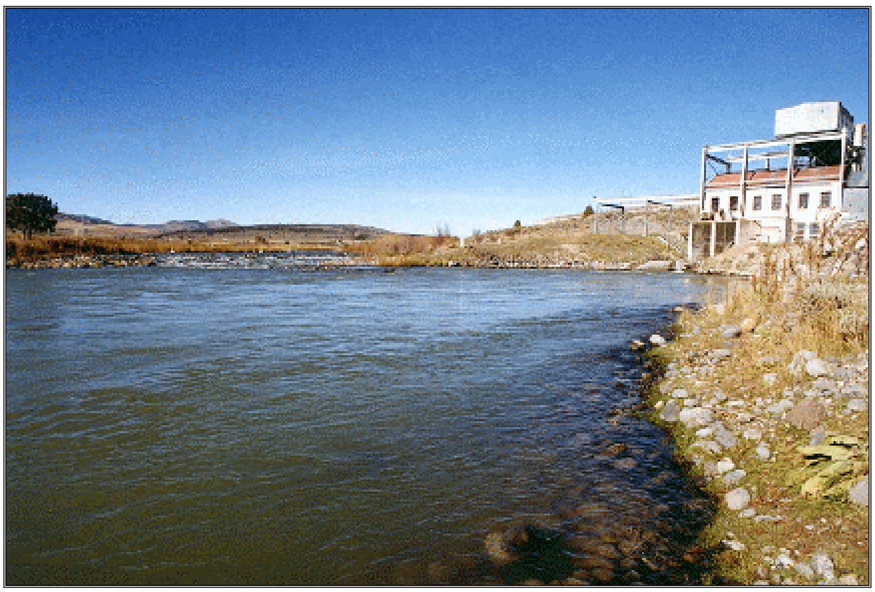
Bear River Hydroelectric
FERC Project No. 20
Grace-Cove Development

2007 Water Quality Summary



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EXECUTIVE SUMMARY

A water quality monitoring study was undertaken on the Bear River within PacifiCorp's Grace/Cove hydroelectric complex (Development) during July, August, and September 2007. This study was implemented to define water quality conditions at four separate locations within this reach of the Bear River. Continuous monitoring probes gathered data for a minimum of seven continuous days during the months of July, August and September at four locations on the Bear River including: above and below Grace Dam, at the mouth of Black Canyon, and below the site of the former Cove Hydroelectric Plant. Water quality grab samples were collected at the same time the probes were checked and were analyzed for nutrients and suspended solids.

Flows below Soda Dam ranged from as high as 1,461 cfs in July to as low as 258 cfs in September. Sampling during September occurred over a period in which the flows were drawn down dramatically over a short time period (504 cfs). Flows below Grace Dam were relatively stable throughout all the sampling periods (83-131 cfs).

Water temperature and dissolved oxygen levels demonstrated distinctive daily patterns over all months at all sites. Specific conductance and turbidity did not consistently show this same pattern. To evaluate this daily variation, ANOVAs were used to compare differences among hours of the day. To account for the daily patterns observed, the data were divided into two twelve-hour data sets; 7 p.m. to 7 a.m. (night) and 7 a.m. to 7 p.m. (day). This distinction separates the warmer and cooler periods of each day, as well as periods of solar radiation and reduces variation within each group. Tukey tests were used to evaluate differences among sites. In order to evaluate correlations among sites, pair-wise linear regressions were calculated for each parameter.

Grab samples collected during this time were generally consistent with the water quality conditions recorded during the 2004 to 2006 instantaneous sampling efforts. Total phosphorous, which generally decreased over the sampling period, was highest overall at GC02 in July (0.077 mg/L). Orthophosphorus, the dissolved portion of phosphorus, as a percentage of phosphorus generally increased over the summer and was often, but not always, highest at GC03.

The concentration of total inorganic nitrogen, which is made up of nitrate, nitrite and ammonia, did not display the same pattern as phosphorous. Total inorganic nitrogen concentrations at GC01 and GC02 were relatively constant and similar to each other during the monitoring season. Nitrogen levels at GC03 were consistently highest among the sampling sites and both GC03 and GC04 showed a sharp increase in nitrogen levels during the final sample taken in mid-September when flows dropped. These increases were due to increases in nitrate and are consistent with the water quality conditions recorded during instantaneous sampling efforts in previous years.

A comparison of each site and sampling event to the IDAPA water quality standards was undertaken using the continuous data collected in this investigation. The instantaneous temperature requirement (temperature must be lower than 22°C) for the prescribed beneficial use

of this section of the Bear River was exceeded at all sites during July and at sites GC01 and GC02 in August. Daily average temperature (temperature must be lower than 19°C) was exceeded at all sites during July and August. Given the poor water quality conditions recorded in the Bear River at the control site (GC01), it is unlikely that the operations of the project contributed to recorded temperature exceedances of IDAPA standards at monitoring sites downstream where exceedances decrease relative to the control site. Monitoring results indicate that the project had little effect on exceedances of water temperature criteria as set forth in the IDAPA.

Exceedances of state water quality standards also decrease with distance downstream during both July and August in the case of dissolved oxygen absolute concentrations (mg/l),. In contrast, during all three monitoring periods, dissolved oxygen (expressed as a percent of atmosphere) exceedance of IDAPA standards for supersaturation at the downstream sites (GC02-GC04) was more frequent than exceedances recorded at the control site (GC01). This pattern has been observed in 2005 and 2006 as well. Physical characteristics of the Bear River vary considerably from the control site as you move downstream to the other monitoring locations. Site GC01 is located in a turbulent reach of the river, whereas the latter monitoring locations are located in areas with more laminar flows. Increased photosynthesis in these laminar reaches drives up oxygen saturation levels. Dissolved oxygen data (expressed as percent of atmosphere) recorded at sites GC02, GC03, and GC04 reflects this local primary production. As with temperature, it is unlikely that project operations significantly contributed to exceedances of dissolved oxygen criteria as set forth in the IDAPA.

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1.0 INTRODUCTION

The primary objective of the Water Quality Monitoring Plan (WQMP) is to accurately define the water quality conditions above, within and below the Grace/Cove hydroelectric complex (Development). The secondary objective is to evaluate the data and determine if the Development has contributed to exceedances of water quality criteria as set forth in the Idaho Water Quality Standards and Wastewater Treatment Requirements (IDAPA 58.01.02). This report will review the parameters, locations, and frequency of sampling conducted during July, August, and September 2007. This report includes data collected and conclusions of the study. In addition, quality assurance/quality control requirements will be reviewed and evaluated in terms of data fitness.

1.1 Bear River Historical Water Quality

The Bear River flows over 500 miles, draining a 4,800,388-acre watershed which includes portions of three states. The regulation of the river's flow and irrigation diversions are under the control of the Bear River Compact and regulated by the Bear River Commission. Water quality within the river falls under the jurisdiction of the states of Idaho, Utah, and Wyoming.

Precipitation within the Bear River basin is distributed unevenly with regards to both time and space. Most of the precipitation in the basin arrives as winter snowfall. Data obtained at the U. S. Weather Bureau stations at Preston, Grace, and Montpelier show that the average monthly precipitation ranges from a high of 1.93 inches in April to a low of 0.65 inches in July. Annual precipitation at these stations ranges from about 8.5 inches to about 23 inches. The 50 percent exceedance value for annual precipitation in Preston, meaning the precipitation one could expect to exceed half of the time, is 16 inches per year while Grace and Montpelier have a value close to 14 inches annually. Over 50 percent of the surface area of the Idaho Bear River basin receives between 10-20 inches of annual precipitation. The distribution of precipitation is influenced by elevation and ranges from less than 10 inches at low elevations to over 55 inches at higher altitudes. Average precipitation over the entire Idaho Bear River basin is 21.4 inches annually.

On the mainstem Bear River in Idaho, there are six gauging stations (not including the two on the inlet and outlet to Bear Lake). A historical review of these data indicates that for the last 30-year period, maximum yield (1.75 to 2.0 million ac-ft) occurred in 1983, 1984 and 1986. Between 1988 and 1995, as well as 2001 to 2004, yields throughout the basin were low (less than 0.50 million ac-ft per year). The 2007 water year was lower than the median value but higher than the recent drought years. For this 30-year period of record, an average of 432,000 ac-ft of water entered the Middle Bear River from Wyoming and 850,000 ac-ft exited at the Utah border. The Idaho portion of the Bear River yielded an average of 517,000 ac-ft of water. Although a large portion is produced within the watershed, the majority of the water entering Utah in the summer is from Bear Lake storage captured from upper basin sources during runoff and released for downstream irrigation in Utah. The storage of 1.42 million ac-ft of water in Bear Lake, represents the majority of storage above Alexander Reservoir near Soda Springs. Irrigation water used for agriculture represents the single largest consumptive use in the basin. A total of 90 irrigation companies serve 177,800 acres of irrigated land in the Middle Bear River. Bear Lake County has the largest number of companies (47) and the largest amount of acreage (75,680 acres), followed by Caribou, Franklin, and Oneida counties. Last Chance Canal, located immediately above this project, withdraws a significant amount of Bear River water during the summer irrigation season. Land is irrigated on both the north and south sides of the river throughout the project area (Last Chance down to Cove).

The Idaho Bear River basin has four major subbasins, or hydrologic units, all within the state of Idaho. This project is located in hydrologic unit #16010202 which extends from below Alexander Reservoir to the Idaho-Utah border. This subbasin has 18 tributaries, four of which are on Idaho's 303(d) list. The remaining three subbasins are designated as providing coldwater and salmonid spawning habitat. Recreation contact is primary or secondary for these three streams. The Bear River in this subbasin has five reaches, all of which are on Idaho's 303(d) list, including the reach containing this project. Nutrients, sediment and flow alteration are the reasons given for the 303(d) listing of the river, reservoir and tributaries in this subbasin.

Water quality studies on the Bear River date back to the 1950s. The Idaho Bear River reach (that portion downstream of the Wyoming-Idaho border) has been the subject of water quality investigations starting as early as 1953 (Clyde 1953). The studies focused on suspended sediments and flow. Several studies have also been conducted on the current condition of and influences on water quality in the reach above Bear Lake, extending as far as Woodruff Reservoir in Wyoming down to the Idaho-Utah state line. Of the studies on Bear River water quality in the project reach (Wyoming-Idaho state line to the Utah-Idaho stateline), the most extensive was completed by ERI in 1998, and is described in detail later in this section. Prior to that discussion, a brief summary of historical water quality investigations on the Bear River system is provided.

Early water quality studies focused on sediments and salinity in the river. Clyde (1953) evaluated sedimentation patterns in the Bear River between Oneida and Cutler reservoirs. Between 1910 and 1950, the riverbed raised six feet due to the deposition of over 110 million tons of sediment. Heimer (1978) measured turbidity and suspended sediments at sites from below Bear Lake to the Utah-Idaho stateline. Based on his 1975 data, sediment loads in the river increased from 98 tons/month (3,000 kg/day) at Soda Springs to 351 tons/month (10,600 kg/day) near Preston, then decreased to 171 tons/month (5,180 kg/day) at the stateline. Waddell (1970), Haws and Hughes (1973), and Hill et al (1973) all summarized water quality data collected in the late 1960s and early 1970s. Most analyses were for major anions and cations only. Over this time period, total dissolved solids (TDS) averaged about 375 mg/liter at the Bear Lake outlet, with little change throughout the Idaho reach.

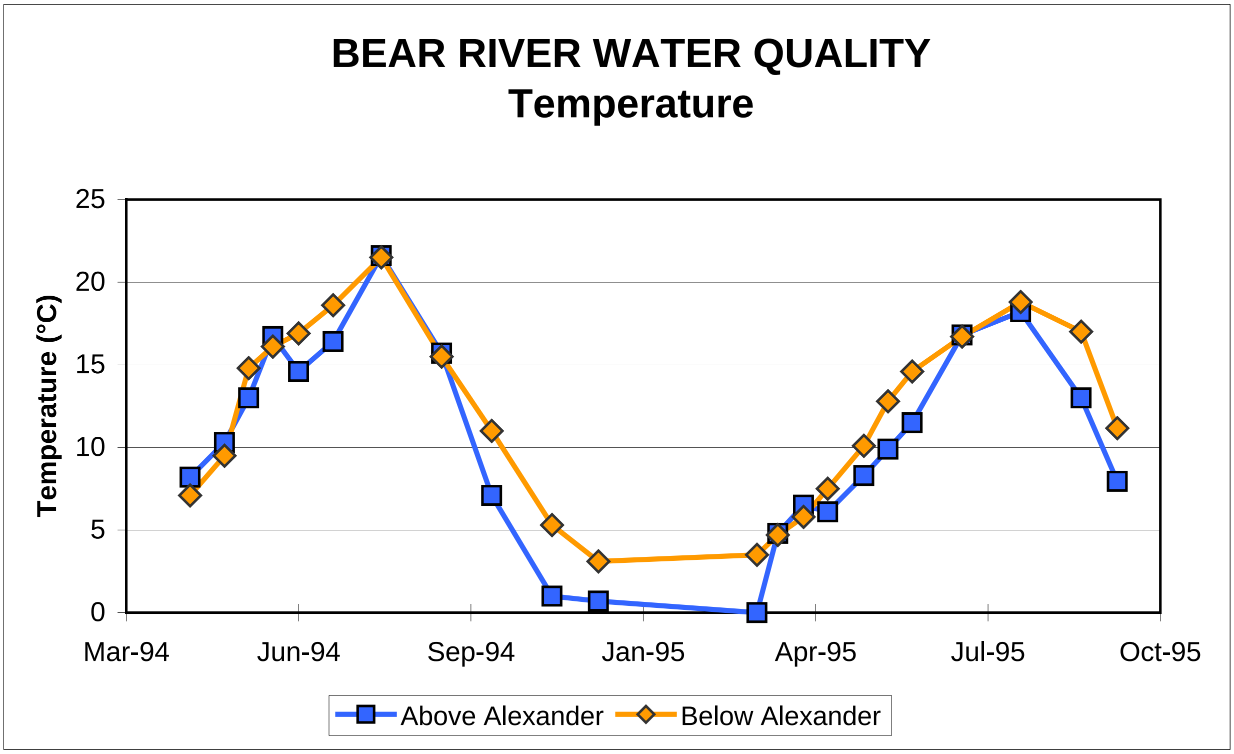
The first extensive water quality study of the Idaho portion of the Bear River was conducted in 1975 and 1976 (Perry 1978), with samples collected every two weeks at 15 stations. Perry concluded that total suspended solids (TSS) and TDS concentrations responded differently in the reaches above and below Oneida. From Bear Lake to above Oneida, TSS and TDS decreased at higher flows due to a dilution effect. However, below Oneida, solids increased during runoff. He attributed this to high sediment inputs from tributaries below Oneida. High nitrate concentrations in Black Canyon, possibly from Grace wastewater treatment plant (WWTP), and fecal coliform contamination in the river near Preston were also identified as water quality problems.

In the late 1970s, the emphasis shifted to nutrient contamination in the river, with most data collected below Oneida Reservoir by Utah State University Water Research Laboratory. Barker et al. (1989) summarized nutrient data collected from Bear Lake outlet to the Idaho-Utah stateline during 1987 and 1988. Average TP concentrations increased from 0.06 mg/liter at Bear Lake outlet to 0.100 mg/liter at the Idaho-Utah stateline. Average orthophosphorus increased from 0.008 to 0.037 mg/liter over the same reach, although on most dates the concentrations were low and relatively constant from site to site. Nitrate concentrations ranged from 0.140 mg/liter at the outlet to 0.860 mg/liter at the state line.

ERI (1998) conducted the most current and extensive water quality investigation on the mainstem Bear River. Twelve sites on the mainstem Bear River were sampled from April 1994 through September 1996 and in 1999-2000 including the inlet and outlet to Bear Lake as well as the outlet to Black Canyon below Grace, Idaho. In addition, several point sources, including the Soda Springs WWTP and the Clear Springs fish hatchery were also sampled. Several monitoring sites on the mainstem and tributaries were also monitored by PacifiCorp as part of their relicensing effort on three hydroelectric facilities in Idaho. Data from several of these sites are included in this review of available information. This study represents the basis for the summary and analysis of water quality conditions in the Middle Bear River watershed used to establish a Middle Bear River TMDL (ERI 2004).

Temperatures within the Bear River at the study location have shown 20° to 22°C difference from the winter to the summer. In the data set from 1994 to 1995, the temperatures throughout the study area reflected the Bear River inflow to Alexander Reservoir. In this data set, the temperature criterion for the study section of the Bear River (Last Chance down to Cove) was exceeded in only 4 to 5 percent of the observations. These data for five stations in the Bear River can be seen in Figure 1.

Dissolved oxygen (Figure 2) was also measured at the same sites as temperature. The data reflect a grab sample measurement and not an electronic data collection. The frequency of exceedances of the coldwater criteria for oxygen concentration at these sites was only 5 to 8 percent of the observations.



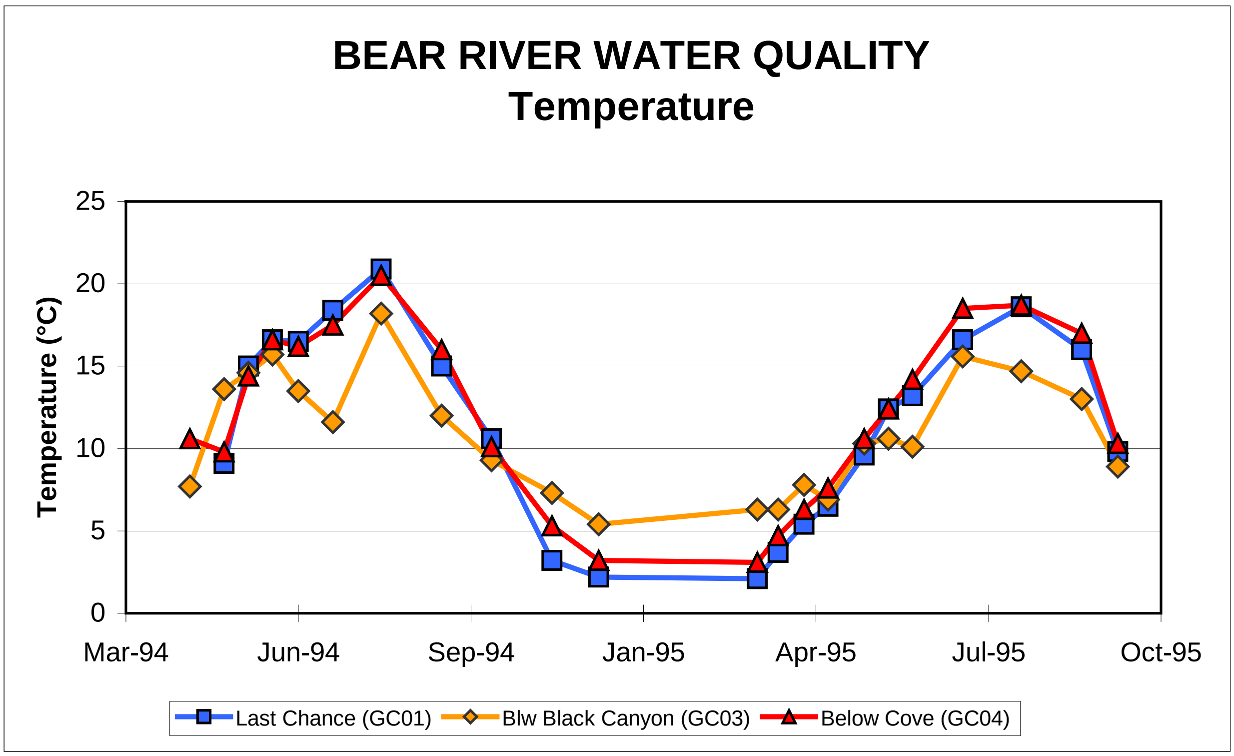
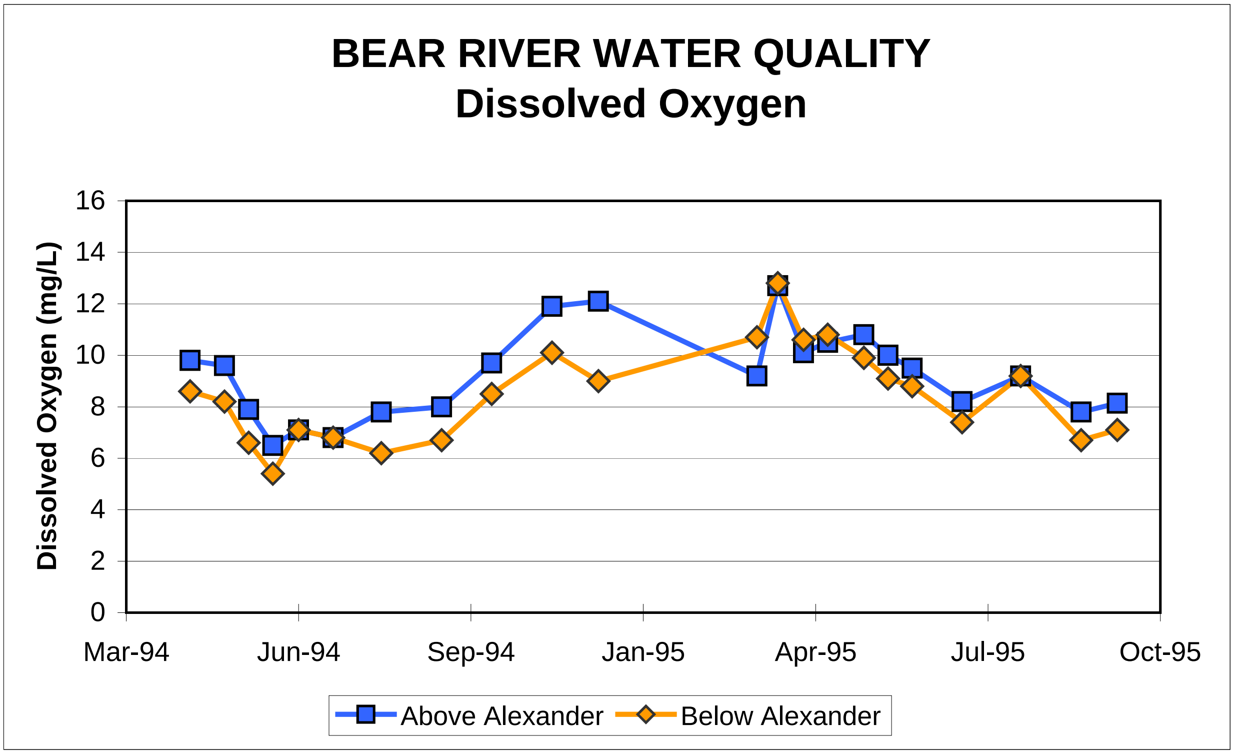


Figure 1. The water temperatures at five locations in the Bear River above Cove from 1994-1996.



