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Statistical Analysis of Kootenai River Temperatures Measured at Bonners Ferry and Libby Dam Tailwater Between 2000 and 2006

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Introduction

The U.S. Fish and Wildlife Service (USFWS) issued their Biological Opinion (BiOp) on the effects of the Operation of Libby Dam on Kootenai River White Sturgeon and Bull Trout and Kootenai Sturgeon Critical Habitat to the U.S. Army Corps of Engineers (COE) and Bonneville Power Administration (BPA), together the Action Agencies, on February 18, 2006. For the 2006 BiOp, the USFWS developed Reasonable and Prudent Alternatives (RPAs) designed to achieve habitat attributes/measures deemed necessary to adequately provide for successful Kootenai sturgeon spawning and natural in-river reproduction in the Kootenai River near Bonners Ferry, Idaho. One of the attributes was "Temperature Fluctuation: Maintain 50 degrees F with no more than 3.6 degree F drop." The 2006 BiOp noted that reducing temperature fluctuations was deemed necessary to adequately provide for successful Kootenai sturgeon spawning and natural in-river reproduction.

Libby Dam uses a selective withdrawal system to reduce the impact of the altered thermal regime on downstream fish habitat and populations, including the endangered Kootenai River white sturgeon. By utilizing a system of bulkheads to remove water from different depths in the reservoir, the selective withdrawal system attempts to produce downstream water temperatures that more closely resemble pre-impoundment conditions. These downstream temperatures are currently regulated according to a temperature rule curve established by the COE in cooperation with the Montana Department of Fish, Wildlife, and Parks (MDFWP). However, compared to pre-dam conditions, Kootenai River temperatures may still be too low, or fluctuate too much during the spring spawning season to promote successful recruitment of the endangered white sturgeon (Paragamian and Wakkinen 2002; Hoffman 2003). Consequently, the USFWS requested Libby Dam to optimize temperature releases from Libby Dam in order to maintain a water temperature measured at Bonners Ferry of 10 °C with no more than a 2 °C drop in temperature at Bonners Ferry. To determine the feasibility of meeting such a temperature request, the COE designed a study to determine the correlation between Libby Dam release temperatures and Bonners Ferry temperature variability.

The Seattle District Corps of Engineers conducted a statistical assessment of historical 2000 to 2006 April-June Kootenai River temperatures measured at the Libby Dam Tailwater Station and Bonners Ferry Station. The purpose of the study was to understand the correlation between water temperatures measured at Libby Dam and Bonners Ferry. The major objectives of the study were to determine (1) if Libby Dam release temperatures and Bonners Ferry water temperature fluctuations are correlated, (2) the importance of other environmental factors such as air temperature, river flow, and tributary temperatures on Bonners Ferry water temperatures, and (3) the amount of temperature variation measured at Bonners Ferry that could be attributed to Libby Dam release temperatures, Bonners Ferry air temperatures, tributary water temperatures, and river flow conditions.

Methods and Materials

Background Information

Libby Dam is located 30 kilometers northeast of Libby, Montana at river kilometer (RK) 357.3 of the Kootenai River (Figure 1). The dam's reservoir, Lake Koocanusa, is 144 kilometers long, extending 70 kilometers into British Columbia, Canada. The dam is a concrete gravity structure rising about 130 meters above bedrock with a top length of about 935 meters. The reservoir has a mean depth of about 38 meters, a maximum depth of about 107 meters at the forebay, and a mean water residence time of about 9 months. Downstream of Libby Dam, the Kootenai River flows to the south for about 5 kilometers to the mouth of the Fisher River and then to the northwest for about 114 kilometers to Bonners Ferry, Idaho through a relatively steep canyon with an average slope of about 1 meter per kilometer. At Bonners Ferry, the river valley widens and the river meanders to the north through a relatively flat section for about 75 kilometers to the Canadian Border (Figure 1). Major tributaries to the Kootenai River between the dam and Bonners Ferry include the Fisher River, Libby Creek, Lake Creek, Yaak River, and Moyie River.

Construction of Libby Dam began in 1966 and in late 1972 the river was impounded and the USACE began to regulate flows on the Kootenai River below the dam for flood control and power production. Beginning in 1977 Libby Dam began to operate a selective withdrawal system to supply water to the penstocks from different thermal layers in the reservoir. By utilizing a system of bulkheads to remove water from different depths in the reservoir, the selective withdrawal system attempts to produce downstream water temperatures that more closely resemble pre-impoundment conditions. Whitfield and Woods (1984) concluded that impoundment substantially altered the natural thermal regime in the Kootenai River. Post-impoundment temperatures were warmer than pre-impoundment temperatures from October through February, similar in March, and cooler from April through September due to the differences in thermal properties between a deep storage reservoir and a free-flowing river.

One objective of using the selective withdrawal system is to reduce the impact of the altered thermal regime on downstream fish habitat and populations, including the endangered Kootenai River white sturgeon. However, compared to pre-dam conditions, Kootenai River temperatures may still be too low, or out of synchrony with flow changes, during the spring spawning season to promote successful recruitment of the endangered white sturgeon (Paragamian and Wakkinen 2002; Hoffman 2003). Monitoring data suggest that sturgeon spawning typically occurs in the Kootenai River in the vicinity of Bonners Ferry between early May and late June, and may be triggered by a combination of environmental factors including increased flows and temperatures during the spring freshet. In general, observed spawning events in the 1990s occurred with the receding flow following the spring freshet, within the range of 7.5^{o} to 14° Celsius (with a 66% probability within 9.5^{o}-12.5^{o} C) near Bonners Ferry (Paragamian and Wakkinen 2002). It is possible that changes in the temporal pattern of water temperatures in the Kootenai River near Bonners Ferry caused by Libby Dam could be disrupting the spawning migration of females.

