EVALUATING THE COLUMBIA RIVER PUMP EXCHANGE PROJECT USING THE STREAM NETWORK TEMPERATURE MODEL

Prepared for:

Kennewick Irrigation District
214 W. 1st Ave.
Kennewick, WA 99336

Prepared by:

Thomas R. Payne & Associates
P.O. Box 4678
890 L Street
Arcata, California 95521
(707) 822-8478

and

Patrick A. Monk
Fish Biologist
P.O. Box 621
Ellensburg, WA 98926
(509) 925-4696

May 2001

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Evaluating the Columbia River Pump Exchange Project Using the Stream Network Temperature Model

Summary

The purpose of this study is to evaluate the potential of the Columbia River Pump Exchange Project (Project) to alter Yakima River water temperatures. The Project proposes to move the diversion points of the Kennewick and Columbia irrigation districts from the lower Yakima River to a pumping plant on the mainstem Columbia River. Moving points of diversion would increase instream flows in the lower Yakima River, while flows in the Columbia River would remain unaffected.

The Stream Network Temperature Model (SNTEMP) was applied to a 47-mile long reach of the Yakima River from Prosser Diversion Dam to the city of West Richland, WA. SNTEMP was applied in two phases: a previously developed model - *Yakima River Water Temperature Model: Prosser Diversion to Chandler Powerhouse* (*1998 Supplement*) (TRPA and Monk 1999), and a new model described in this report. Both models were calibrated utilizing hydrological and meteorological data from 1997 and 2000, with one model additionally utilizing data from 1995. The models were applied to simulate daily average (mean) and daily maximum water temperatures, under current conditions and with the Project in place. Two water-year types were chosen to evaluate alternatives: 1992, simulating drought year conditions, and 2000, simulating average water-year conditions.

The results of the modeling indicated that the Project could influence mean and maximum daily water temperatures under certain conditions in the Prosser Reach of the Yakima River, from Prosser Dam to the Chandler Powerhouse. The influence of the Project on water temperatures in this reach was most pronounced under drought year conditions. During drought years the Project could reduce mean daily water temperatures on average by 0.35°C, with a maximum single day decrease of as much as 1.82°C. Maximum daily water temperatures were decreased in the Chandler bypass reach under drought year conditions on the average by 1.13°C, with an extreme cooling day of 2.83°C.

In this same reach in an average water-year, the predicted average cooling influence of the Project on mean daily temperatures was 0.20°C with a largest, single day decrease of 0.94°C. In an average water-year Project could reduce maximum daily water temperatures on average by 0.68°C, with the most extreme, single day cooling of 1.61°C.

Flow alterations due to the Project did not significantly influence simulated water temperatures in the Yakima River downstream from Chandler Powerhouse to West Richland. The large volume of return flow water from the Chandler Powerhouse appeared to be the primary influence on water temperatures in this reach. At West Richland the maximum daily temperature was decreased by 0.49°C and 0.31°C in drought and normal years respectively, while the daily mean temperature was only decreased by 0.2°C and 0.12°C.

Introduction

The Kennewick Irrigation District and the Columbia Irrigation District have proposed development of the Columbia River Project (Project). The Project would remove two large irrigation diversions from the lower Yakima River, Washington, replacing them with a single irrigation water pumping station that would draw water from the Columbia River near Kennewick, Washington. Existing irrigation systems would require extensive modifications to accommodate the pumping plant; reports describing the project estimate the cost will be approximately $50 million. Objectives of the Project include improved irrigation water management and the enhancement of salmon and steelhead populations in the Yakima River Basin through increased instream flows.

This study addresses the effects the Project could have on water temperatures of the lower Yakima River. The process-oriented temperature model SNTEMP (Theurer et al., 1984) was used to predict water temperatures in this reach under various simulated flow regimes. Measurements of stream temperature, flow, geometry, and localized meteorology were utilized in the construction and calibration of the temperature model. Alternative river flow releases below Prosser Diversion Dam were modeled under various flow and water-year scenarios to evaluate the effect of increased river flows on resulting water temperatures.

Existing Conditions

The Kennewick Irrigation District (KID) and the Columbia Irrigation District (CID) both obtain water from diversion dams located on the lower Yakima River. KID's diversion is at Prosser Dam (river mile 47.1); CID diverts water from the right bank of the river at Wanawish Dam (river mile 18) (Figure 1). Lower Yakima River flow consists of unregulated runoff from the Cascade mountains, water released from Bureau of Reclamation-Yakima Irrigation Project storage reservoirs in the upper Yakima River watershed, and irrigation return water.

During the irrigation season (April to October), water is diverted by the Bureau of Reclamation (BOR) at Prosser Dam in to the Chandler Power Canal. The water is conveyed 11 miles to the Chandler Power and Pumping Plant to: (1) meet the irrigation demands of KID, (2) operate two hydraulic turbines which pump water across the Yakima River into the Kennewick Canal, and (3) generate hydroelectric power which BOR makes available to Bonneville Power Administration. Irrigation water pumped across the Yakima River at Chandler is conveyed by KID to irrigate 20,200 acres of agricultural, urban, and suburban land near the Tri-Cities area of Washington.

The Chandler Canal has a capacity of 1500 cfs. During peak irrigation demand KID must divert 740 cfs of water. However, less than half of this water (330 cfs) is actually diverted into the Kennewick Canal to be used for irrigation. The additional 410 cfs of water that KID diverts at Prosser Dam is used to power hydraulic turbine pumps. The pumps lift the irrigation water to the Kennewick Canal, which is across the Yakima River from Chandler and at a higher elevation. The pumping water is returned to the Yakima River at Chandler along with any water diverted for hydroelectric generation. During the non-irrigation season the canal may divert up to 1500 cfs for hydroelectric generation.

The Columbia Irrigation District (CID) diverts approximately 200 cfs from Wanawish Dam (river-mile 18) on the lower Yakima River. The Project

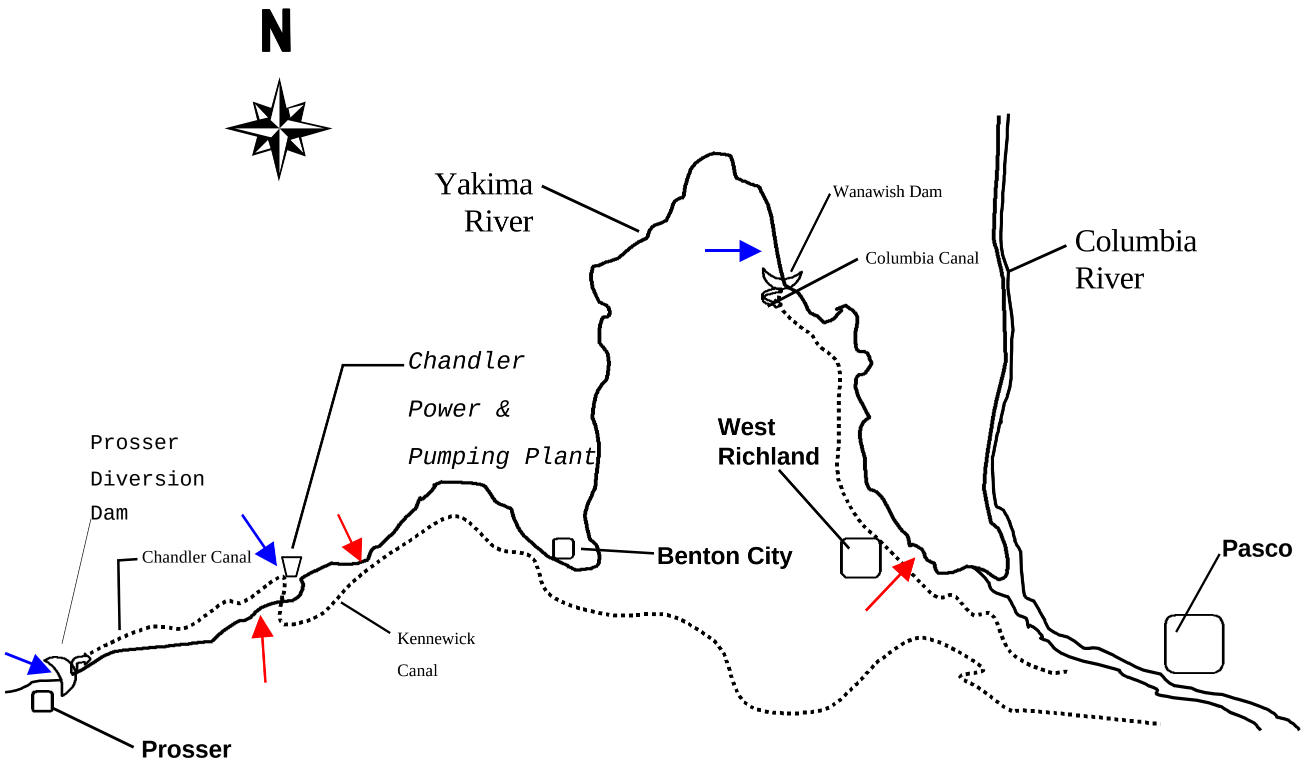


Figure 1. Project area for the Columbia River pump exchange (not to scale). *Prosser Reach* is from Prosser Diversion Dam to just downstream of Chandler Power and Pumping Plant; *Columbia Reach* is from downstream of Chandler Power & Pumping Plant to West Richland. Red and blue arrows indicate locations where water temperature data was collected; red arrows indicate locations where water temperatures were not only collected, but also simulated to compare conditions with and without the pump exchange project.

Table 1. Yakima River target flows specified by Congress in Section 1205 (a)(1), Title XII, P.L. 103-434.

Water Supply Estimate for Period (million acre-feet):				Target Flow From Date of Estimate Thru October Downstream of (cubic feet per second):	
April thru September	May thru September	June thru September	July thru September	Sunnyside Diversion Dam	Prosser Diversion Dam
3.2	2.9	2.4	1.9	600	600
2.9	2.65	2.2	1.7	500	500
2.65	2.4	2.0	1.5	400	400
Less than line 3 water supply				300	300

proposal would allow CID to obtain irrigation water from the same Columbia River pumping station as KID, eliminating the need for the CID diversion at Wanawish. This water would remain as instream flows to the mouth of the Yakima River.

In 1994 the United State Congress set target flows in the Yakima River below Prosser Diversion Dam (Table 1). After the spring run-off, flows during most of the irrigation season (July-October) range from 300-600 cfs, depending upon the water supply available.

In summary, the Project would increase flows in the lower Yakima River during the irrigation season. Flows during the base flow period would be increased over current conditions by about 700 cfs in the reach from Prosser Dam to the Chandler Powerhouse, by about 300 cfs from the Chandler Powerhouse to Wanawish Dam, and by about 500 cfs from Wanawish Dam to the confluence of the Yakima and Columbia rivers. The minimum target flows specified by Congress in Table 1 could consequently increase by 700 cfs, providing a range of minimum flows below Prosser from 1,000-1,300 cfs.

Effects of the Columbia River Pump Exchange Project

Water temperature is an important fish habitat parameter because it affects fish growth, behavior, and survival. Temperature is particularly important to evaluate in the context of the Project because warm water temperatures have been associated with high juvenile salmonid mortality in the lower Yakima River (Sandford and Ruehle 1996). There have been suggestions that increasing flows in the lower Yakima River could decrease water temperatures, benefiting juvenile salmon survival. Improving juvenile migrant survival through the lower Yakima River to the Columbia River may improve adult returns to the Yakima Basin (McMichael et al. 1999). Determining the impacts the Project could have on water temperatures is critical for the assessment of project benefits.

Existing studies do not completely agree on the importance of stream flow as a factor affecting stream temperature in the lower Yakima. Lilga (1998) was unable to develop a relationship between flow and temperature for the lower Yakima River during the height of the irrigation season, instead finding water temperature was most responsive to air temperature. In contrast, McMichael et al. (1999) described a significant, inverse relationship between discharge and water temperature, with increasing flows coinciding with decreasing water temperatures. Vaccaro (1986) undertook an extensive effort to develop a model of factors influencing Yakima River water temperatures. Vaccaro found air temperature was the dominant factor influencing water temperature, although in certain circumstances reservoir releases were able to affect water temperatures in the lower river. TRPA and Monk (1999) developed a model which simulated a slight decrease in mean daily water temperatures when flows below Prosser Dam were increased.

In order to resolve uncertainties regarding the important of stream flow, the specific flow alterations associated with the Project were evaluated in the analyses described below.

Model Development and Refinement

Stream Network Temperature Model

Implementing the Project would alter the stream flow patterns that have existed in the lower Yakima River for over 40 years. The evaluation of water temperature effects of the Project was accomplished using the computer-based model SNTEMP. This model has the benefits of being peer-reviewed, published, and widely applied. SNTEMP incorporates (1) a complete solar model that includes both topographic and riparian vegetation shade; (2) a meteorological correction model to account for the change in air temperature, relative humidity, and atmospheric pressure as a function of elevation; (3) a complete set of heat flux components to account for all significant heat sources; (4) a heat transport model to determine longitudinal water temperature changes; (5) regression models to smooth or complete known water temperature data sets; (6) a flow mixing model at tributary junctions; and (7) calibration equations to help eliminate bias and reduce errors at calibration nodes (Theurer et al, 1984).

New Modeling

For purposes of modeling, calibration, and gaming, the study area was divided into two Yakima River reaches. Prior to this analysis, an existing SNTEMP model (noted hereafter as the *Prosser Reach* model) had been developed for the 12.5 mile Prosser Reach of the Yakima River extending from the Prosser Diversion to a point 1 mile downstream of the Chandler Powerhouse return (TRPA 1996; TRPA & Monk 1999). (This downstream location was chosen because it was assumed that the Chandler Canal return flows would have adequately mixed with river flows.) This model was calibrated and verified using data gathered during 1995 and 1997. Additional data for 2000 was collected and incorporated into the existing model to test its calibration and further enhance its predictive capability.

The second modeled river reach (called the *Columbia Reach* model) began where the Prosser model ended and continued downstream to river mile 6, near the city of West Richland, WA. Data for 1997 and 2000 was collected and used in the construction and calibration of this model.

Modeled within the Prosser reach are the Chandler Canal and two existing diversions, the Prosser Diversion on the river at Prosser, and the Kennewick Irrigation District diversion out of the terminus of the Chandler Canal. The Columbia Reach includes the Columbia Irrigation District diversion on the Yakima River at Wanawish Dam.

SNTEMP Data Requirements for 1995, 1997, 2000

The SNTEMP model requires calibration data for three major categories: hydrology, meteorology, and stream geometry. Additionally, a premise when developing a temperature model for a river such as the Yakima, is to first calibrate the model utilizing as much real, measured data as is available. Hogan et al. (1973) found that analysis of data for a period of two years leads to the same general distribution of equilibrium water temperatures as does a ten-year period. Thus a model calibrated with two to three years of data should perform as well as one calibrated with numerous years of data.

The development of the existing Prosser Reach temperature model (TRPA and Monk 1999) was based solely upon 1995 and 1997 data. Subsequently, a complete data set was collected in 2000 and this new data was added to the existing model.

For the Columbia Reach model, a complete water temperature data set existed for 1997. A complete data set was collected in 2000 for use in the synthesis of this model.

The stream geometry data for the Prosser model did not change from that originally derived for the 1995/1997 model. Stream geometry data and shade data for the Kennewick model were obtained from existing sources such as USGS quad maps, or collected as part of a habitat mapping study (TRPA 1995).

Hydrology

The hydrology data for 2000 was acquired from the same sources as those relied on in 1995 and 1997. BOR stream gaging records were again used to determine levels of discharge in the river and into the canals in the various reaches.

Site-specific water temperatures in the two study reaches were obtained through the placement of 32K Optic Stowaway temperature loggers (Onset Computer Corporation, Pocasset, MA). In addition to those locations within the Prosser Reach as noted in the 1996 TRPA report, loggers were also 0.7 miles upstream of the Wanawish Dam, and at river-mile 6 near the city of West Richland. Each temperature logger was checked for accuracy through a range of temperatures prior to installation. The loggers were in place and collected data from early June through mid October each year, for a minimum of 128 days.

Meteorology

For the Prosser Reach model, climate data near the Prosser Diversion Dam was collected. Onset data loggers were located near the Prosser Diversion Dam, recording air temperature and relative humidity.

Mean daily wind speed and solar radiation values were obtained from the meteorological station of Washington State University Public Agricultural Weather System. Weather data from throughout the Columbia Plateau is stored at the Irrigated Agriculture Research and Extension Center (WSU-IAREC) at Prosser, Washington. Solar Radiation values were again converted to percent possible sun values as noted in the 1996 report (TRPA 1996).

Daily mean air temperature, relative humidity, wind speed, and converted percent possible sun values recorded at WSU-Pasco were averaged with those recorded at Prosser, and used in the Columbia Reach model analysis. The mid point of this reach is approximately half way between Prosser and Pasco. Averaging the two meteorological values was done to more accurately reflected local weather conditions.

Model Calibration

Calibration of the temperature model is the process by which certain parameters are adjusted to allow the model to more accurately predict observed water temperatures. Adjustments are often needed to correct for differences in physical conditions between the water surface where temperature change occurs and the sites of data collection. For instance, the Prosser station air temperature logger, although near the river, was in a tree above a gravel road and recorded air temperatures may have been influenced by heat reflected or retained by the gravel. Any differences in conditions could affect the ability of the model to reproduce observed water temperatures and warrant calibration adjustments. These calibrations should be within reasonable limits, as defined in the documentation for the models (Bartholow 1989).

Prosser Reach Model Calibration

The original Prosser 1995 model had been calibrated utilizing adjustment of two of the climate parameters, air temperature and solar radiation. The input data to these parameters are modified globally (the entire input data set of the specified parameter) by the application of a constant and coefficient modifier to each daily input value. The global calibration factors were used in the computer program to modify the meteorological parameters according to the general form of:

$$Y = a_0+a_1y$$

where:
- Y is the modified meteorological parameter
- y is the original input meteorological parameter
- a_0 is the calibration constant factor
- a_1 is the calibration coefficient factor

The objective of calibration is to achieve a mean bias error of 0°C and simultaneously attempt to maximize the standard deviation (R^2) of the regression between observed data and predicted values and minimize the mean error (Bartholow 1989). Further criteria include:

1 - No more than 10% of the simulated temperatures greater than 1°C from measured temperatures.
2 - No single simulated temperature greater than 1.5°C from measured temperatures.
3 - The mean of the absolute values of the observed minus the predicted is less than 0.5°C (probable error).
4 - No trend in spatial, temporal, or “temperature” error.

Testing of numerous combinations of constants and coefficients air temperature and solar radiation resulted in the following calibration choices for the 1995:

	Constant	Coefficient
Air temperature	a_0=1.30,	a_1=0.92
Solar radiation	a_0=10,	a_1=0.97,

The global calibrations for the 1995 Prosser model for air temperature and solar radiation tend to increase low numbers while decreasing high numbers, thus reducing the overall range of air temperature.