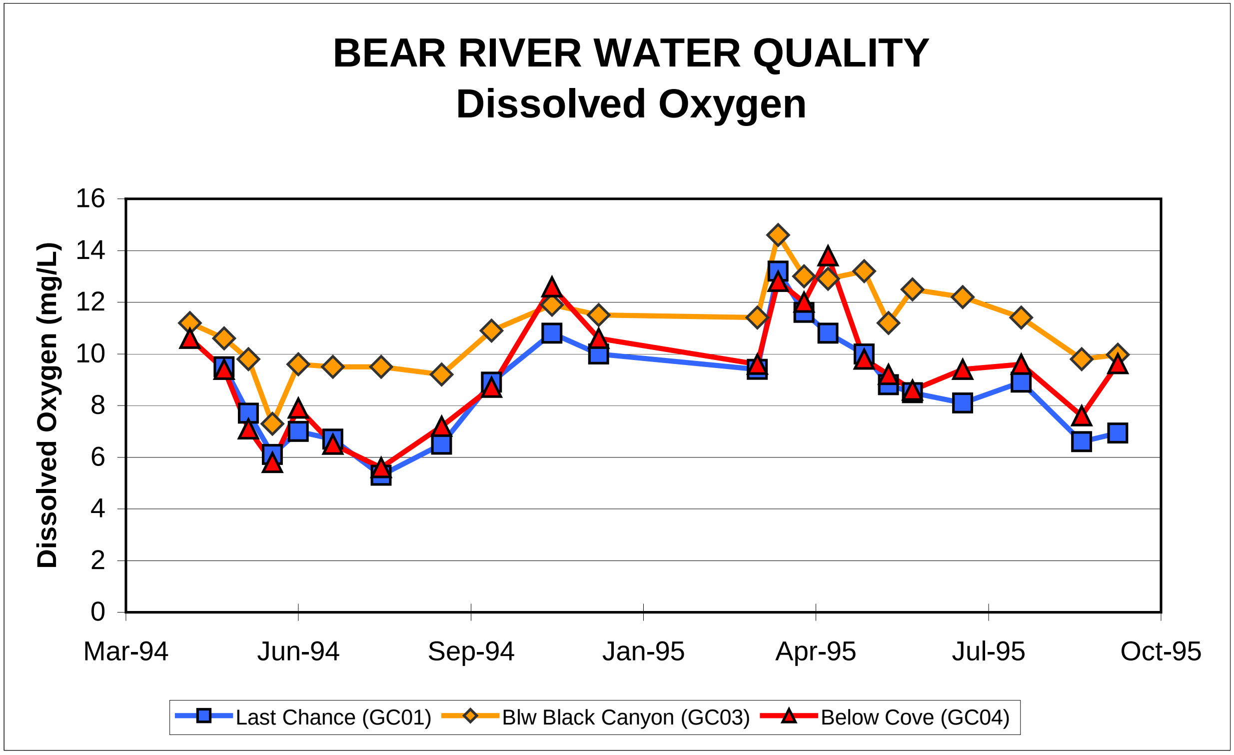
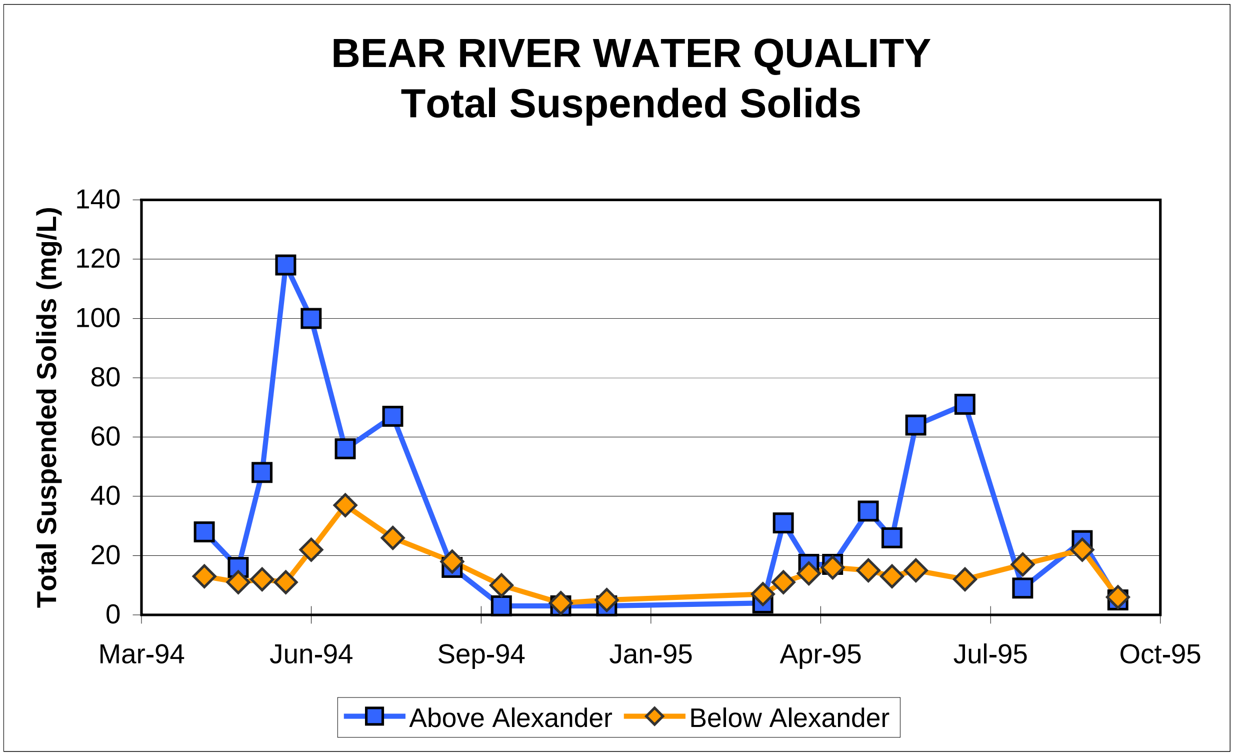


Figure 2. The dissolved oxygen concentrations at five locations in the Bear River above Cove from 1994-1996.

The concentrations of total suspended solids (TSS) were far more variable than for other parameters throughout the study reach. Alexander Reservoir, located downstream of the Bear Lake Marsh Outlet, receives Bear River water year round. TSS concentrations above Alexander Reservoir were similar to concentrations observed at the Bear Lake Marsh outlet, though there were more exceedances of the TSS criterion. Two out of the five runoff months exceeded the 60 mg/l criterion during the 1994-1996 study. There was only one base flow criterion exceedance, occurring during August. Highest concentrations occurred in June, July and August (73, 62, and 60 mg/L, respectively), with the lowest occurring in December, January and February (17, 8.8 and 7.0 mg/L, respectively). At the Bear River below Alexander Reservoir, the number of exceedances decreased to zero (Figure 3).

Total phosphorus and orthophosphorus are pollution indicators and the mainstem Bear River has historically recorded high levels of both (ERI 1998). During ERI's 1994-1996 studies, the Bear River flowing into Alexander Reservoir exceeded the 0.050 mg/L criterion eleven of the twelve months. For nine of those exceedance, average concentrations were two to three times the allowable level. With extremely high levels of phosphorous entering Alexander Reservoir, it is not unexpected that the reservoir is also acting as a nutrient source for the soluble fraction of both phosphorous (ortho-phosphate) and nitrogen (nitrate, nitrite and ammonia). Historical data indicates that both these nutrients are leaving the reservoir in higher concentrations than are entering (Figures 4, 5 and 6). Although the overall effect is to remove vast amounts of nitrogen and phosphorous, the transformation below the reservoir has resulted in a clear (sediment removed) nutrient enriched ecosystem. This results in an abundance of rooted macrophytes and attached algae in the downstream reaches of the Bear River. This area is within the study location of this project (Last Chance to Cove). In addition, an inspection of Figures 4 through 6 also shows that Black Canyon outflows contain significant concentrations of orthophosphorus and total inorganic nitrogen. The source of these nutrients is undocumented but surface irrigation is suspected to contribute significantly. In total, the subject reach of the Bear River that is reflective of a highly productive, riverine system with high densities of primary producers.



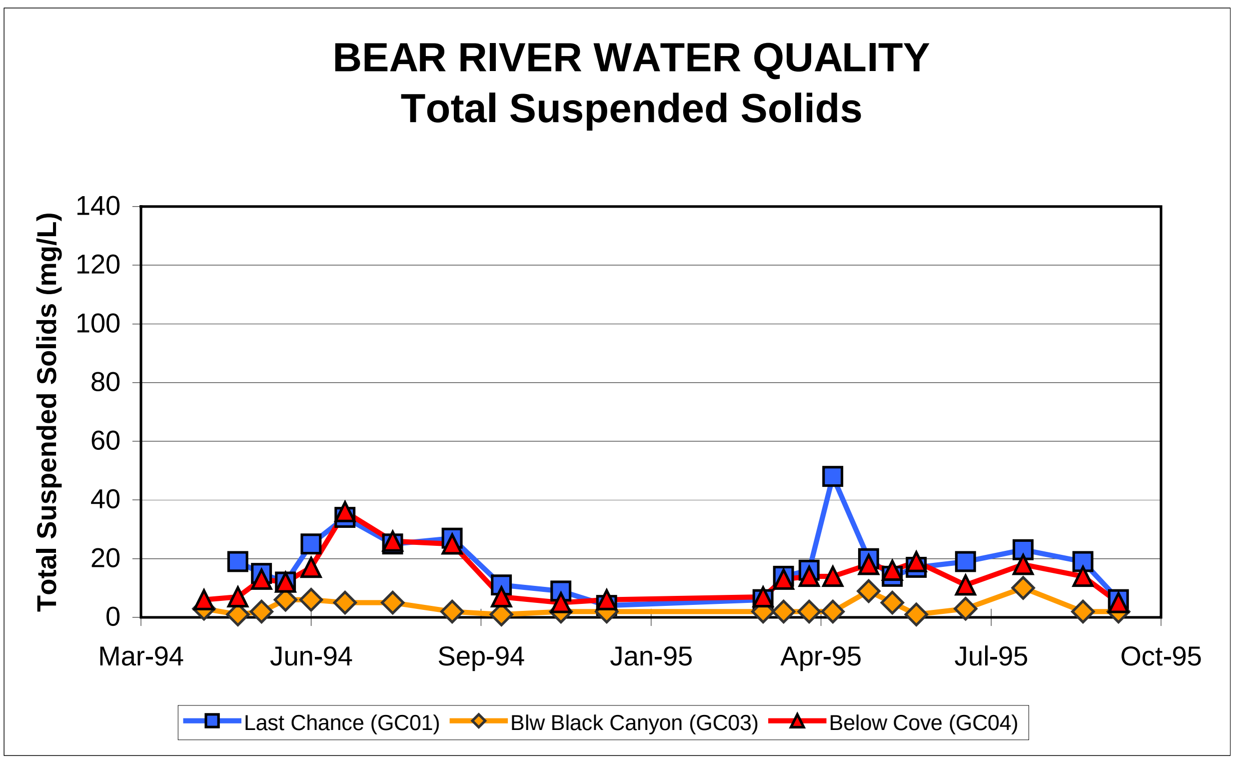
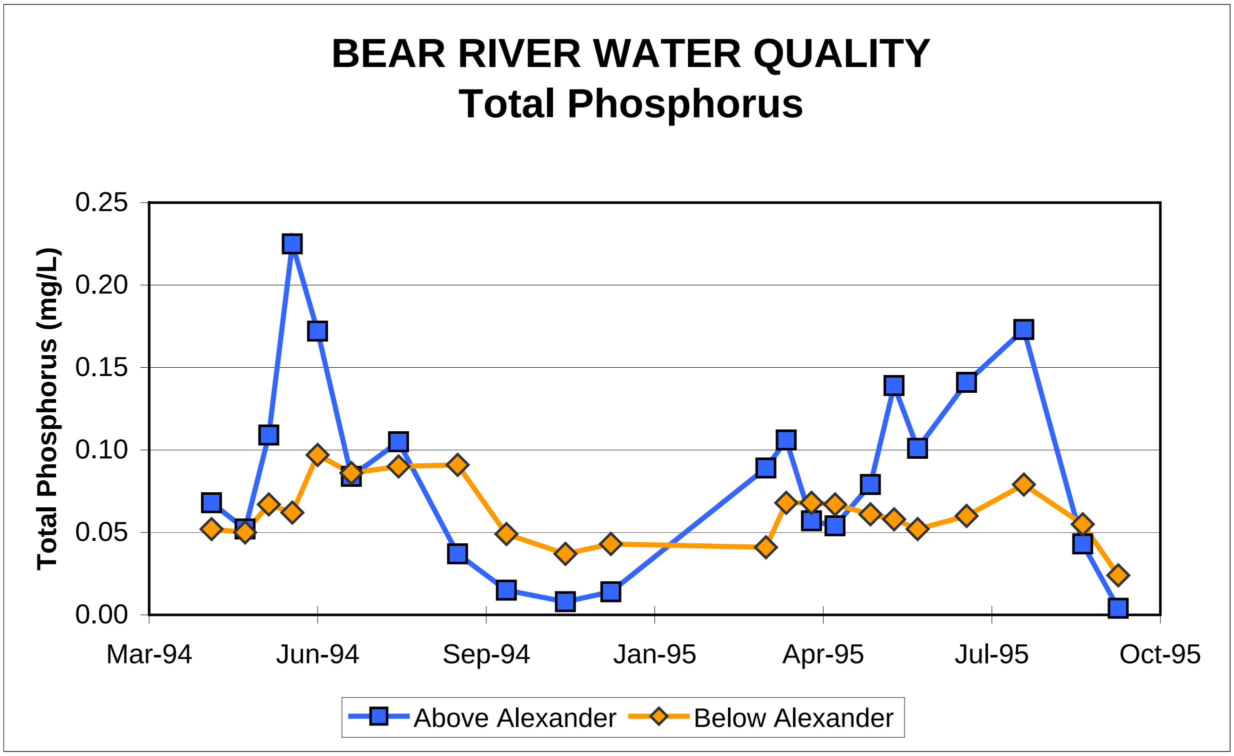


Figure 3. The total suspended solids concentrations at five locations in the Bear River above Cove from 1994-1996.



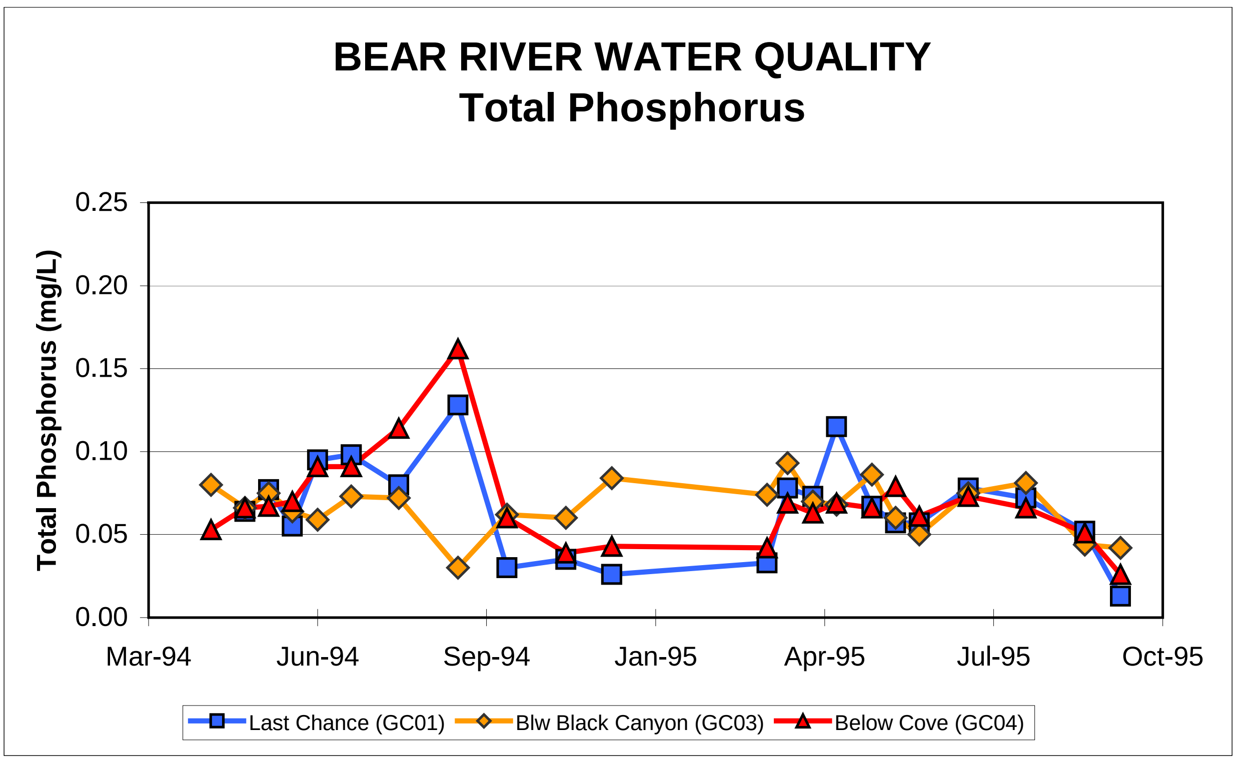
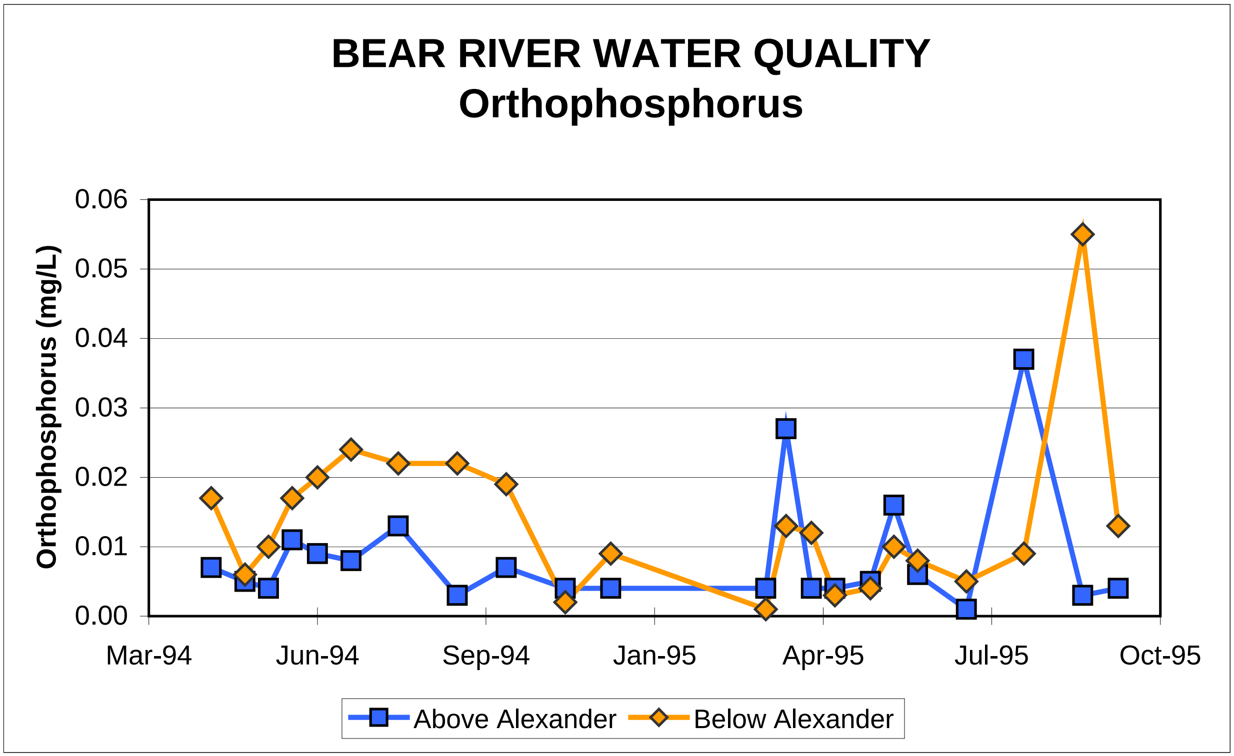


Figure 4. The total phosphorus concentrations at five locations in the Bear River above Cove from 1994-1996.