Figure 1. Location of Libby Dam, Bonners Ferry and the Kootenai River watershed.

Climate

The climate of the study area is influenced by easterly moving weather systems from the Pacific Ocean. Winters are generally cloudy, cool, and wet, with November through March being the wettest months. Most of the snowpack in the mountains falls between November and April. Summers are typically warm and dry, with little rainfall occurring from June through September. The mean annual precipitation at Libby is about 49.3 cm (USDA 1995). Total annual snowfall varies with elevation, with about 150 cm near the dam to an estimated 750 cm in some mountain areas. The average monthly temperatures at Libby range from -5.6°C in January to 18.8°C in July, with extremes recorded in the vicinity of the dam of – 43.3 °C and 43.7°C (USACE 1984).

Statistical Analysis

Multiple Linear Regression

Multiple linear regression (MLR) is a statistical method used to model the linear relationship between a dependant variable and one or more independent variables. The goal of this statistical method is to explain as much of the variation in the dependant variable with multiple independent variables, and to leave a minimal amount of variation to be explained by unknown noise in the data (Helsel and Hirsch 2002). Multiple linear regression is used instead of simple linear regression when scientific knowledge and experience suggests that multiple explanatory variables are responsible for the variation. For example, the temperature of river water at a specific location is influenced by several variables including upstream water temperature, air temperature, tributary temperatures, flows and others. MLR results predict how much of the variance of the dependent variable can be explained by all independent variables. This value is denoted as R square "R^2" and is basically a measure of how good a prediction of the dependent variable can be made using all independent variables. In addition, MLR results measure how strongly each independent variable influences the dependent variable. This value is denoted as beta "β" and is basically a measure of which independent variable has the greatest impact on the dependent variable . Although MLR is a powerful statistical tool, it can be misused when (1) the variables are not truly independent of one another, a problem known as multicolinearity, (2) the data are serially correlated, a problem known as serial-correlation or auto-correlation, (3) the relationship between the dependent and independent variables are not linear, and (4) the variance is not constant, a problem known as heteroscedasticity (Helsel and Hirsch 2002).

Multicolinearity is the term used to describe when one or more of the independent variables is closely related to another independent variable. In general, correlation among independent variables is not unusual and multicolinearity alone does not invalidate the regression, meaning the results of the MLR can still be used to some extent (Helsel and Hirsch 2002). However, multicolinearity has several negative results including if the intercorrelation is high, the significance of the correlated variables may be questionable (Zar 1984). Additionally, high intercorrelation can result in large standard errors in the regression leading to inconclusive

interpretations of the statistical significance of the data (Zar 1984). An example of multicolinearity between two independent variables would be precipitation and river flow. Because an increase in precipitation will directly contribute to an increase in river flow these two variables are likely too closely related to be truly independent variables.

Serial-correlation or auto-correlation refers to the dependence or correlation in time sequence between the regression residuals. Such a time sequence correlation violates the major assumption used in regression models, that the data are independent, and serial-correlation can invalidate the regression model (Helsel and Hirsch 2002). Generally, when time series data is collected at a high frequency (hourly or daily) serial-correlation usually exists. When serial correlation is present the estimate of the regression coefficient is uncertain, and the predicted variability may seriously underestimate the true variability. Serial-correlation is determined through an analysis of regression residuals. If serial correlation is present, the data must be transformed to produce a regression model that does not suffer from serial-correlation.

Violations of linearity can be serious because the regression model assumes linearity of the data and can thus result in errors in predictions. Thus it is important not to try and fit non-linear data to a linear model. Similarly, heteroscedasticity (i.e. having a non-constant variance) violations result in difficulty determining the true standard deviation in the regression model. In general, heteroscedasticity will result in the variance of the errors increasing over time leading to unrealistic confidence intervals and unequal weighting of the data.

Methods for Analysis of Residuals

An analysis of regression residuals consists of examining plots of residuals and calculating statistical tests on the residuals. Performing the analysis is a critical step in any regression model because it will test the validity of the basic assumptions needed to perform a viable regression model.

The overall significance of the regression model is determined by conducting an Analysis of Variance (ANOVA) test. The significance of the overall model is calculated using an F-Test. If the F-Test is significant (i.e. $p < 0.05$) then the regression results are not likely due to sample error and represent a valid regression model.

In general three types of residual plots address whether or not the regression model adheres to the basic assumptions required for a significant test. Plotting (1) residuals vs. predicted, (2) residuals vs. time, and (3) plotting normality of residuals will provide information regarding if the basic assumptions of the regression model (i.e. multicolinearity, serial-correlation, linearity, heteroscedasticity) are valid. A scatterplot of residuals vs. predicted should show no correlation and should be evenly distributed around the regression line if the model is valid. Violation is indicated by a pattern in the scatterplot. Non-linearity is shown by an uneven distribution around the regression line. Heteroscedasticity is shown by residual getting larger and more spread out (i.e. a flared pattern) at the upper or lower boundaries. A time series plot of residuals will show if a trend or serial-correlation exits. Serial-correlation is indicated by a pattern in the scatterplot.