These global calibration factors in the 1995 Prosser model resulted in the following quality control results at the river validation nodes, which were considered acceptable:

Stream Reach Validation Node	Correlation Coefficient (R^2)	Mean Error (°C)	Probable Error (+/-°C)	Maximum Error (°C)	Bias (+/-°C)
0.6 km upstream Chandler Powhs	0.9931	-0.01	0.40	1.63	0.03
1.6 km dwnstream Chandler Powhs	0.9943	0.03	0.31	1.65	0.02

Testing Prosser 1997 Data With 1995 Calibration

The 1995 Prosser model’s global calibration parameters were applied to the 1997 Prosser data set of hydrological and meteorological conditions to test the statistics of predicted versus measured water temperatures for 1997. This type of testing (i.e. validation) “splits” the data into separate parts to independently evaluate the original calibration. Validation resulted in the following quality control results at the two river nodes:

Stream Reach Validation Node	Correlation Coefficient (R^2)	Mean Error (°C)	Probable Error (+/-°C)	Maximum Error (°C)	Bias (+/-°C)
0.6 km upstream Chandler Powhs	0.9929	0.17	0.32	1.33	0.03
1.6 km dwnstream Chandler Powhs	0.9941	0.20	0.28	1.52	0.02

Although these were acceptable results according to the standard criteria, the mean error and bias were slightly higher than normally desirable, therefore, the 1995 and 1997 data were merged and the combined data set recalibrated. Recalibration of the combined model through iterative testing of different combinations of constants and coefficients for the climate variables resulted in the following choices for the 1995 calibration:

	Constant	Coefficient
Air temperature	a_0=1.50,	a_1=0.88

With the revised calibration no further adjustments to the solar radiation data were required. Final calibration of the model was achieved by applying these factors to air temperatures, then running the model. This resulted in the following quality control results at the two river nodes (1995 and 1997 combined):

Stream Reach Validation Node	Correlation Coefficient (R^2)	Mean Error (°C)	Probable Error (+/-°C)	Maximum Error (°C)	Bias (+/-°C)
0.6 km upstream Chandler Powhs	0.9919	-0.03	0.30	-1.44	0.02
1.6 km dwnstream Chandler Powhs	0.9923	0.05	0.29	1.55	0.02

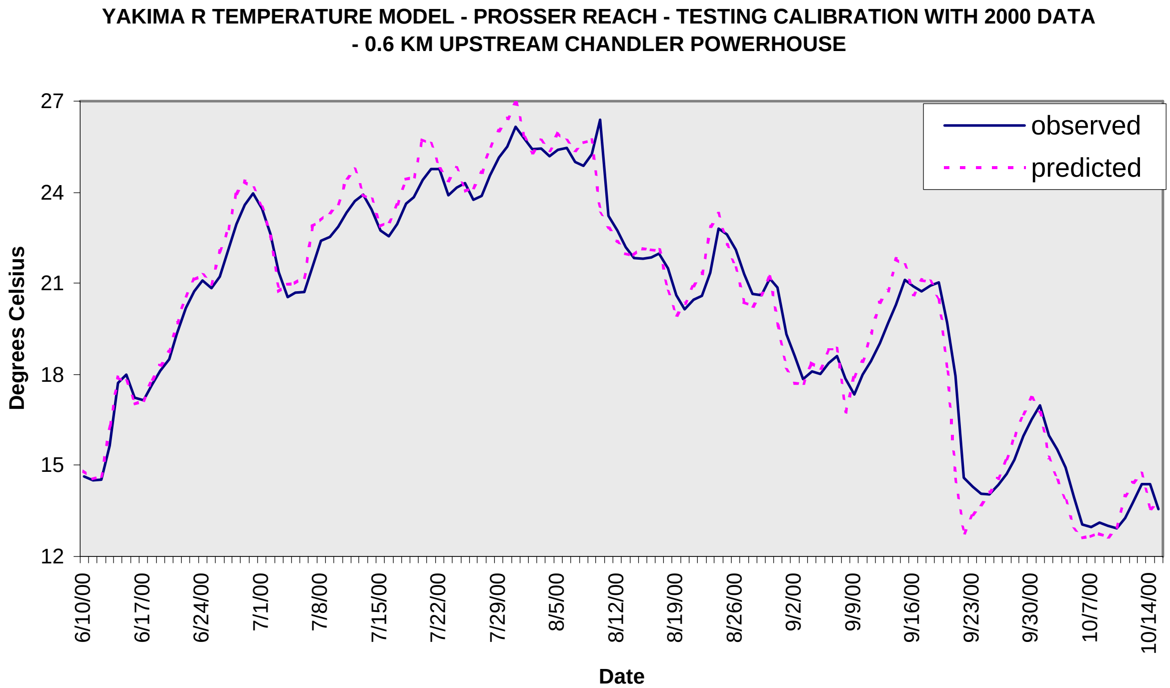
Testing the Calibration of the Prosser Model with 2000 data

Once the model was calibrated with data from 1995 and 1997, it was tested by comparing the observed data collected in 2000 to the water temperatures predicted by the model. This resulted in the following quality control results:

Stream Reach Validation Node	Correlation Coefficient (R^2)	Mean Error (^{0}C)	Probable Error (+/-^{0}C)	Maximum Error (^{0}C)	Bias (+/-^{0}C)
0.6 km upstream Chandler Powhs	0.9824	0.12	0.55	-3.41	0.05
1.6 km dwnstream Chandler Powhs	0.9818	0.07	0.49	2.95	0.04

For both river validation nodes the correlation between observed and predicted temperatures was high, mean errors approached zero, probable error was below 0.50, and bias was low. Although maximum error was higher than the 1.5^{0}C specified above for a "good" calibration, all other criteria were well within the standards. Maximum errors occurred on days that aren’t well reflected by average conditions, for example when storm fronts were arriving and very rapid changes in air temperatures were observed.

Figure 2 illustrates the measured and predicted water temperatures for the Yakima River at validation sites both upstream and downstream of the Chandler Powerhouse under 2000 weather and flow conditions. In both years at both locations, the predicted data closely track the observed data, with only minor variation on certain days.



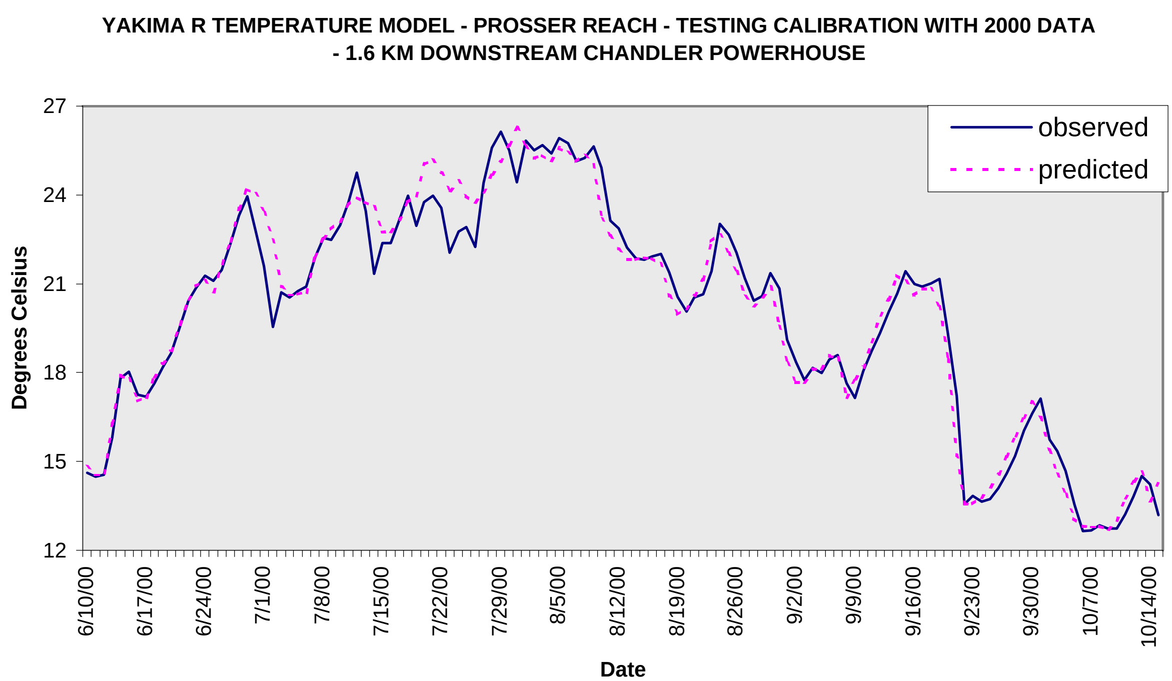


Figure 2. Water temperatures predicted by the calibrated SNTEMP model of the Prosser Reach are compared to data observed for 2000.

Columbia Reach Model Calibration

The Columbia Reach model, from Kiona down to the mouth of the Yakima River, was developed in a similar manner as the Prosser Reach model. The model was generated using data collected June through October 1997. In addition to the hydrology and meteorology data collected at Prosser, additional data was collected from a WSU weather station at Pasco, Washington.

Global calibration adjustments were made to the following variables:

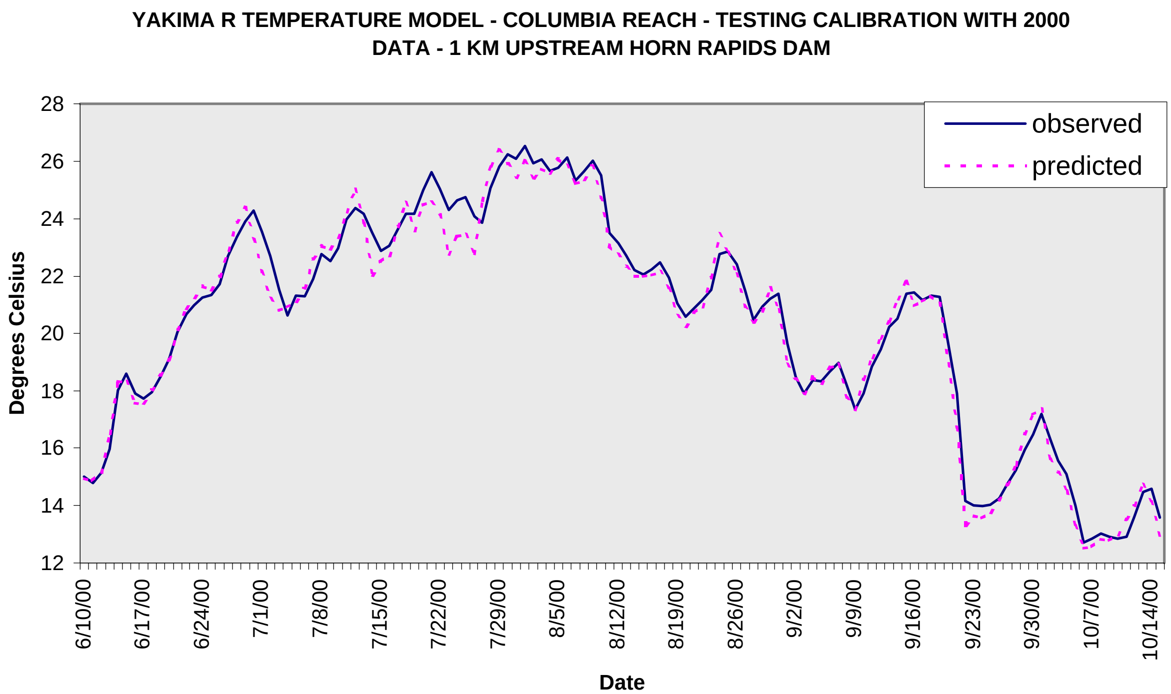
	Constant	Coefficient
Air temperature	1.50	0.88
Wind speed	0.90	0.18
% sunshine	0.35	0.55

Statistical results of the observed versus predicted daily mean water temperatures for the Columbia Reach model using only 1997 data are as follows:

Stream Reach Validation Node	Correlation Coefficient (R^2)	Mean Error (^0C)	Probable Error (+/-^0C)	Maximum Error (^0C)	Bias (+/-^0C)
1.0 km upstream Wanawish Dam	0.9954	0.02	0.23	-0.99	0.02
RM 6 at city of Richland	0.9896	0.02	0.37	-1.55	0.03

The model appeared well calibrated to the 1997 data. Meteorology and hydrology data for 2000 was applied to the model. Figure 3 shows the water temperatures predicted by the model as compared to those observed for 2000. Statistical results of this simulation are as follows:

Stream Reach Validation Node	Correlation Coefficient (R^2)	Mean Error (^0C)	Probable Error (+/-^0C)	Maximum Error (^0C)	Bias (+/-^0C)
1.0 km upstream Wanawish Dam	0.9911	-0.15	0.35	-1.54	0.03
RM 6 at city of Richland	0.9875	0.13	0.43	-1.68	0.04



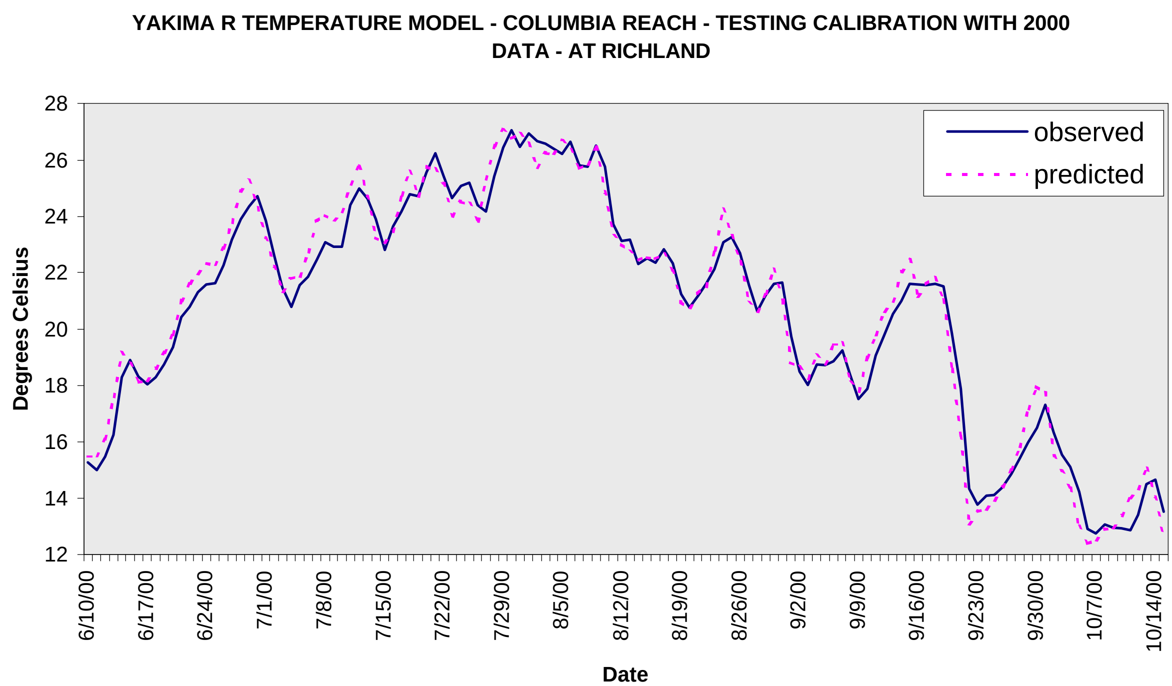


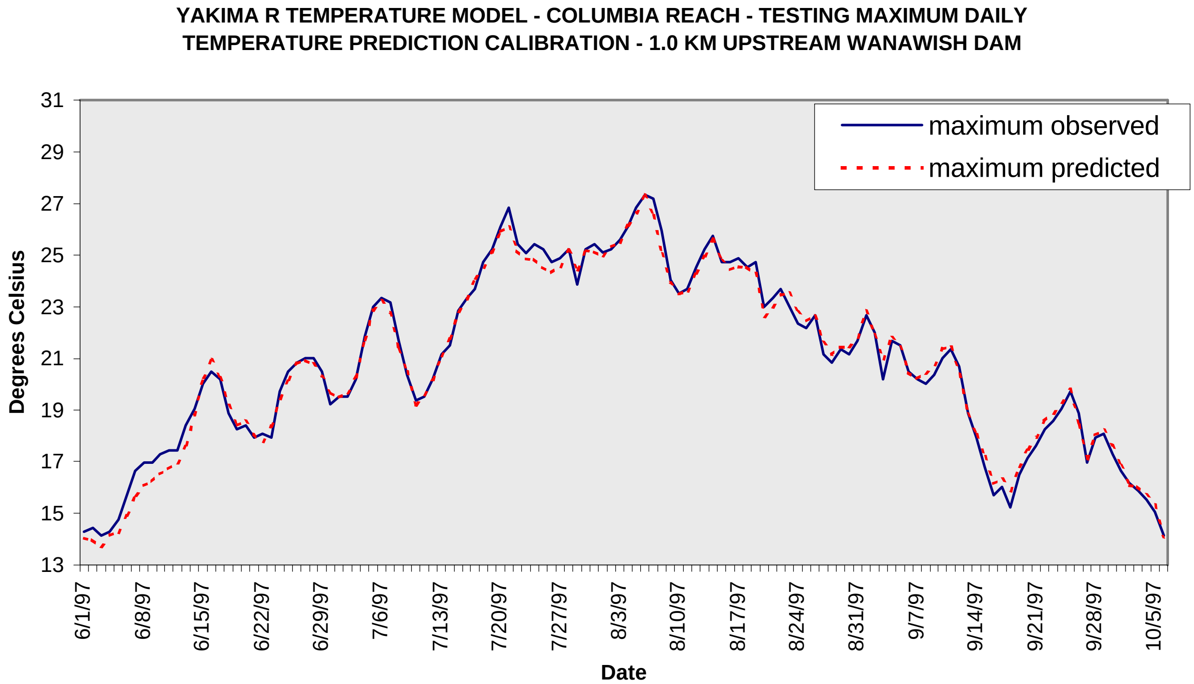
Figure 3. Water temperatures predicted by the calibrated SNTEMP model of the Columbia Reach are compared to data observed for 2000.

Daily Maximum Water Temperature Calibration

The SNTEMP model was also used to predict daily maximum water temperatures under current conditions as compared to those with the Project in place. (Note-the model does not have the capacity to predict daily minimum temperatures). The SNTEMP does not generally predict daily temperature extremes as well as daily averages (Bartholow 1987). Daily temperature maximums are very sensitive to water travel time, which was the parameter adjusted to achieve more accurate temperature predictions.

The Columbia Reach model predicted the observed (measured) maximum daily water temperatures well (R-squared 0.99) for both 1997 and 2000 and was not calibrated at all (Figures 4 & 5). The Columbia Reach model was run with a Manning's n value of 0.030, which is roughly equivalent to a travel time of 1,625 seconds/km. Daily maximum water temperatures were generated for a site located about 1.0 km upstream of Wanawish Dam, and for the Yakima River at West Richland.

SNTEMP did not predict daily maximum water temperatures in the Prosser Reach as accurately as in the Columbia Reach, and calibration was required. A Manning's n of 0.155 (travel time = 4,300 seconds/km) was applied for the Prosser Reach model. For this reach, the daily maximum model was calibrated using data for 1997 and 2000. Figure 6 shows the observed versus predicted data (R-squared 0.98 for 1997).