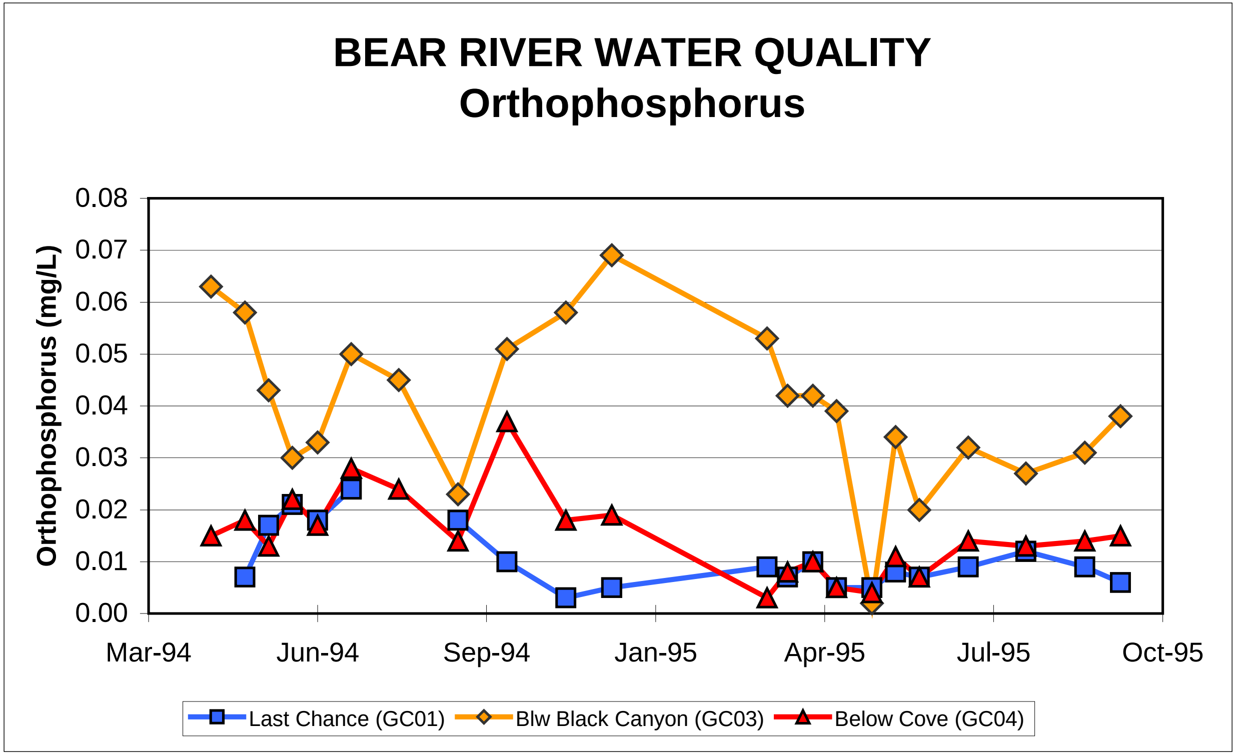


Figure 5. The orthophosphorus concentrations at five locations in the Bear River above Cove from 1994-1996.

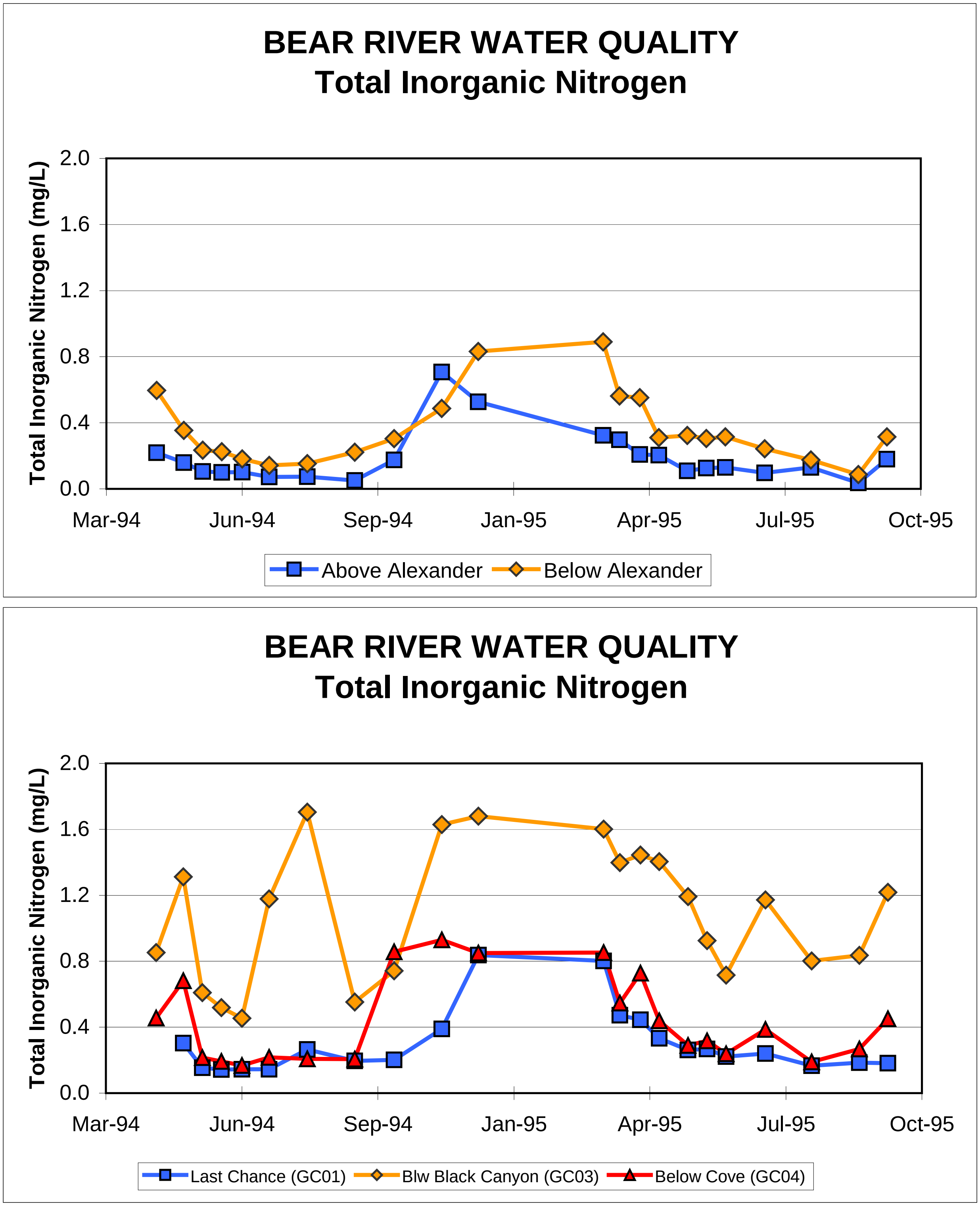


Figure 6. The total inorganic nitrogen concentrations at five locations in the Bear River above Cove from 1994-1996.

2.0 MONITORING LOCATIONS

The Grace WQMP includes sampling at four locations. These sites were continuously monitoring with YSI probes during three periods in 2007. In addition to the continuous monitoring, water quality samples (grab) were collected. These locations can be seen in Figures 7 and 8 and are described below.

GC01: Located below the outfall of the Last Chance Hydroelectric Plant and above the influence of the Grace forebay. This site represents the upstream control which will define water quality conditions entering the Development.

GC02: Located below the Grace Diversion Dam at the head of Black Canyon. This site will define the water quality conditions at the head of the bypass reach and will also define water quality conditions of Grace Diversion Dam water releases.

GC03: Located at the exit of the Bear River from Black Canyon. This site will define the water quality conditions resulting from the combination of the Grace Diversion Dam flow releases and the inflowing springs or point sources accruing within Black Canyon.

GC04: Located below the outfall of the former Cove Hydroelectric Plant. This site represents the water quality conditions leaving the Grace/Cove Hydroelectric complex and represents the cumulative effects of the Development and land uses between the upper forebay of the Grace Diversion Dam and the former site of the outfall of the Cove plant.

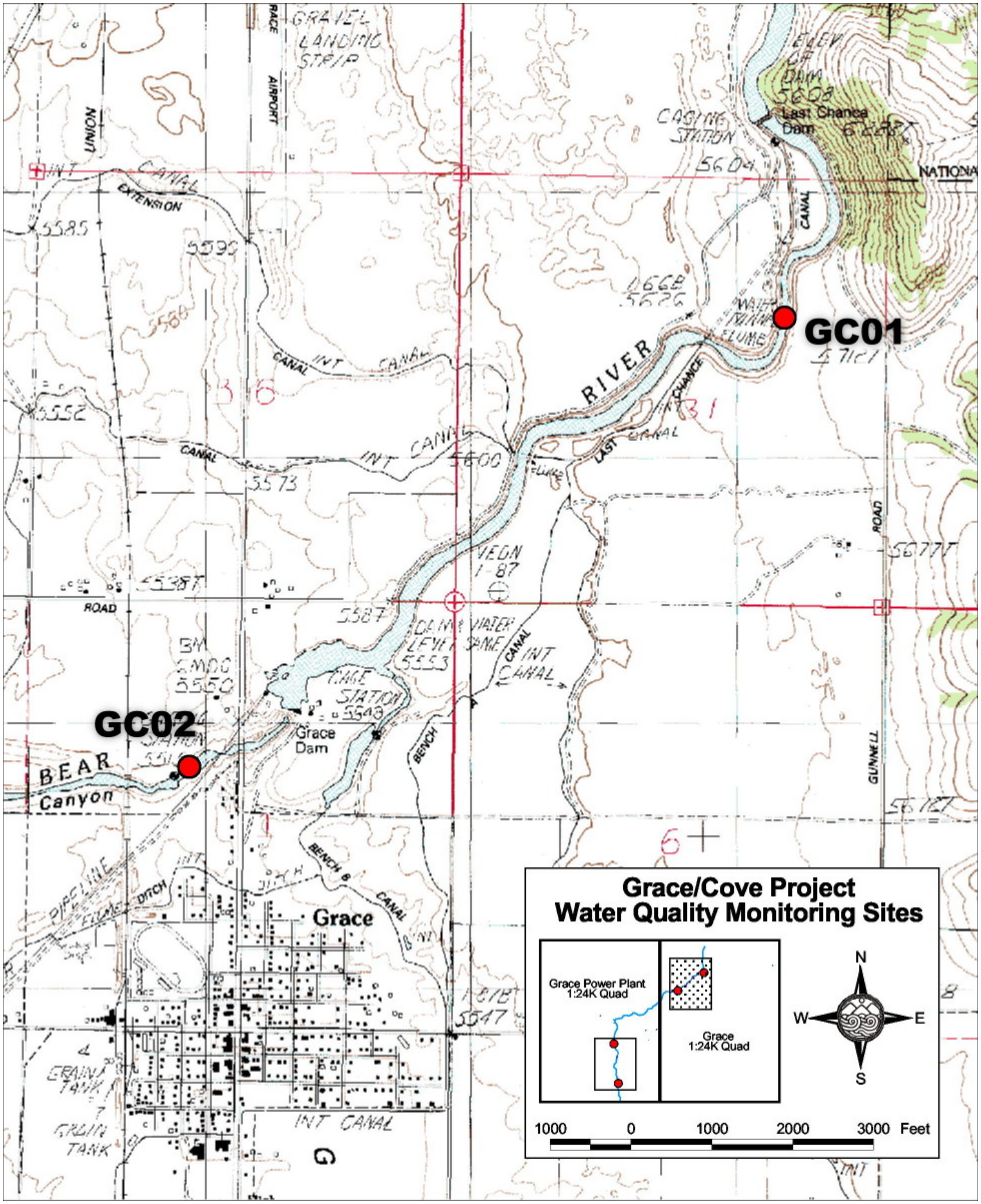


Figure 7. The location of the uppermost monitoring sites for the Grace/Cove WQMP.

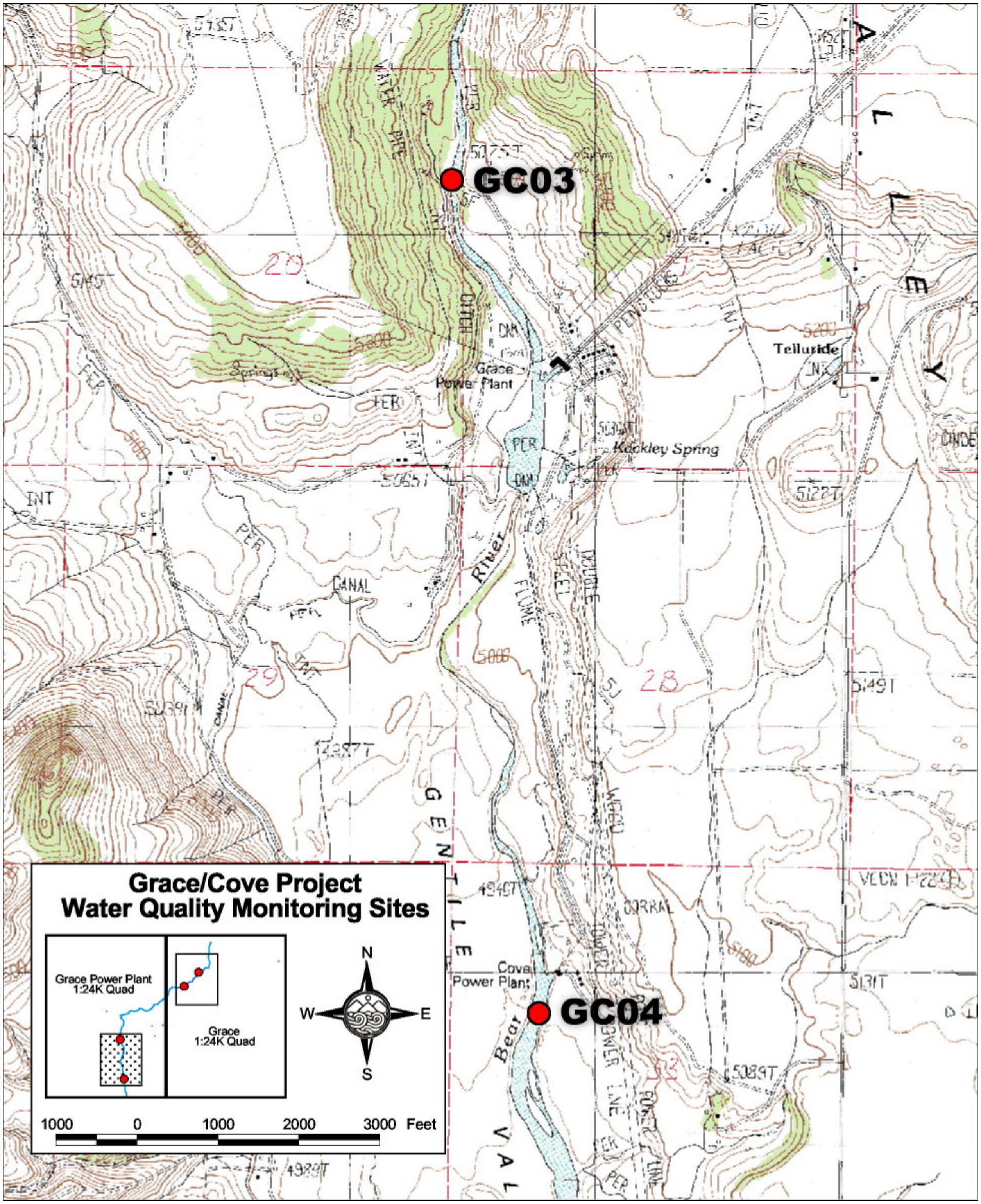


Figure 8. The location of the lowermost monitoring sites for the Grace/Cove WQMP.

2.1 Monitoring Frequency

Continuous monitoring probes (YSI Model 6920) collected dissolved oxygen, temperature, turbidity and specific conductance measurements at 15-minute intervals (reported hourly) over continuous periods from July 8 through July 15, August 5 through August 12 and September 6 through September 13, 2007. The Grace-Cove WQMP requires a minimum of continuous 7-day periods of hourly data for each month between July and September.

In addition to the continuous electronic data, water quality “grab” samples were also collected. Samples were returned to ERI’s laboratory for analysis. Parameters analyzed are described in the following section. Samples were taken once in July and twice during August and September.

Flows in the Bear River immediately below the Grace Diversion Dam were monitored hourly and reported as average daily flows. This location corresponds to the continuous water quality station, GC02.

2.2 Monitoring Parameters

As noted above, two separate data sets were collected as part of the Grace-Cove WQMP. The parameters are defined below.

2.2.1 Continuously Monitoring Probes

YSI Model 6920 probes were installed by ERI at each of the four sites and were programmed to collect data at 15-minute intervals over three 7-day periods. Parameters recorded included:

1) specific conductance (µmhos/cm);
2) temperature (°C);
3) dissolved oxygen (mg/L and % saturation); and,
4) turbidity (NTU)

2.2.2 Instantaneous Sampling

Grab samples were collected twice during each of the three continuous monitoring 7-day periods. Samples were analyzed by ERI’s EPA and state of Utah certified laboratory. Water quality parameters included:

1) total phosphorus (mg/L);
2) orthophosphorus (mg/L);
3) ammonia (mg/L);
4) nitrate (mg/L);

5) nitrite (mg/L);

6) total suspended solids (mg/L); and,

7) turbidity (NTU)

3.0 MONITORING RESULTS

As noted in the previous sections, water quality data were instantaneously collected at four sites in the Bear River above, within and below the Grace-Cove Development. The collection and analysis of the data is intended to address the major objectives of the program. Those objectives are:

1) Characterize water quality conditions in the Grace bypass reach; and,

2) Help determine the Development’s contribution, if any, to exceedances of water quality criteria as set forth in the Idaho Water Quality Standards and Wastewater Treatment Requirements, IDAPA 53.01.02 (Water Quality Standards).

3.1 Continuous Monitoring

3.1.1 Site Hydrology

The monthly sampling events spanned a range of hydrological conditions on the Bear River (Figure 9) Flows below Soda Dam at site GC01 ranged from as high as 1,461 cubic feet per second (cfs) in July to as low as 258 cfs in September.

The first sampling period (July 8 through July 15) was characterized by flows ranging from 1,172 to 1,461 cfs below Soda Dam (reflected in sites GC01 and GC04). Flows varied slightly around 1,430 cfs during the first three days and then dropped to near 1,200 cfs for the last four days of this week. Flow below Grace Dam (GC02) ranged from 103 cfs to 131 cfs, first increasing and then decreasing slightly. Flow at GC03 is not gauged, but reflects those flows at GC02 plus the ungauged discharge from multiple springs in Black Canyon (Figure 9). Differences between the two stations reflect the conditions at the sites as a result of the diversion of water through the Grace power plant (sites GC01 vs. GC02) and the subsequent mixing of bypass flows with groundwater discharge from Black Canyon.

The second sampling period occurred between August 5 and August 12. Flows decreased for the first five days and then increased slightly ranging from 810 cfs to 926 cfs below Soda Dam. Flows below Grace Dam ranged from 83 cfs to 113 cfs.

The last sampling event occurred between September 6 and September 13 and included the lowest flows of the study period. Flows steadily decreased from 762 cfs to 258 cfs below Soda Dam over the 7-day sampling period. Flows below Grace Dam were steady around 84 cfs for the first five days and then increased to 101 cfs by the last day of the sampling period.