The distribution of residuals should be normal or near-normal. Although some departure from normal is expected, the departure should not be substantial (Helsel and Hirsch 2002).

A powerful statistical test used to determine serial-correlation is the Durbin-Watson (D-W) statistic. The D-W statistic tests the null hypothesis of no serial-correlation against the alternative hypothesis of positive serial-correlation. A D-W statistic with a value between 0 and 1.5 indicates positive serial-correlation, a value between 1.5 and 2.5 indicates no serial-correlation, and a value greater than 2.5 indicates negative serial correlation (Statistica 2007).

Multicolinearity can be difficult to detect in a regression model. Helsel and Hirsch (2002) suggest using the variance inflation factor (VIF) to estimate if multicolineartiy is a problem. An ideal VIF indicating no multicolinearity would equal 1. Serious problems with multicolinearity are indicated when the VIF is greater than 10. Additionally, multicolinearity can be assessed by assessing the tolerance values of the independent variables. Low tolerance values indicate colinearity may be a problem. In general, a tolerance value less than 0.1 indicates serious problems with colinearity (Helsel and Hirsch 2002).

Interpreting R Square and Beta Values

Multiple linear regression results will predict how much of the variance of the dependent variable can be explained by all independent variables as well as the impact each individual independent variable has on the dependent variable . The R square "R^2" value is a measure of the correlation between the dependent variable and all independent variables. The R^2 value indicates the proportion of the variance in the dependent variable that is accounted for by the MLR model. Because R^2 can over estimates the correlation of the regression model, an adjusted R^2 is calculated which takes into account the number of independent variables as well as the number of observations. In addition, MLR results measure how strongly each independent variable influences the dependent variable. This value is denoted as beta "β" and is basically a measure of which independent variable has the greatest impact on the dependent variable .

The beta value "β" is a measure of how strong each independent variable influences the dependent variable. By using the standardized beta value one can evaluate which variables have a greater impact on the dependent variable. Because beta is measured in units of standard deviations, it provides a baseline from which all independent variables can be measured from. Consequently, the higher the beta value, the greater the impact on the dependent variable. Positive beta values indicate the independent variable increases the dependent variable while negative beta values indicate a decrease to the dependent variable.

Kootenai River Multiple Linear Regression Model

Variables and Time Periods

A regression model was used to determine the correlation between Bonners Ferry water temperatures to other environmental factors. Because many environmental factors contribute to

the temperature of water in the Kootenai River at Bonners Ferry, a multiple linear regression model was used instead of a simple regression model. For the multiple linear regression model used in this analysis the following dependent and independent variables were used:

- Dependent Variable:
  - Kootenai River Temperatures at Bonners Ferry
- Independent Variable:
  - Libby Dam Tailwater Temperature
  - Bonners Ferry Air Temperature
  - Tributary Water Temperatures
  - Kootenai River Flow
  - Tributary Flow.

These independent variables were chosen because each was deemed potentially capable of impacting water temperatures in the Kootenai River at Bonners Ferry while maintaining independence from each other and attempting to minimize intercorrelation between variables. Because little temperature data existed on tributaries to the Kootenai River between Libby Dam and Bonners Ferry, Yaak River temperatures and flows were used as a surrogate for all Tributary Water Temperature and Flow.

The time period chosen for the multiple linear regression was April through June for the years 2000 through 2006. The 2000 to 2006 period was chosen because Libby Dam operations were relatively consistent during this time period resulting in little year to year variability in system operations that may impact river temperatures. The months of April, May, and June were chosen for the regression model because these dates represent the most critical time period to achieve water temperatures of 10°C at Bonners Ferry. Daily average water temperatures and flows for the Kootenai River and Tributaries were calculated from hourly measurements collected by the Seattle District at the Libby Dam Tailwater Station (Station LBQM), Yaak River Station (Station TYRM), and the Kootenai River at Bonners Ferry Station (Station BFEI) (Figure 2). Daily average air temperatures were calculated from hourly measurements collected by the National Weather Service at the Bonners Ferry airport (Figure 2)

Temperature and total dissolved gas studies by Schneider et al (2004) estimated a 7.25 hour time of travel between Libby Dam and Kootenai Falls, about 42 kilometers downstream of the dam, based upon average Kootenai River velocities and measured changes in temperature and dissolved gas saturations in the river during spillway releases in 2002. Based upon these data, a time of travel from Libby Dam to Bonners Ferry, about 125 kilometers downstream of the dam, was estimated to be about 22 hours. To allow for simpler comparisons of Libby Dam temperature data to Bonners Ferry temperature data, travel time was accounted for by lagging Bonners Ferry temperatures by 24 hours when compared to Libby Dam temperatures.