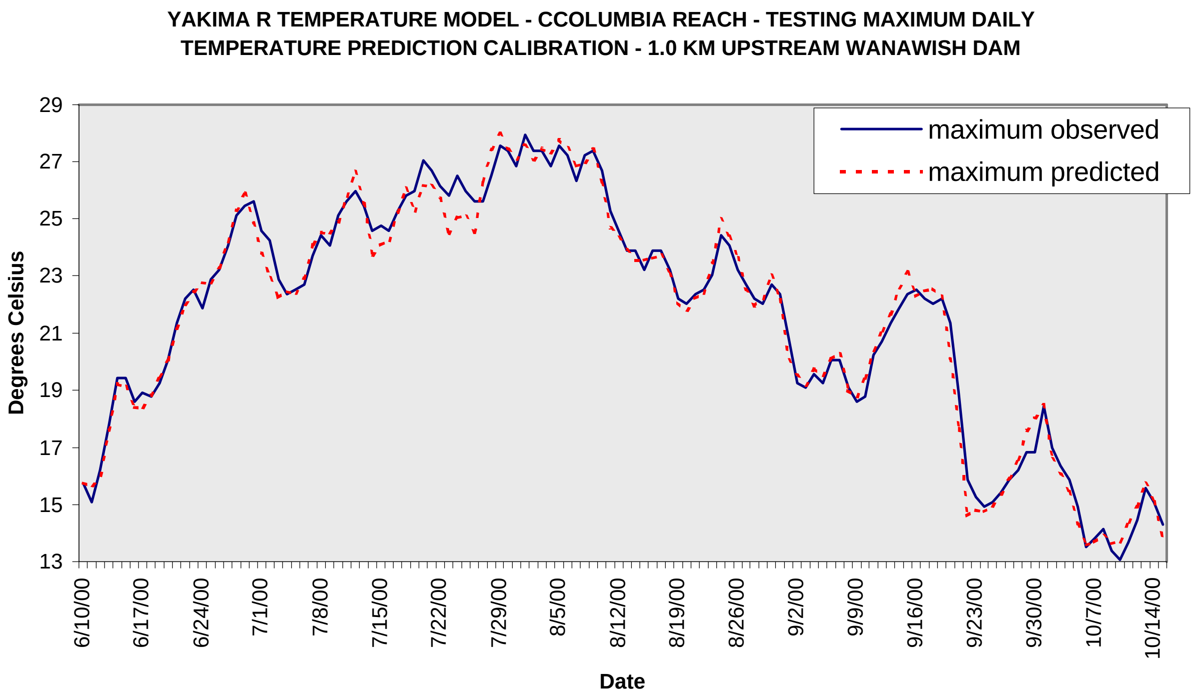
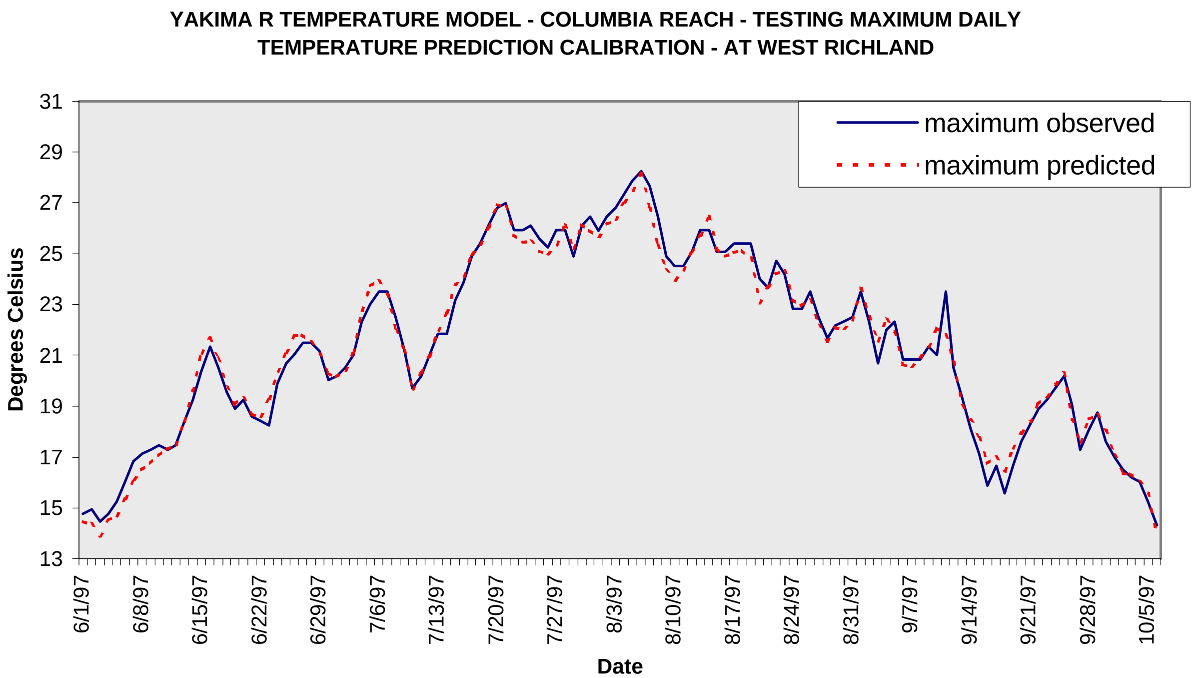


Figure 4. Observed and predicted daily maximum water temperatures for the Yakima River upstream of Wanawish dam during 1997 and 2000.



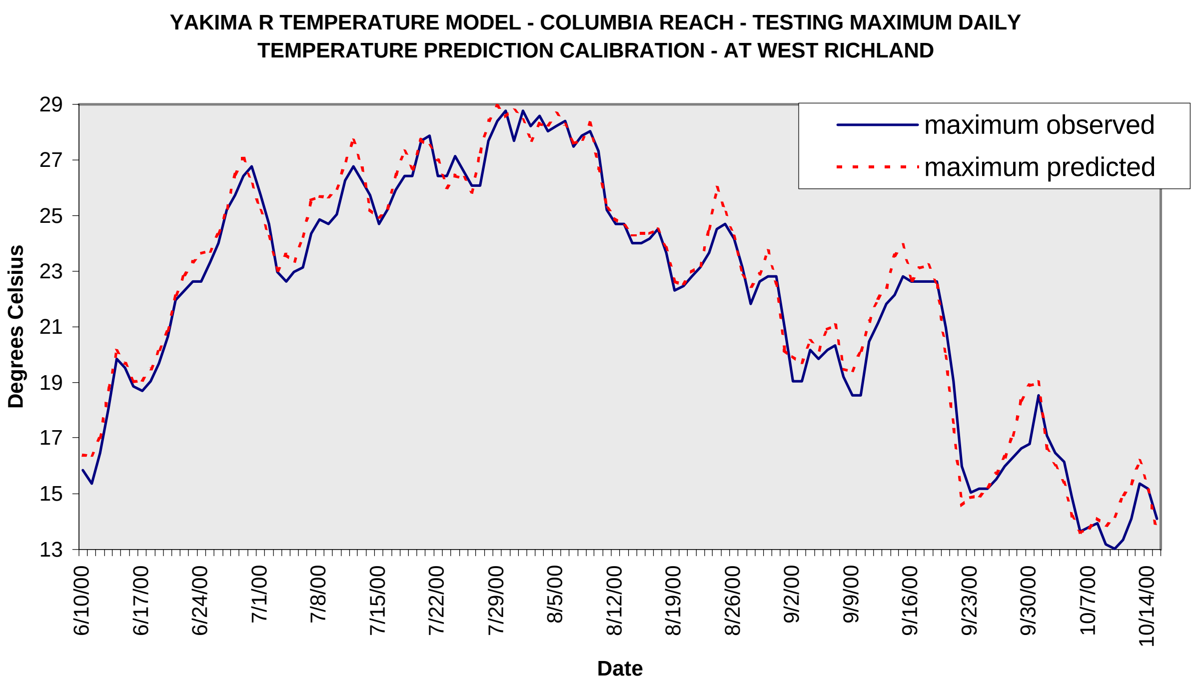
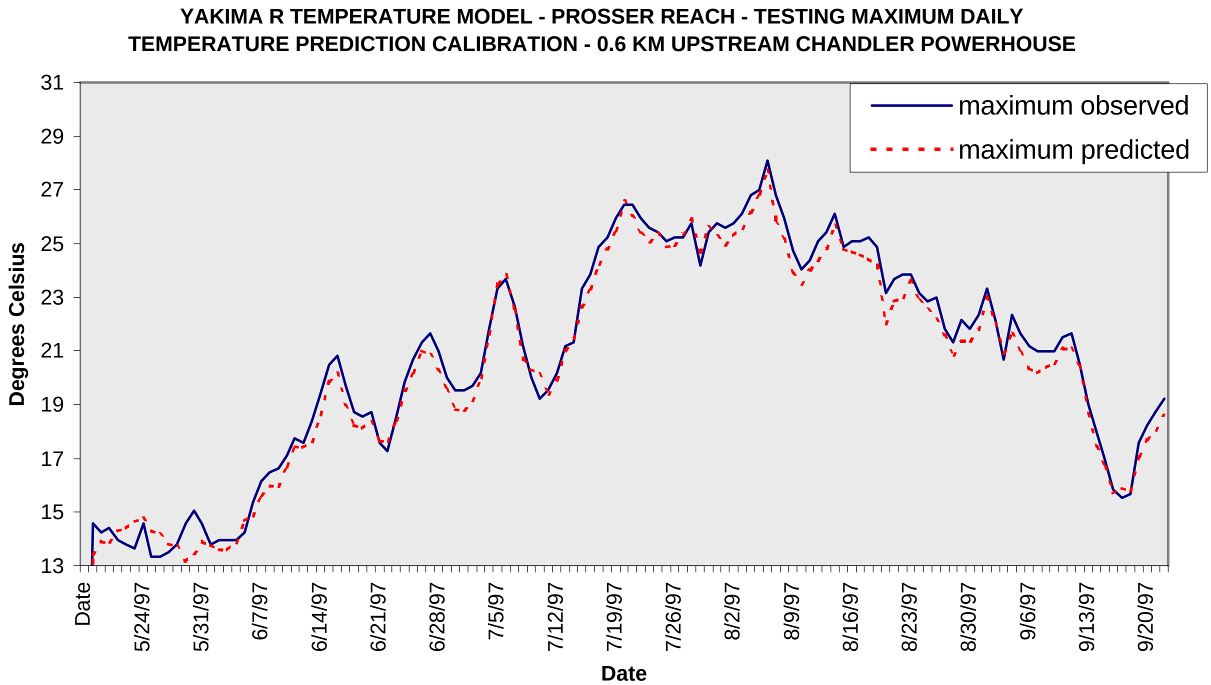


Figure 5. Observed and predicted daily maximum water temperatures for the Yakima River near West Richland during 1997 and 2000.



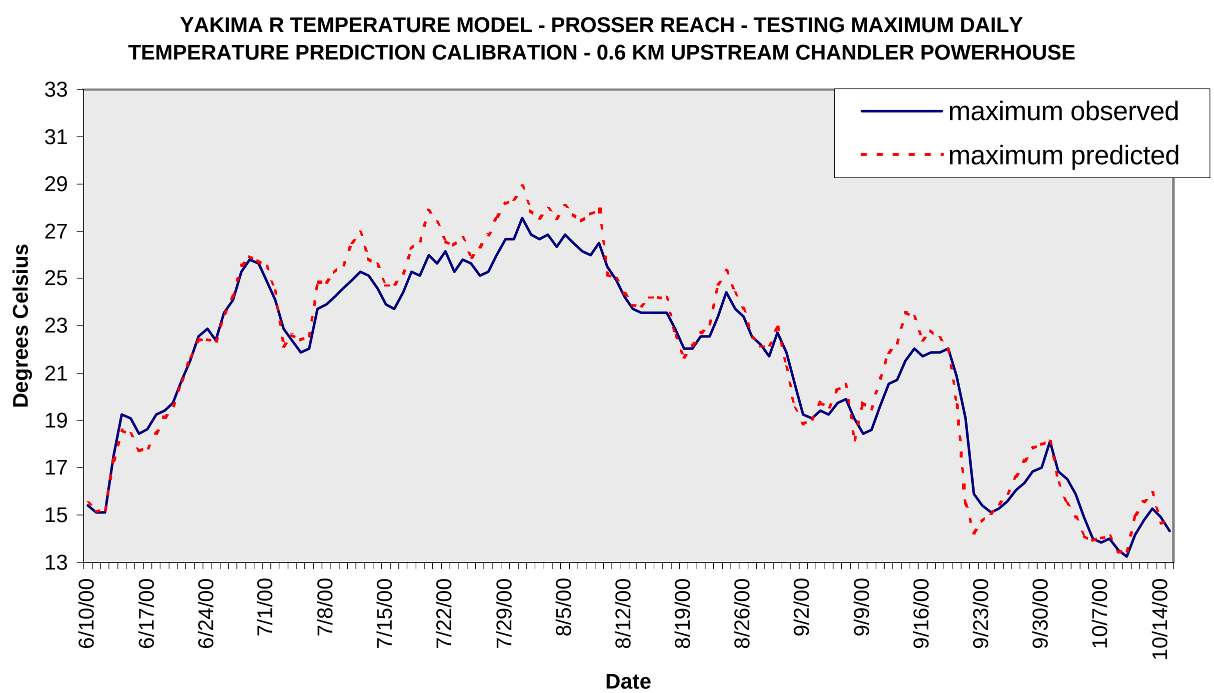


Figure 6. Observed and predicted daily maximum water temperatures in the Prosser Reach upstream of the Chandler Powerhouse for data collected in 1997 and 2000.

Results

To assess the cooling effect of increased flows in the Yakima River, the model was gamed by altering the amount of flow in the river while leaving all other parameters unchanged under two scenarios: 1992 flow and weather conditions, representing a drought-year scenario, and under 2000 flow and weather conditions, representing average streamflow conditions (USBR, unpublished data). Simulations were made by modeling flows, with and without the Project in place, at three locations on the mainstem Yakima River: upstream of Chandler Powerhouse, downstream of Chandler Powerhouse, and near Richland (Figure 1). Under the proposed Project, stream flow below Prosser were increased from observed lows of about 300 cfs to simulated low flows of about 900 cfs. Below Chandler Powerhouse changes in flow are less dramatic, due to the large amount of return flow from the Chandler Canal: low flows ranged around 600 cfs without the project, with the project flows rarely dropped below 1000 cfs. Below Wanawish dam, drought year flows were as low as 600 cfs, while low flows with the project were around 1100 cfs. Thus, implementing the Project would nearly double or triple instream flows in the lower Yakima River, depending upon the location (see Appendix A for detailed graphs of flow alterations and meteorology data).

Mean Daily Temperatures. Mean daily water temperatures were simulated at the three locations described above. Of the 138 days modeled under drought conditions (1992), mean daily water temperature was lowered on the average 0.35^{0}C upstream from Chandler Return (Figure 7), and 0.20^{0}C at West Richland (Figure 9). In the Prosser Reach, the maximum difference of 1.78°C between with- and without-project water temperatures occurred on June 23, 1992. In the Columbia Reach at West Richland, the maximum difference between with-and without-project water temperatures of 0.49° C occurred on May 24, 1992. Table 1 in Appendix B provides daily mean water temperature differences, with and without the Project in place, under 1992 conditions.

No significant temperature change was predicted downstream of the Chandler Powerhouse return (Figure 8). The large volume of water entering the Yakima River from the Chandler Powerhouse is the primary influence on water temperatures in this reach. However, it should be noted that under all flows throughout the summer, river temperatures exceed temperatures suitable for salmonids.

Under average water-year conditions the Project does not appear to influence water temperatures as significantly as under the drought year scenario. The SNTEMP model simulated less than 0.20^0 C on average of cooling under 2000 water-year conditions in the Prosser Reach upstream from Chandler Powerhouse (Figure 10).   On average the Project resulted in a 0.12^{0}C difference with the project flows in place at West Richland (Figure 12). Similar to the drought year scenario, water temperatures below the Chandler Powerhouse (Figure 11) were nearly unaffected by the simulated pump exchange. The maximum difference between with- and without-project conditions in the Prosser Reach was 0.94° C on July 7, 2000. The maximum difference with the project in place at West Richland was 0.31° C on July 7, 2000. Table 2 in Appendix B provides daily mean water temperature differences, with and without the Project in place, under 2000 conditions.

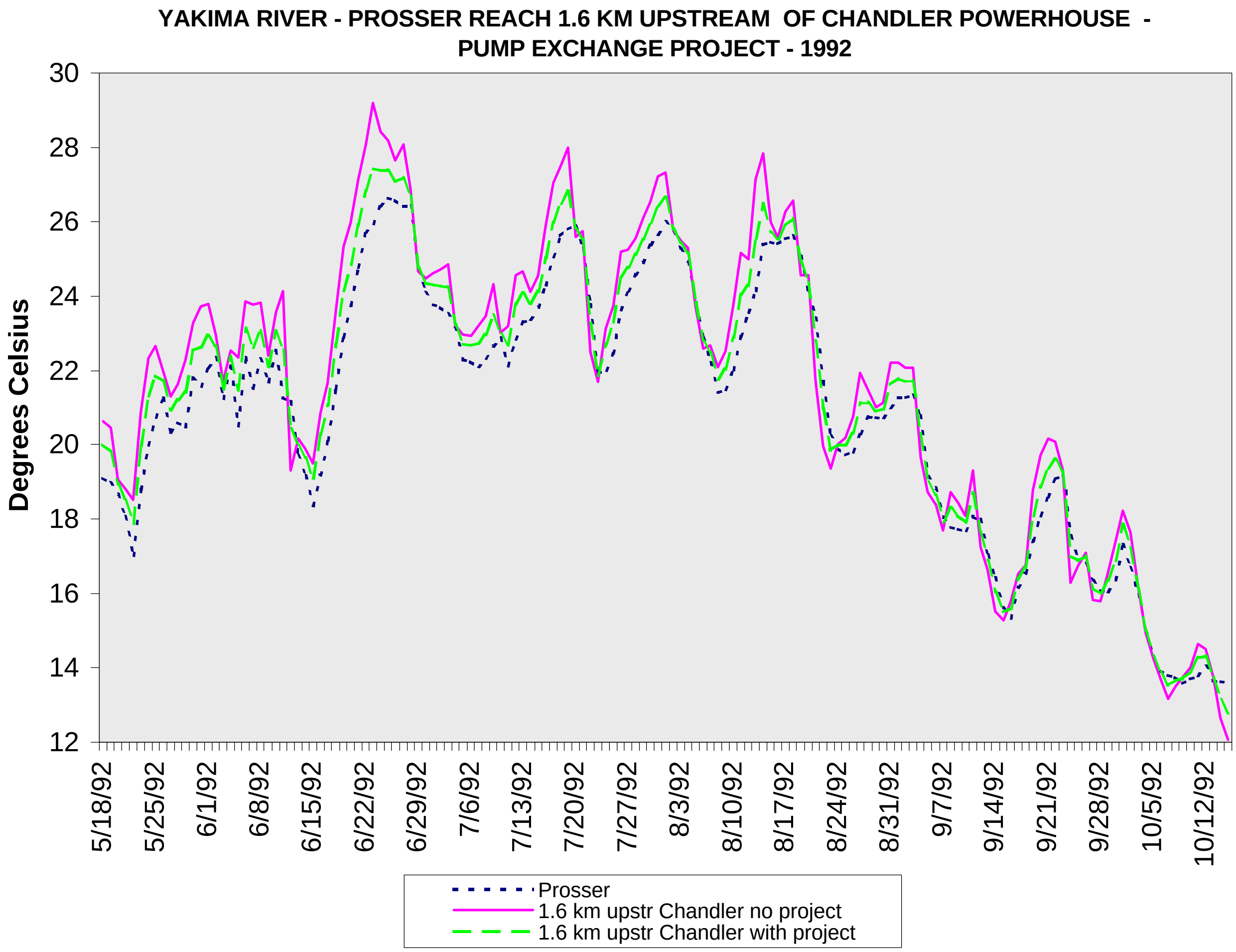


Figure 7. Simulated mean daily water temperatures with (green) and without (magenta) Project in the Yakima River, Prosser Reach, just upstream of the Chandler Powerhouse under 1992 conditions. Water temperatures at Prosser Dam (blue) were measured in 1992.