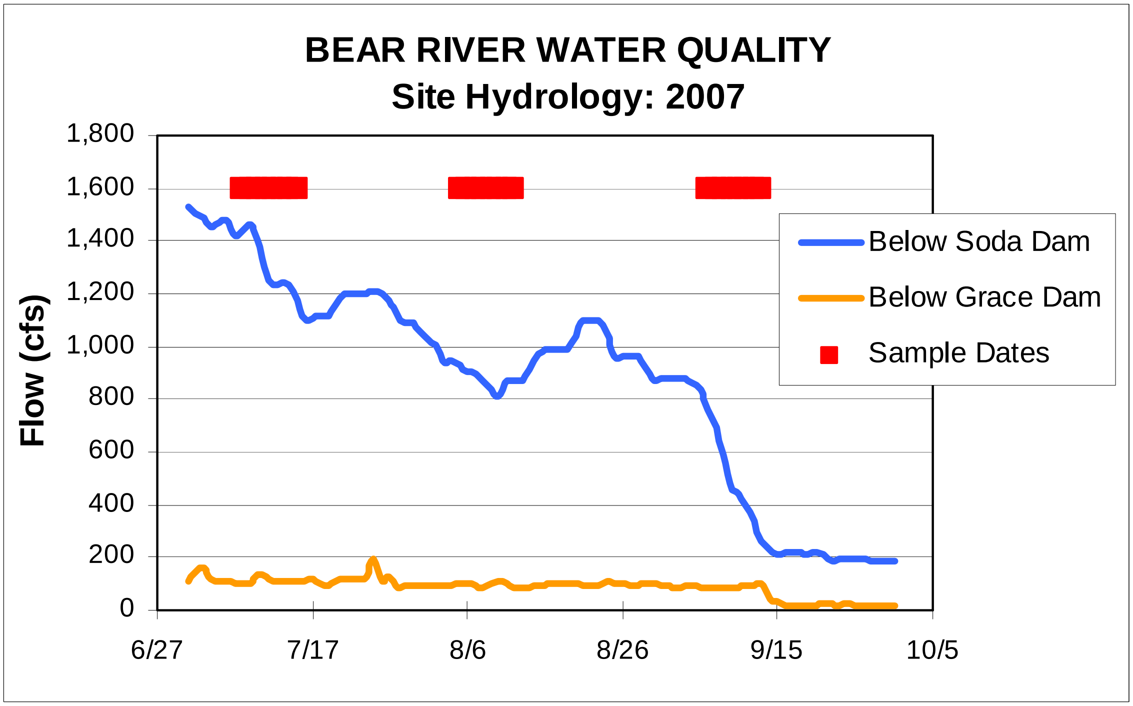


Figure 9. Flows recorded in the Bear River during the 2007 monitoring period.

3.1.2 Site Water Quality

3.1.2.1 July 2007 Water Quality

The water quality data collected continuously at the four stations are plotted in Figures 10 through 14. A summary of water quality attributes at each site during the sample period in July (July 8-15) is provided in Table 1. The table contains the number of observations, average, minimum and maximum values and variance statistics for each parameter recorded. Large mats of periphytic algae were common throughout the study area and often lodged onto the probes, causing artificially high turbidity readings. The probes were visited at least once every 48 hours and any debris was cleaned at each visit. Interpretation of short term deviations from overall patterns includes recognition of the impact of these algae mats on the water quality probes.

At stations GC01 and GC03 for each day of measurement, maximum water temperatures (21-23.5°C) were reached between 3:00 p.m. and 4:30 p.m. At stations GC02 and GC04, daily maximum water temperatures (21.5-24°C) were reached between 4:00 p.m. and 7:00 p.m. Minimum temperatures (16.9-21.8°C) occurred between 7:00 and 9:00 a.m. Dissolved oxygen expressed as mg/l (Figure 11) and percent saturation (Figure 12) followed similar diel patterns. Specific conductance and turbidity did not have a consistent diel pattern for all sites. Turbidity levels varied among sites with GC03 and GC04 recording the greatest number of peak events (Figure 13).

To characterize diel variation, a one-way ANOVA was conducted for each parameter. The data were blocked by time of day so that observations within each hour (i.e. 6 p.m.) were compared to observations at every other hour. The analysis assumes that each hourly block includes at least 28 replicates (4 observations/hr over 7 days). The results of the one-way ANOVA for each site and each parameter are shown in Table 2. The ANOVAs indicate that for temperature and dissolved oxygen (percent saturation and concentration) there are significant differences among hours of the day (p-value<0.001) at all four sites. There were no significant daily variations in conductance or turbidity in July.

In order to partition the daily variation confirmed by the ANOVAs, the oxygen and temperature data were divided into two 12-hour data sets; 7 p.m. to 7 a.m. (night) and 7 a.m. to 7 p.m. (day) This distinction separates the warmer and cooler periods of each day, as well as the solar input availability, and reduces variation within each group. Two additional analyses were completed to detect statistically significant differences among sites for the monitored parameters. Tukey tests were completed to determine which pairs of sites were different for each parameter. In addition, paired linear regressions were run between sites to determine the correlations among sites.

The Tukey analysis tested for differences among all possible pairs of sites for each parameter and time period (Table 3). The meaningful comparisons describing the effect of the hydroelectric complex are those relative to the control site (GC01). The temperature at GC01 was significantly

Table 1. The descriptive statistics of the instantaneous data collected on the Bear River in July 2007.

Date	N	Range	Min	Max	Mean	Standard Error	Standard Deviation	Variance
Temperature (°C)								
GC01	673	2.45	20.9	23.4	22.1	0.02	0.63	0.40
GC02	673	2.94	21.2	24.1	22.4	0.03	0.68	0.46
GC03	673	5.73	16.9	22.6	19.6	0.06	1.54	2.38
GC04	673	2.48	20.8	23.3	21.9	0.02	0.53	0.28
Specific Conductance (µmho/cm)								
GC01	672	0.01	0.67	0.69	0.68	0	0	0
GC02	673	0.03	0.68	0.71	0.70	0	0.01	0
GC03	671	0.23	0.64	0.87	0.74	0	0.07	0
GC04	673	0.06	0.64	0.70	0.68	0	0.02	0
Dissolved Oxygen (%)								
GC01	673	34.3	65.4	99.7	75.2	0.31	8.15	66.4
GC02	673	48.3	63.5	112	80.8	0.48	12.5	157
GC03	664	86.9	51.6	139	89.6	0.98	25.3	639
GC04	673	27.0	75.3	102	86.0	0.24	6.23	38.8
Dissolved Oxygen (mg/L)								
GC01	673	2.79	5.72	8.51	6.54	0.02	0.64	0.41
GC02	673	4.02	5.44	9.46	6.98	0.04	1.03	1.07
GC03	664	7.72	4.71	12.4	8.17	0.08	2.19	4.78
GC04	673	2.46	6.43	8.89	7.51	0.02	0.54	0.29
Turbidity (NTU)								
GC01	673	259	9.5	268	39.4	0.45	11.7	138
GC02	672	47.5	20.8	68.3	33.1	0.31	7.99	63.9
GC03	670	92.6	0.4	93	2.31	0.20	5.28	37.7
GC04	671	341	18.6	359	45.3	1.46	37.7	1420

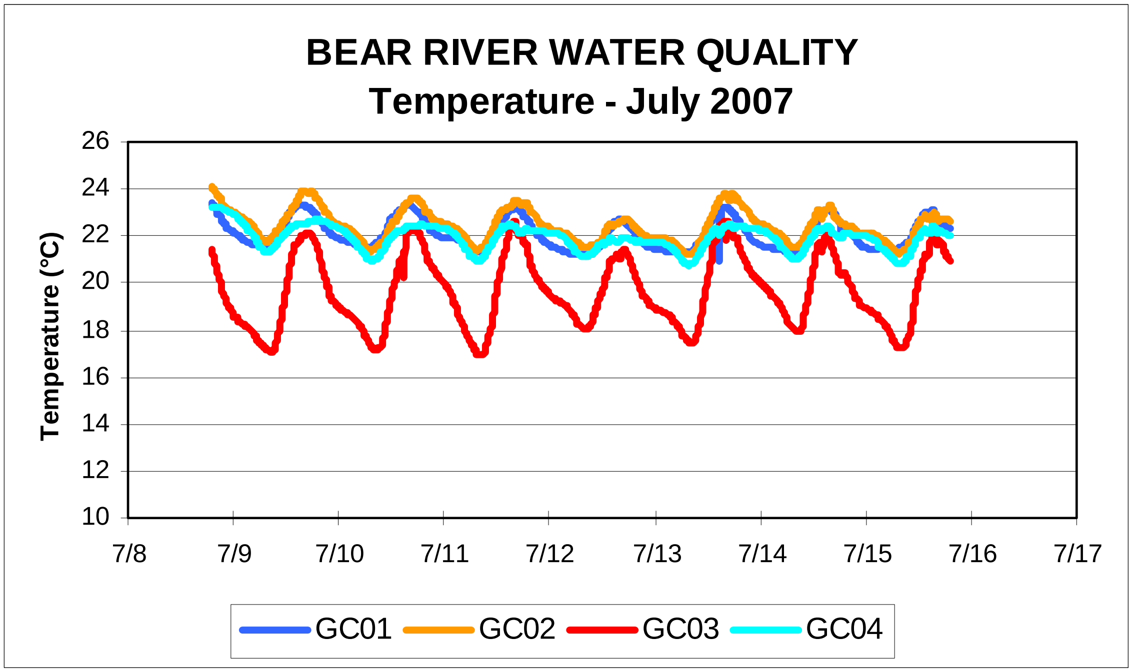


Figure 10. Temperature at the four monitoring locations during July 2007.

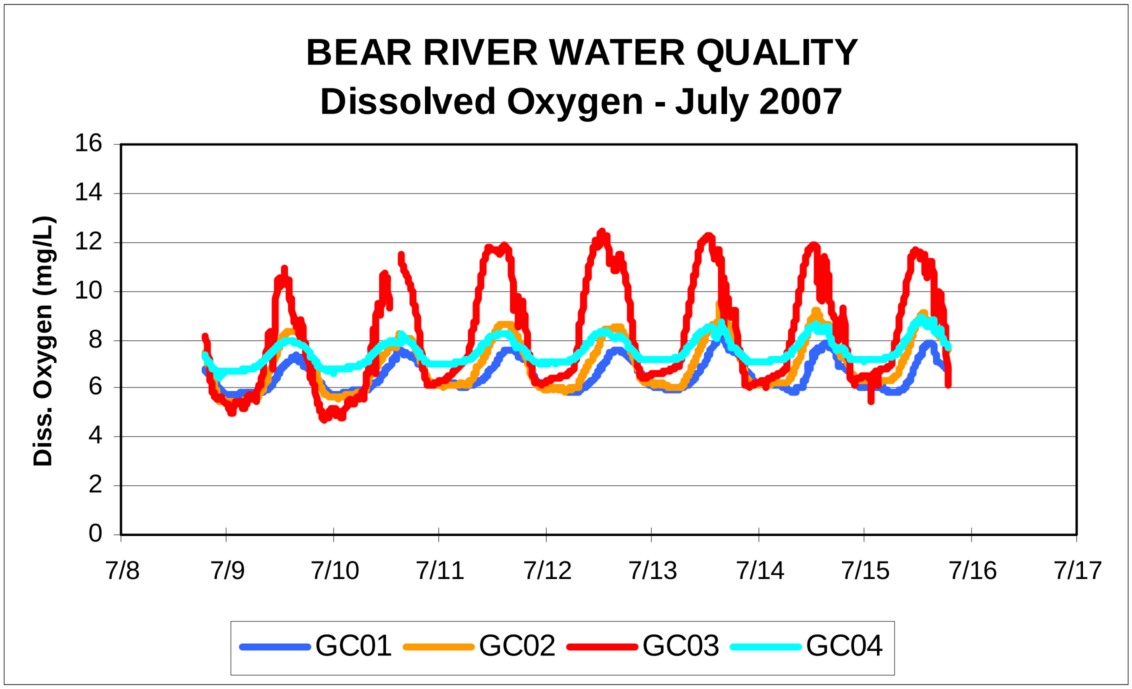


Figure 11. Dissolved oxygen (mg/L) at the four monitoring locations during July 2007.

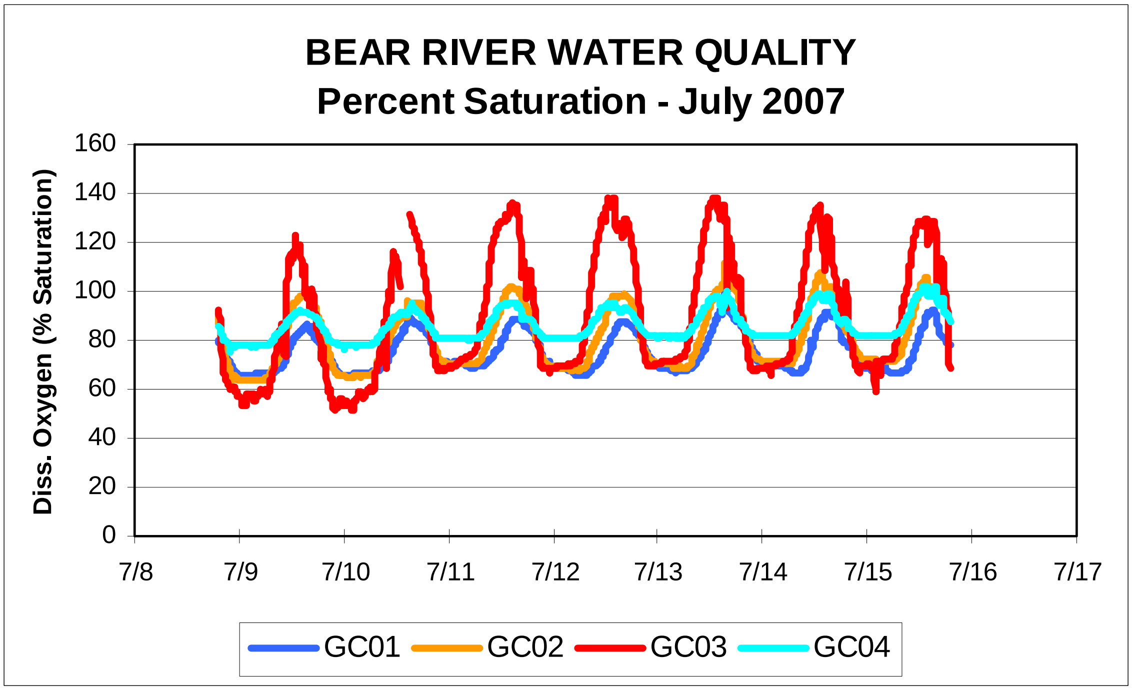


Figure 12. Dissolved oxygen (% saturation) at the four monitoring locations during July 2007.

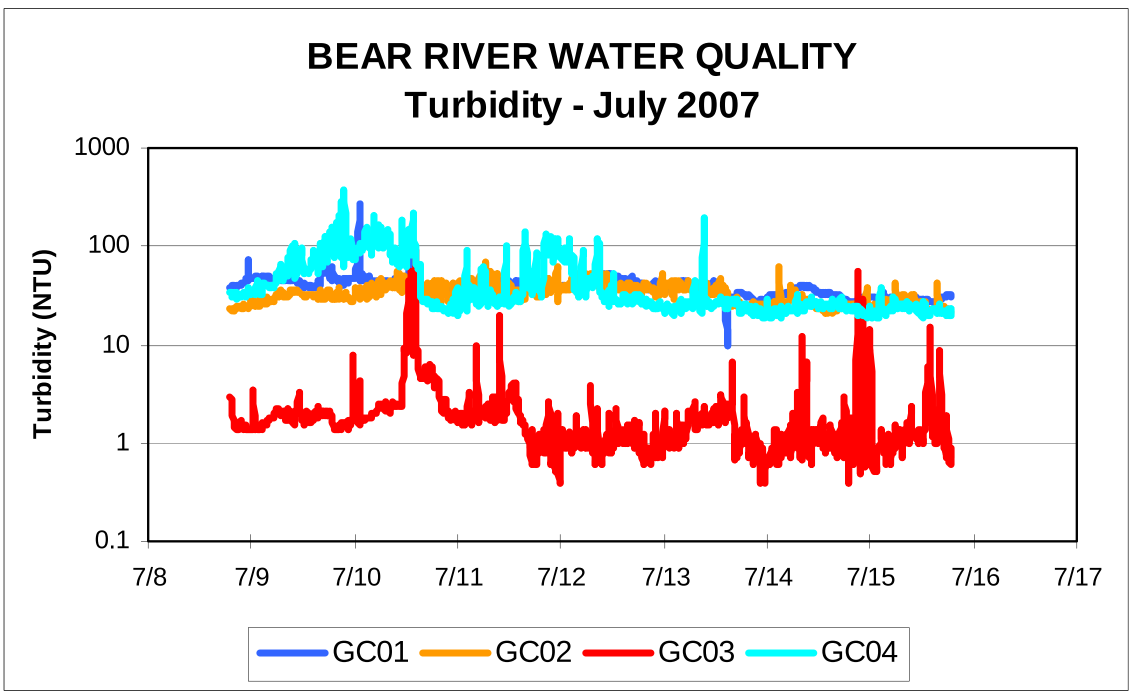


Figure 13. Turbidity at the four monitoring locations during July 2007.

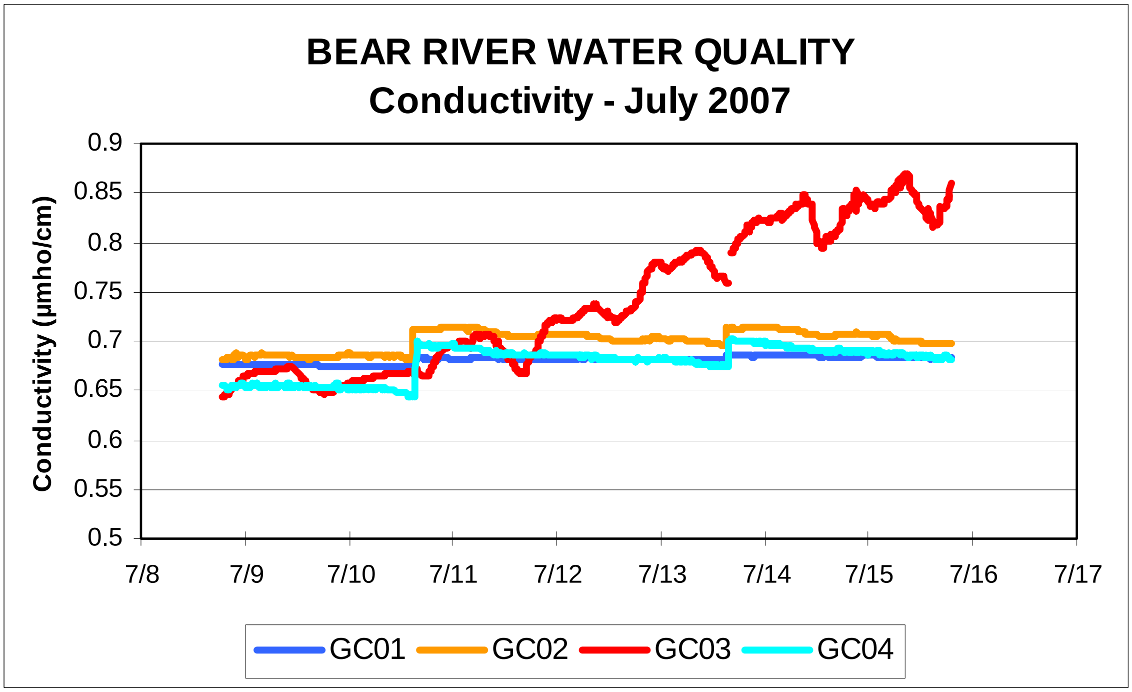


Figure 14. Specific conductance at the four monitoring locations during July 2007.

different ($p<0.05$) from all other sites at night, but was not significantly different from GC02 during the day when sites GC01 and GC02 were both warmer than the downstream sites. Percent saturation of dissolved oxygen at the downstream sites was also significantly higher than GC01 during the day, but at night GC04 was the only site significantly higher than GC01. Dissolved oxygen concentrations showed patterns similar to dissolved oxygen saturation levels, with the exception of site GC03 which did not have oxygen saturation levels significantly different form GC01 at night but did have significantly higher oxygen concentrations at night. This divergence reflects the degree to which both temperature and oxygen concentration affect oxygen saturation as cooler water can dissolve more oxygen. Turbidity was significantly higher at GC04 and significantly lower at GC03 as compared to GC01. Specific conductance showed the opposite pattern as GC03 and GC02 both had significantly higher levels than GC01 and GC04.

By comparing the differences between adjacent sample sites (GC01 vs GC02; GC02 vs. GC03; GC03 vs. GC04) it is possible to evaluate the systematic change in water quality parameters as water moves through the hydroelectric complex. In the case of temperature, significant differences occurred at all adjacent sample sites at night ($p<0.05$) and between each pair of adjacent sites during the day except between GC01 and GC02. GC01 consistently had the lowest oxygen levels (concentration and saturation) but the difference between the oxygen levels at GC01 and GC02 was only significant during the day. GC02 consistently had lower oxygen concentrations than GC03 during the day, but lower concentrations did not reflect lower saturation levels at night. The trend in oxygen levels between sites GC03 and GC04 reversed from day to night. During the day, oxygen levels were significantly higher at GC03, but at night the opposite was true. At no time did oxygen levels appear to be negatively impacted by the hydroelectric complex. There was no significant change in turbidity between sites GC01 and GC02, but GC03 had dramatically lower turbidity levels and GC04 had significantly higher turbidity levels than the control site. Differences in specific conductance among sites were small but statistically significant. Specific conductance increased form site GC01 to GC02 and again from GC02 to GC03 and then decreased to levels not significantly different from GC01 at site GC04. Although specific conductance is often correlated with turbidity in rivers, this was not the case during this sampling period at any of the sites.