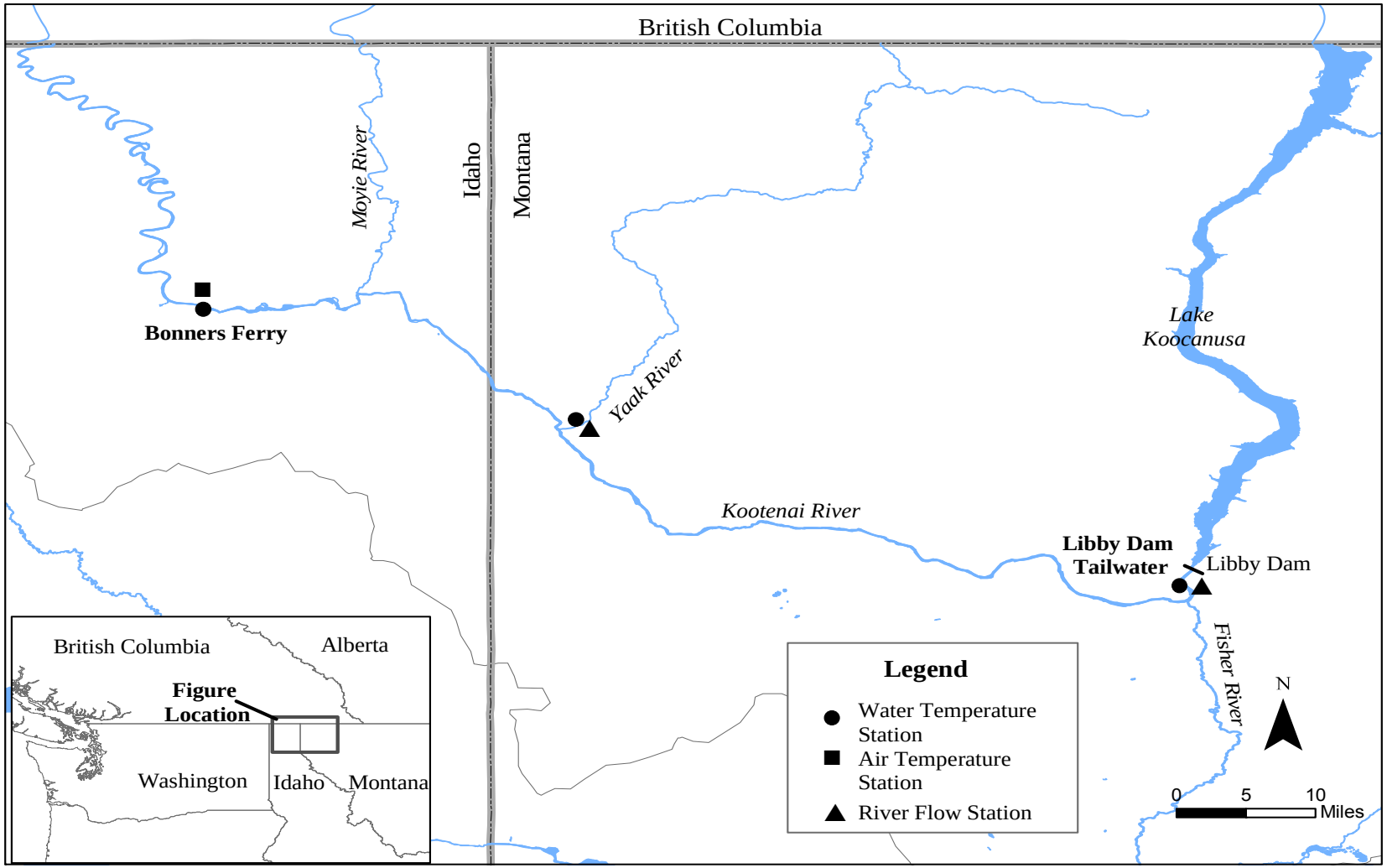

Figure 2. Location of water temperature, air temperature, and river flow monitoring stations within the Kootenai River watershed.

Analysis of Residuals

An analysis of residuals on the multiple linear regression of all April through June data between 2000 and 2006 is shown in Figure 3. The distribution of residuals is near normal and no pattern is seen when residuals are plotted against predicted values indicating linear data with no heteroscedacity. However, a pattern is seen when residuals are plotted against time, indicating serial-correlation of the data. A Durbin-Watson test value of 0.567 indicated positive serial correlation confirming the results of the time series residual plot. Because the data are time series data collected over a period of months serial correlation is a common problem with running the multiple linear regression and had to be fixed before the regression model could be used.

In order to remove the serial-correlation, the data were transformed using a random number generator. Each time series data was assigned a random number. The random numbers were then sorted to produce a series of random data sets with no time series influence. A re-running of the residuals analysis shown in Figure 4, indicates that the data are near normal with no pattern seen when residuals are plotted against predicted values and when residuals are plotted against time. A Durbin-Watson value of 1.97 confirmed that using a random number generator to sort the data eliminated serial correlation problems with the time series data.