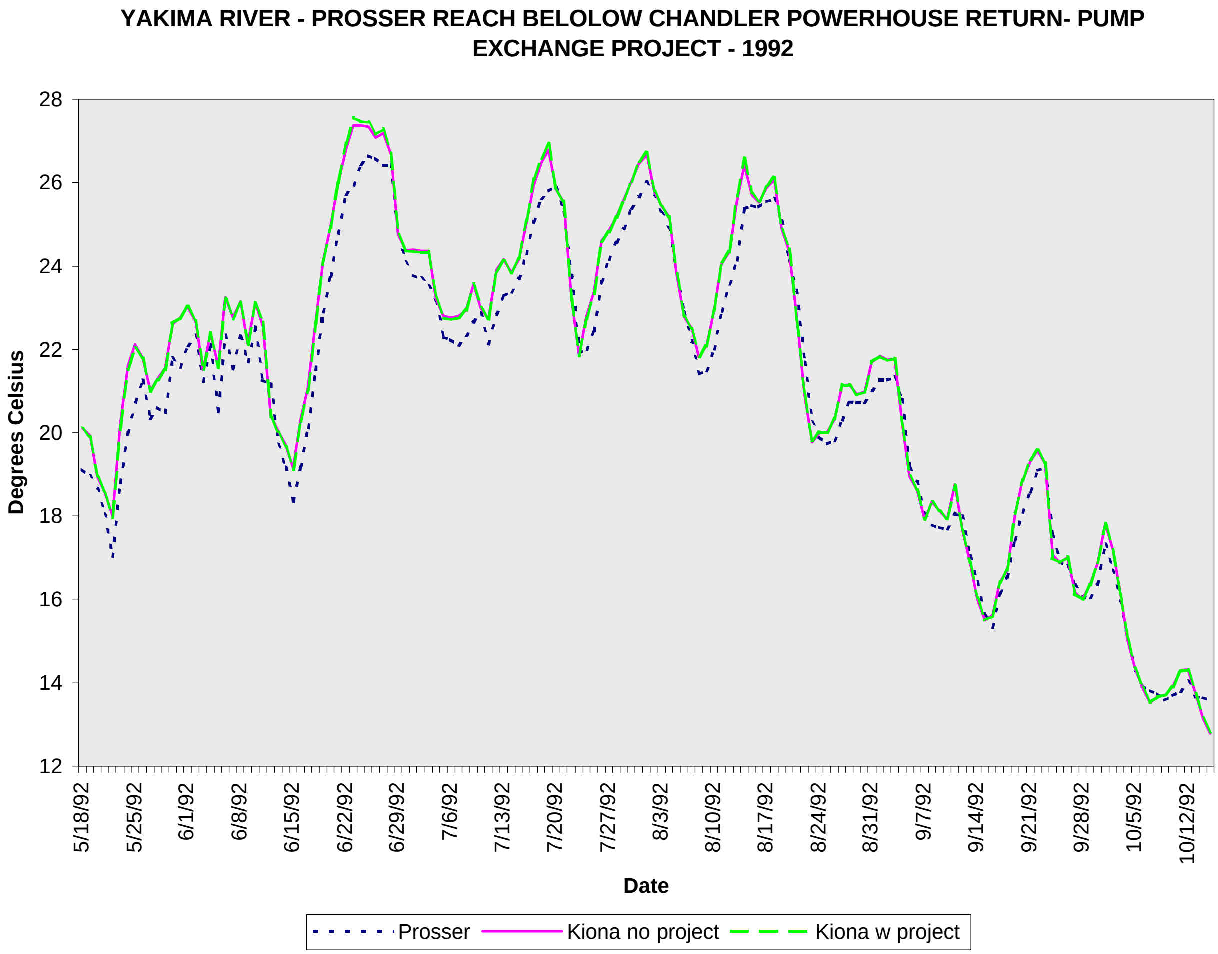


Figure 8. Simulated mean daily water temperatures with (green) and without (magenta) Project in the Yakima River, Prosser Reach, just downstream of the Chandler Powerhouse under 1992 conditions. Water temperatures at Prosser Dam (blue) were measured in 1992.

YAKIMA RIVER - PROSSER TO W. RICHLAND - PUMP EXCHANGE PROJECT - 1992

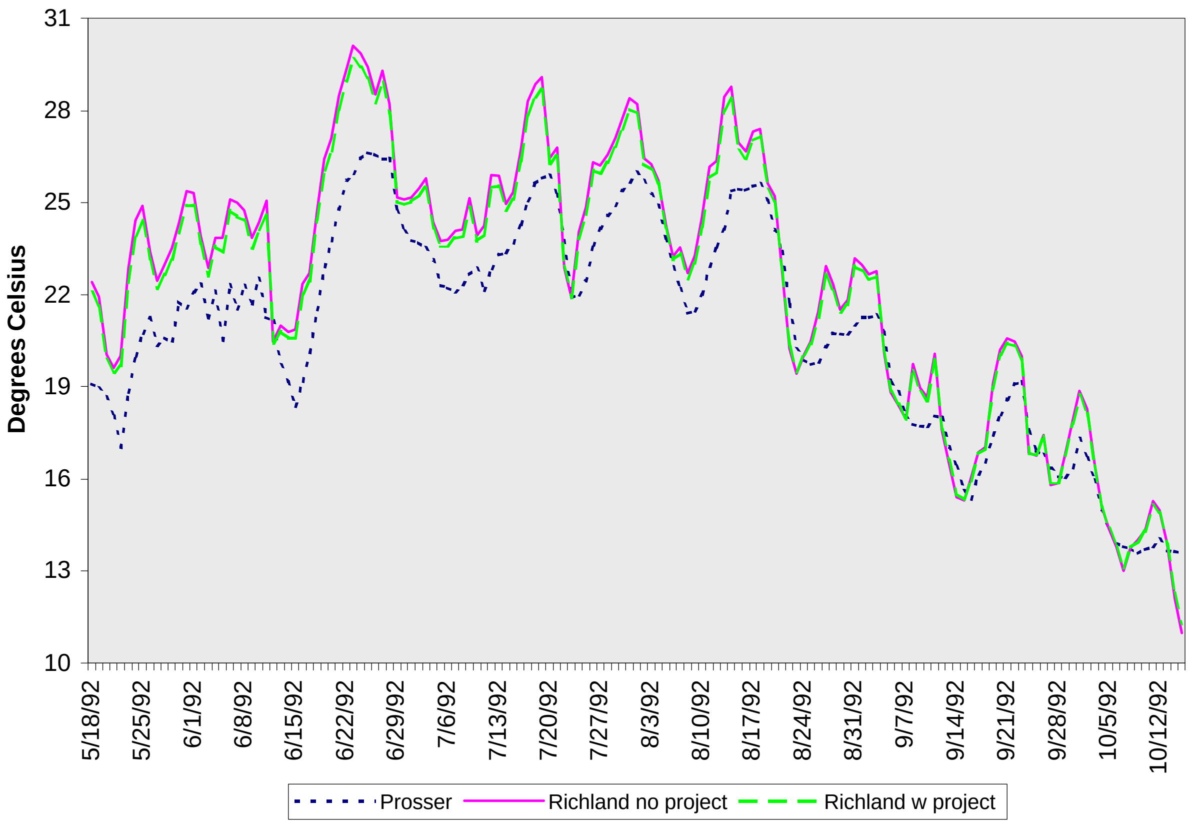


Figure 9. Simulated mean daily water temperatures with (green) and without (magenta) Project in the Yakima River, Columbia Reach, near West Richland, under 1992 conditions. Water temperatures at Prosser Dam (blue) were measured in 1992.

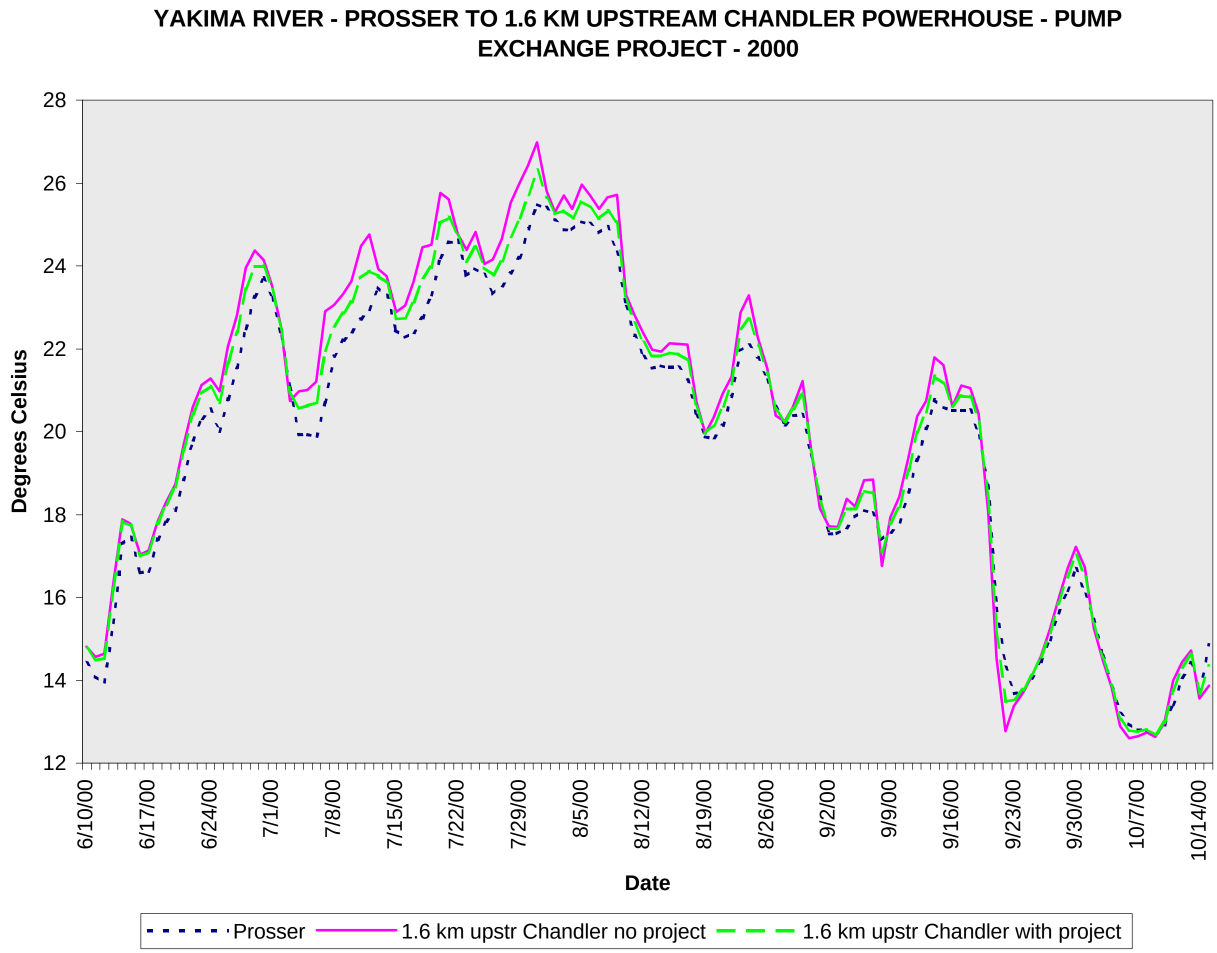


Figure 10. Simulated mean daily water temperatures with (green) and without (magenta) Project in the Yakima River, Prosser Reach, just upstream of the Chandler Powerhouse under 2000 conditions. Water temperatures at Prosser Dam (blue) were measured in 2000.

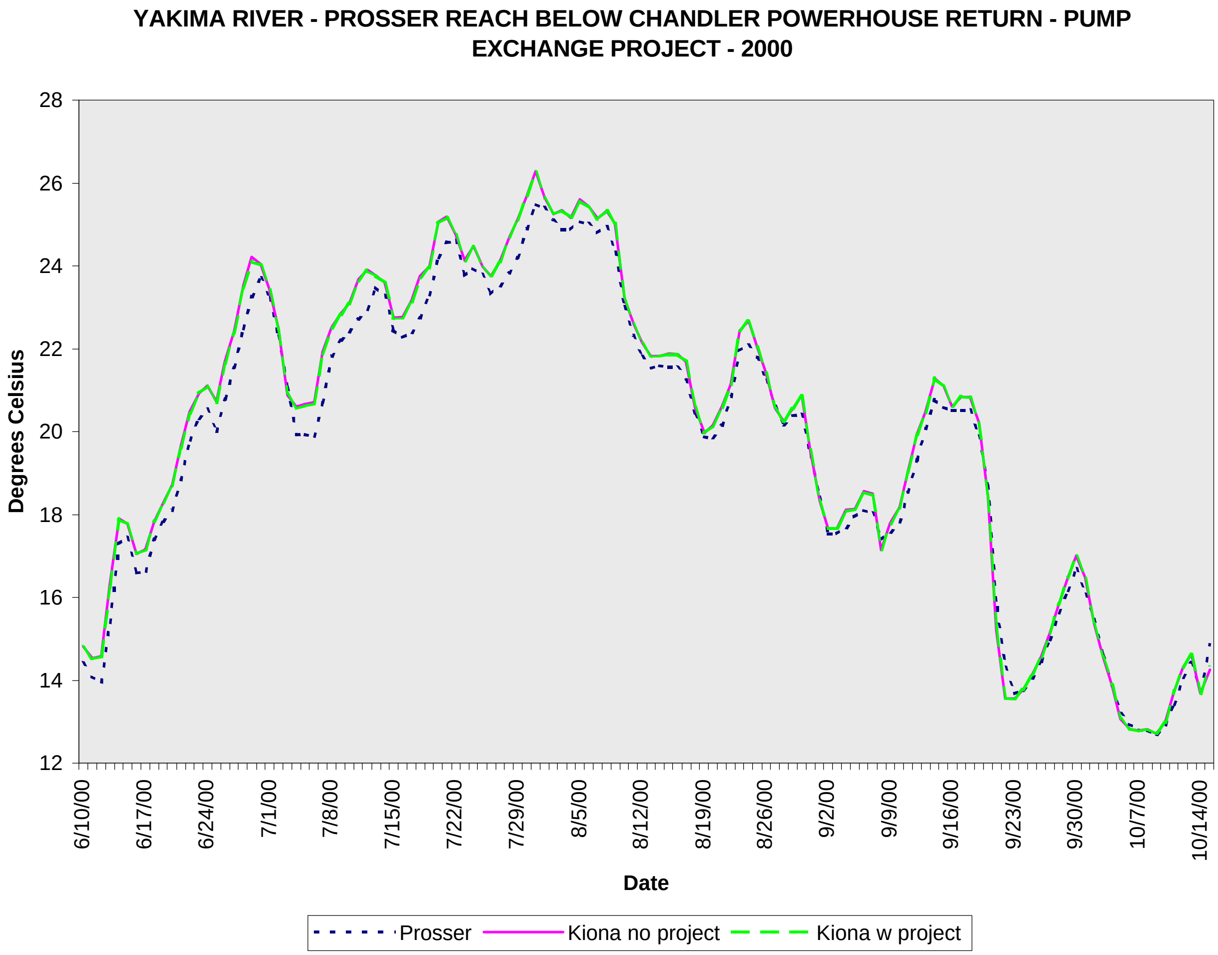


Figure 11. Simulated mean daily water temperatures with (green) and without (magenta) Project in the Yakima River, Prosser Reach, just downstream of the Chandler Powerhouse under 2000 conditions. Water temperatures at Prosser Dam (blue) were measured in 2000.

YAKIMA RIVER - PROSSER TO WEST RICHLAND - PUMP EXCHANGE PROJECT - 2000

Figure 12. Simulated mean daily water temperatures with (green) and without (magenta) Project in the Yakima River, Columbia Reach, near West Richland under 2000 conditions. Water temperatures at Prosser Dam (blue) were measured in 2000.

Maximum daily water temperatures. Under 1992 drought conditions, the SNTEMP model simulated an average 1.07°C decrease in maximum daily water temperatures associated with the Project in the Prosser Reach above the Chandler Powerhouse (Figure 13). The most significant single day decrease at this location was predicted to be 2.83°C, occurring on June 23, 1992 (Table 4, Appendix B). Under average water-year conditions experienced in 2000, temperatures at this site were on average 0.68°C cooler with the Project conditions in place (Figure 13). The most significant single day decrease in maximum daily temperature in an average water-year was predicted to be 1.61°C (Table 4, Appendix B).

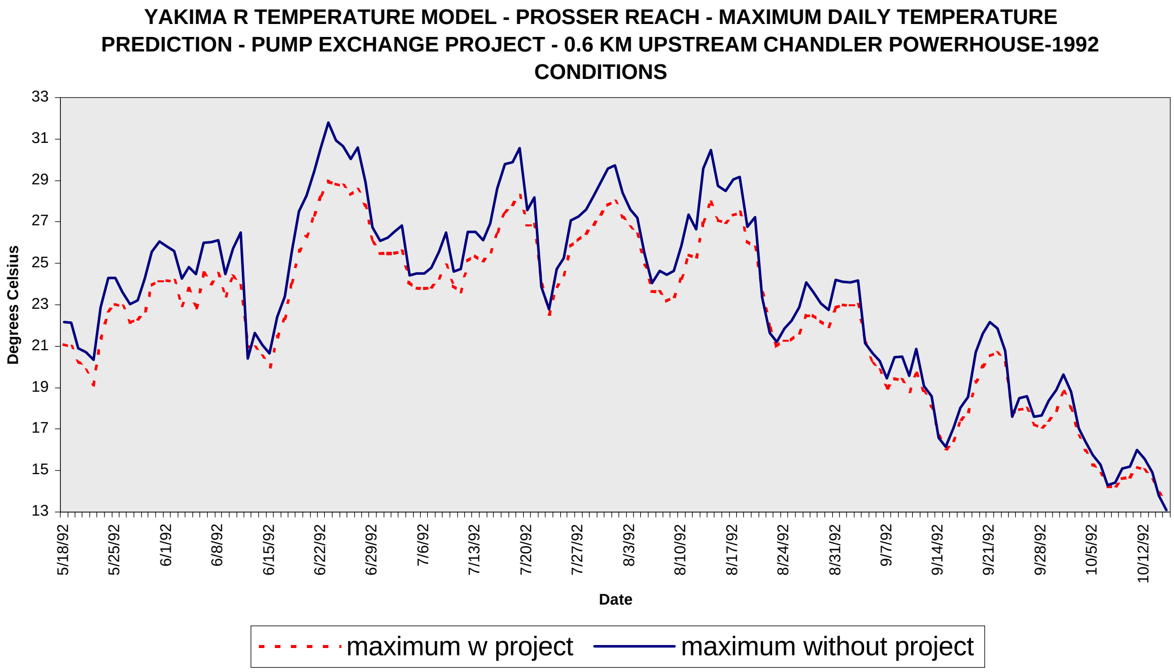
Similar to the mean daily temperature model, temperatures in other reaches of the river were not significantly influenced by the Project scenario (Figure 14). At West Richland under drought conditions, the average difference between daily maximum water temperatures with- and without-project conditions was 0.49°C. The maximum difference was 0.88°C, occurring on July 17, 1992. Under average water-year conditions the Project produced an average daily maximum temperature difference of 0.31°C, while the maximum temperature difference of 0.56°C occurred on July 28 and 29, 2000 at West Richland (Table 4, Appendix B).

Discussion

Water temperatures influence Pacific salmon survival and distribution in a variety of ways that are species and life-stage specific. During the irrigation season, April through October, adult and juvenile steelhead trout, spring chinook, fall chinook, and coho salmon are found in the Project area. In general these life stages prefer mean daily water temperatures less than 18°C, while mean daily temperatures in excess of 24°C are considered lethal (Bjornn and Reiser 1991).

During the summer months, water temperatures in the lower Yakima River frequently exceed mean daily temperatures considered unsuitable for salmonids, usually from late June through August (Figures 7-12). In the low-flow reach from Prosser Dam to the Chandler Powerhouse, the Project could improve water temperature conditions for salmonids by 1-2°C depending upon the conditions. This improvement may be beneficial to salmonids, particularly when conditions are reduced below a threshold value such as a lethal limit. However, in the context of the entire Project area (Figure 1), water temperatures downstream of the Prosser Reach will not be significantly influenced by Project conditions.

The SNTEMP model indicated water temperatures in the lower Yakima River are not highly responsive to alterations of the flow regime of the lower river. This suggests that water temperatures generally reached equilibrium with air temperatures by the time the water reaches the Prosser area, consistent with the findings of both Lilga (1998) and Vaccaro (1986). McMichael et al. (1999) correlated decreases in water temperature with increases in flow in the lower Yakima River, but these flow increases were due to spring runoff events or reservoir releases, not to alterations of the diversion at Prosser. McMichael et al. did not attempt to examine other factors influencing water temperatures such as air temperatures, thus their correlation did not establish a cause and effect relationship. An extensive modeling project, from the headwaters down to Prosser, would be required to determine the influence of reservoir operations or runoff events on the water temperature of the lower Yakima River.