Pair-wise linear regressions were used to determine if the same pattern of changes were occurring at each site for each parameter. In other words, could the observations at any site predict the values of another site, even if the values were different? The regressions for the entire July data set (n=672) are shown in Table 5. The table includes the coefficient of determination (R^2), the significance level of the regression relationship and the coefficient value of the linear predictor. Because of the large sample size, a large proportion of the regressions are significant. Inspection of the R^2 value indicates what proportion of the variability at a site can be explained by the second site. The coefficient value (β) indicates the effect of the correlation, or the change in predicted value for every unit of change in the predictor value. For example, the variability in

Table 2. The ANOVA for determining if there is a significant difference among the parameter values at each hour of the day. This analysis is assuming each hour (e.g. 6:00 p.m.) has seven replicates over the study in July 2007.

		Sum of Squares	df	Mean Square	F	P-value	Significant variation by time of day
Temperature (°C)							
GC01	Between Groups	225	23	9.79	145	0.000	yes
	Within Groups	43.8	648	0.068			
	Total	269	671				
GC02	Between Groups	236	23	10.3	87.1	0.000	yes
	Within Groups	76.3	648	0.118			
	Total	312	671				
GC03	Between Groups	1460	23	63.5	292	0.000	yes
	Within Groups	141	648	0.218			
	Total	1600	671				
GC04	Between Groups	141	23	6.13	80.4	0.000	yes
	Within Groups	49.4	648	0.076			
	Total	190	671				
Specific Conductance (μmho/cm)							
GC01	Between Groups	0.015	23	0.00066	1.01	0.449	no
	Within Groups	0.422	647	0.00065			
	Total	0.437	670				
GC02	Between Groups	0.003	23	0.00012	1.08	0.359	no
	Within Groups	0.069	648	0.00011			
	Total	0.072	671				
GC03	Between Groups	0.103	23	0.00447	0.684	0.864	no
	Within Groups	4.24	648	0.00654			
	Total	4.34	671				
GC04	Between Groups	0.006	23	0.00026	0.944	0.538	no
	Within Groups	0.175	648	0.00027			
	Total	0.181	671				
Dissolved Oxygen (%)							
GC01	Between Groups	41000	23	1780	321	0.000	yes
	Within Groups	3590	648	5.54			
	Total	44600	671				
GC02	Between Groups	97800	23	4250	349	0.000	yes
	Within Groups	7890	648	12.2			

		Sum of Squares	df	Mean Square	F	P-value	Significant variation by time of day
	Total	106000	671				
GC03	Between Groups	336000	23	14600	87.6	0.000	yes
	Within Groups	108000	648	167			
	Total	444000	671				
GC04	Between Groups	22700	23	989	192	0.000	yes
	Within Groups	3340	648	5.15			
	Total	26000	671				
Dissolved Oxygen (mg/L)							
GC01	Between Groups	246	23	10.7	252	0.000	yes
	Within Groups	27.5	648	0.042			
	Total	274	671				
GC02	Between Groups	655	23	28.5	303	0.000	yes
	Within Groups	60.8	648	0.094			
	Total	716	671				
GC03	Between Groups	2500	23	109	83.1	0.000	yes
	Within Groups	847	648	1.31			
	Total	3340	671				
GC04	Between Groups	165.2	23	7.18	157	0.000	yes
	Within Groups	29.7	648	0.046			
	Total	194.9	671				
Turbidity (NTU)							
GC01	Between Groups	4620	23	201	1.48	0.069	no
	Within Groups	87800	648	136			
	Total	925	671				
GC02	Between Groups	37960	23	1650	1.09	0.349	no
	Within Groups	979600	648	1510			
	Total	1018000	671				
GC03	Between Groups	161000	23	6990	1.05	0.393	no
	Within Groups	4296000	648	6630			
	Total	4457000	671				
GC04	Between Groups	47700	23	2070	0.709	0.839	no
	Within Groups	1895000	648	2920			
	Total	1943000	671				

Table 3. The results of the TUKEY tests to determine significant differences (p-value, 0.05) between means for different pairs of sample locations. The analysis has been grouped for the hours of 7 p.m. to 7 a.m. (night) and 7 a.m. to 7 p.m. (day) for parameters that demonstrate significant differences among hours of the day as determined by ANOVAs.

Comparison	Difference in Means	Standard Error	q	Critical q value	Significant Difference?
Day Dissolved Oxygen (mg/L)					
GC01 vs GC02	0.86	0.06	14.67	3.66	yes
GC01 vs GC03	2.94	0.06	50.11	3.66	yes
GC01 vs GC04	1.05	0.06	17.93	3.66	yes
GC02 vs GC03	2.08	0.06	35.45	3.66	yes
GC02 vs GC04	0.19	0.06	3.27	3.66	no
GC03 vs GC04	1.89	0.06	32.18	3.66	yes
Night Dissolved Oxygen (mg/L)					
GC01 vs GC02	0.02	0.03	0.56	3.66	no
GC01 vs GC03	0.22	0.03	7.25	3.66	yes
GC01 vs GC04	0.89	0.03	29.88	3.66	yes
GC02 vs GC03	0.2	0.03	6.68	3.66	yes
GC02 vs GC04	0.87	0.03	29.32	3.66	yes
GC03 vs GC04	0.67	0.03	22.64	3.66	yes
Day Dissolved Oxygen (%)					
GC01 vs GC02	10.3	0.7	14.48	3.66	yes
GC01 vs GC03	29	0.7	40.96	3.66	yes
GC01 vs GC04	11.2	0.7	15.8	3.66	yes
GC02 vs GC03	18.8	0.7	26.48	3.66	yes
GC02 vs GC04	0.9	0.7	1.32	3.66	no
GC03 vs GC04	17.8	0.7	25.16	3.66	yes
Night Dissolved Oxygen (%)					
GC01 vs GC02	1	0.4	2.71	3.66	no
GC01 vs GC03	1.1	0.4	3.09	3.66	no
GC01 vs GC04	10.5	0.4	29.57	3.66	yes
GC02 vs GC03	2.1	0.4	5.8	3.66	yes
GC02 vs GC04	9.5	0.4	26.86	3.66	yes

Comparison	Difference in Means	Standard Error	q	Critical q value	Significant Difference?
GC03 vs GC04	11.6	0.4	32.66	3.66	yes
Day Temperature (°C)					
GC01 vs GC02	0.16	0.06	2.72	3.66	no
GC01 vs GC03	2.36	0.06	39.54	3.66	yes
GC01 vs GC04	0.52	0.06	8.63	3.66	yes
GC02 vs GC03	2.52	0.06	42.26	3.66	yes
GC02 vs GC04	0.68	0.06	11.36	3.66	yes
GC03 vs GC04	1.84	0.06	30.9	3.66	yes
Night Temperature (°C)					
GC01 vs GC02	2.44	0.04	65.95	3.66	yes
GC01 vs GC03	0.14	0.04	3.85	3.66	yes
GC01 vs GC04	2.23	0.04	60.34	3.66	yes
GC02 vs GC03	2.58	0.04	69.8	3.66	yes
GC02 vs GC04	0.21	0.04	5.61	3.66	yes
GC03 vs GC04	2.37	0.04	64.19	3.66	yes
Specific Conductance (µmho/cm)					
GC01 vs GC02	0.02	0.002	12.14	3.66	yes
GC01 vs GC03	0.058	0.002	34.64	3.66	yes
GC01 vs GC04	0.002	0.002	0.93	3.66	no
GC02 vs GC03	0.038	0.002	22.5	3.66	yes
GC02 vs GC04	0.022	0.002	13.07	3.66	yes
GC03 vs GC04	0.059	0.002	35.57	3.66	yes
Turbidity (NTU)					
GC01 vs GC02	4.9	2.04	2.39	3.66	no
GC01 vs GC03	32.7	2.04	16.01	3.66	yes
GC01 vs GC04	7.7	2.04	3.76	3.66	yes
GC02 vs GC03	27.8	2.04	13.62	3.66	yes
GC02 vs GC04	12.5	2.04	6.15	3.66	yes
GC03 vs GC04	40.3	2.04	19.76	3.66	yes

Table 4. A summary of TUKEY test results for the five water quality parameters measured continuously in July 2007.

	GC01	GC02	GC03	GC04	Rank
Mean Day Temperature (°C)	22.3	22.5	20	21.8	GC03<GC04<GC01=GC02
Mean Night Temperature (°C)	21.8	22.4	19.2	22	GC03<GC01<GC04<GC02
Mean Day DO (%)	80	90	109	91	GC01<GC02=GC04<GC03
Mean Night DO (%)	71	72	70	81	GC03=GC01=GC02<GC04
Mean Day DO (mg/L)	6.89	7.75	9.84	7.94	GC01<GC02=GC04<GC03
Mean Night DO (mg/L)	6.19	6.21	6.41	7.08	GC01=GC02<GC03<GC04
Mean Spec. Conductance (µm/cm)	0.68	0.7	0.738	0.678	GC04=GC01<GC02<GC03
Mean Turbidity (NTU)	39.5	34.6	6.8	47.1	GC03<GC02=GC01<GC04

Table 5. The results of the paired linear regressions between the four sample sites on the Bear River during July 2007.

	N	Adjusted R Square	Significance	Coefficient (ß)
Temperature (°C)				
GC01 vs GC02	672	0.77	0	0.94
GC01 vs GC03	672	0.73	0	2.08
GC01 vs GC04	672	0.49	0	0.59
GC02 vs GC03	672	0.76	0	1.97
GC02 vs GC04	672	0.82	0	0.71
GC03 vs GC04	672	0.52	0	0.25
Specific Conductance (µmho/cm)				
GC01 vs GC02	672	0.02	0	0.06
GC01 vs GC03	672	0.01	0.035	0.26
GC01 vs GC04	672	0.02	0	0.09
GC02 vs GC03	672	0.19	0	3.39
GC02 vs GC04	672	0.9	0	1.5
GC03 vs GC04	672	0.32	0	0.11
Dissolved Oxygen (%)				
GC01 vs GC02	672	0.86	0	1.43
GC01 vs GC03	672	0.49	0	2.22
GC01 vs GC04	672	0.68	0	0.63
GC02 vs GC03	672	0.73	0	1.75
GC02 vs GC04	672	0.9	0	0.47
GC03 vs GC04	672	0.82	0	0
Dissolved Oxygen (mg/L)				
GC01 vs GC02	672	0.83	0	1.48
GC01 vs GC03	672	0.42	0	2.27
GC01 vs GC04	672	0.61	0	0.66
GC02 vs GC03	672	0.69	0	1.8
GC02 vs GC04	672	0.88	0	0.49
GC03 vs GC04	672	0.81	0	0.22
Turbidity (NTU)				
GC01 vs GC02	672	0	0.114	0.2
GC01 vs GC03	672	0	0.709	0.1
GC01 vs GC04	672	0.06	0	1.12
GC02 vs GC03	672	0	0.974	0
GC02 vs GC04	672	0	0.195	0.07
GC03 vs GC04	672	0	0.791	-0.01

temperature at site GC01 can explain only 49 percent of the variability in temperature at GC04 ($p < 0.05$), but can explain 77 percent of the temperature variability at GC02 ($p < 0.05$). Similarly, although the regression of site GC01 on GC02 has a similar coefficient of determination as the regression of GC02 on GC03 ($r^2 = 0.77, 0.76$), the former relationship has as coefficient of 0.94 whereas the latter relationship has a coefficient of 1.97. This means that although changes in GC02 account for approximately 76 percent of the variation in both GC01 and GC03, for every degree that the temperature at GC02 changes, on average the temperature at GC01 will change 1.06 degrees and the temperature at GC03 will change 1.97 degrees. Overall, temperatures and oxygen levels were highly correlated among sites ($0.42<R^2<0.90$). However, oxygen saturation levels showed a tighter relationship than absolute concentrations of dissolved oxygen. Specific conductance levels showed very low levels of correlation with the exception of sites GC02 and GC04, which were highly correlated ($R^2 = 0.9$; $\beta=1.5$). Turbidity observations showed no correlations among sites.

3.1.2.2 August 2007 Water Quality

The water quality data collected continuously at the four stations are plotted in Figures 15 through 19. General patterns were similar to observations in July. A summary of water quality attributes at each site during the sample period in August (August 5-12) is provided in Table 6. The table contains the number of observations, average, minimum and maximum values and variance statistics for each parameter.

Maximum water temperatures recorded at each station ranged from 21.5°C to 22.7°C, with the greatest range in temperature occurring at GC03 which exhibited large daily fluctuations. Minimum temperatures ranged from 14.7°C to 18.9°C (Figure 15). Dissolved oxygen expressed as mg/l (Figure 16) and percent saturation (Figure 17) exhibited similar diel patterns with the greatest range occurring in GC04. Specific conductance and turbidity did not have a consistent diel pattern for all sites. Turbidity levels varied considerably in space and time with GC04 recording the greatest number of peak events (similar to other months). Though GC03 had overall lower turbidity readings during August, it experienced more variability than GC01 and GC02 (Figure 18).

To characterize diel variation a one-way ANOVA was conducted for each parameter. The data were blocked by time of day so that observations within each hour (i.e. 6 p.m.) were compared to observations at every other hour. The analysis assumes that each hourly block includes at least 28 replicates (4 observations/hr over 7 days). The results of the one-way ANOVA for each site and each parameter are shown in Table 7. The ANOVAs indicate that there are significant differences among times of day (p-value<0.001) for temperature and dissolved oxygen (percent saturation and concentration) at all four sites, just as seen in the July observations. Conductance was significantly different among times of day at all sites except GC02. Significant differences in turbidity among hours of the day only occurred at GC01.

Table 6. The descriptive statistics of the instantaneous data collected on the Bear River in August 2007.

Date	N	Range	Min	Max	Mean	Standard Error	Standard Deviation	Variance
Temperature (°C)								
GC01	673	3.87	18.8	22.7	20.6	0.04	0.91	0.84
GC02	672	3.15	19.4	22.6	20.8	0.03	0.75	0.56
GC03	673	6.8	14.7	21.5	18.3	0.07	1.74	3.02
GC04	673	2.95	18.9	21.9	20.3	0.03	0.71	0.51
Specific Conductance (µmho/cm)								
GC01	673	0.017	0.620	0.637	0.63	0	0	0
GC02	672	0.015	0.638	0.653	0.65	0	0	0
GC03	673	0.087	0.695	0.782	0.75	0	0.02	0
GC04	673	0.032	0.601	0.633	0.62	0	0.01	0
Dissolved Oxygen (%)								
GC01	673	39.4	64.4	104	79.2	0.41	10.6	113
GC02	673	60.9	63.4	124	84.1	0.57	14.7	216
GC03	673	70.5	80.1	151	108	0.88	22.8	521
GC04	673	129	10.3	139	81.4	0.74	19.2	368
Dissolved Oxygen (mg/L)								
GC01	673	3.41	5.77	9.18	7.09	0.03	0.89	0.79
GC02	673	5.26	5.58	10.8	7.51	0.05	1.27	1.61
GC03	673	6.46	7.27	13.7	10.1	0.08	2	4.01
GC04	673	11.3	0.92	12.3	7.34	0.07	1.71	2.92
Turbidity (NTU)								
GC01	673	41.1	20.3	61.4	27.5	0.14	3.54	12.5
GC02	667	94.7	12.1	106.8	19.4	0.37	9.5	90.3
GC03	533	123	0	123	6.92	0.68	15.7	248
GC04	658	405	8.7	414	34.6	1.2	30.7	940

Table 7. The ANOVA for determining if there is a significant difference between the parameter values over time of day. This analysis is assuming each hour (e.g. 6:00 p.m.) has seven replicates over the study in August 2007.

		Sum of Squares	df	Mean Square	F	P-value	Significant variation by time of day
Temperature (°C)							
GC01	Between Groups	274	23	11.9	27.0	0.000	yes
	Within Groups	287	648	0.443			
	Total	561	671				
GC02	Between Groups	77.1	23	3.35	6.99	0.000	yes
	Within Groups	310	648	0.479			
	Total	387	671				
GC03	Between Groups	1830	23	79.5	261	0.000	yes
	Within Groups	198	648	0.305			
	Total	2030	671				
GC04	Between Groups	115	23	5.02	14.4	0.000	yes
	Within Groups	225	648	0.348			
	Total	341	671				
Specific Conductance (µmho/cm)							
GC01	Between Groups	0.0009	23	0.0000	2.19	0.001	yes
	Within Groups	0.0121	648	0.0000			
	Total	0.0130	671				
GC02	Between Groups	0.0140	23	0.0006	1.04	0.409	no
	Within Groups	0.3774	648	0.0006			
	Total	0.3914	671				
GC03	Between Groups	0.0949	23	0.0041	33.3	0.000	yes
	Within Groups	0.0803	648	0.0001			
	Total	0.1751	671				
GC04	Between Groups	0.0020	23	0.0001	2.76	0.000	yes
	Within Groups	0.0205	648	0.0000			
	Total	0.0226	671				
Dissolved Oxygen (%)							
GC01	Between Groups	68900	23	2996	280	0.000	yes
	Within Groups	6930	648	10.7			
	Total	75800	671				
GC02	Between Groups	133000	23	5800	325	0.000	yes
	Within Groups	11600	648	17.9			

		Sum of Squares	df	Mean Square	F	P-value	Significant variation by time of day
	Total	145000	671				
GC03	Between Groups	337000	23	14670	740	0.000	yes
	Within Groups	12900	648	19.8			
	Total	350000	671				
GC04	Between Groups	60400	23	2624	9.11	0.000	yes
	Within Groups	187000	648	288			
	Total	247000	671				
Dissolved Oxygen (mg/L)							
GC01	Between Groups	447	23	19.4	150	0.000	yes
	Within Groups	83.8	648	0.129			
	Total	530	671				
GC02	Between Groups	985	23	42.8	281	0.000	yes
	Within Groups	98.9	648	0.153			
	Total	1080	671				
GC03	Between Groups	2570	23	112	547	0.000	yes
	Within Groups	132	648	0.204			
	Total	2697	671				
GC04	Between Groups	429	23	18.6	7.87	0.000	yes
	Within Groups	1530	648	2.37			
	Total	1960	671				
Turbidity (NTU)							
GC01	Between Groups	2040	23	88.8	9.043	0.000	yes
	Within Groups	6370	648	9.82			
	Total	8410	671				
GC02	Between Groups	37100	23	1620	0.787	0.749	no
	Within Groups	133000	648	2050			
	Total	1370000	671				
GC03	Between Groups	539000	23	23400	1.24	0.205	no
	Within Groups	1230000	648	18950			
	Total	12800000	671				
GC04	Between Groups	799000	23	34720	0.797	0.737	no
	Within Groups	28200000	648	43550			
	Total	29000000	671				

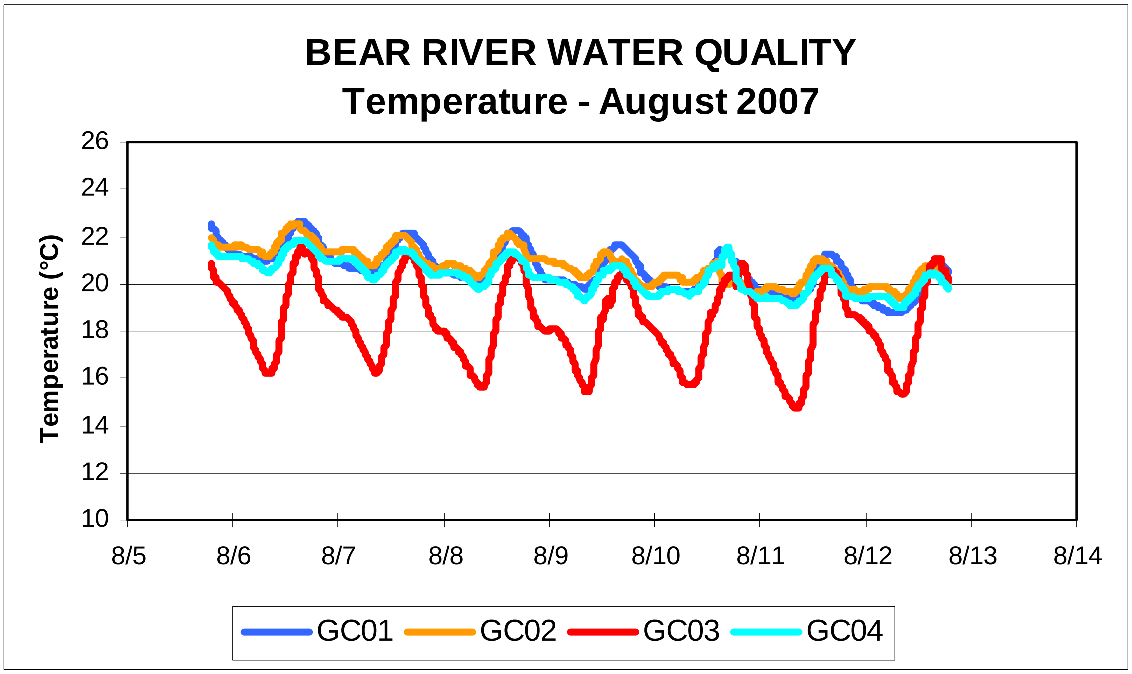


Figure 15. Temperature at the four monitoring locations during August 2007.