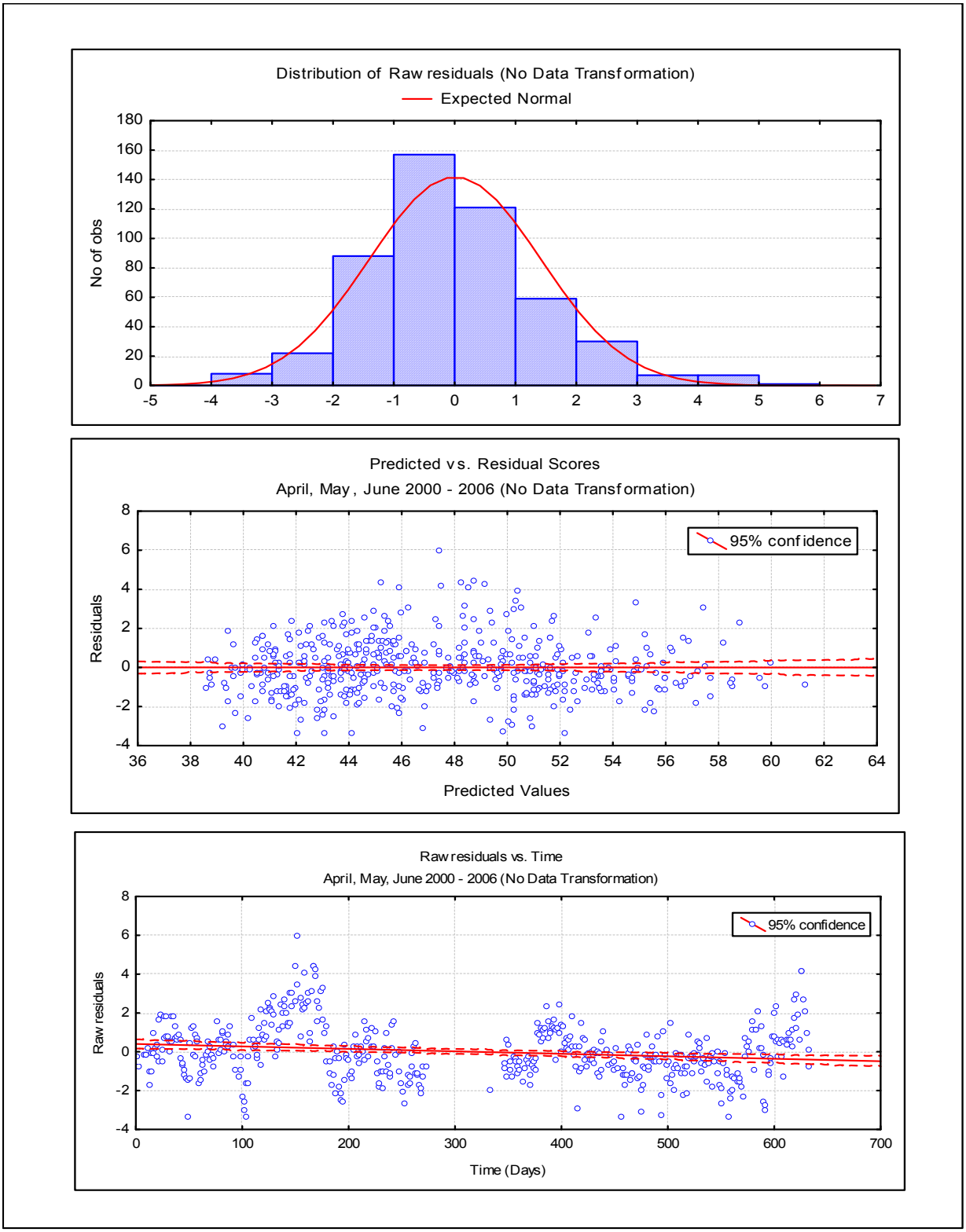

Figure 3. Residuals analysis for non-transformed data.

