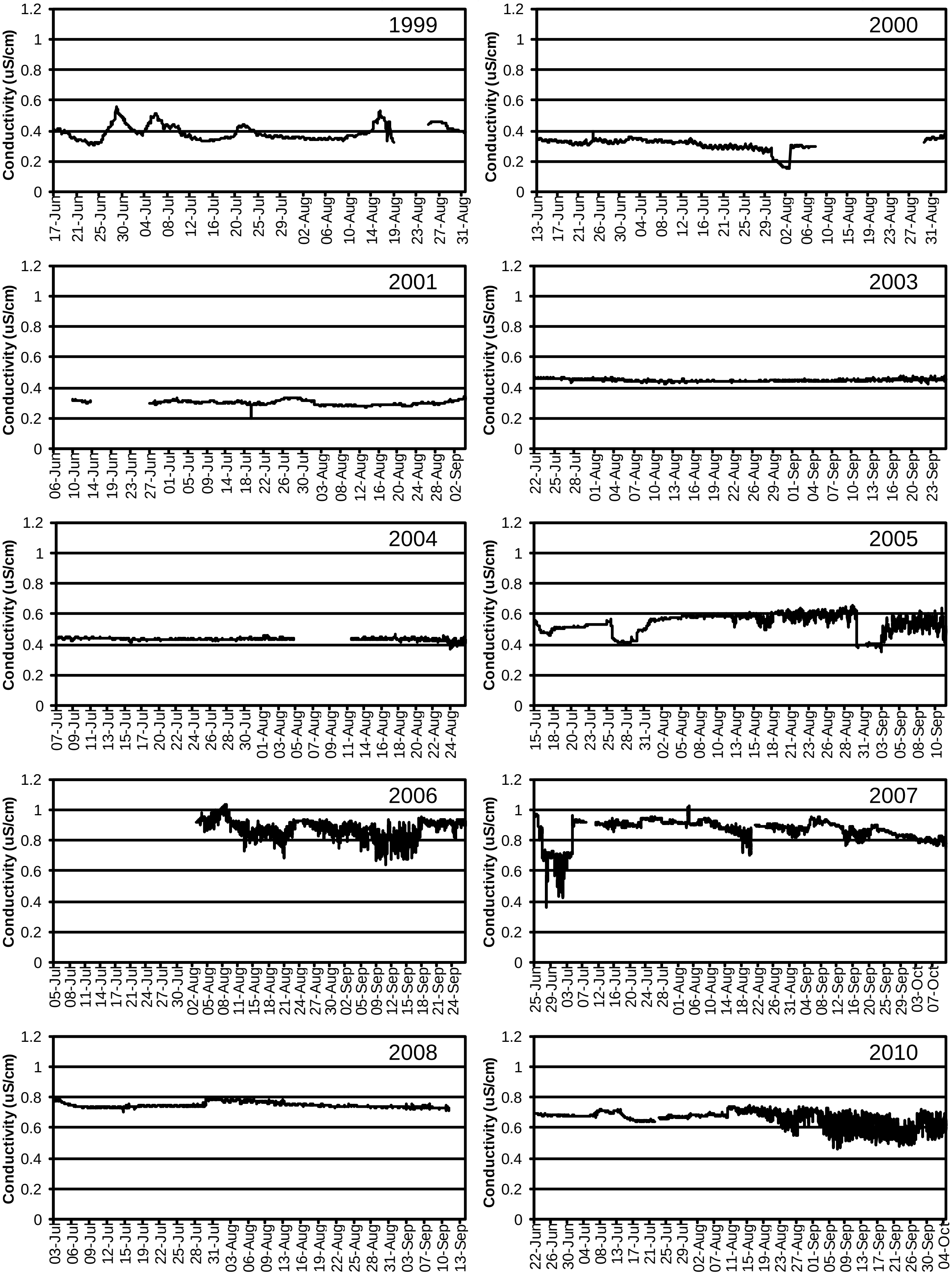
* Note: no data for 2002 and 2009

Summer water temperature (≤ hourly) in the Little Bow River d/s Twin Valley Reservoir, 1999-2010