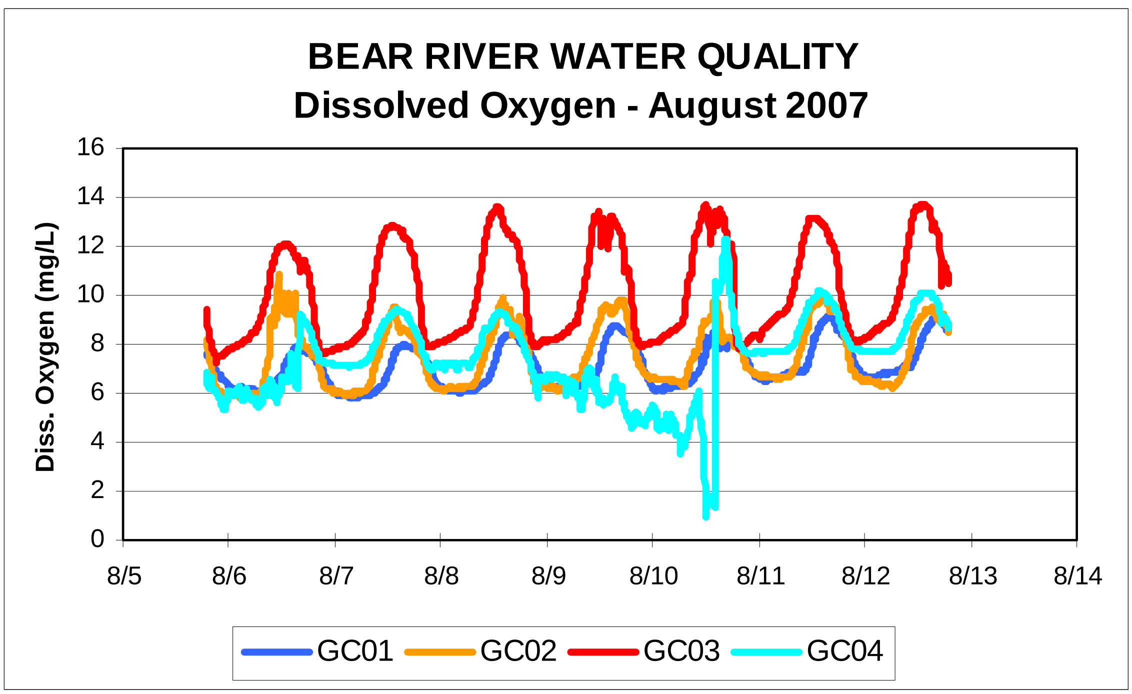


Figure 16. Dissolved oxygen (mg/L) at the four monitoring locations during August 2007.

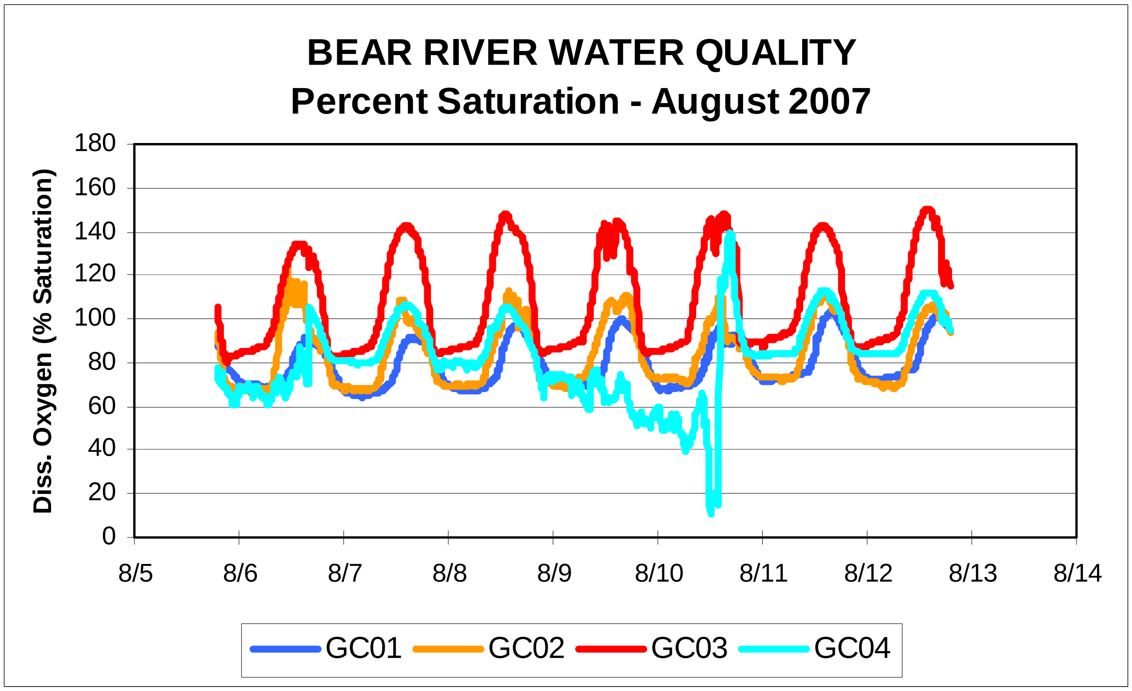


Figure 17. Dissolved oxygen (% saturation) at the four monitoring locations during August 2007.

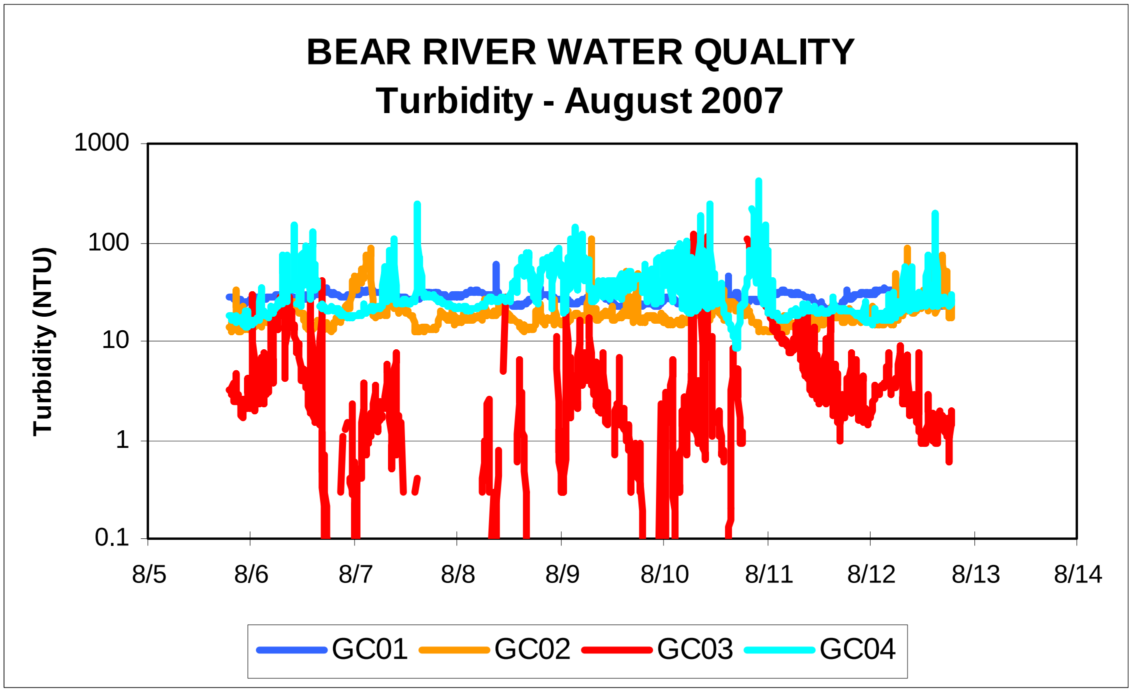


Figure 18. Turbidity at the four monitoring locations during August 2007.

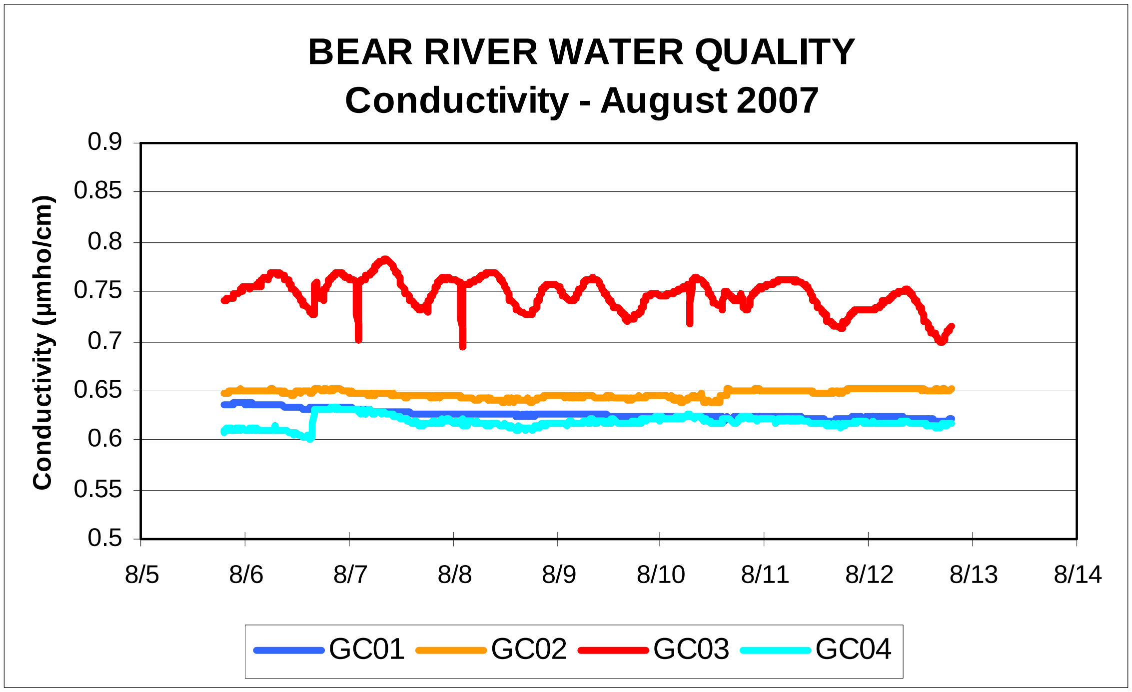


Figure 19. Specific conductance at the four monitoring locations during August 2007.

In order to partition the daily variation confirmed by the ANOVAs, the data were divided into two 12-hour data sets for all the parameters: 7 p.m. to 7 a.m. (night) and 7 a.m. to 7 p.m. (day). This distinction separates the warmer and cooler periods of each day, as well as the solar input availability, and reduces variation within each group. Two additional analyses were completed to detect statistically significant differences between sites for the monitored parameters. Tukey tests were completed to determine which pairs of sites were different for each parameter. Additionally, paired linear regressions were run between sites to determine the degree of correlation among sites that may be significantly different.

The Tukey analysis tested for differences among all possible pairs of sites for each parameter (Table 8). The meaningful comparisons describing the effect of the hydroelectric complex are those relative to the control site (GC01). The temperature at GC01 was significantly different ($p<0.05$) from all sites during the night, but was not significantly different from GC02 during the day. Dissolved oxygen (both percent saturation and concentration) was not significantly different from GC02 during the night, but was during the day. Dissolved oxygen at GC01 was significantly different when compared to GC03 and GC04 for both night and day. With the exception of GC02, percent saturation of dissolved oxygen was also significantly different from GC01 for daytime and night at the downstream sites. Daytime dissolved oxygen concentration was significantly different from GC01 at all sites except GC02, but concentrations at GC03 were the only significant difference during the night. There were no significant differences in turbidity during August.

By comparing the differences between adjacent sample sites (GC01 vs GC02; GC02 vs. GC03; GC03 vs. GC04) one can evaluate the systematic change in water quality parameters as water moves through the hydroelectric complex. With the exception of GC01 and GC02 during the daytime hours, there were significant differences in temperature at all adjacent sample sites ($p<0.05$). Significant differences in dissolved oxygen (concentration and saturation) were observed among all adjacent sites during the day, but at night GC03 had higher levels of oxygen than the other three sites which were not significantly different from each other using either measure of dissolved oxygen. Turbidity did not change significantly from site GC01 through GC03, but was significantly higher at site GC04. Specific conductance steadily increased from site GC01 to GC03 and then dropped back down to levels equivalent to GC01 at site GC04. The lack of correlation between turbidity and specific conductance observed during July continued during August.

Pair-wise linear regressions were used to determine if the same pattern of changes were occurring at each site for each parameter. The regressions for the entire August data set ($n=672$) are shown in Table 10. The table includes the coefficient of determination (R^2), the significance level of the regression relationship and the coefficient value of the linear predictor (β). Because of the large sample size, a large proportion of the regressions are significant. Inspection of the R^2 value indicates what proportion of the variability at a site can be explained by the second site.

Table 8. The results of the TUKEY tests to determine significant differences (p-value, 0.05) between means for different sample locations. The analysis has been grouped for the hours of 7 p.m. to 7 a.m. (night) and 7 a.m. to 7 p.m. (day) for hourly data collected in August of 2007.

Comparison	Difference in Means	Standard Error	q	Critical q value	Significant Difference?
Day Dissolved Oxygen (mg/L)					
GC01 vs GC02	0.6	0.08	7.46	3.66	yes
GC01 vs GC03	3.4	0.08	45.32	3.66	yes
GC01 vs GC04	0.9	0.08	12.32	3.66	yes
GC02 vs GC03	4	0.08	52.78	3.66	yes
GC02 vs GC04	0.4	0.08	4.86	3.66	yes
GC03 vs GC04	4.4	0.08	57.64	3.66	yes
Night Dissolved Oxygen (mg/L)					
GC01 vs GC02	0.1	0.04	2.38	3.66	no
GC01 vs GC03	1.7	0.04	42.92	3.66	yes
GC01 vs GC04	0.1	0.04	3.18	3.66	no
GC02 vs GC03	1.8	0.04	45.3	3.66	yes
GC02 vs GC04	0.2	0.04	5.56	3.66	yes
GC03 vs GC04	1.6	0.04	39.74	3.66	yes
Day Dissolved Oxygen (%)					
GC01 vs GC02	11	0.89	11.85	3.66	yes
GC01 vs GC03	43	0.89	48.41	3.66	yes
GC01 vs GC04	3	0.89	3.83	3.66	yes
GC02 vs GC03	33	0.89	36.56	3.66	yes
GC02 vs GC04	7	0.89	8.02	3.66	yes
GC03 vs GC04	40	0.89	44.58	3.66	yes
Night Dissolved Oxygen (%)					
GC01 vs GC02	1	0.43	1.81	3.66	no
GC01 vs GC03	15	0.43	33.65	3.66	yes
GC01 vs GC04	1	0.43	2.4	3.66	no
GC02 vs GC03	15	0.43	35.46	3.66	yes
GC02 vs GC04	2	0.43	4.21	3.66	yes
GC03 vs GC04	13	0.43	31.26	3.66	yes

Comparison	Difference in Means	Standard Error	q	Critical q value	Significant Difference?
Day Sp Cond					
GC01 vs GC02	0.01	0.001072385	7.74	3.66	yes
GC01 vs GC03	0.03	0.001072385	25.14	3.66	yes
GC01 vs GC04	0.13	0.001072385	117.95	3.66	yes
GC02 vs GC03	0.02	0.001072385	17.41	3.66	yes
GC02 vs GC04	0.12	0.001072385	110.21	3.66	yes
GC03 vs GC04	0.1	0.001072385	92.81	3.66	yes
Night Specific Conductance (µmho/cm)					
GC01 vs GC02	0.02	0.0004	49.31	3.66	yes
GC01 vs GC03	0.12	0.0004	311.6	3.66	yes
GC01 vs GC04	0.01	0.0004	20.17	3.66	yes
GC02 vs GC03	0.1	0.0004	262.28	3.66	yes
GC02 vs GC04	0.03	0.0004	69.48	3.66	yes
GC03 vs GC04	0.13	0.0004	331.77	3.66	yes
Turbidity (NTU)					
GC01 vs GC02	5	4.9	0.95	3.66	no
GC01 vs GC03	7	4.9	1.39	3.66	no
GC01 vs GC04	27	4.9	5.48	3.66	yes
GC02 vs GC03	2	4.9	0.44	3.66	no
GC02 vs GC04	31	4.9	6.43	3.66	yes
GC03 vs GC04	34	4.9	6.87	3.66	yes
Day Temperature (°C)					
GC01 vs GC02	0.1	0.07	0.76	3.66	no
GC01 vs GC03	2.3	0.07	33.34	3.66	yes
GC01 vs GC04	0.4	0.07	5.64	3.66	yes
GC02 vs GC03	2.4	0.07	34.1	3.66	yes
GC02 vs GC04	0.4	0.07	6.39	3.66	yes
GC03 vs GC04	1.9	0.07	27.71	3.66	yes
Night Temperature (°C)					
GC01 vs GC02	0.2	0.05	4.42	3.66	yes
GC01 vs GC03	2.3	0.05	48.92	3.66	yes

Comparison	Difference in Means	Standard Error	q	Critical q value	Significant Difference?
GC01 vs GC04	0.2	0.05	4.55	3.66	yes
GC02 vs GC03	2.5	0.05	53.34	3.66	yes
GC02 vs GC04	0.4	0.05	8.97	3.66	yes
GC03 vs GC04	2.1	0.05	44.37	3.66	yes

Table 9. A summary of TUKEY test results for the five water quality parameters measured continuously in August 2007.

	GC01	GC02	GC03	GC04	Rank
Mean Day Temperature (°C)	20.9	20.9	18.6	20.5	GC03<GC04<GC01=GC02
Mean Night Temperature (°C)	20.4	20.6	18.1	20.2	GC03<GC04<GC01<GC02
Mean Day DO (%)	84	95	127	88	GC01<GC04<GC02<GC03
Mean Night DO (%)	74	73	89	75	GC02=GC01=GC04<GC03
Mean Day DO (mg/L)	7.5	8.4	11.9	7.9	GC01<GC04<GC02<GC03
Mean Night DO (mg/L)	6.7	6.6	8.4	6.8	GC02=GC01=GC04<GC03
Mean Day Spec. Cond. (µm/cm)	0.63	0.64	0.74	0.62	GC04=GC01<GC02<GC03
Mean Night Spec. Cond. (µm/cm)	0.63	0.65	0.75	0.62	GC04=GC01<GC02<GC03
Mean Turbidity (NTU)	28	23	21	54	GC03=GC02=GC01<GC04

Table 10. The results of the paired linear regressions between the four sample sites on the Bear River during August 2007.

	N	Adjusted R Square	Significance	Coefficient (ß)
Temperature (°C)				
GC01 vs GC02	672	0.66	0	0.7
GC01 vs GC03	672	0.59	0	1.5
GC01 vs GC04	672	0.85	0	0.7
GC02 vs GC03	672	0.24	0	1.1
GC02 vs GC04	672	0.77	0	0.8
GC03 vs GC04	672	0.46	0	0.3
Specific Conductance (µmho/cm)				
GC01 vs GC02	672	0	0.16	-0.3
GC01 vs GC03	672	0.23	0	1.8
GC01 vs GC04	672	0.01	0.01	-0.1
GC02 vs GC03	672	0	0.51	0
GC02 vs GC04	672	0.01	0	0
GC03 vs GC04	672	0.11	0	0.1
Dissolved Oxygen (%)				
GC01 vs GC02	672	0.65	0	1.11
GC01 vs GC03	672	0.5	0	1.51
GC01 vs GC04	672	0.17	0	0.74
GC02 vs GC03	672	0.83	0	1.41
GC02 vs GC04	672	0.13	0	0.46
GC03 vs GC04	672	0.19	0	0.37
Dissolved Oxygen (mg/L)				
GC01 vs GC02	672	0.65	0	1.15
GC01 vs GC03	672	0.37	0	1.37
GC01 vs GC04	672	0.16	0	0.78
GC02 vs GC03	672	0.75	0	1.37
GC02 vs GC04	672	0.12	0	0.46
GC03 vs GC04	672	0.15	0	0.33
Turbidity (NTU)				
GC01 vs GC02	672	0.001	0.21	-0.62
GC01 vs GC03	672	0.006	0.03	-3.3
GC01 vs GC04	672	0.005	0.04	-4.69
GC02 vs GC03	672	-0.001	0.7	-0.05
GC02 vs GC04	672	-0.001	0.64	-0.08
GC03 vs GC04	672	-0.001	0.65	0.03

The coefficient value (β) indicates the effect of the correlation, or the change in predicted value for every unit of change in the predictor value. This coefficient value captures the relative magnitude of any correlated variation. Sites with identical dynamics would have both a coefficient of determination and a coefficient value equal to 1. In these data, site GC03 is consistently more variable and so comparisons including GC03 consistently have coefficients considerably different from 1.