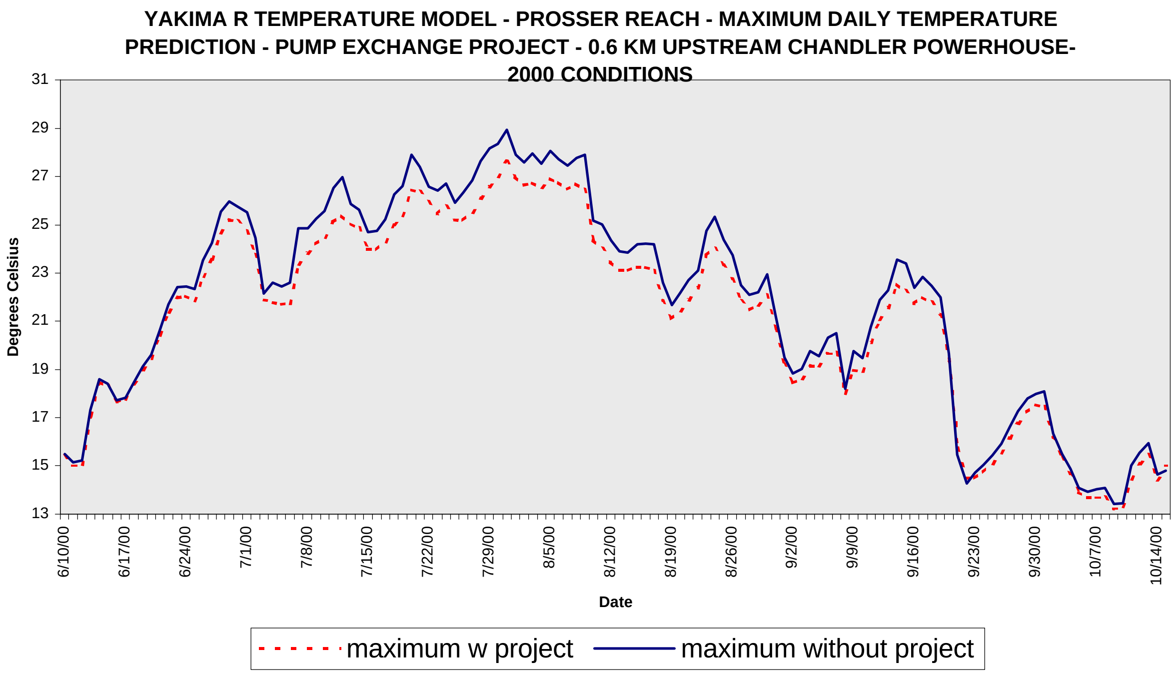
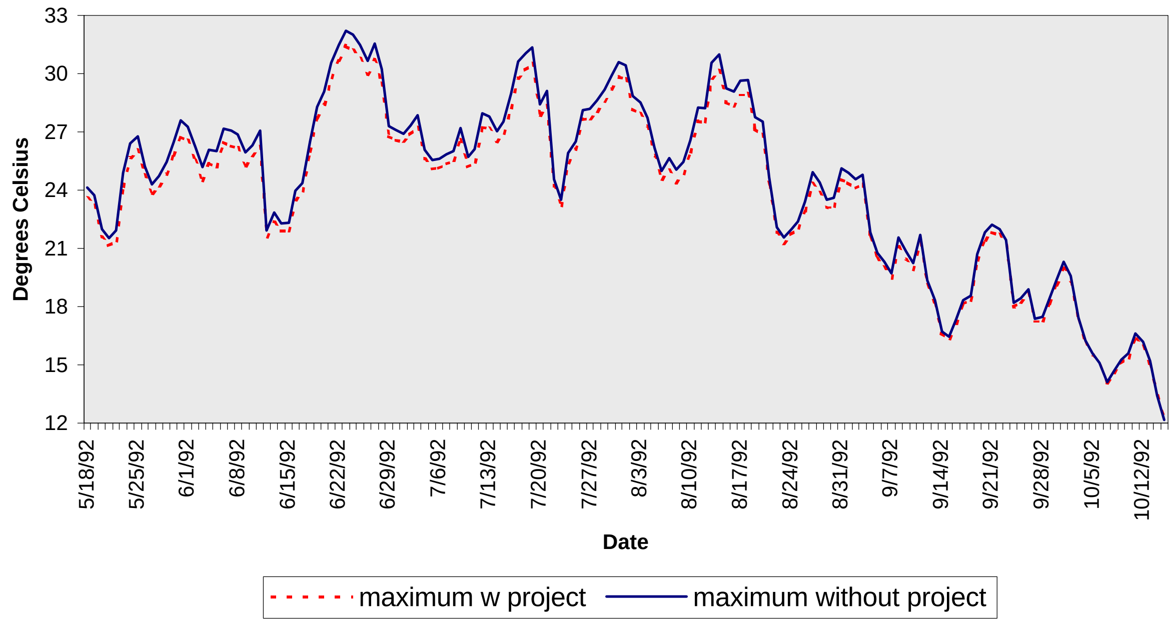


Figure 13. Maximum daily water temperatures in the Chandler bypass reach of the Yakima River, with (red) and without (blue) Project conditions, during drought (1992) and average (2000) water-year conditions.

YAKIMA R TEMPERATURE MODEL - COLUMBIA REACH AT WEST RICHLAND - MAXIMUM DAILY TEMPERATURE PREDICTION -1992 CONDITIONS



YAKIMA R TEMPERATURE MODEL - COLUMBIA REACH AT WEST RICHLAND- MAXIMUM DAILY TEMPERATURE PREDICTION -2000 CONDITIONS

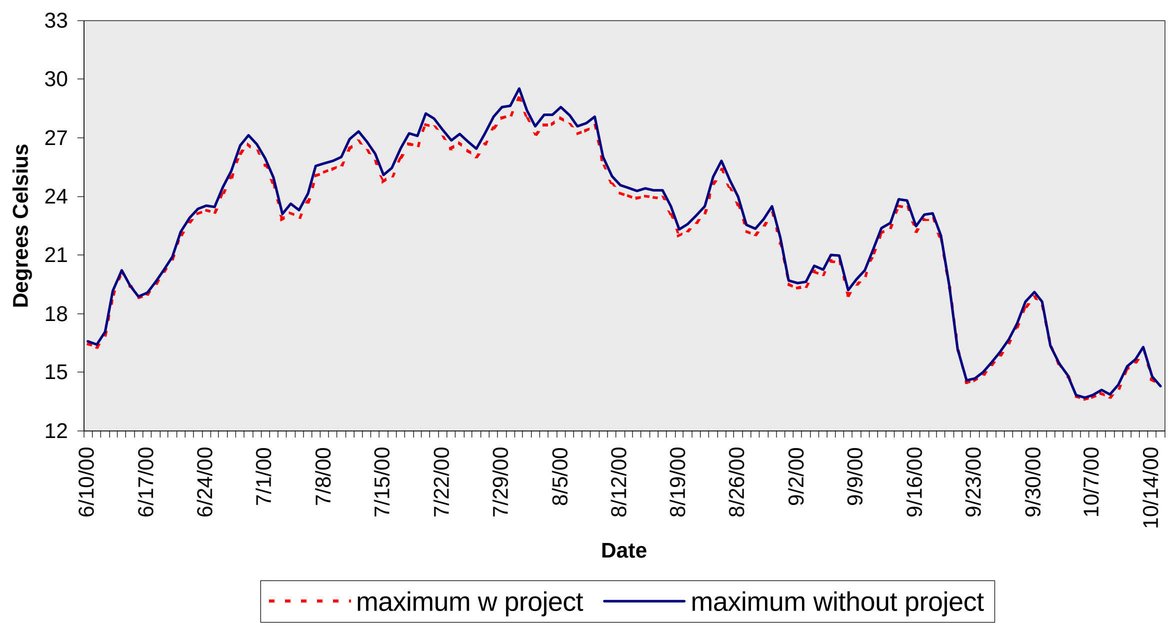


Figure 14. Maximum daily water temperatures in the Yakima River at West Richland. Temperatures were simulated with the SNTEMP model, with (red) and without (blue) Project conditions, during drought (1992) and average (2000) water-year conditions.

References

Armour, C.L. 1991. Guidance for evaluating and recommending temperature regimes to protect fish. Instream Flow Paper 28. United States Fish and Wildlife Service Biological Report 90(22). Washington, D.C. 13 pp.

Bartholow, J.M. 1989. Stream temperature investigations: field and analytical methods. Instream Flow Information Paper No. 13. U.S. Fish and Wildlife Service Biological Report 89 (17). 139 pp.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Am. Fish. Soc. Special Publication 19:83-138

Hogan, C.M., L.C. Patmore, and H. Seidman. 1973. Statistical prediction of equilibrium temperature from standard meteorological data bases. Environmental Protection Technology Series. EPA-600/2-73-003. USEPA, Washington, D.C. 271 pp.

Lilga, M.C. 1998. Effects of flow augmentation on stream temperatures in the lower Yakima River. Master’s Thesis, Washington State University-Tri Cities, Pasco, WA. 89 pp.

McAfee, W.R. 1966. Rainbow trout. Pages 192-215 *in* A. Calhoun, editor. Inland fisheries management. California Department of Fish and Game. Sacramento, California. 546 pp.

McMichael, G.A., A.L. Fritts, T.N. Pearsons, and J.L. Dunnigan. 1998. Lower Yakima River predatory fish monitoring: progress report 1998. Washington Dept. Fish & Wildlife, Olympia, WA. 39 pp.

Raleigh, R.F., T. Hickman, R.C. Solomon, and P.C. Nelson. 1984. Habitat suitability information: Rainbow trout. United States Fish and Wildlife Service FWS/OBS-82/10.60. 64 pp.

Raleigh, R.F., W.J. Miller, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: Chinook salmon. United States Fish and Wildlife Service, Biological Report 82(10.122). 64 pp.

Reiser, D.W., and T.C. Bjornn. 1979. Habitat requirements of anadromous salmonids. Volume 1 *in* W.R. Meehan, editor. Influence of forest and rangeland management on anadromous fish habitat in western North America. United States Forest Service, Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-96. Portland, Oregon.

Sandford, B.P., and T. E. Ruehle. 1996. Juvenile salmonid pit-tag studies at Prosser Dam and the Chandler Canal fish collection facility, Yakima River, 1991 and 1992. Final Report to Bonneville Power Administration, Portland OR. DOE/BP-07099-2.

Theurer, F.D., K.A. Voos, and W.J. Miller. 1984. Instream water temperature model. Instream Flow Information Paper 16. Cooperative Instream Flow and Aquatic System Group, U.S. Fish and Wildlife Service. Fort Collins, Colorado.

Thomas R. Payne & Associates. 1996. Yakima River Water Temperature Model: Prosser Diversion to Chandler Powerhouse. Prepared for the Yakima River Basin Defense Coalition, Yakima, Washington.

Thomas R. Payne & Associates, and P.A. Monk. 1999. Yakima River water temperature model: Prosser Diversion to Chandler Powerhouse (1998 supplement). Prepared for Yakima River Basin Defense Coalition. Thomas R. Payne & Assoc., Arcata, CA 95521.

Vaccaro, J.J., 1986. Simulation of streamflow temperatures in the Yakima River Basin, Washington, April-October 1981. Water Resources Investigations Report 85-4232. U.S. Dept. of Interior Geological Survey, Tacoma, WA. 91 pp.

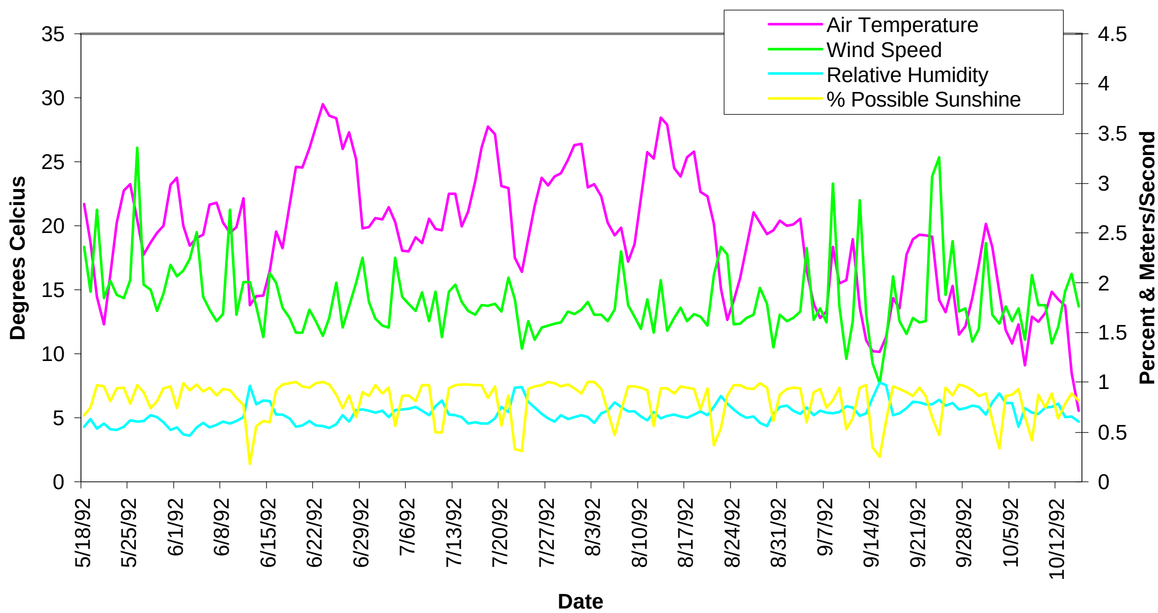
Acknowledgements

Chuck Garner and Ben Volk of Kennewick Irrigation District provided support and assistance in the field. Jim Esget of the Bureau of Reclamation initiated the environmental review of the Columbia River Pump Exchange Project, and Steve Croci of the U.S. Fish and Wildlife Service also assisted in the field and in the environmental review process.

Appendix A

Hydrology and Meteorology Data

Prosser Reach Temperature Model Meteorological Data - 1992



Columbia Reach Temperature Model Meteorological Data - 1992

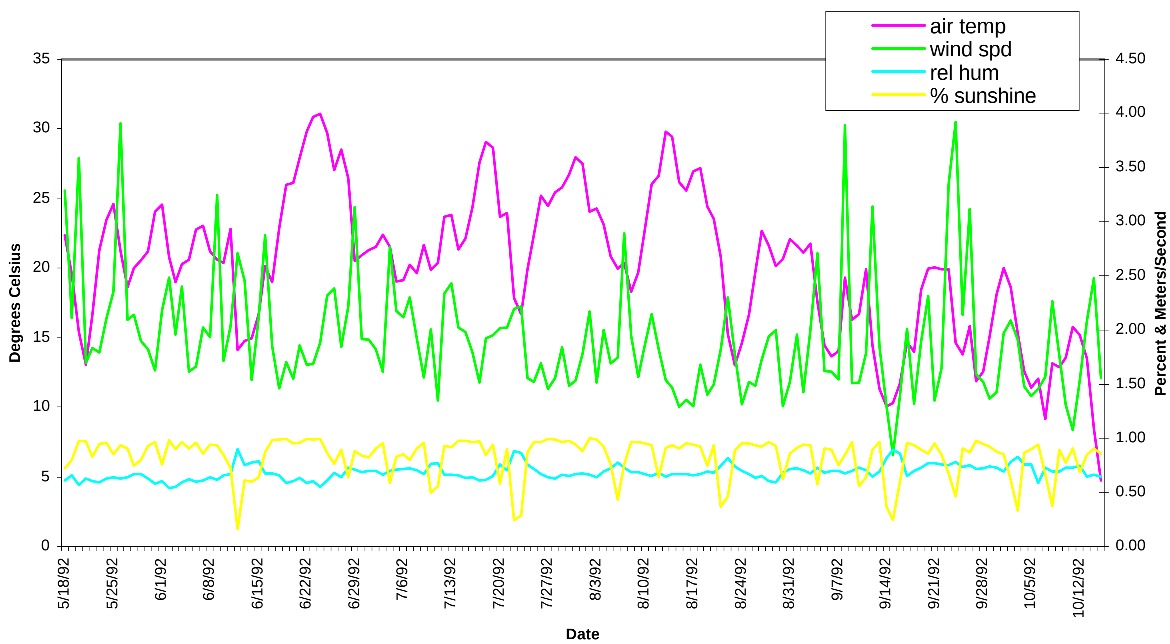


Figure 1. Meteorological data collected during 1992, representing drought year conditions.

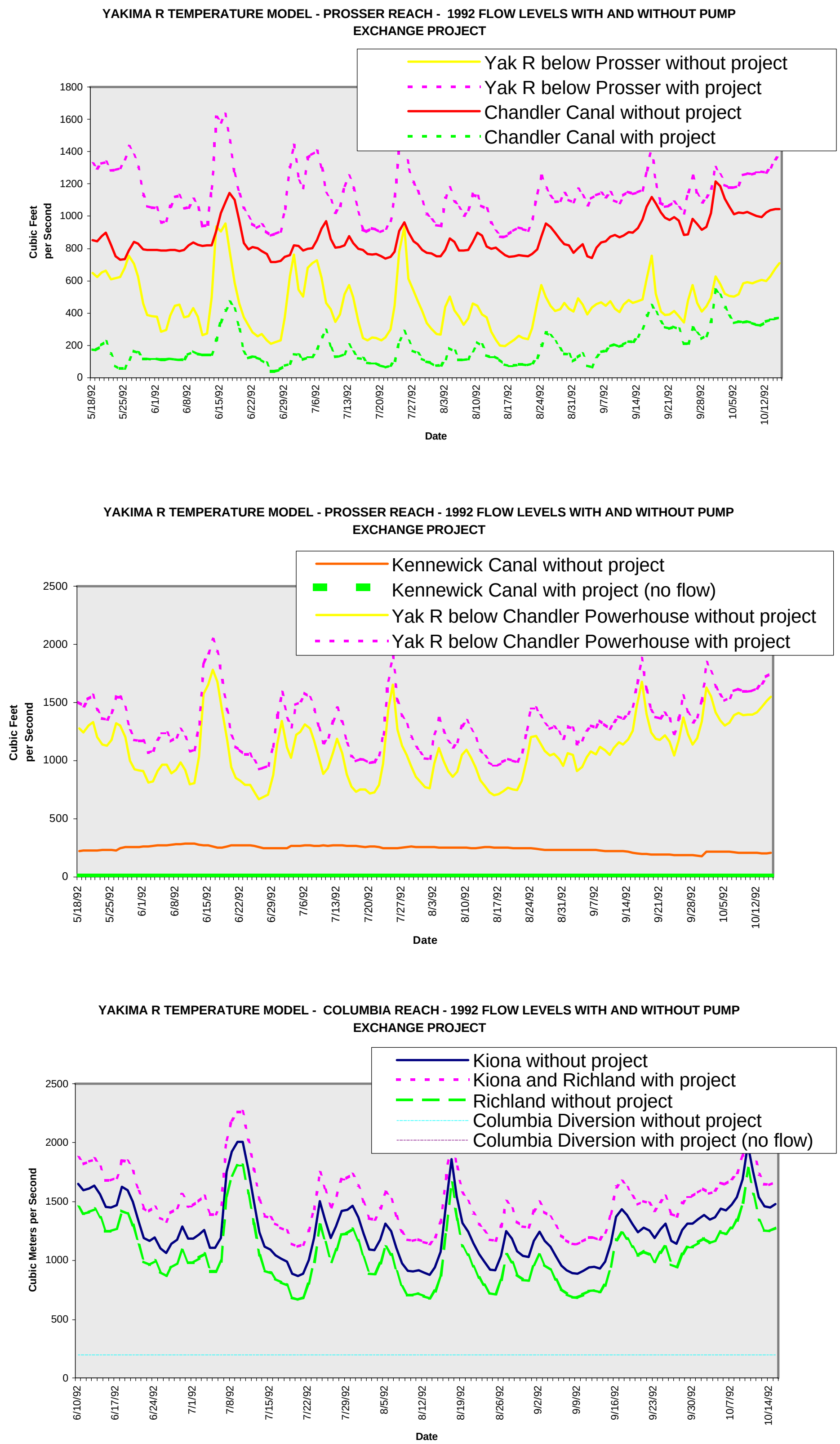
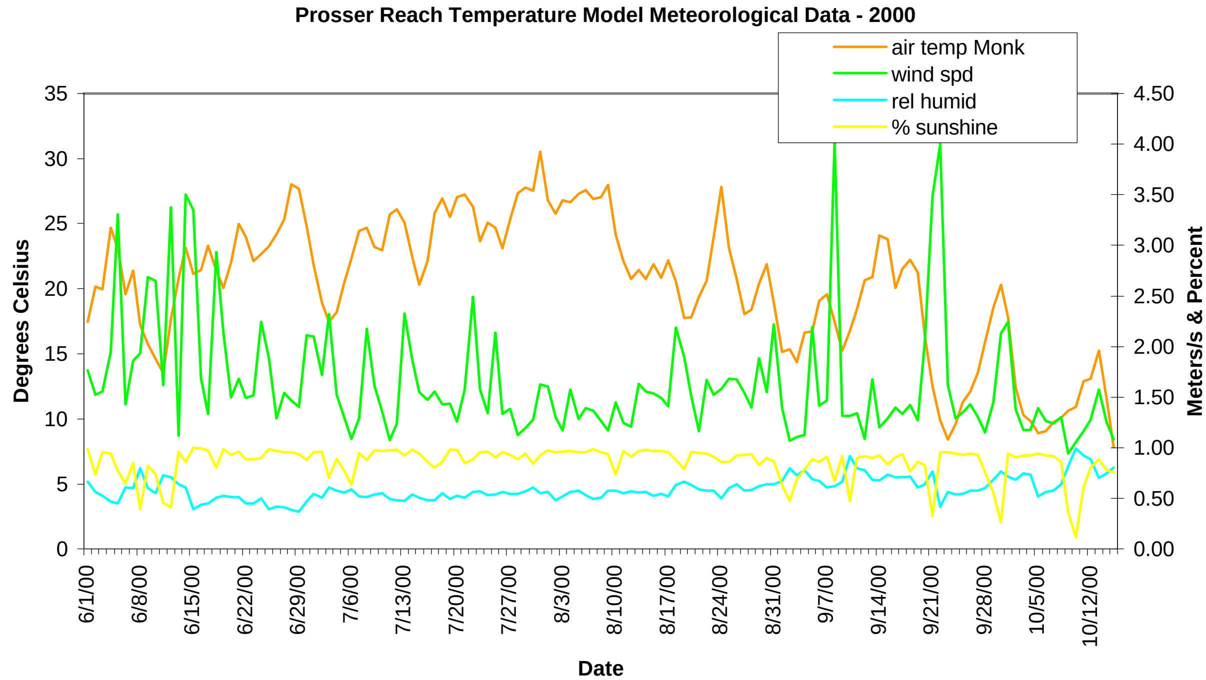


Figure 2. Project flows in the Yakima River below Prosser Dam (top), Chandler Powerhouse (middle) and Wanawish Dam, with and without Project, 1992.