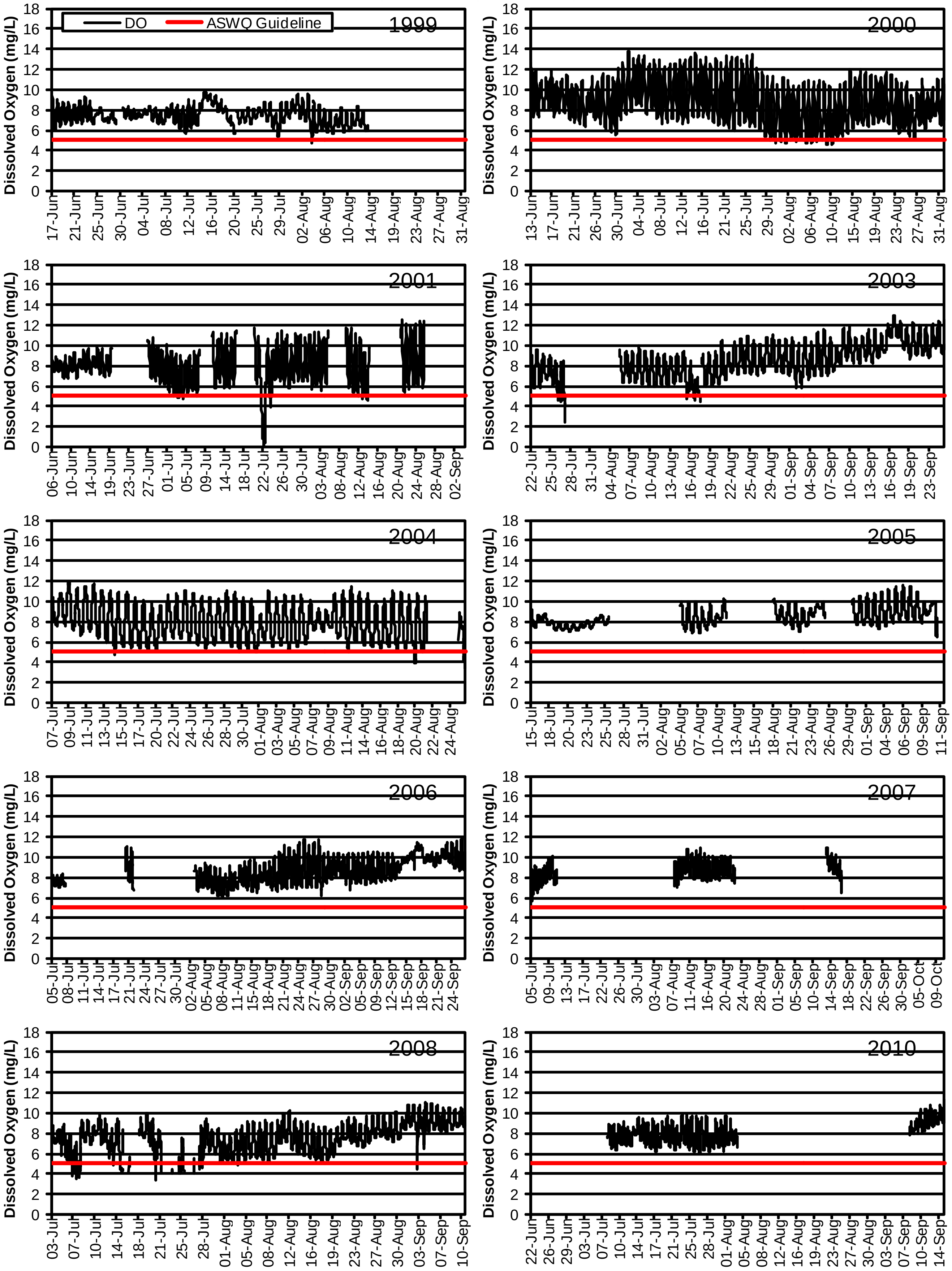
* Note: no data for 2002 and 2009

Summer pH (≤ hourly) in the Little Bow River d/s Twin Valley Reservoir, 1999-2010