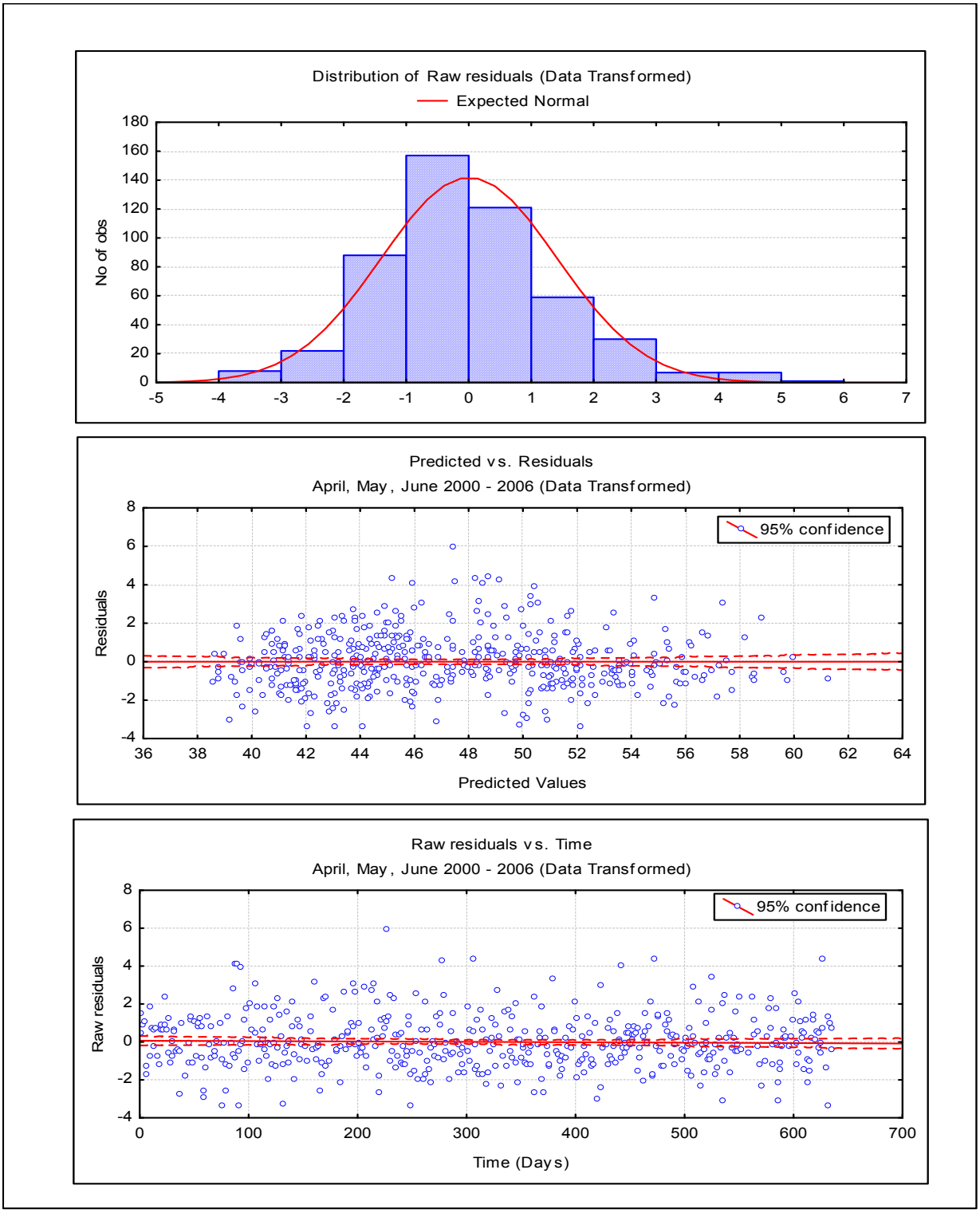

Figure 4. Residuals analysis for transformed data.

Results and Discussion

Multiple linear regression was performed on transformed data. The regression was conducted on all April through June data as well as on individual monthly data for the 2000 to 2006 time period. Table 1 presents the regression statistics for the different time periods. Figure 5 graphically present the data.

April through June Time Period

Multiple linear regression results performed on all April through June data from 2000 through 2006 for Bonners Ferry Water Temperature data are presented in Table 1. The ANOVA F-Test value of 1194.8 was highly significant ($p < 0.0000$) indicating a valid regression model. The adjusted R^2 value of 0.92 using April through June data shows that the regression model accounted for 92 percent of the variance in Bonners Ferry water temperatures. The Durbin-Watson Serial Correlation statistic of 1.97 is within the range (1.5 to 2.5) that indicates no serial correlation for the regression model. Tolerance values and VIF Test values suggest that some multicolinearity exists with the regression but is not a serious enough problem to invalidate the results.

The standardized beta values for the April through June data show that Libby Tailwater Water Temperatures and Bonners Ferry Air Temperatures had the greatest impact on Bonners Ferry Water Temperatures. Both these variables had a positive correlation with Bonners Ferry water temperatures, meaning as Libby Tailwater temperatures or Bonners Ferry air temperatures increased, then the Bonners Ferry water temperatures increased. Yaak River Water Temperatures and Kootenai River Flow had the next greatest impact on temperatures. However, the Yaak River water temperature had a positive correlation with Bonners Ferry water temperatures, while the Kootenai River Flow had a negative correlation. These data suggest that as the Kootenai River flow increase/decrease, Bonners Ferry water temperatures decrease/increase, respectively. Tributary flows had a minor negative correlation. Figure 5 graphically shows the standardized beta values and their individual impact on Bonners Ferry water temperatures. Standardized beta values greater than 0 were positively correlated with Bonners Ferry water temperatures while those values less than 0 were negatively correlated.

April Time Period

Multiple linear regression results performed on April data from 2000 through 2006 for Bonners Ferry Water Temperature data are presented in Table 1. The ANOVA F-Test value of 110.5 was highly significant ($p < 0.0000$) indicating a valid regression model. The adjusted R^2 value of 0.78 using April data indicates that the regression model accounted for 78 percent of the variance in Bonners Ferry water temperatures during the month of April. These data suggest that other

Table 1. Multiple linear regression test results.