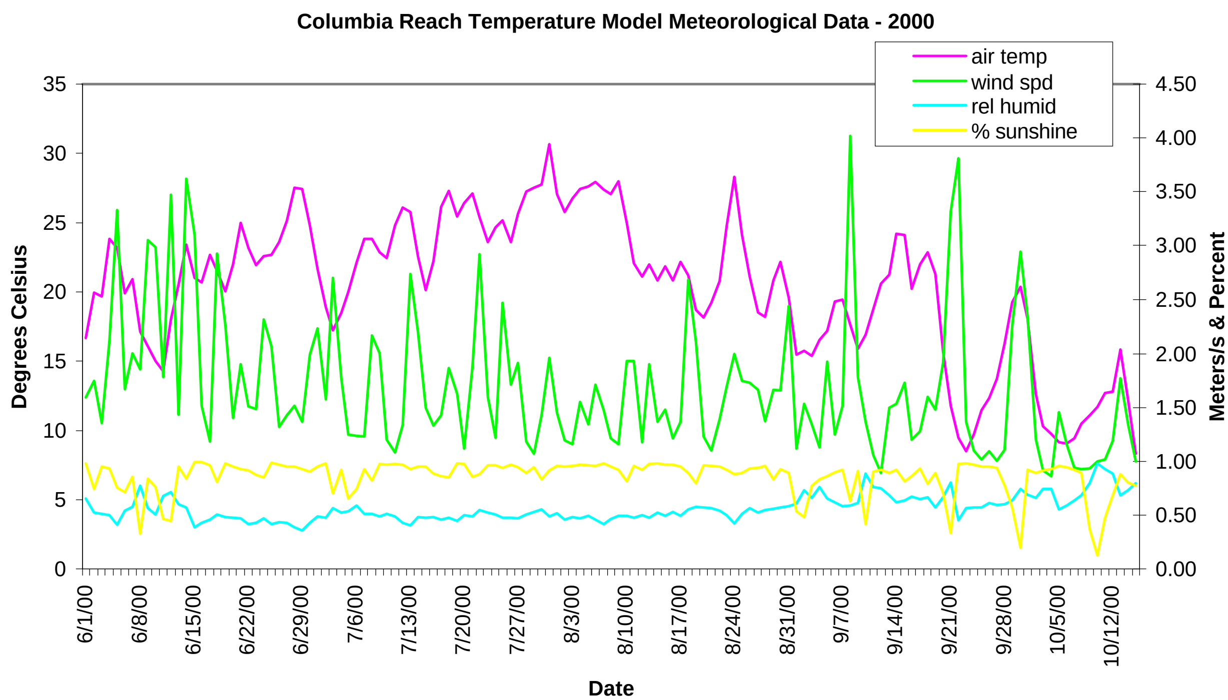


Figure 3. Meteorological data collected during 2000, representing average conditions.

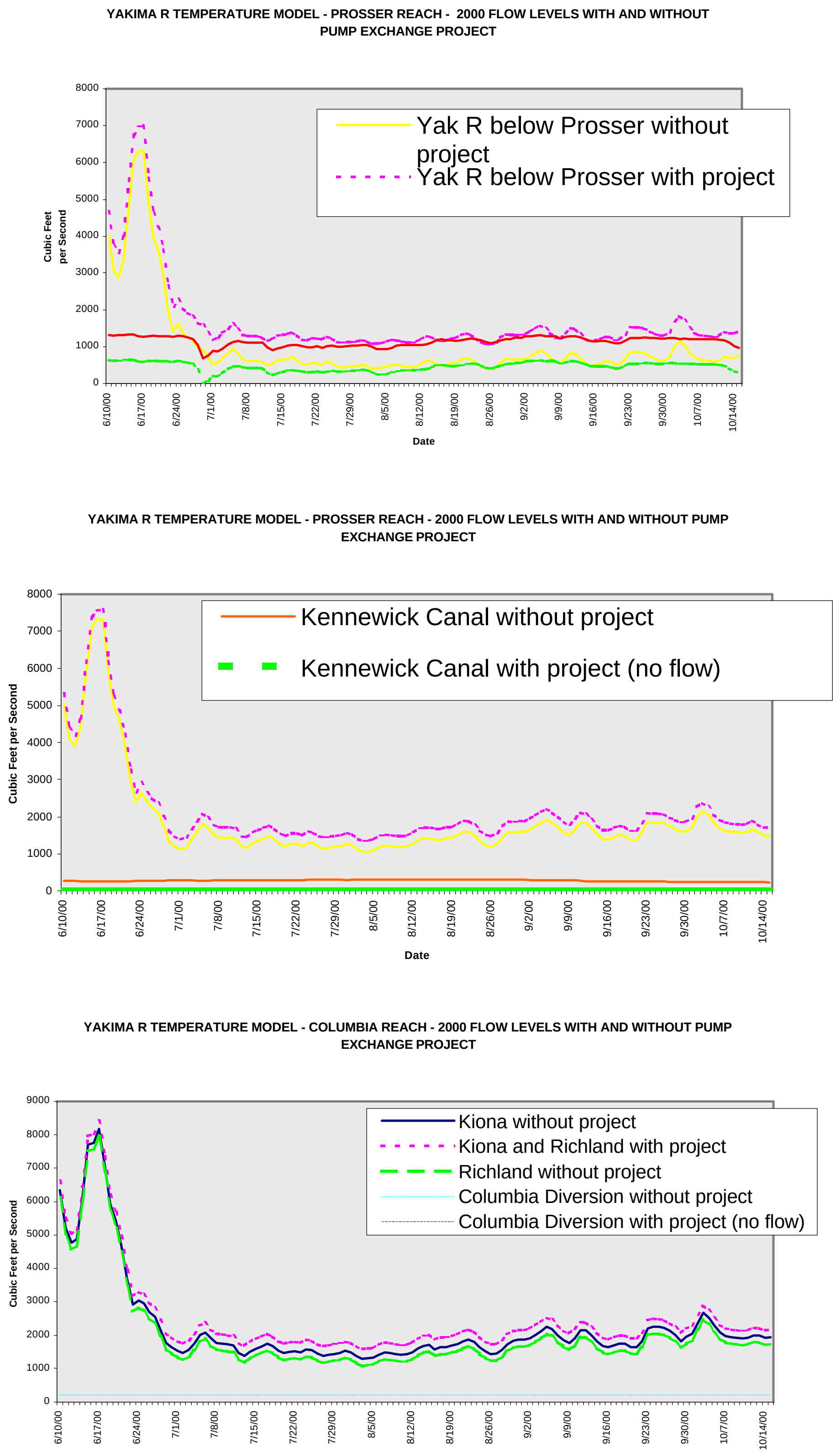


Figure 4. Project flows in the Yakima River below Prosser Dam (top), Chandler Powerhouse (middle) and Wanawish Dam, with and without Project, 2000.

APPENDIX B

Model Results in Tabular Format

Table 1. Differences between daily mean water temperatures, with and without the Columbia River pump exchange in place, at three locations in the lower Yakima River. Water temperatures water temperatures simulated under current conditions were subtracted from water temperatures simulated under proposed conditions to calculate the differences.

1992 YAKIMA RIVER WITH AND WITHOUT PUMP EXCHANGE

Location	0.6 KM upstream of Chandler			1.5 KM downstream of Chandler			At West Richland		
Date	Without project	With project	Difference	Without project	With project	Difference	Without project	With project	Difference
5/18/92	20.64	20	0.64	20.11	20.09	0.02	22.42	22.09	0.33
5/19/92	20.46	19.82	0.64	19.93	19.9	0.03	21.94	21.63	0.31
5/20/92	19.07	18.94	0.13	18.96	18.95	0.01	20.07	19.9	0.17
5/21/92	18.82	18.52	0.3	18.56	18.55	0.01	19.62	19.45	0.17
5/22/92	18.52	17.87	0.65	18	17.96	0.04	20.02	19.69	0.33
5/23/92	20.87	19.97	0.9	20.22	20.15	0.07	22.84	22.39	0.45
5/24/92	22.32	21.31	1.01	21.61	21.51	0.1	24.41	23.92	0.49
5/25/92	22.65	21.86	0.79	22.12	22.03	0.09	24.89	24.42	0.47
5/26/92	21.98	21.72	0.26	21.8	21.78	0.02	23.4	23.16	0.24
5/27/92	21.3	20.93	0.37	21.02	20.99	0.03	22.44	22.21	0.23
5/28/92	21.62	21.21	0.41	21.29	21.26	0.03	22.95	22.66	0.29
5/29/92	22.28	21.41	0.87	21.55	21.51	0.04	23.53	23.16	0.37
5/30/92	23.27	22.54	0.73	22.62	22.61	0.01	24.35	24.01	0.34
5/31/92	23.73	22.64	1.09	22.74	22.75	-0.01	25.38	24.9	0.48
6/1/92	23.79	22.94	0.85	23.02	23.03	-0.01	25.32	24.91	0.41
6/2/92	22.94	22.65	0.29	22.66	22.68	-0.02	23.91	23.66	0.25
6/3/92	21.69	21.49	0.2	21.5	21.51	-0.01	22.89	22.6	0.29
6/4/92	22.54	22.37	0.17	22.38	22.39	-0.01	23.86	23.57	0.29
6/5/92	22.35	21.46	0.89	21.6	21.56	0.04	23.85	23.39	0.46
6/6/92	23.85	23.13	0.72	23.26	23.22	0.04	25.11	24.75	0.36
6/7/92	23.77	22.61	1.16	22.75	22.73	0.02	25	24.55	0.45
6/8/92	23.83	23.07	0.76	23.14	23.13	0.01	24.76	24.43	0.33
6/9/92	22.4	22.1	0.3	22.13	22.12	0.01	23.85	23.51	0.34
6/10/92	23.57	23.07	0.5	23.11	23.11	0	24.36	24.11	0.25
6/11/92	24.13	22.55	1.58	22.55	22.64	-0.09	25.05	24.59	0.46
6/12/92	19.31	20.44	-1.13	20.41	20.38	0.03	20.47	20.42	0.05
6/13/92	20.17	19.99	0.18	20.03	20.01	0.02	21.01	20.79	0.22
6/14/92	19.89	19.65	0.24	19.72	19.68	0.04	20.78	20.59	0.19
6/15/92	19.49	19.09	0.4	19.16	19.11	0.05	20.86	20.58	0.28
6/16/92	20.88	20.28	0.6	20.34	20.28	0.06	22.34	22.03	0.31
6/17/92	21.66	21.07	0.59	21.07	21.03	0.04	22.7	22.45	0.25
6/18/92	23.63	22.69	0.94	22.64	22.63	0.01	24.74	24.44	0.3
6/19/92	25.32	24.14	1.18	24.13	24.13	0	26.43	26.06	0.37
6/20/92	25.97	24.84	1.13	24.91	24.92	-0.01	27.08	26.69	0.39
6/21/92	27.13	25.91	1.22	25.96	26.01	-0.05	28.48	28.04	0.44
6/22/92	28.08	26.83	1.25	26.81	26.92	-0.11	29.37	28.95	0.42
6/23/92	29.2	27.42	1.78	27.37	27.55	-0.18	30.11	29.68	0.43

Table 1 Continued

6/24/92	28.43	27.38	1.05	27.37	27.46	-0.09	29.85	29.41	0.44
6/25/92	28.18	27.38	0.8	27.34	27.45	-0.11	29.42	29.06	0.36
6/26/92	27.66	27.09	0.57	27.08	27.16	-0.08	28.54	28.25	0.29
6/27/92	28.07	27.19	0.88	27.18	27.29	-0.11	29.3	28.92	0.38
6/28/92	26.87	26.68	0.19	26.68	26.69	-0.01	28.22	27.91	0.31
6/29/92	24.67	24.75	-0.08	24.75	24.75	0	25.16	25.04	0.12
6/30/92	24.48	24.35	0.13	24.38	24.37	0.01	25.11	24.95	0.16
7/1/92	24.61	24.31	0.3	24.39	24.36	0.03	25.18	25.03	0.15
7/2/92	24.71	24.28	0.43	24.35	24.33	0.02	25.45	25.24	0.21
7/3/92	24.85	24.24	0.61	24.36	24.33	0.03	25.79	25.49	0.3
7/4/92	23.22	23.23	-0.01	23.23	23.23	0	24.37	24.16	0.21
7/5/92	22.96	22.71	0.25	22.79	22.76	0.03	23.75	23.56	0.19
7/6/92	22.94	22.68	0.26	22.75	22.72	0.03	23.79	23.59	0.2
7/7/92	23.18	22.73	0.45	22.79	22.76	0.03	24.08	23.84	0.24
7/8/92	23.47	22.95	0.52	22.94	22.94	0	24.12	23.9	0.22
7/9/92	24.32	23.5	0.82	23.56	23.56	0	25.14	24.84	0.3
7/10/92	23.01	22.99	0.02	23	23	0	23.94	23.74	0.2
7/11/92	23.2	22.68	0.52	22.73	22.73	0	24.25	23.94	0.31
7/12/92	24.57	23.78	0.79	23.91	23.87	0.04	25.9	25.51	0.39
7/13/92	24.67	24.08	0.59	24.16	24.13	0.03	25.87	25.55	0.32
7/14/92	24.11	23.79	0.32	23.84	23.83	0.01	24.97	24.75	0.22
7/15/92	24.54	24.13	0.41	24.16	24.18	-0.02	25.34	25.11	0.23
7/16/92	25.89	25.02	0.87	25	25.09	-0.09	26.69	26.37	0.32
7/17/92	27.06	25.98	1.08	25.94	26.07	-0.13	28.28	27.85	0.43
7/18/92	27.48	26.49	0.99	26.48	26.58	-0.1	28.86	28.43	0.43
7/19/92	27.98	26.81	1.17	26.78	26.92	-0.14	29.08	28.69	0.39
7/20/92	25.59	25.82	-0.23	25.83	25.81	0.02	26.44	26.28	0.16
7/21/92	25.74	25.53	0.21	25.53	25.55	-0.02	26.79	26.51	0.28
7/22/92	22.51	23.26	-0.75	23.21	23.19	0.02	22.9	22.92	-0.02
7/23/92	21.7	21.86	-0.16	21.84	21.85	-0.01	21.93	21.9	0.03
7/24/92	23.12	22.69	0.43	22.78	22.74	0.04	24.07	23.83	0.24
7/25/92	23.74	23.29	0.45	23.38	23.33	0.05	24.85	24.62	0.23
7/26/92	25.2	24.53	0.67	24.61	24.58	0.03	26.32	26.04	0.28
7/27/92	25.25	24.77	0.48	24.84	24.82	0.02	26.2	25.95	0.25
7/28/92	25.56	25.12	0.44	25.17	25.16	0.01	26.57	26.31	0.26
7/29/92	26.1	25.53	0.57	25.59	25.6	-0.01	27.1	26.82	0.28
7/30/92	26.54	25.97	0.57	26.01	26.03	-0.02	27.7	27.39	0.31
7/31/92	27.21	26.42	0.79	26.44	26.5	-0.06	28.4	28.05	0.35
8/1/92	27.33	26.65	0.68	26.66	26.72	-0.06	28.22	27.92	0.3
8/2/92	25.78	25.8	-0.02	25.8	25.8	0	26.44	26.28	0.16
8/3/92	25.48	25.42	0.06	25.43	25.43	0	26.26	26.08	0.18
8/4/92	25.29	25.15	0.14	25.17	25.17	0	25.74	25.63	0.11
8/5/92	23.73	23.82	-0.09	23.82	23.82	0	24.27	24.17	0.1
8/6/92	22.6	22.81	-0.21	22.78	22.79	-0.01	23.25	23.15	0.1
8/7/92	22.68	22.48	0.2	22.5	22.5	0	23.55	23.33	0.22
8/8/92	22.1	21.78	0.32	21.81	21.82	-0.01	22.71	22.51	0.2