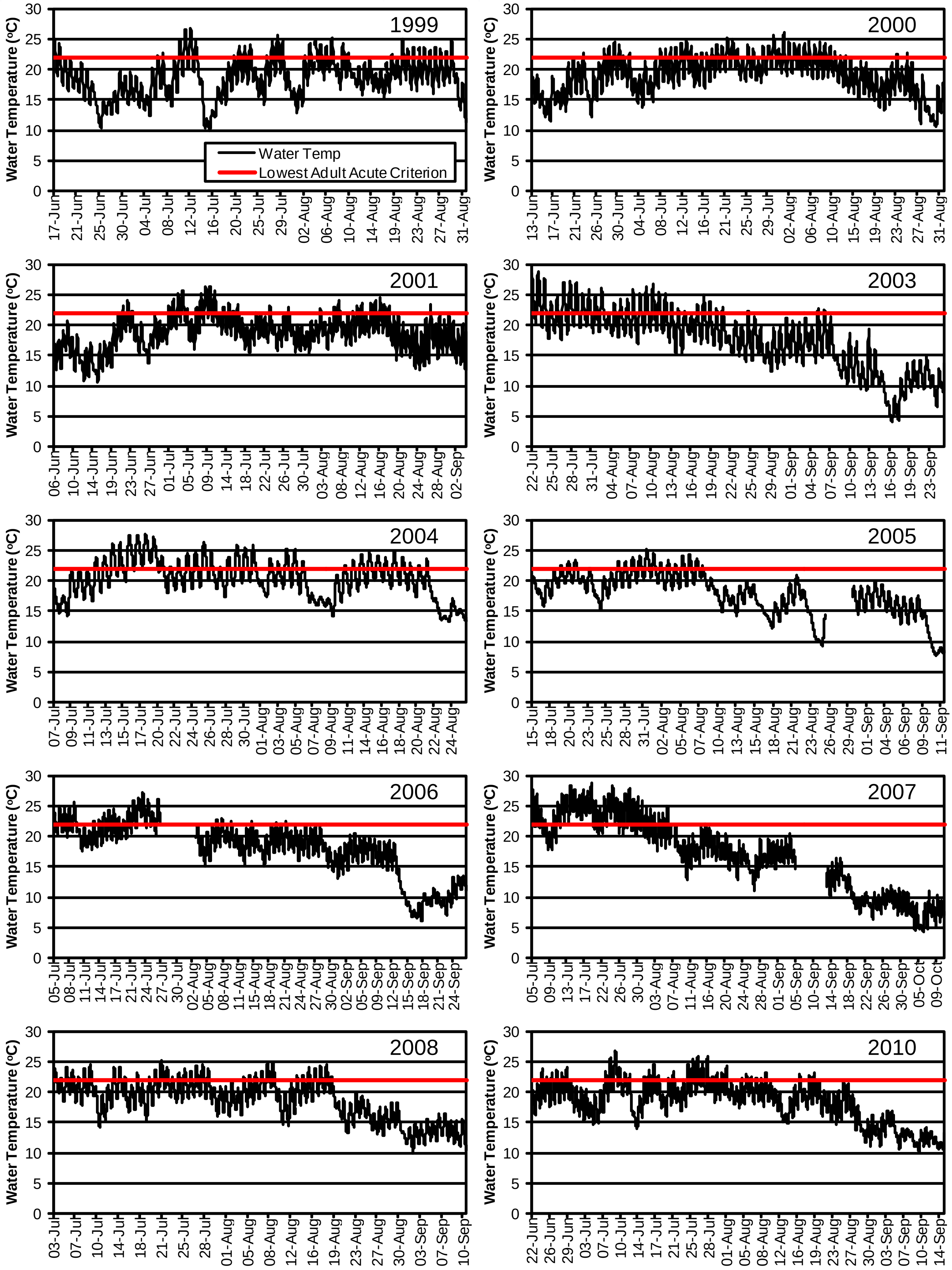
* Note: no data for 2002 and 2009

Summer conductivity (≤ hourly) in the Little Bow River d/s Twin Valley Reservoir, 1999-2010