The variation in temperatures at the control site GC01 was generally a good predictor of the variability in temperature at the other three sampling sites ($0.59<R^2<0.85$). Site GC03 demonstrated the most variation in temperature within the August sampling period as compared to GC01 (β=1.5), whereas GC02 and GC04 were less variable than the control site GC01 (β=0.7). Dissolved oxygen saturation levels were more correlated among sites than absolute concentrations of dissolved oxygen and were somewhat correlated in sites GC01 through GC03 ($0.50<R^2<0.83$) whereas oxygen dynamics at GC04 appeared to be relatively independent of the other sites ($0.13<R^2<0.19$). The correlations among site GC01-GC03 in oxygen levels also showed sites GC02 and GC03 to have more variation than the control site GC01 (1.11<β<1.51) whereas site GC04 was considerably less variable than GC01 (β=0.74). Specific conductance levels showed very low levels of correlation with the exception of sites GC01 and GC03, which were only mildly correlated ($R^2 = 0.23$; β=1.8). Similar to July, August turbidity observations showed no correlations among sites.

Overall, the August sampling reflected cooler water temperatures, elevated levels of dissolved oxygen with greater daily variation, slightly lower levels of conductivity and more frequent peaks in turbidity than the July sampling. These overall trends were combined with some shifts in the relationships among sites, especially at night.

3.1.2.3 September 2007 Water Quality

The water quality data collected continuously at the four stations in September are plotted in Figures 20 through 24. A summary of water quality attributes at each site during the sample period in September (September 6-12) is provided in Table 11. The table contains the number of observations, average, minimum and maximum values and variance statistics for each parameter.

Temperature and dissolved oxygen demonstrated daily patterns similar to July and August although daily temperature and dissolved oxygen ranges were larger. Maximum water temperatures recorded at each station ranged from 18.8°C to 19.2°C, with the greatest range in temperature occurring at GC03 and GC04. Minimum temperatures ranged from 11.5°C to 15.3°C. The variability in GC03 temperatures was consistent with observations in July and August, but GC04 got much colder at night in September. This shift was coincident with the drop in flows during the September observation period. Dissolved oxygen expressed as mg/l (Figure 21) and percent saturation (Figure 22) also exhibited diel cycles with all the lower sites showing

Table 11. The descriptive statistics of the instantaneous data collected on the Bear River in September 2007.

Date	N	Range	Min	Max	Mean	Standard Error	Standard Deviation	Variance
Temperature (°C)								
GC01	673	4.63	14.7	19.3	17.0	0.04	1.16	1.34
GC02	673	3.67	15.3	19.0	17.1	0.04	0.99	0.98
GC03	673	7.25	11.5	18.8	15.5	0.06	1.66	2.77
GC04	673	7.73	12.2	19.9	16.4	0.07	1.91	3.63
Specific Conductance (µmho/cm)								
GC01	673	0.107	0.615	0.722	0.71	0	0.01	0
GC02	673	0.014	0.632	0.646	0.64	0	0	0
GC03	672	0.130	0.600	0.73	0.71	0	0.01	0
GC04	673	0.073	0.693	0.766	0.72	0	0.01	0
Dissolved Oxygen (%)								
GC01	673	72.5	86.7	159	116	0.59	15.3	233
GC02	673	38.1	71.2	109	86.1	0.37	9.59	91.9
GC03	672	52.8	64.0	117	84.2	0.57	14.7	215
GC04	673	57.1	72.7	130	97.6	0.59	15.2	231
Dissolved Oxygen (mg/L)								
GC01	673	6.64	8.37	15.0	11.2	0.06	1.52	2.32
GC02	673	3.49	6.89	10.4	8.29	0.03	0.86	0.75
GC03	672	5.15	6.22	11.4	8.38	0.05	1.37	1.87
GC04	673	4.87	7.58	12.5	9.50	0.05	1.24	1.55
Turbidity (NTU)								
GC01	673	28.1	9.9	38.0	17.1	0.13	3.34	11.1
GC02	673	131	6.2	137	11.6	0.24	6.21	38.6
GC03	668	89.6	2.5	92.1	5.11	0.24	6.15	37.8
GC04	370	59.1	1.9	61	9.5	0.21	5.44	29.6

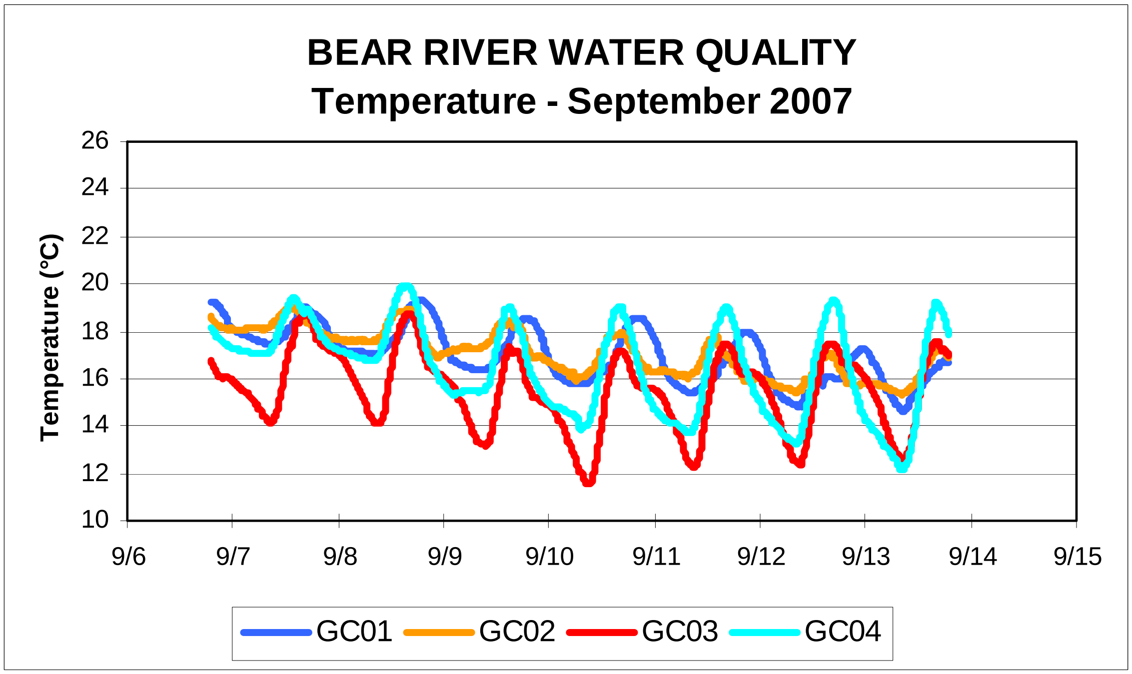


Figure 20. Temperature at the four monitoring locations during September 2007.

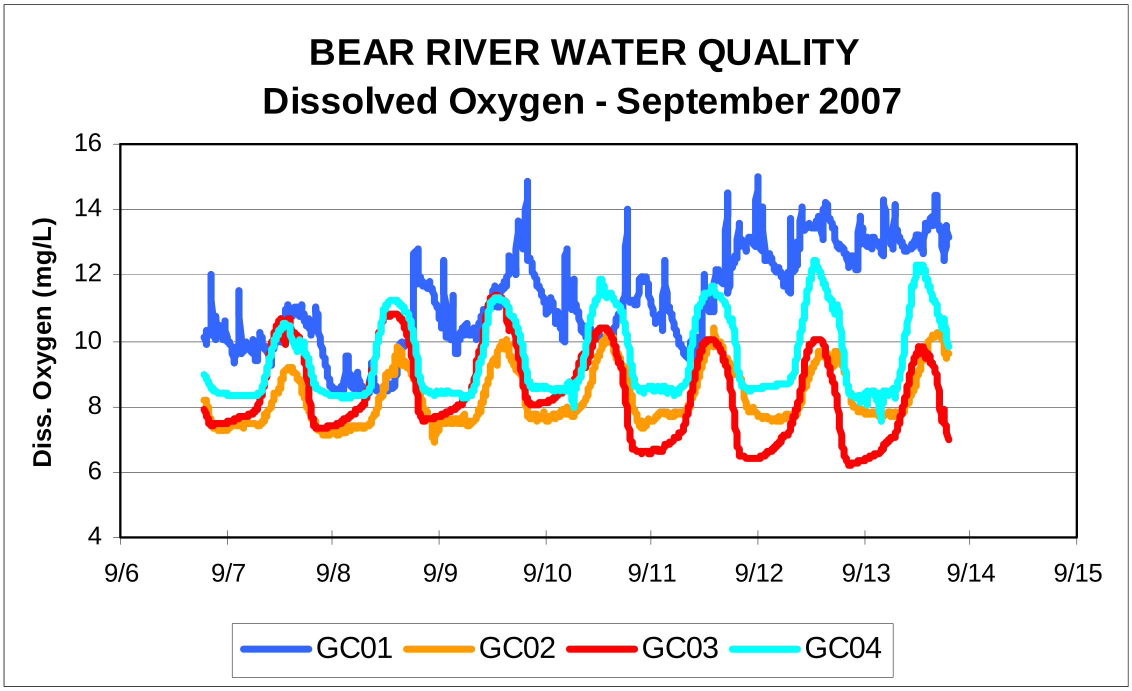


Figure 21. Dissolved oxygen (mg/L) at the four monitoring locations during September 2007.

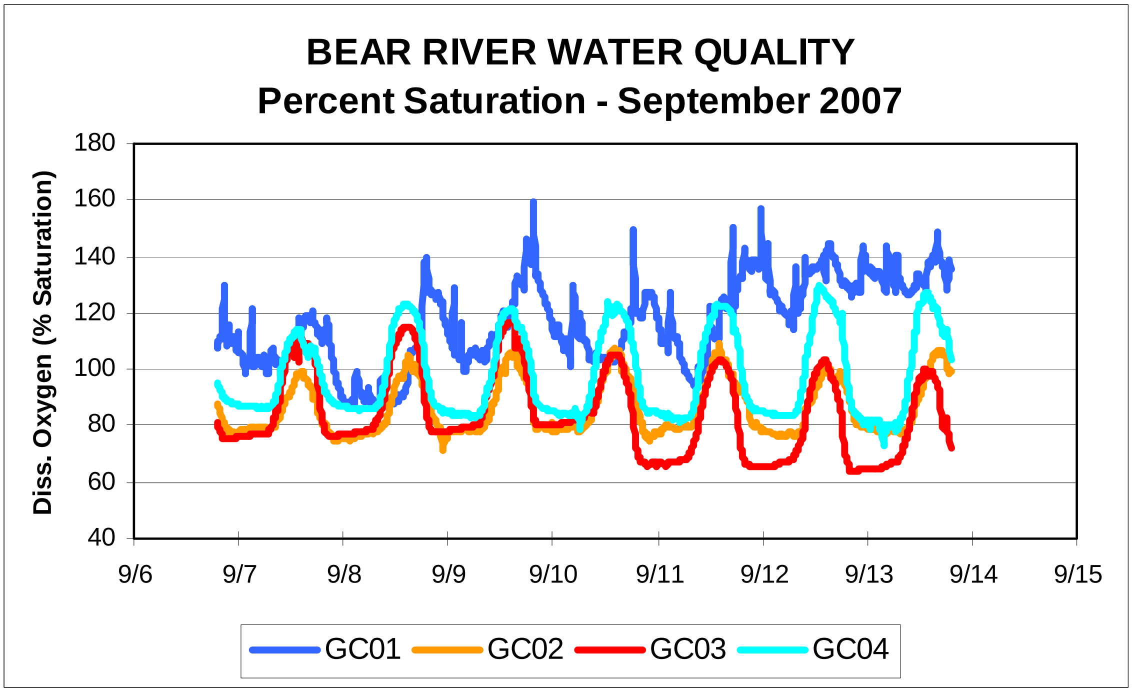


Figure 22. Dissolved oxygen (% saturation) at the four monitoring locations during September 2007.

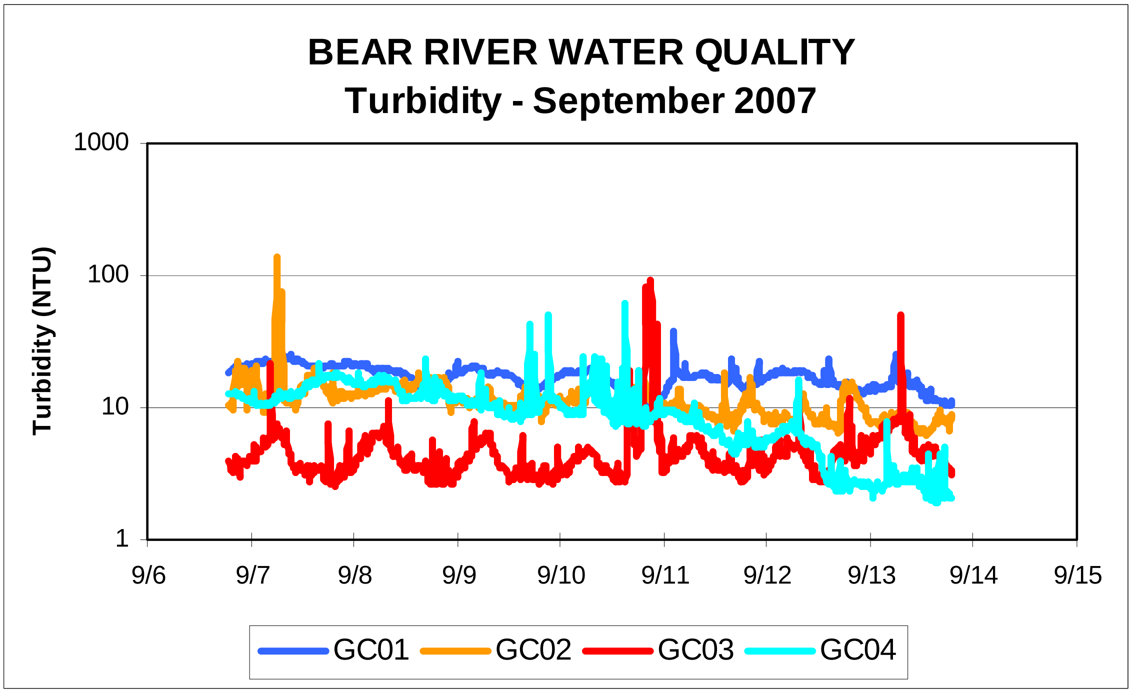


Figure 23. Turbidity at the four monitoring locations during September 2007.

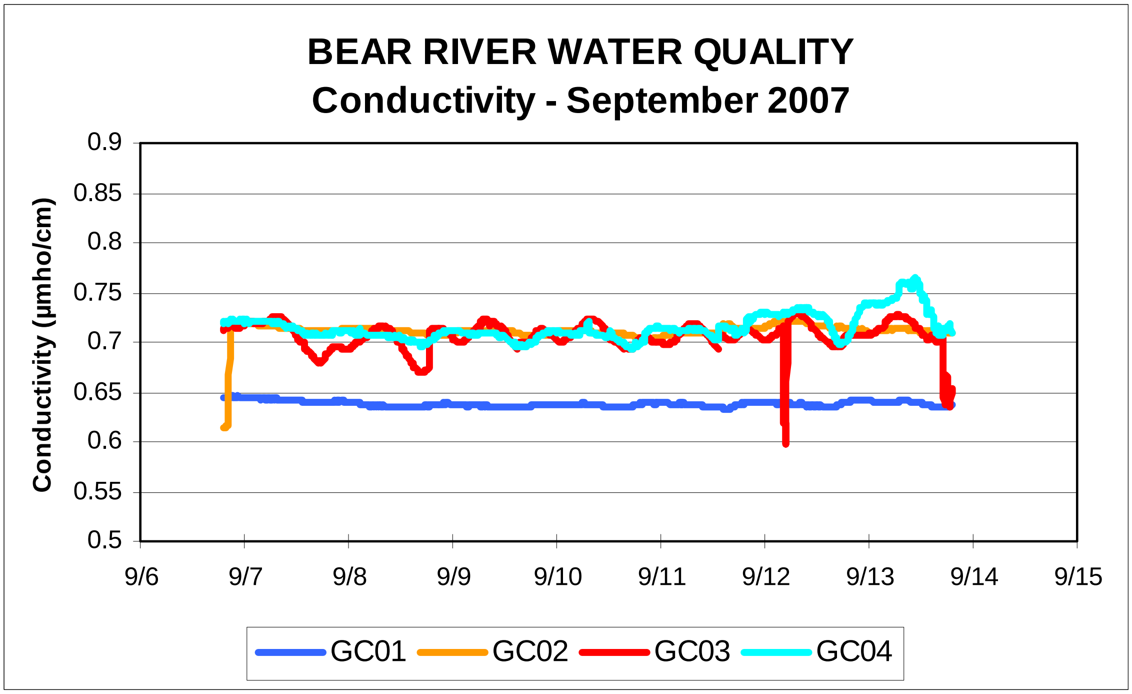


Figure 24. Specific conductance at the four monitoring locations during September 2007.

a similar daily pattern. Daily minima in dissolved oxygen saturation levels ranged from 64 percent to 87 percent, while oxygen saturation maxima reached 109 percent to 159 percent.

GC01 exhibited unique variability over the underlying diurnal patterns with many short peaks in oxygen during the course of each day. This pattern in the data is unique to this site, month and year and therefore unlikely to reflect actual oxygen dynamics. It is suspected that low flow conditions compromised the performance of the oxygen sensing membrane and distorted readings of dissolved oxygen. Due to concern about the accuracy of these data, they are reported but not further analyzed in this report. The suspect readings do not indicate poor water quality conditions and do not compromise evaluation of water quality compliance in this reach.

Specific conductance and turbidity did not have a consistent diel pattern at all the sites during September, although turbidity did show daily patterns at sites GC03 and GC04. Turbidity levels varied among sites with generally higher levels at GC01 and lower levels at GC03. However, turbidity levels had distinct spikes at GC03 and GC04 that were much higher than average levels at any of the sampling locations. Specific conductance was consistently lowest at GC02 while the other three sites were relatively stable and similar to each other.

To characterize diel variation, a one-way ANOVA was conducted for each parameter. The data were blocked by time of day so that observations within each hour (i.e. 6 p.m.) were compared to observations at every other hour. The analysis assumes that each hourly block includes at least 28 replicates (4 observations/hr over 7 days). The results of the one-way ANOVA for each site and each parameter are shown in Table 12. The ANOVAs indicate there were significant differences among times of day (p-value<0.001) at all four sites for temperature and conductivity. Turbidity demonstrated significant differences among times of day only at sites GC01 and GC02 ($p<0.01$).

In order to partition the daily variation confirmed by the ANOVAS, the data were divided into two 12-hour data sets: 7 p.m. to 7 a.m. (night) and 7 a.m. to 7 p.m. (day). This distinction separates the warmer and cooler periods of each day, as well as the solar input availability, and reduces variation within each group. Two additional analyses were completed to detect statistically significant differences between sites for the monitored parameters. Tukey tests were completed to determine which pairs of sites were different for each parameter. Paired linear regressions were run between sites to determine the degree of similarity.

The Tukey analysis tested for differences among all possible pairs of sites for each parameter (Table 13). The meaningful comparisons describing the effect of the hydroelectric complex are those relative to the control site (GC01). The temperature at GC01 was significantly different ($p<0.001$) from all the other sites in September. GC03 was consistently the coldest site monitored. At night, GC01 was consistently warmer than the other sites. During the day, the two warmest sites (GC02 and GC04) were not significantly different from each other but were warmer than GC01.

Table 12. The ANOVA for determining if there is a significant difference between the parameter values over time of day. This analysis is assuming each hour (e.g. 6:00 p.m.) has seven replicates over the study in September 2007.