Table 1 Continued

8/9/92	22.52	22.04	0.48	22.09	22.08	0.01	23.27	23.04	0.23
8/10/92	23.74	22.9	0.84	22.95	22.94	0.01	24.5	24.22	0.28
8/11/92	25.16	24.04	1.12	24.04	24.08	-0.04	26.16	25.8	0.36
8/12/92	25	24.28	0.72	24.34	24.34	0	26.36	25.99	0.37
8/13/92	27.13	25.55	1.58	25.51	25.67	-0.16	28.45	27.99	0.46
8/14/92	27.84	26.49	1.35	26.42	26.58	-0.16	28.78	28.39	0.39
8/15/92	25.98	25.73	0.25	25.7	25.75	-0.05	26.96	26.71	0.25
8/16/92	25.57	25.53	0.04	25.53	25.54	-0.01	26.68	26.43	0.25
8/17/92	26.27	25.9	0.37	25.88	25.93	-0.05	27.31	27.03	0.28
8/18/92	26.57	26.08	0.49	26.06	26.12	-0.06	27.4	27.15	0.25
8/19/92	24.56	24.91	-0.35	24.91	24.88	0.03	25.62	25.44	0.18
8/20/92	24.56	24.36	0.2	24.36	24.39	-0.03	25.21	25.04	0.17
8/21/92	21.75	22.77	-1.02	22.78	22.69	0.09	22.87	22.79	0.08
8/22/92	19.96	20.97	-1.01	20.91	20.87	0.04	20.24	20.33	-0.09
8/23/92	19.36	19.85	-0.49	19.78	19.8	-0.02	19.44	19.5	-0.06
8/24/92	20.01	20	0.01	20.01	20.01	0	20.06	20.04	0.02
8/25/92	20.19	20.01	0.18	20.01	20.01	0	20.48	20.4	0.08
8/26/92	20.75	20.31	0.44	20.32	20.32	0	21.46	21.27	0.19
8/27/92	21.93	21.12	0.81	21.13	21.14	-0.01	22.94	22.65	0.29
8/28/92	21.45	21.14	0.31	21.15	21.15	0	22.34	22.13	0.21
8/29/92	21.01	20.91	0.1	20.92	20.92	0	21.53	21.42	0.11
8/30/92	21.14	20.96	0.18	20.98	20.98	0	21.84	21.69	0.15
8/31/92	22.21	21.62	0.59	21.7	21.7	0	23.19	22.93	0.26
9/1/92	22.21	21.79	0.42	21.85	21.84	0.01	22.98	22.78	0.2
9/2/92	22.07	21.71	0.36	21.75	21.74	0.01	22.66	22.5	0.16
9/3/92	22.06	21.72	0.34	21.77	21.77	0	22.77	22.59	0.18
9/4/92	19.67	20.29	-0.62	20.19	20.2	-0.01	20.1	20.11	-0.01
9/5/92	18.74	18.99	-0.25	18.96	18.97	-0.01	18.83	18.85	-0.02
9/6/92	18.37	18.65	-0.28	18.62	18.63	-0.01	18.41	18.45	-0.04
9/7/92	17.7	17.93	-0.23	17.91	17.92	-0.01	17.95	17.94	0.01
9/8/92	18.73	18.31	0.42	18.34	18.34	0	19.76	19.53	0.23
9/9/92	18.43	18.11	0.32	18.12	18.12	0	18.97	18.83	0.14
9/10/92	18.09	17.92	0.17	17.93	17.93	0	18.66	18.54	0.12
9/11/92	19.3	18.71	0.59	18.75	18.74	0.01	20.09	19.87	0.22
9/12/92	17.25	17.66	-0.41	17.65	17.65	0	17.6	17.6	0
9/13/92	16.63	16.89	-0.26	16.87	16.88	-0.01	16.54	16.6	-0.06
9/14/92	15.52	16.04	-0.52	16.02	16.03	-0.01	15.41	15.52	-0.11
9/15/92	15.28	15.5	-0.22	15.5	15.5	0	15.3	15.33	-0.03
9/16/92	15.78	15.61	0.17	15.62	15.61	0.01	15.99	15.93	0.06
9/17/92	16.53	16.41	0.12	16.41	16.41	0	16.86	16.81	0.05
9/18/92	16.78	16.71	0.07	16.71	16.71	0	17.02	16.98	0.04
9/19/92	18.77	18.09	0.68	18.04	18.06	-0.02	19.11	18.97	0.14
9/20/92	19.72	18.88	0.84	18.82	18.86	-0.04	20.21	20.04	0.17
9/21/92	20.17	19.36	0.81	19.31	19.35	-0.04	20.57	20.42	0.15
9/22/92	20.08	19.6	0.48	19.57	19.59	-0.02	20.46	20.35	0.11
9/23/92	19.3	19.28	0.02	19.27	19.28	-0.01	19.99	19.9	0.09

Table 1 Continued

9/24/92	16.29	17.02	-0.73	17.07	17	0.07	16.85	16.84	0.01
9/25/92	16.75	16.89	-0.14	16.88	16.88	0	16.77	16.79	-0.02
9/26/92	17.1	17	0.1	17.01	17.01	0	17.43	17.37	0.06
9/27/92	15.83	16.15	-0.32	16.16	16.15	0.01	15.81	15.86	-0.05
9/28/92	15.79	16	-0.21	16	16	0	15.85	15.87	-0.02
9/29/92	16.59	16.35	0.24	16.35	16.35	0	16.83	16.77	0.06
9/30/92	17.34	16.89	0.45	16.87	16.88	-0.01	17.94	17.81	0.13
10/1/92	18.24	17.86	0.38	17.82	17.82	0	18.87	18.72	0.15
10/2/92	17.65	17.23	0.42	17.19	17.19	0	18.27	18.11	0.16
10/3/92	16.19	16.12	0.07	16.12	16.12	0	16.45	16.42	0.03
10/4/92	14.93	15.02	-0.09	15.02	15.03	-0.01	15.09	15.09	0
10/5/92	14.25	14.33	-0.08	14.33	14.34	-0.01	14.38	14.39	-0.01
10/6/92	13.71	13.87	-0.16	13.87	13.88	-0.01	13.78	13.8	-0.02
10/7/92	13.17	13.53	-0.36	13.52	13.54	-0.02	13.01	13.1	-0.09
10/8/92	13.52	13.67	-0.15	13.67	13.68	-0.01	13.76	13.77	-0.01
10/9/92	13.75	13.71	0.04	13.71	13.72	-0.01	13.99	13.97	0.02
10/10/92	14.01	13.9	0.11	13.91	13.91	0	14.35	14.29	0.06
10/11/92	14.65	14.28	0.37	14.3	14.29	0.01	15.29	15.15	0.14
10/12/92	14.5	14.32	0.18	14.33	14.32	0.01	14.99	14.9	0.09
10/13/92	13.75	13.75	0	13.75	13.75	0	13.89	13.88	0.01
10/14/92	12.66	13.15	-0.49	13.14	13.16	-0.02	12.11	12.29	-0.18
10/15/92	12.07	12.79	-0.72	12.78	12.81	-0.03	10.98	11.28	-0.3
		mean cooling	0.345629		mean cooling	-0.00563		mean cooling	0.20
		max cooling	1.78		max cooling	-0.18		max cooling	0.49
		date	6/23/92		date	33778		date	5/24/92

Table 2. Differences between daily mean water temperatures, with and without the Columbia River pump exchange in place, at three locations in the lower Yakima River. Water temperatures simulated under current conditions were subtracted from water temperatures simulated under proposed conditions to calculate the differences.

2000 YAKIMA RIVER WITH AND WITHOUT PUMP EXCHANGE

Location	0.6 KM upstream of Chandler			1.5 KM downstream of Chandler			At West Richland		
Date	Without project	With project	Difference	Without project	With project	Difference	Without project	With project	Difference
06/10/00	14.82	14.78	0.04	14.82	14.81	0.01	15.66	15.61	0.05
06/11/00	14.56	14.49	0.07	14.53	14.52	0.01	15.54	15.47	0.07
06/12/00	14.64	14.53	0.11	14.59	14.57	0.02	16.14	16.02	0.12
06/13/00	16.33	16.19	0.14	16.28	16.25	0.03	17.99	17.85	0.14
06/14/00	17.89	17.83	0.06	17.9	17.89	0.01	19.24	19.17	0.07
06/15/00	17.77	17.74	0.03	17.78	17.78	0	18.55	18.52	0.03
06/16/00	17.03	17	0.03	17.05	17.05	0	17.96	17.92	0.04
06/17/00	17.13	17.09	0.04	17.16	17.15	0.01	18.16	18.11	0.05
06/18/00	17.83	17.79	0.04	17.84	17.83	0.01	18.76	18.71	0.05
06/19/00	18.29	18.24	0.05	18.29	18.28	0.01	19.24	19.18	0.06
06/20/00	18.74	18.66	0.08	18.72	18.7	0.02	19.87	19.79	0.08
06/21/00	19.69	19.55	0.14	19.63	19.6	0.03	21.06	20.94	0.12
06/22/00	20.59	20.42	0.17	20.47	20.44	0.03	21.65	21.53	0.12
06/23/00	21.13	20.91	0.22	20.93	20.91	0.02	22.01	21.88	0.13
06/24/00	21.27	21.09	0.18	21.11	21.09	0.02	22.24	22.12	0.12
06/25/00	20.97	20.7	0.27	20.72	20.69	0.03	22.02	21.87	0.15
06/26/00	22.05	21.66	0.39	21.69	21.64	0.05	23.03	22.85	0.18
06/27/00	22.79	22.4	0.39	22.43	22.38	0.05	23.8	23.61	0.19
06/28/00	23.95	23.44	0.51	23.53	23.46	0.07	25.01	24.78	0.23
06/29/00	24.37	23.99	0.38	24.21	24.09	0.12	25.4	25.14	0.26
06/30/00	24.13	23.99	0.14	24.04	24.02	0.02	24.9	24.75	0.15
07/01/00	23.52	23.42	0.1	23.42	23.42	0	24.09	23.97	0.12
07/02/00	22.53	22.46	0.07	22.48	22.47	0.01	23	22.89	0.11
07/03/00	20.73	20.91	-0.18	20.88	20.91	-0.03	21.41	21.34	0.07
07/04/00	20.96	20.57	0.39	20.61	20.57	0.04	21.83	21.61	0.22
07/05/00	21	20.63	0.37	20.66	20.62	0.04	21.83	21.64	0.19
07/06/00	21.2	20.7	0.5	20.71	20.67	0.04	22.61	22.33	0.28
07/07/00	22.89	21.95	0.94	21.93	21.88	0.05	23.83	23.52	0.31
07/08/00	23.06	22.54	0.52	22.52	22.5	0.02	24.03	23.78	0.25
07/09/00	23.32	22.85	0.47	22.84	22.82	0.02	24.04	23.84	0.2
07/10/00	23.63	23.12	0.51	23.1	23.08	0.02	24.23	24.04	0.19
07/11/00	24.47	23.69	0.78	23.67	23.63	0.04	25.1	24.85	0.25
07/12/00	24.75	23.89	0.86	23.91	23.89	0.02	25.38	25.11	0.27
07/13/00	23.92	23.75	0.17	23.77	23.76	0.01	24.83	24.63	0.2
07/14/00	23.76	23.59	0.17	23.6	23.59	0.01	24.3	24.16	0.14
07/15/00	22.88	22.73	0.15	22.74	22.73	0.01	23.24	23.14	0.1
07/16/00	23.03	22.74	0.29	22.76	22.74	0.02	23.68	23.51	0.17
07/17/00	23.61	23.12	0.49	23.16	23.12	0.04	24.76	24.48	0.28
07/18/00	24.44	23.72	0.72	23.75	23.7	0.05	25.48	25.17	0.31
07/19/00	24.5	23.96	0.54	23.97	23.95	0.02	25.16	24.94	0.22

Table 2 continued

07/20/00	25.76	25.03	0.73	25.05	25.03	0.02	26.3	26.07	0.23
07/21/00	25.59	25.16	0.43	25.18	25.16	0.02	26.19	26	0.19
07/22/00	24.77	24.73	0.04	24.74	24.74	0	25.66	25.5	0.16
07/23/00	24.38	24.12	0.26	24.13	24.12	0.01	24.95	24.8	0.15
07/24/00	24.81	24.45	0.36	24.47	24.45	0.02	25.33	25.17	0.16
07/25/00	24.04	23.96	0.08	23.97	23.96	0.01	24.94	24.76	0.18
07/26/00	24.15	23.77	0.38	23.76	23.76	0	24.49	24.35	0.14
07/27/00	24.64	24.11	0.53	24.1	24.09	0.01	25.2	24.99	0.21
07/28/00	25.53	24.7	0.83	24.7	24.68	0.02	26.15	25.87	0.28
07/29/00	26.01	25.14	0.87	25.12	25.1	0.02	26.65	26.37	0.28
07/30/00	26.42	25.71	0.71	25.69	25.68	0.01	26.85	26.64	0.21
07/31/00	26.97	26.3	0.67	26.28	26.27	0.01	27.71	27.47	0.24
08/01/00	25.8	25.65	0.15	25.64	25.64	0	26.51	26.36	0.15
08/02/00	25.29	25.25	0.04	25.25	25.25	0	25.63	25.55	0.08
08/03/00	25.7	25.32	0.38	25.34	25.33	0.01	26.12	25.96	0.16
08/04/00	25.36	25.15	0.21	25.16	25.16	0	26.14	25.95	0.19
08/05/00	25.96	25.56	0.4	25.59	25.57	0.02	26.56	26.36	0.2
08/06/00	25.7	25.41	0.29	25.43	25.41	0.02	26.21	26.06	0.15
08/07/00	25.37	25.13	0.24	25.13	25.12	0.01	25.68	25.58	0.1
08/08/00	25.64	25.33	0.31	25.32	25.32	0	25.86	25.76	0.1
08/09/00	25.71	25.05	0.66	25.02	25.02	0	26.18	25.98	0.2
08/10/00	23.3	23.2	0.1	23.2	23.2	0	24.14	23.96	0.18
08/11/00	22.82	22.61	0.21	22.61	22.6	0.01	23.07	22.98	0.09
08/12/00	22.38	22.15	0.23	22.16	22.14	0.02	22.66	22.56	0.1
08/13/00	21.98	21.82	0.16	21.82	21.81	0.01	22.57	22.44	0.13
08/14/00	21.93	21.82	0.11	21.82	21.82	0	22.44	22.34	0.1
08/15/00	22.14	21.9	0.24	21.88	21.87	0.01	22.6	22.48	0.12
08/16/00	22.11	21.88	0.23	21.86	21.86	0	22.47	22.36	0.11
08/17/00	22.1	21.72	0.38	21.69	21.68	0.01	22.5	22.36	0.14
08/18/00	20.72	20.6	0.12	20.59	20.59	0	21.68	21.5	0.18
08/19/00	19.95	19.96	-0.01	19.96	19.96	0	20.64	20.53	0.11
08/20/00	20.33	20.15	0.18	20.15	20.13	0.02	20.81	20.69	0.12
08/21/00	20.91	20.61	0.3	20.6	20.58	0.02	21.28	21.16	0.12
08/22/00	21.32	21.14	0.18	21.14	21.13	0.01	21.79	21.69	0.1
08/23/00	22.87	22.48	0.39	22.44	22.43	0.01	23.34	23.19	0.15
08/24/00	23.29	22.72	0.57	22.66	22.66	0	24.09	23.86	0.23
08/25/00	22.27	22.07	0.2	22.05	22.05	0	23.02	22.85	0.17
08/26/00	21.5	21.41	0.09	21.41	21.41	0	22.09	21.96	0.13
08/27/00	20.38	20.54	-0.16	20.56	20.56	0	20.64	20.63	0.01
08/28/00	20.24	20.24	0	20.24	20.24	0	20.52	20.47	0.05
08/29/00	20.61	20.55	0.06	20.55	20.55	0	21.23	21.12	0.11
08/30/00	21.22	20.9	0.32	20.88	20.86	0.02	21.85	21.69	0.16
08/31/00	19.6	19.56	0.04	19.56	19.56	0	20.29	20.18	0.11
09/01/00	18.15	18.31	-0.16	18.33	18.34	-0.01	18.35	18.36	-0.01
09/02/00	17.71	17.67	0.04	17.67	17.67	0	18.25	18.17	0.08
09/03/00	17.7	17.67	0.03	17.67	17.67	0	18.19	18.12	0.07
09/04/00	18.38	18.13	0.25	18.11	18.09	0.02	19.03	18.89	0.14
09/05/00	18.19	18.13	0.06	18.13	18.12	0.01	18.84	18.75	0.09

Table 2 continued

09/06/00	18.83	18.57	0.26	18.56	18.54	0.02	19.55	19.4	0.15
09/07/00	18.84	18.52	0.32	18.49	18.47	0.02	19.43	19.29	0.14
09/08/00	16.76	17.09	-0.33	17.15	17.15	0	17.81	17.72	0.09
09/09/00	17.93	17.8	0.13	17.79	17.78	0.01	18.17	18.11	0.06
09/10/00	18.42	18.19	0.23	18.17	18.15	0.02	19.04	18.9	0.14
09/11/00	19.35	19.06	0.29	19.04	19.02	0.02	20	19.86	0.14
09/12/00	20.37	19.97	0.4	19.94	19.92	0.02	21.01	20.87	0.14
09/13/00	20.74	20.48	0.26	20.46	20.45	0.01	21.23	21.13	0.1
09/14/00	21.79	21.34	0.45	21.28	21.28	0	22.37	22.22	0.15
09/15/00	21.61	21.14	0.47	21.09	21.09	0	22.28	22.11	0.17
09/16/00	20.61	20.61	0	20.61	20.61	0	20.94	20.9	0.04
09/17/00	21.11	20.86	0.25	20.84	20.84	0	21.54	21.44	0.1
09/18/00	21.05	20.84	0.21	20.83	20.82	0.01	21.71	21.59	0.12
09/19/00	20.44	20.22	0.22	20.22	20.21	0.01	20.51	20.47	0.04
09/20/00	18.06	18.42	-0.36	18.44	18.44	0	18.07	18.13	-0.06
09/21/00	14.54	15.16	-0.62	15.21	15.21	0	15.07	15.1	-0.03
09/22/00	12.77	13.49	-0.72	13.56	13.57	-0.01	13.08	13.17	-0.09
09/23/00	13.38	13.54	-0.16	13.55	13.56	-0.01	13.34	13.38	-0.04
09/24/00	13.71	13.77	-0.06	13.77	13.78	-0.01	13.69	13.71	-0.02
09/25/00	14.11	14.12	-0.01	14.13	14.13	0	14.22	14.22	0
09/26/00	14.57	14.56	0.01	14.56	14.56	0	14.74	14.72	0.02
09/27/00	15.22	15.15	0.07	15.15	15.14	0.01	15.37	15.34	0.03
09/28/00	15.98	15.86	0.12	15.85	15.85	0	16.26	16.21	0.05
09/29/00	16.69	16.49	0.2	16.47	16.47	0	17.42	17.3	0.12
09/30/00	17.22	17.02	0.2	17	17	0	18.19	18.04	0.15
10/01/00	16.73	16.49	0.24	16.47	16.46	0.01	17.32	17.21	0.11
10/02/00	15.25	15.37	-0.12	15.37	15.38	-0.01	15.24	15.27	-0.03
10/03/00	14.49	14.56	-0.07	14.56	14.57	-0.01	14.41	14.44	-0.03
10/04/00	13.83	13.88	-0.05	13.88	13.89	-0.01	13.78	13.81	-0.03
10/05/00	12.9	13.06	-0.16	13.07	13.08	-0.01	12.69	12.75	-0.06
10/06/00	12.61	12.8	-0.19	12.82	12.83	-0.01	12.5	12.56	-0.06
10/07/00	12.66	12.77	-0.11	12.78	12.79	-0.01	12.6	12.64	-0.04
10/08/00	12.75	12.82	-0.07	12.82	12.82	0	12.89	12.89	0
10/09/00	12.63	12.7	-0.07	12.71	12.72	-0.01	12.93	12.91	0.02
10/10/00	12.96	12.99	-0.03	12.99	12.99	0	13.56	13.49	0.07
10/11/00	13.99	13.76	0.23	13.74	13.73	0.01	14.34	14.26	0.08
10/12/00	14.45	14.32	0.13	14.32	14.31	0.01	14.67	14.62	0.05
10/13/00	14.73	14.63	0.1	14.63	14.63	0	15.14	15.08	0.06
10/14/00	13.57	13.68	-0.11	13.68	13.68	0	13.7	13.71	-0.01
10/15/00	13.87	14.34	-0.47	14.27	14.32	-0.05	13.3	13.48	-0.18
		mean cooling	0.196484	mean cooling		0.01	mean cooling		0.12
		max cooling	0.94	max cooling		0.12	max cooling		0.31
		date	7/7/00	date		6/29/00	date		7/7/00

Table 3. Differences between daily maximum water temperatures, with and without the Columbia River pump exchange in place, at two locations in the lower Yakima River for 1992 conditions. Water temperatures simulated under current conditions were subtracted from water temperatures simulated under proposed conditions to calculate the differences.