Statistical Comparrison	Time Period	Years	N	R^2	ANOVA F-Test	Std. Beta	p	Durbin-Watson Serial Correlation[1]	Tolerance Value for Multi-Colinearity	VIF Test Multi-Colinearity
Bonners Ferry Water Temperature vs.										
All Parameters	April, May, June	2000-2006	500	0.92	1194.80		0.0000	1.98		
Libby Tailwater Water Temperature	April, May, June	2000-2006	500			0.575	0.0000		0.2887	3.46
Bonners Ferry Air Temperature	April, May, June	2000-2006	500			0.433	0.0000		0.4483	2.23
Yakk River Water Temperature	April, May, June	2000-2006	500			0.141	0.0000		0.4558	2.19
Kootenai River Flow	April, May, June	2000-2006	500			-0.150	0.0000		0.4982	2.01
Tributary Flow	April, May, June	2000-2006	500			-0.090	0.0000		0.9379	1.07
Bonners Ferry Water Temperature vs.										
All Parameters	April	2000-2006	163	0.78	110.50		0.0000	2.02		
Libby Tailwater Water Temperature	April	2000-2006	163			0.304	0.0000		0.7733	1.29
Bonners Ferry Air Temperature	April	2000-2006	163			0.675	0.0000		0.7904	1.27
Yakk River Water Temperature	April	2000-2006	163			0.108	0.0157		0.7272	1.38
Kootenai River Flow	April	2000-2006	163			-0.070	0.0761		0.8718	1.15
Tributary Flow	April	2000-2006	163			-0.060	0.0932		0.9542	1.05
Bonners Ferry Water Temperature vs.										
All Parameters	May	2000-2006	175	0.83	168.98		0.0000	2.00		
Libby Tailwater Water Temperature	May	2000-2006	175			0.451	0.0000		0.7301	1.37
Bonners Ferry Air Temperature	May	2000-2006	175			0.575	0.0000		0.7946	1.26
Yakk River Water Temperature	May	2000-2006	175			0.129	0.0011		0.6600	1.52
Kootenai River Flow	May	2000-2006	175			-0.230	0.0000		0.8060	1.24
Tributary Flow	May	2000-2006	175			-0.210	0.0000		0.8415	1.19
Bonners Ferry Water Temperature vs.										
All Parameters	June	2000-2006	162	0.82	146.31		0.0000	1.62		
Libby Tailwater Water Temperature	June	2000-2006	162			0.509	0.0000		0.5741	1.74
Bonners Ferry Air Temperature	June	2000-2006	162			0.391	0.0000		0.6495	1.54
Yakk River Water Temperature	June	2000-2006	162			0.157	0.0002		0.6801	1.47
Kootenai River Flow	June	2000-2006	162			-0.260	0.0000		0.6299	1.59
Tributary Flow	June	2000-2006	162			-0.250	0.0000		0.8760	1.14

Notes:

1: A Durbin-Watson value between 0-1.5 indicates positive serial correlation, a value between 1.5 and 2.5 indicates no serial correlation, a value between 2.5 and 4.0 indicates negative serial correlation.

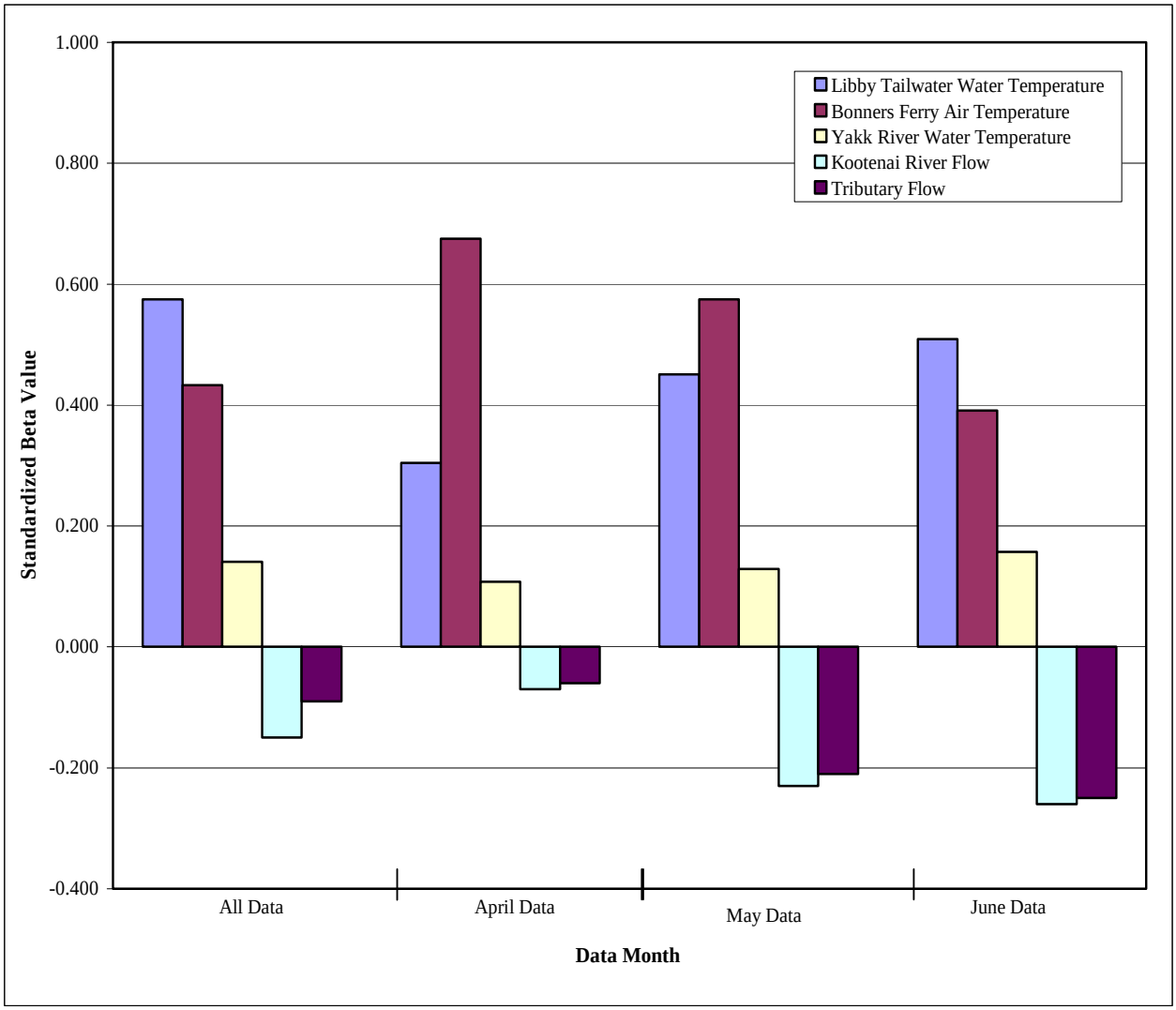

Figure 5. Multiple linear regression standardized beta values.