		Sum of Squares	**df**	**Mean Square**	**F**	**P-value**	**Significant variation by time of day**
Temperature (°C)							
GC01	Between Groups	416	23	18.1	24.4	0.000	yes
	Within Groups	481	649	0.7			
	Total	897	672				
GC02	Between Groups	135	23	5.9	7.27	0.000	yes
	Within Groups	524	649	0.8			
	Total	659	672				
GC03	Between Groups	1510	23	65.7	122	0.000	yes
	Within Groups	350	649	0.5			
	Total	1860	672				
GC04	Between Groups	1535	23	66.7	47.8	0.000	yes
	Within Groups	905	649	1.4			
	Total	2440	672				
Specific Conductance (µmho/cm)							
GC01	Between Groups	0.011	23	0	4.88	0.000	yes
	Within Groups	0.064	649	0			
	Total	0.075	672				
GC02	Between Groups	0.002	23	0	14.9	0.000	yes
	Within Groups	0.003	649	0			
	Total	0.005	672				
GC03	Between Groups	0.086	23	0.004	4.65	0.000	yes
	Within Groups	0.52	649	0.001			
	Total	0.606	672				
GC04	Between Groups	0.024	23	0.001	6.86	0.000	yes
	Within Groups	0.1	649	0			
	Total	0.124	672				
Turbidity (NTU)							
GC01	Between Groups	1860	23	81	9.35	0.000	yes
	Within Groups	5610	649	9			
	Total	7480	672				
GC02	Between Groups	1530	23	67	1.77	0.010	yes
	Within Groups	24400	649	38			

		Sum of Squares	df	Mean Square	F	P-value	Significant variation by time of day
	Total	26000	672				
GC03	Between Groups	128000	23	5560	0.96	0.520	no
	Within Groups	3760000	648	5810			
	Total	3890000	671				
GC04	Between Groups	7820	23	340	1.41	0.100	no
	Within Groups	157000	649	241			
	Total	164000	672				

Table 13. The results of the TUKEY tests to determine significant differences (p-value, 0.05) between means for different sample locations. The analysis has been grouped for the hours of 7 p.m. to 7 a.m. (night) and 7 a.m. to 7 p.m. (day) for hourly data collected in September of 2007.

Comparison	Difference in Means	Standard Error	q	Critical q value	Significant Difference?
Day Temperature (°C)					
GC01 vs GC02	0.6	0.09	6.13	3.66	yes
GC01 vs GC03	1.2	0.09	13.77	3.66	yes
GC01 vs GC04	0.3	0.09	3.82	3.66	yes
GC02 vs GC03	1.8	0.09	19.9	3.66	yes
GC02 vs GC04	0.2	0.09	2.31	3.66	no
GC03 vs GC04	1.6	0.09	17.59	3.66	yes
Night Temperature (°C)					
GC01 vs GC02	0.39	0.06	6.28	3.66	yes
GC01 vs GC03	1.78	0.06	28.66	3.66	yes
GC01 vs GC04	1.47	0.06	23.66	3.66	yes
GC02 vs GC03	1.39	0.06	22.38	3.66	yes
GC02 vs GC04	1.08	0.06	17.38	3.66	yes
GC03 vs GC04	0.31	0.06	5	3.66	yes
Day Specific Conductance (µmho/cm)					
GC01 vs GC02	0.01	0.001	8.97	3.66	yes
GC01 vs GC03	0	0.001	1.05	3.66	no
GC01 vs GC04	0.08	0.001	64.15	3.66	yes
GC02 vs GC03	0.01	0.001	7.92	3.66	yes
GC02 vs GC04	0.07	0.001	55.18	3.66	yes
GC03 vs GC04	0.07	0.001	63.1	3.66	yes
Night Specific Conductance (µmho/cm)					
GC01 vs GC02	0.07	0.001	116.8	3.66	yes
GC01 vs GC03	0	0.001	3.77	3.66	yes
GC01 vs GC04	0.01	0.001	11.5	3.66	yes
GC02 vs GC03	0.07	0.001	113.03	3.66	yes
GC02 vs GC04	0.08	0.001	128.3	3.66	yes
GC03 vs GC04	0.01	0.001	15.27	3.66	yes

Comparison	Difference in Means	Standard Error	q	Critical q value	Significant Difference?
Day Turbidity (NTU)					
GC01 vs GC02	5	0.7	7.46	3.66	yes
GC01 vs GC03	11	0.7	15.55	3.66	yes
GC01 vs GC04	7	0.7	10.61	3.66	yes
GC02 vs GC03	6	0.7	8.09	3.66	yes
GC02 vs GC04	2	0.7	3.15	3.66	no
GC03 vs GC04	3	0.7	4.94	3.66	yes
Night Turbidity (NTU)					
GC01 vs GC02	1.33	2.92	0.45	3.66	no
GC01 vs GC03	6.01	2.92	2.06	3.66	no
GC01 vs GC04	0.2	2.92	0.07	3.66	no
GC02 vs GC03	4.69	2.92	1.61	3.66	no
GC02 vs GC04	1.12	2.92	0.38	3.66	no
GC03 vs GC04	5.81	2.92	1.99	3.66	no

Table 14. A summary of TUKEY test results for the five water quality parameters measured continuously in September 2007.

	GC01	**GC02**	**GC03**	**GC04**	**Rank**
Mean Day Temperature (°C)	16.8	17.3	15.5	17.1	GC03<GC01<GC04=GC02
Mean Night Temperature (°C)	17.2	16.8	15.4	15.7	GC03<GC04<GC02<GC01
Mean Day Spec. Cond. (µm/cm)	0.712	0.637	0.702	0.713	GC02<GC03=GC01<GC04
Mean Night Spec. Cond. (µm/cm)	0.71	0.64	0.708	0.717	GC02<GC03<GC01<GC04
Mean Day Turbidity (NTU)	16.5	11.4	5.7	9.2	GC03<GC04=GC02<GC01
Mean Night Turbidity (NTU)	17.7	11.9	13	11.7	GC04=GC02=GC03=GC01

Turbidity patterns showed diurnal variation in September. At night, all sites were statistically equivalent as peaks at each site were much larger than any differences among them. However during the day, GC01 was significantly more turbid than GC02 and GC04 while GC03 was significantly less turbid. These patterns can be seen in the plots of turbidity in Figure 20.

The relative levels of specific conductance among sites was consistent between night and day. GC04 consistently had the highest specific conductance and GC02 consistently had the lowest. Site GC01 had higher conductivity readings than GC03 at night, but they were statistically equivalent during the day.

By comparing the differences between adjacent sample sites (GC01 vs GC02; GC02 vs. GC03; GC03 vs. GC04) we can evaluate the systematic change in water quality parameters as water moves through the hydroelectric complex. In September, there were significant differences in temperature at all adjacent sample sites ($p<0.05$). Specific conductance also had significant differences between all adjacent sample sites. Significant differences occurred in turbidity at all adjacent sites during the day, but turbidity was not significantly different at any of the sites at night.

Pair-wise linear regressions were used to determine if the same pattern of changes were occurring at each site for each parameter. The regressions for the entire September data set ($n=672$) are shown in Table 15. The table includes the coefficient of determination (R^2), the significance level of the regression relationship and the coefficient value of the linear predictor (β). Because of the large sample size, a large proportion of the regressions are significant. Inspection of the R^2 value indicates what proportion of the variability at a site can be explained by the second site. The coefficient value (β) indicates the effect of the correlation, or the change in predicted value for every unit of change in the predictor value. This coefficient value captures the relative magnitude of any correlated variation. Sites with identical dynamics would have both a coefficient of determination and a coefficient value equal to 1.

The variation in temperatures at the control site GC01 was generally a poor predictor of the variability in temperature at the other three sampling sites ($0.39<R^2<0.47$). Specific conductance levels showed very low levels of correlation with the exception of sites GC02 and GC04, which were only mildly correlated ($R^2 = 0.20$; $\beta=2.2$). Similar to earlier sampling periods, September turbidity observations showed no correlations among sites.

Overall, the September monitoring revealed a shift from August that continued the shift from July to August. As flows continued to drop, the data reflect cooler temperatures and elevated levels of dissolved oxygen. Specific conductance levels increased from levels observed in August and turbidity levels were slightly lower with fewer peaks.

Table 15. The results of the paired linear regressions between the four sample sites on the Bear River during September 2007.

	N	Adjusted R Square	Significance	Coefficient (ß)
Temperature (°C)				
GC01 vs GC02	672	0.47	0	0.59
GC01 vs GC03	672	0.47	0	0.98
GC01 vs GC04	672	0.39	0	1.04
GC02 vs GC03	672	0.3	0	0.93
GC02 vs GC04	672	0.66	0	1.57
GC03 vs GC04	672	0.66	0	0.93
Specific Conductance (µmho/cm)				
GC01 vs GC02	672	0.01	0.01	0
GC01 vs GC03	672	0	0.58	0.1
GC01 vs GC04	672	0.01	0	0.2
GC02 vs GC03	672	0.04	0	2.2
GC02 vs GC04	672	0.2	0	2.2
GC03 vs GC04	672	0.03	0	0.1
Turbidity (NTU)				
GC01 vs GC02	672	0.047	0	0.4107
GC01 vs GC03	672	0.001	0.57	0.4935
GC01 vs GC04	672	0.017	0	0.6384
GC02 vs GC03	672	0	0.85	0.0883
GC02 vs GC04	672	0.006	0.03	0.2163
GC03 vs GC04	672	0	0.97	0.0002

3.2 Instantaneous Data

Grab samples were collected once in July and twice in August and September. The results of analysis by ERI's laboratory can be seen in Table 16.

Concentrations of total phosphorous, which generally decreased over the sampling period, were highest at GC02 in July (0.077 mg/L). The relative levels of total phosphorus among sites varied over time without any site consistently higher or lower than the others. Orthophosphorus, the dissolved portion of phosphorus, was relatively constant over the summer but did show a slight decreasing trend. The highest reading was at GC04 in early September (0.028 mg/L) whereas the lowest reading was at GC02 in late September (0.008 mg/L). Orthosphosphorus as a percentage of phosphorus generally increased over the summer and was often, but not always, highest at GC03.

The concentration of total inorganic nitrogen, which is made up of nitrate, nitrite and ammonia, did not display the same pattern as phosphorous. Total inorganic nitrogen concentrations at GC01 and GC02 were relatively constant and similar to each other during the monitoring season. Nitrogen levels at GC03 were consistently highest among the sampling sites and both GC03 and GC04 showed a sharp increase in nitrogen levels during the final sample taken in mid-September when flows dropped. These increases were due to increases in nitrate and are consistent with the water quality conditions recorded during instantaneous sampling efforts in previous years.

3.3 Water Quality Compliance

The second objective of this investigation was to help determine the Development's contribution, if any, to exceedances of water quality criteria as set forth in the Idaho Water Quality Standards and Wastewater Treatment Requirements, IDAPA 53.01.02 (Water Quality Standards). A comparison of each site and sample event to the IDAPA Water Quality Standards was undertaken utilizing the hourly data collected in this investigation. The results of that analysis can be seen in Table 17.

The instantaneous temperature requirement (temperature must be lower than 22°C) for the prescribed beneficial use of this section of the Bear River was exceeded at all sites during July and at sites GC01 and GC02 in August. Daily average temperature (temperature must be lower than 19°C) was exceeded at all sites during July and August.

Given the poor water quality conditions recorded in the Bear River at the control site (GC01), it is unlikely that the operations of the project contributed to recorded temperature exceedances of IDAPA standards at monitoring sites downstream where exceedances decrease relative to the control site. Monitoring results indicate that the project had little effect on exceedances of water temperature criteria as set forth in the IDAPA.

Table 16. The water quality data collected as grab samples within the Bear River during 2007.

Date	Site	Log#	NH_3 (mg/L)	NO_2 (mg/L)	NO_3+NO_2 (mg/L)	TIN (mg/L)	OP (mg/L)	TP (mg/L)	TSS (mg/L)	Turbidity (NTU)
07/04/07	GC01	70694	0.051	0.069	0.009	0.12	0.021	0.053	23	16
	GC02	70695	0.068	0.11	0.01	0.178	0.023	0.077	21	12
	GC03	70696	0.024	0.534	0.006	0.557	0.021	0.031	3	2
	GC04	70697	0.037	0.206	0.012	0.242	0.027	0.064	26	17
08/01/07	GC01	70798	0.047	0.133	0.013	0.18	0.026	0.059	20	15
	GC02	70799	0.038	0.109	0.009	0.148	0.021	0.051	16	10
	GC03	70800	0.046	0.516	0.006	0.562	0.022	0.039	6	3
	GC04	70801	0.035	0.249	0.01	0.284	0.027	0.057	16	14
08/13/07	GC01	70856	0.035	0.122	0.009	0.156	0.023	0.048	13	12
	GC02	70857	0.035	0.129	0.007	0.165	0.016	0.047	10	9
	GC03	70858	0.033	0.395	0.005	0.428	0.009	0.03	4	2
	GC04	70859	0.029	0.235	0.006	0.265	0.016	0.054	20	11
09/03/07	GC01	70947	0.042	0.066	0.005	0.108	0.011	0.029	10	12
	GC02	70948	0.033	0.064	0.003	0.097	0.012	0.032	11	13
	GC03	70949	0.029	0.463	0.004	0.493	0.022	0.035	6	7
	GC04	70950	0.031	0.191	0.004	0.221	0.028	0.041	14	13
09/14/07	GC01	70976	0.029	0.137	0.004	0.166	0.015	0.029	5	7
	GC02	70977	0.03	0.086	0.004	0.116	0.008	0.023	5	5
	GC03	70978	0.031	0.855	0.007	0.886	0.025	0.032	2	1
	GC04	70979	0.06	0.879	0.007	0.939	0.021	0.037	5	1

Table 17. The frequency of exceedances of relevant IDAPA 53.01.02 Water Quality Standards for the Bear River within the study site.

	Instant. Temperature (>22°C)		Daily Average Temperature (>19°C)		Instant. DO (<6 mg/L)		DO, % Sat. (>100%)	
	% Exceed	**N**	**% Exceed**	**N**	**% Exceed**	**N**	**% Exceed**	**N**
July								
GC01	46%	672	100%	7	22%	672	0%	672
GC02	69%	672	100%	7	16%	672	0%	672
GC03	8%	672	86%	7	14%	672	27%	672
GC04	50%	672	100%	7	0%	672	0%	672
August								
GC01	9%	672	100%	7	5%	672	0%	672
GC02	6%	672	100%	7	5%	672	3%	672
GC03	0%	672	14%	7	0%	672	41%	672
GC04	0%	672	100%	7	21%	672	5%	672
September								
GC01	0%	672	0%	7				
GC02	0%	672	0%	7	0%	672	0%	672
GC03	0%	672	0%	7	0%	672	6%	672
GC04	0%	672	0%	7	0%	672	28%	672

The second parameter subject to water quality standards is dissolved oxygen. The instantaneous concentration was lower than the required standard of 6 mg/L in July and August at most sites although GC03 was in full compliance in August and GC04 was in full compliance in July. This standard was not violated as frequently in August. The only exception to increased dissolved oxygen over the summer was at site GC04 in August when there was a brief problem with the oxygen sensor that resulted in artificially low readings. The associated parameter of dissolved oxygen (expressed as a percent of atmosphere) exceeded water quality standards (must be less than 110%) at GC03 during the month of July and at most sites during August and September with the exceptions of GC01 in August and GC02 in September.

In the case of dissolved oxygen (mg/l), exceedances decrease with distance downstream during both July and August. During all three monitoring periods, dissolved oxygen (expressed as a percent of atmosphere) exceedance of IDAPA standards at the downstream sites (GC02-GC04) was more frequent than exceedances recorded at the control site (GC01). This pattern has been observed in 2005 and 2006 as well. Physical characteristics of the Bear River vary considerably from the control site as you move downstream to the other monitoring locations. Site GC01 is located in a turbulent reach of the river, whereas the latter monitoring locations are located in areas with more laminar flows. Increased photosynthesis in these laminar reaches drives up oxygen saturation levels. Dissolved oxygen data (expressed as percent of atmosphere) recorded at sites GC02, GC03, and GC04 reflects this local primary production. As with temperature, it is unlikely that project operations significantly contributed to exceedances of dissolved oxygen criteria as set forth in the IDAPA.

4.0 QUALITY CONTROL

This section will evaluate the quality assurance of sampling, sample handling, field techniques, field analyses, and data treatment. The procedures for calibration, maintenance, and downloading of the YSI Model 6920, used for the continuous monitoring task of this Development, will also be included in this section.

Specific data quality objectives for accuracy and precision of sampling are for measurements to fall within a 95 percent confidence interval around the true value. The confidence interval for each parameter is based on prior knowledge of the measurement system and is generated from the EPA publication “Estimation of Generic Acceptance Limits for Quality Control Purposes for Use in a Water Pollution Laboratory” (May 1991).

4.1 Continuously Monitoring Probes

Four YSI Model 6920 monitoring probes were installed at each of the stations. A backup probe was available in the case that any problems were encountered with the equipment. Custom steel boxes were built in order to house, conceal and protect each probe. The probes were calibrated for each parameter according to the manufacturer's specifications (YSI 2001) before being placed in the field. Data were downloaded at the end of each continuous 7-day monitoring period using a laptop computer and the software EcoWatch for Windows. Each time the monitoring field crew was at the site, a grab sample was also taken. The probe was placed in a known calibration standard to record turbidity drift. This in situ measurement was compared to the standard and percent error was determined. The probe was then cleaned and calibrated in the field were run prior to and after the continuous 7-day sampling period. The QA/QC data is provided in Table 20. The program determined that the turbidity measurements for GC04 in August should be disqualified as per Table 19.

Table 18. Rating continuous water quality records (Source: USGS, 2000. WRIR 00-4252, Table 9).

Measured physical property	RATINGS			
	Excellent	**Good**	**Fair**	**Poor**
Water temperature	≤ ± 0.2°C	> ± 0.2 to 0.5°C	> ± 0.5 to 0.8°C	> ± 0.8°C
Specific Conductance	≤ ± 3 %	> ± 3 to 10 %	> ± 10 to 15 %	> ± 15 %
Dissolved oxygen	≤ ± 0.3 mg/L	> ± 0.3 to 0.5 mg/L	> ± 0.3 to 1.0 mg/L	> ± 1.0 mg/L
pH	≤ ± 0.2 unit	> ± 0.2 to 0.5 units	> ± 0.5 to 0.8 units	> ± 0.8 units
Turbidity	≤ ± 5 %	> ± 5 to 10 %	> ± 10 to 15 %	> ± 15%

Table 19. Rejection criteria for continuous water-quality monitoring sensors.

Constituent	Manufacturer's Specifications[a]	Maximum Allowable Limits (USGS)[b]
Water temperature	> ± 0.15°C	> ± 2.0°C
Specific Conductance	> ± 0.5 %	> ± 30 %
Dissolved oxygen	> ± 0.2 mg/L or ± 2%, whichever is greater	> ± 2.0 mg/L or ± 20%, whichever is greater
pH	> ± 0.2 units	> ± 2.0 units
Turbidity	> ± 5% or 2 NTU whichever is greater	> ± 30%

[a] YSI Incorporated. 6-Series Environmental Monitoring Systems Operations Manual

[b] USGS, 2000. WRIR 00-4252, Table 8.

Table 20. Turbidity calibration data and percent error for continuous monitoring turbidity measurements taken during the summer of 2007.

	Standard: 40 NTU		**Standard: 80 NTU**		**Avg % Error**
	Turbidity (NTU)	**% Error**	**Turbidity (NTU)**	**% Error**	
July 16, 2007					
GC01	38.4	4%	59.1	26%	15%
GC02	44.5	11%	63.7	20%	16%
GC03	48	20%	64.5	19%	20%
GC04	38	5%	55.5	31%	18%
August 22, 2007					
GC01	28.6	29%	71.2	11%	20%
GC02	24.5	39%	69.3	13%	26%
GC03	21	48%	71.6	11%	29%
GC04	18.9	53%	71.4	11%	32%
September 14, 2007					
GC01	35.1	12%	76.2	5%	9%
GC02	38.6	4%	81.2	2%	3%
GC03	38.8	3%	75.5	6%	4%
GC04	40.3	1%	80.9	1%	1%

5.0 REFERENCES

Barker, K.W., D.L. Sorensen, J.C. Anderson, J.M. Ihnat. 1989. Bear River Water Quality: Bioavailable Phosphorus Measurement, Sources and Control. UWRL, Utah State University, Logan, Utah

Clyde, C.G. 1953. Sediment Movement in Bear River, Utah. A Thesis Submitted to the Civil Engineering Department, Utah State University. Logan, Utah.

Ecosystems Research Institute. 1998. Water Quality Study for the Bear River in Idaho. Logan, Utah.

Haws, F.W. and T.C. Hughes. 1973. Hydrologic Inventory of the Bear River Study Unit. UWRL, Utah State University, Logan, Utah.

Heimer, J.T. 1978. Turbidity concentrations and suspended sediment discharge in streams in southeastern Utah. Idaho Department of Fish and Game, Region 5.

Hill, R.W., E.K. Israelsen, and P.J. Riley. 1973. Computer Simulation of the hydrologic and salinity flow systems within the Bear River basin. Research Project Technical Completion Report. OWRT. Utah State University. Logan, Utah.

Perry, J. 1978. Water Quality Status Report. Bear River (Wyoming Border to the Utah Border). Idaho department of Health and Welfare, Division of Environment. Pocatello, Idaho.

Waddell, K.M. 1970. Quality of Surface Water in the Bear River Basin, Utah, Wyoming and Idaho. Utah Basic Data Release No. 18. U.S. Geological Survey in Cooperation with the Utah Division of Water Rights.