1992 Yakima River Daily Maximum With and Without Pump Exchange

	0.6 KM upstream of Chandler			At West Richland		
Date	without project	with project	difference	without project	with project	difference
5/18/92	22.18	21.09	1.09	24.14	23.61	0.53
5/19/92	22.13	20.99	1.14	23.75	23.22	0.53
5/20/92	20.92	20.22	0.7	22.01	21.6	0.41
5/21/92	20.7	19.84	0.86	21.55	21.14	0.41
5/22/92	20.35	19.14	1.21	21.93	21.37	0.56
5/23/92	22.87	21.37	1.5	24.88	24.17	0.71
5/24/92	24.29	22.7	1.59	26.39	25.67	0.72
5/25/92	24.29	23.04	1.25	26.75	26.06	0.69
5/26/92	23.62	22.92	0.7	25.22	24.77	0.45
5/27/92	23.02	22.15	0.87	24.28	23.82	0.46
5/28/92	23.21	22.31	0.9	24.72	24.2	0.52
5/29/92	24.25	22.7	1.55	25.46	24.81	0.65
5/30/92	25.55	23.96	1.59	26.48	25.81	0.67
5/31/92	26.07	24.12	1.95	27.58	26.75	0.83
6/1/92	25.79	24.18	1.61	27.29	26.57	0.72
6/2/92	25.59	24.15	1.44	26.2	25.55	0.65
6/3/92	24.26	22.94	1.32	25.19	24.48	0.71
6/4/92	24.82	23.76	1.06	26.08	25.4	0.68
6/5/92	24.5	22.85	1.65	26.01	25.2	0.81
6/6/92	25.99	24.52	1.47	27.16	26.49	0.67
6/7/92	26.02	24.01	2.01	27.06	26.28	0.78
6/8/92	26.1	24.48	1.62	26.87	26.19	0.68
6/9/92	24.47	23.41	1.06	25.94	25.26	0.68
6/10/92	25.7	24.37	1.33	26.32	25.76	0.56
6/11/92	26.46	23.9	2.56	27.05	26.24	0.81
6/12/92	20.41	21	-0.59	21.93	21.6	0.33
6/13/92	21.65	20.94	0.71	22.87	22.33	0.54
6/14/92	21.05	20.52	0.53	22.28	21.9	0.38
6/15/92	20.67	19.98	0.69	22.33	21.9	0.43
6/16/92	22.42	21.47	0.95	23.95	23.48	0.47
6/17/92	23.38	22.34	1.04	24.36	23.95	0.41
6/18/92	25.59	24.06	1.53	26.5	26	0.5
6/19/92	27.5	25.59	1.91	28.31	27.71	0.6
6/20/92	28.26	26.28	1.98	29.1	28.41	0.69
6/21/92	29.45	27.33	2.12	30.56	29.78	0.78
6/22/92	30.57	28.3	2.27	31.48	30.7	0.78
6/23/92	31.78	28.95	2.83	32.22	31.43	0.79

Table 3
continued

6/24/92	30.92	28.83	2.09	32.02	31.21	0.81
6/25/92	30.63	28.75	1.88	31.5	30.77	0.73
6/26/92	30.01	28.32	1.69	30.65	29.95	0.7
6/27/92	30.58	28.56	2.02	31.56	30.73	0.83
6/28/92	28.92	27.77	1.15	30.22	29.52	0.7
6/29/92	26.73	26	0.73	27.31	26.8	0.51
6/30/92	26.09	25.46	0.63	27.08	26.6	0.48
7/1/92	26.23	25.49	0.74	26.89	26.51	0.38
7/2/92	26.52	25.49	1.03	27.34	26.86	0.48
7/3/92	26.83	25.56	1.27	27.86	27.23	0.63
7/4/92	24.41	24.07	0.34	26.07	25.6	0.47
7/5/92	24.52	23.83	0.69	25.56	25.11	0.45
7/6/92	24.51	23.8	0.71	25.62	25.15	0.47
7/7/92	24.81	23.86	0.95	25.84	25.36	0.48
7/8/92	25.54	24.29	1.25	26.02	25.53	0.49
7/9/92	26.5	24.9	1.6	27.21	26.59	0.62
7/10/92	24.59	23.91	0.68	25.72	25.2	0.52
7/11/92	24.73	23.61	1.12	26.1	25.45	0.65
7/12/92	26.52	25.1	1.42	27.97	27.25	0.72
7/13/92	26.53	25.37	1.16	27.81	27.21	0.6
7/14/92	26.11	25.11	1	27.03	26.48	0.55
7/15/92	26.91	25.55	1.36	27.54	26.92	0.62
7/16/92	28.6	26.52	2.08	29	28.24	0.76
7/17/92	29.78	27.48	2.3	30.64	29.76	0.88
7/18/92	29.88	27.84	2.04	31.07	30.21	0.86
7/19/92	30.55	28.27	2.28	31.34	30.52	0.82
7/20/92	27.58	26.84	0.74	28.44	27.86	0.58
7/21/92	28.18	26.85	1.33	29.12	28.36	0.76
7/22/92	23.84	23.98	-0.14	24.56	24.23	0.33
7/23/92	22.8	22.54	0.26	23.53	23.2	0.33
7/24/92	24.73	23.87	0.86	25.9	25.41	0.49
7/25/92	25.27	24.45	0.82	26.52	26.11	0.41
7/26/92	27.05	25.82	1.23	28.14	27.63	0.51
7/27/92	27.23	26.1	1.13	28.2	27.66	0.54
7/28/92	27.61	26.45	1.16	28.62	28.04	0.58
7/29/92	28.23	26.88	1.35	29.19	28.57	0.62
7/30/92	28.87	27.37	1.5	29.9	29.2	0.7
7/31/92	29.59	27.81	1.78	30.6	29.85	0.75
8/1/92	29.71	28	1.71	30.45	29.72	0.73
8/2/92	28.39	27.22	1.17	28.84	28.2	0.64
8/3/92	27.59	26.75	0.84	28.52	27.93	0.59
8/4/92	27.18	26.39	0.79	27.71	27.28	0.43
8/5/92	25.5	24.91	0.59	26.19	25.76	0.43
8/6/92	24.06	23.67	0.39	24.99	24.57	0.42
8/7/92	24.65	23.62	1.03	25.65	25.04	0.61

Table 3
Continued

8/8/92	24.44	23.17	1.27	25.05	24.41	0.64
8/9/92	24.63	23.39	1.24	25.45	24.85	0.6
8/10/92	25.88	24.29	1.59	26.56	25.96	0.6
8/11/92	27.35	25.42	1.93	28.24	27.55	0.69
8/12/92	26.65	25.29	1.36	28.21	27.54	0.67
8/13/92	29.55	26.99	2.56	30.58	29.75	0.83
8/14/92	30.45	27.94	2.51	30.98	30.18	0.8
8/15/92	28.73	27.1	1.63	29.25	28.54	0.71
8/16/92	28.47	26.97	1.5	29.06	28.32	0.74
8/17/92	29.05	27.33	1.72	29.66	28.9	0.76
8/18/92	29.17	27.46	1.71	29.68	28.97	0.71
8/19/92	26.76	26.05	0.71	27.74	27.14	0.6
8/20/92	27.22	25.76	1.46	27.52	26.88	0.64
8/21/92	23.36	23.56	-0.2	24.68	24.23	0.45
8/22/92	21.65	21.87	-0.22	22.09	21.8	0.29
8/23/92	21.22	21	0.22	21.56	21.23	0.33
8/24/92	21.88	21.24	0.64	22.01	21.69	0.32
8/25/92	22.22	21.31	0.91	22.39	22.03	0.36
8/26/92	22.87	21.64	1.23	23.4	22.93	0.47
8/27/92	24.09	22.47	1.62	24.91	24.33	0.58
8/28/92	23.62	22.48	1.14	24.4	23.87	0.53
8/29/92	23.05	22.2	0.85	23.53	23.11	0.42
8/30/92	22.75	21.95	0.8	23.59	23.16	0.43
8/31/92	24.22	22.87	1.35	25.15	24.57	0.58
9/1/92	24.11	23.01	1.1	24.89	24.4	0.49
9/2/92	24.07	22.97	1.1	24.56	24.12	0.44
9/3/92	24.18	23	1.18	24.79	24.28	0.51
9/4/92	21.15	21.17	-0.02	21.85	21.55	0.3
9/5/92	20.67	20.18	0.49	20.78	20.48	0.3
9/6/92	20.29	19.84	0.45	20.29	20.03	0.26
9/7/92	19.45	18.99	0.46	19.72	19.44	0.28
9/8/92	20.49	19.44	1.05	21.57	21.08	0.49
9/9/92	20.51	19.38	1.13	20.85	20.44	0.41
9/10/92	19.58	18.81	0.77	20.24	19.88	0.36
9/11/92	20.87	19.69	1.18	21.71	21.26	0.45
9/12/92	19.09	18.81	0.28	19.33	19.09	0.24
9/13/92	18.57	18.08	0.49	18.33	18.13	0.2
9/14/92	16.57	16.68	-0.11	16.7	16.62	0.08
9/15/92	16.16	16.05	0.11	16.46	16.34	0.12
9/16/92	17.03	16.45	0.58	17.33	17.12	0.21
9/17/92	18.03	17.48	0.55	18.32	18.12	0.2
9/18/92	18.55	17.84	0.71	18.55	18.33	0.22
9/19/92	20.72	19.28	1.44	20.71	20.38	0.33
9/20/92	21.62	20.03	1.59	21.8	21.43	0.37
9/21/92	22.16	20.56	1.6	22.22	21.85	0.37

Table 3
continued

9/22/92	21.86	20.69	1.17	22	21.69	0.31
9/23/92	20.8	20.16	0.64	21.42	21.14	0.28
9/24/92	17.61	17.75	-0.14	18.19	17.99	0.2
9/25/92	18.49	17.96	0.53	18.44	18.21	0.23
9/26/92	18.57	17.98	0.59	18.88	18.65	0.23
9/27/92	17.59	17.23	0.36	17.37	17.22	0.15
9/28/92	17.65	17.09	0.56	17.46	17.26	0.2
9/29/92	18.36	17.43	0.93	18.43	18.15	0.28
9/30/92	18.92	17.9	1.02	19.4	19.09	0.31
10/1/92	19.64	18.82	0.82	20.31	19.97	0.34
10/2/92	18.81	18.01	0.8	19.59	19.25	0.34
10/3/92	17.06	16.67	0.39	17.45	17.29	0.16
10/4/92	16.41	15.95	0.46	16.22	16.11	0.11
10/5/92	15.76	15.27	0.49	15.61	15.48	0.13
10/6/92	15.28	14.86	0.42	15.07	14.95	0.12
10/7/92	14.3	14.26	0.04	14.09	14.05	0.04
10/8/92	14.41	14.25	0.16	14.69	14.59	0.1
10/9/92	15.11	14.61	0.5	15.24	15.08	0.16
10/10/92	15.21	14.7	0.51	15.56	15.36	0.2
10/11/92	16	15.19	0.81	16.62	16.31	0.31
10/12/92	15.57	15.03	0.54	16.18	15.93	0.25
10/13/92	14.93	14.54	0.39	15.18	15	0.18
10/14/92	13.81	13.92	-0.11	13.41	13.4	0.01
10/15/92	13.09	13.49	-0.4	12.17	12.3	-0.13
		Mean cooling	1.058874	Mean cooling		0.490993
		Max cooling	2.83	Max cooling		0.88
		Date	6/23/92	Date		7/17/92

Table 4. Differences between daily maximum water temperatures, with and without the Columbia River pump exchange in place, at two locations in the lower Yakima River for year 2000 conditions. Water temperatures simulated under current conditions were subtracted from water temperatures simulated under proposed conditions to calculate the differences.

2000 Yakima River Daily Maximum With and Without Pump Exchange

	0.6 KM upstream of Chandler			At West Richland		
Date	without project	with project	difference	without project	with project	difference
6/10/00	15.96	15.92	0.04	16.57	16.48	0.09
6/11/00	15.69	15.65	0.04	16.41	16.29	0.12
6/12/00	16.03	15.96	0.07	17.06	16.9	0.16
6/13/00	18.02	17.93	0.09	19.17	18.98	0.19
6/14/00	19.31	19.26	0.05	20.2	20.09	0.11
6/15/00	18.89	18.87	0.02	19.45	19.39	0.06
6/16/00	18.24	18.22	0.02	18.88	18.82	0.06
6/17/00	18.38	18.34	0.04	19.06	18.99	0.07
6/18/00	18.99	18.96	0.03	19.63	19.55	0.08
6/19/00	19.57	19.52	0.05	20.26	20.15	0.11
6/20/00	20.12	20.06	0.06	20.93	20.81	0.12
6/21/00	21.21	21.13	0.08	22.2	22.03	0.17
6/22/00	22.01	21.92	0.09	22.9	22.69	0.21
6/23/00	22.49	22.4	0.09	23.36	23.13	0.23
6/24/00	22.67	22.57	0.1	23.55	23.33	0.22
6/25/00	22.45	22.34	0.11	23.45	23.19	0.26
6/26/00	23.46	23.32	0.14	24.5	24.2	0.3
6/27/00	24.23	24.08	0.15	25.29	24.97	0.32
6/28/00	25.47	25.28	0.19	26.62	26.22	0.4
6/29/00	26.1	25.86	0.24	27.15	26.69	0.46
6/30/00	25.76	25.61	0.15	26.67	26.29	0.38
7/1/00	25.09	24.96	0.13	25.95	25.57	0.38
7/2/00	24.14	24	0.14	24.96	24.56	0.4
7/3/00	22.36	22.27	0.09	23.11	22.79	0.32
7/4/00	22.51	22.33	0.18	23.62	23.18	0.44
7/5/00	22.32	22.17	0.15	23.3	22.95	0.35
7/6/00	22.76	22.57	0.19	24.14	23.7	0.44
7/7/00	24.14	23.92	0.22	25.56	25.06	0.5
7/8/00	24.49	24.32	0.17	25.7	25.25	0.45
7/9/00	24.75	24.58	0.17	25.82	25.4	0.42
7/10/00	24.98	24.81	0.17	26.03	25.61	0.42
7/11/00	25.71	25.51	0.2	26.92	26.44	0.48
7/12/00	26.07	25.86	0.21	27.34	26.8	0.54
7/13/00	25.74	25.55	0.19	26.82	26.32	0.5
7/14/00	25.32	25.17	0.15	26.19	25.78	0.41
7/15/00	24.35	24.21	0.14	25.1	24.74	0.36
7/16/00	24.52	24.36	0.16	25.45	25.05	0.4
7/17/00	25.23	25.03	0.2	26.49	26	0.49
7/18/00	25.9	25.67	0.23	27.22	26.7	0.52

Table 4
continued

7/19/00	25.97	25.78	0.19	27.08	26.59	0.49
7/20/00	27.08	26.88	0.2	28.23	27.72	0.51
7/21/00	27	26.83	0.17	27.99	27.54	0.45
7/22/00	26.51	26.36	0.15	27.45	27.04	0.41
7/23/00	25.94	25.77	0.17	26.87	26.43	0.44
7/24/00	26.27	26.1	0.17	27.18	26.76	0.42
7/25/00	25.83	25.66	0.17	26.8	26.36	0.44
7/26/00	25.57	25.41	0.16	26.46	26.02	0.44
7/27/00	26.11	25.9	0.21	27.18	26.66	0.52
7/28/00	26.83	26.61	0.22	28.06	27.5	0.56
7/29/00	27.3	27.07	0.23	28.56	28	0.56
7/30/00	27.58	27.4	0.18	28.63	28.16	0.47
7/31/00	28.34	28.15	0.19	29.5	29.02	0.48
8/1/00	27.46	27.3	0.16	28.38	27.95	0.43
8/2/00	26.89	26.75	0.14	27.6	27.2	0.4
8/3/00	27.23	27.04	0.19	28.17	27.66	0.51
8/4/00	27.16	26.96	0.2	28.18	27.65	0.53
8/5/00	27.55	27.34	0.21	28.55	28.03	0.52
8/6/00	27.26	27.08	0.18	28.15	27.69	0.46
8/7/00	26.85	26.69	0.16	27.6	27.21	0.39
8/8/00	27.01	26.86	0.15	27.75	27.36	0.39
8/9/00	27.03	26.83	0.2	28.08	27.59	0.49
8/10/00	25.07	24.89	0.18	26.01	25.54	0.47
8/11/00	24.32	24.16	0.16	25.05	24.64	0.41
8/12/00	23.85	23.69	0.16	24.58	24.18	0.4
8/13/00	23.63	23.47	0.16	24.45	24.05	0.4
8/14/00	23.53	23.39	0.14	24.26	23.91	0.35
8/15/00	23.62	23.48	0.14	24.4	24.03	0.37
8/16/00	23.59	23.44	0.15	24.34	23.96	0.38
8/17/00	23.51	23.35	0.16	24.34	23.94	0.4
8/18/00	22.5	22.33	0.17	23.47	23.04	0.43
8/19/00	21.59	21.46	0.13	22.32	21.98	0.34
8/20/00	21.86	21.7	0.16	22.59	22.23	0.36
8/21/00	22.28	22.13	0.15	23	22.66	0.34
8/22/00	22.78	22.65	0.13	23.47	23.15	0.32
8/23/00	24.2	24.05	0.15	25.02	24.65	0.37
8/24/00	24.74	24.55	0.19	25.84	25.37	0.47
8/25/00	23.94	23.77	0.17	24.84	24.4	0.44
8/26/00	23.2	23.03	0.17	23.98	23.55	0.43
8/27/00	22.07	21.95	0.12	22.55	22.23	0.32
8/28/00	21.81	21.68	0.13	22.36	22.04	0.32
8/29/00	22.17	22.04	0.13	22.86	22.53	0.33
8/30/00	22.66	22.5	0.16	23.49	23.12	0.37
8/31/00	21.2	21.07	0.13	21.89	21.58	0.31
9/1/00	19.43	19.37	0.06	19.7	19.53	0.17
9/2/00	18.99	18.89	0.1	19.55	19.3	0.25
9/3/00	19.09	18.99	0.1	19.64	19.4	0.24
9/4/00	19.7	19.57	0.13	20.45	20.16	0.29

Table 4
continued

9/5/00	19.62	19.52	0.1	20.25	20	0.25
9/6/00	20.22	20.09	0.13	21	20.7	0.3
9/7/00	20.2	20.05	0.15	20.97	20.65	0.32
9/8/00	18.6	18.5	0.1	19.21	18.93	0.28
9/9/00	19.28	19.16	0.12	19.78	19.5	0.28
9/10/00	19.53	19.41	0.12	20.22	19.93	0.29
9/11/00	20.64	20.52	0.12	21.39	21.11	0.28
9/12/00	21.59	21.47	0.12	22.4	22.12	0.28
9/13/00	21.99	21.88	0.11	22.64	22.38	0.26
9/14/00	23.04	22.91	0.13	23.87	23.55	0.32
9/15/00	22.88	22.75	0.13	23.78	23.42	0.36
9/16/00	22.01	21.91	0.1	22.46	22.21	0.25
9/17/00	22.44	22.32	0.12	23.08	22.79	0.29
9/18/00	22.41	22.29	0.12	23.12	22.82	0.3
9/19/00	21.58	21.48	0.1	21.98	21.75	0.23
9/20/00	19.41	19.35	0.06	19.45	19.32	0.13
9/21/00	16.09	16.04	0.05	16.21	16.09	0.12
9/22/00	14.61	14.57	0.04	14.59	14.48	0.11
9/23/00	14.6	14.56	0.04	14.67	14.57	0.1
9/24/00	14.86	14.81	0.05	14.99	14.88	0.11
9/25/00	15.29	15.23	0.06	15.52	15.38	0.14
9/26/00	15.75	15.69	0.06	16.03	15.88	0.15
9/27/00	16.37	16.3	0.07	16.68	16.51	0.17
9/28/00	17.11	17.04	0.07	17.51	17.33	0.18
9/29/00	17.92	17.82	0.1	18.62	18.35	0.27
9/30/00	18.32	18.23	0.09	19.11	18.85	0.26
10/1/00	17.95	17.85	0.1	18.59	18.34	0.25
10/2/00	16.29	16.26	0.03	16.36	16.28	0.08
10/3/00	15.41	15.39	0.02	15.44	15.38	0.06
10/4/00	14.78	14.75	0.03	14.85	14.78	0.07
10/5/00	13.92	13.89	0.03	13.84	13.79	0.05
10/6/00	13.73	13.7	0.03	13.71	13.64	0.07
10/7/00	13.77	13.73	0.04	13.83	13.73	0.1
10/8/00	13.91	13.85	0.06	14.11	13.96	0.15
10/9/00	13.61	13.57	0.04	13.85	13.73	0.12
10/10/00	13.92	13.86	0.06	14.34	14.18	0.16
10/11/00	14.83	14.76	0.07	15.29	15.1	0.19
10/12/00	15.36	15.29	0.07	15.68	15.52	0.16
10/13/00	15.85	15.78	0.07	16.27	16.08	0.19
10/14/00	14.64	14.59	0.05	14.78	14.66	0.12
10/15/00	14.72	14.76	-0.04	14.3	14.36	-0.06
		Mean cooling	0.123359		Mean cooling	0.306797
		Max cooling	0.24		Max cooling	0.56
		Date	6/29/00		Date	7/28/00