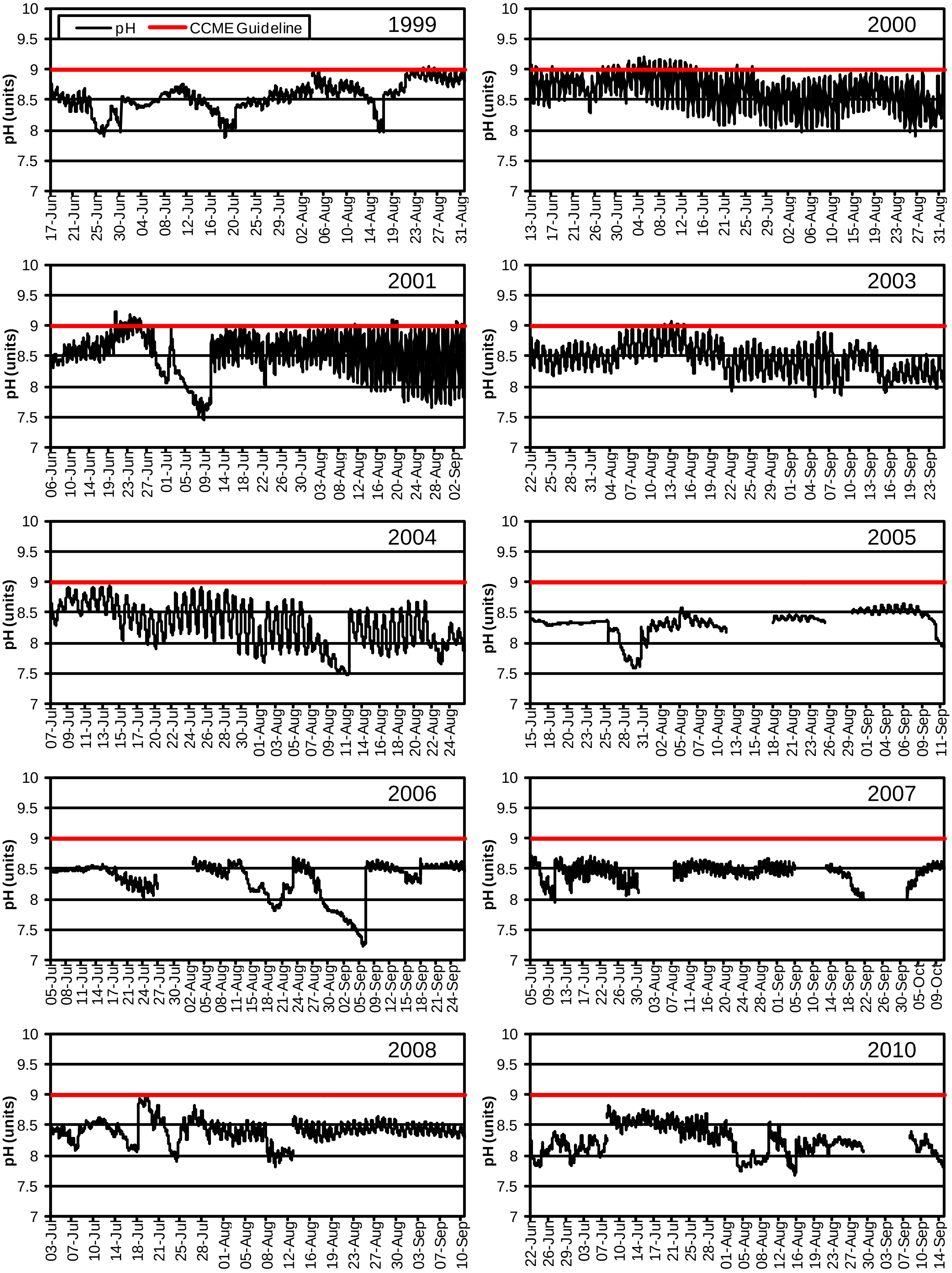
* Note: no data for 2002 and 2009

Summary dissolved oxygen (≤ hourly) in Mosquito Creek at Hwy 529, 1999-2010



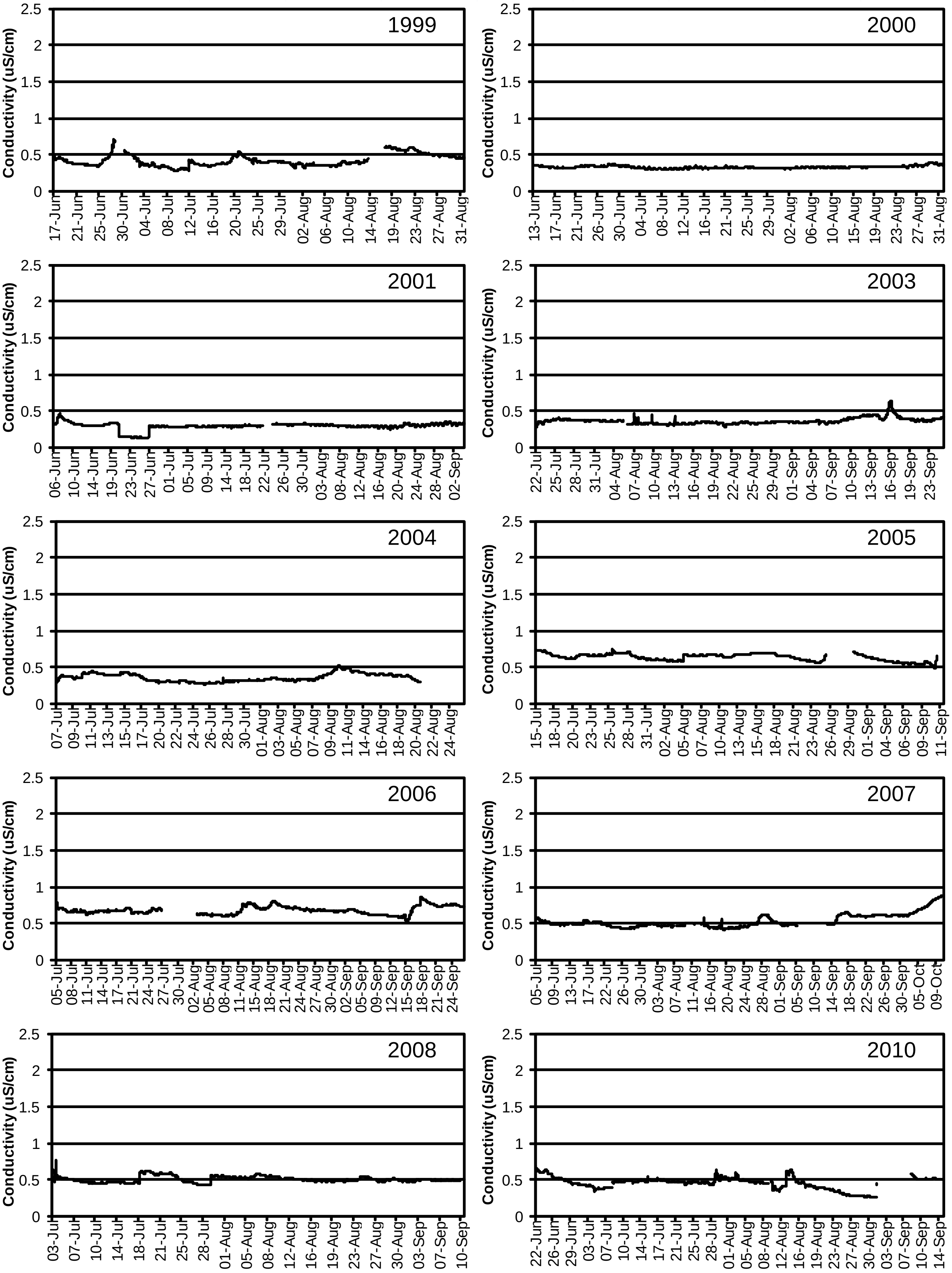
* Note: no data for 2002 and 2009

Summer water temperature (≤ hourly) in Mosquito Creek at Hwy 529, 1999-2010



* Note: no data for 2002 and 2009

Summer pH (≤ hourly) in Mosquito Creek at Hwy 529, 1999-2010



* Note: no data for 2002 and 2009

Summer conductivity (≤ hourly) in Mosquito Creek at Hwy 529, 1999-2010