environmental factors in the month of April are impacting water temperatures at Bonners Ferry. The Durbin-Watson Serial Correlation statistic of 2.02 is within the range (1.5 to 2.5) that indicates no serial correlation for the regression model. Tolerance values and VIF Test values were within the range suggesting that multicolinearity was not a problem.

The standardized beta values for the April data show that Bonners Ferry air temperatures were the most highly correlated with Bonners Ferry water temperatures. During April, Libby Tailwater Water Temperatures had less of an impact on Bonners Ferry Water Temperatures. Both these variables were positively correlated with Bonners Ferry temperatures. Yaak River Water Temperatures, Kootenai River Flow, and Tributary Flow all had minor impacts on temperatures in April when compared to air temperatures. The Yaak River water temperatures were positively correlated with Bonners Ferry water temperatures, while the Kootenai River and Tributary Flow were negatively correlated. Figure 5 graphically shows the standardized beta values and their overall correlations with Bonners Ferry water temperatures.

May Time Period

Multiple linear regression results performed on April data from 2000 through 2006 for Bonners Ferry Water Temperature data are presented in Table 1. The ANOVA F-Test value of 168.98 was highly significant ($p < 0.0000$) indicating a valid regression model. The adjusted R^2 value of 0.83 using May data indicates that the regression model accounted for 83 percent of the variance in Bonners Ferry water temperatures during the month of May. Thus, the regression model using only May data accounted for slightly more of the variance in Bonners Ferry water temperature than the April data. The Durbin-Watson Serial Correlation statistic of 2.00 is within the range (1.5 to 2.5) that indicates no serial correlation for the regression model. Tolerance values and VIF Test values were within the range suggesting that multicolinearity was not a problem.

The standardized beta values for the May data show that Bonners Ferry air temperatures were the most highly correlated with Bonners Ferry water temperatures. However, Libby Tailwater water temperatures were also highly correlated to Bonners Ferry water temperatures in May and had a considerably greater correlation than in April. Yaak River water temperatures continued to have only a minor impact in May. All three of these variables were positively correlated with Bonners Ferry water temperatures. Flows in the Kootenai River and Tributaries had a much greater negative correlation in May compared to April. Figure 5 graphically shows the standardized beta values and their overall correlations with Bonners Ferry water temperatures.

June Time Period

Multiple linear regression results performed on April data from 2000 through 2006 for Bonners Ferry Water Temperature data are presented in Table 1. The ANOVA F-Test value of 146.31 was highly significant ($p < 0.0000$) indicating a valid regression model. The adjusted R^2 value of 0.82 using June data indicates that the regression model accounted for 82 percent of the variance in Bonners Ferry water temperatures during the month of May. Thus, the regression model using

only June data was similar to May data results and accounted for slightly more of the variance in Bonners Ferry water temperature than the April data. The Durbin-Watson Serial Correlation statistic of 1.62 is within the range (1.5 to 2.5) that indicates no serial correlation for the regression model. Tolerance values and VIF Test values were within the range suggesting that multicolinearity was not a problem.

The standardized beta values for the June data show that Libby Tailwater water temperatures were the most highly correlated with Bonners Ferry water temperatures. However, Bonners Ferry air temperatures were still highly correlated with Bonners Ferry water temperatures in June, although considerably less than in April and May. Yaak River water temperatures continued to have only a minor impact in June. All three of these variables were positively correlated with Bonners Ferry water temperatures. Similar to May, flows in the Kootenai River and Tributaries were negatively correlated with Bonners Ferry water temperatures in June and considerably greater than predicted for April. Figure 5 graphically shows the standardized beta values and their overall correlation with Bonners Ferry water temperatures.

Conclusion

Evaluation of the multiple linear regression results yielded the following conclusions:

- Regression of Bonners Ferry Water Temperatures vs. Libby Dam Water Temperatures, Bonners Ferry Air Temperatures, Tributary Water Temperatures, Kootenai River Flow, and Tributary Flow showed significant serial correlation of the data. The data were transformed using a random number generator and serial correlation was eliminated.
- Multiple linear regression indicates that during the April through June time period, Bonners Ferry Air Temperatures and Libby Dam Water Temperatures were the most highly correlated with Bonners Ferry Water Temperatures.
- During April through June, Libby Dam Water Temperatures were not solely responsible for Bonners Ferry Water Temperatures. Indeed, during the months of April and May, Bonners Ferry Air Temperatures were more highly correlated with Bonners Ferry Water Temperatures than were Libby Dam Water Temperatures.
- Libby Dam Water Temperatures had the greatest correlation with Bonners Ferry Water Temperatures during the month of June.
- Flow in the Kootenai River and Tributaries had a negative influence on Bonners Ferry Water Temperatures, suggesting that as flows decrease Bonners Ferry Water Temperatures increase.

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