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A Synopsis of Model Quality from the Department of Ecology's Total Maximum Daily Load Technical Studies

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Abstract

The Washington State Department of Ecology (Ecology) conducted a study of quality metrics for modeling and other analyses completed as part of Total Maximum Daily Load (TMDL) technical studies. This report provides a synopsis of quality metrics from 41 of Ecology's TMDL analyses.

These results support Ecology's efforts to improve quality assurance for water quality modeling by providing some context for the level of model quality that might be expected in future studies. The report gives recommendations for improved and more consistent reporting of model quality metrics.

Ecology conducted this study with the support of an internship through the Masters of Environmental Studies program at The Evergreen State College.

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Introduction

It is critically important that computer modeling used to support the clean-up of polluted water bodies is of a high quality. The Washington State Department of Ecology (Ecology) is working on improving and documenting its modeling quality assurance methods. Part of this effort includes better understanding the expected level of quality produced by those methods as part of water quality studies.

This study was initiated to review numerical models used in the creation of Total Maximum Daily Load (TMDL) studies and synthesize findings related to the quality of those models. Findings from this study will be incorporated into a larger study of modeling by Ecology's Environmental Assessment Program.

This study was conducted as part of an internship through the Master of Environmental Studies program at The Evergreen State College.

Methods

TMDL studies that Ecology had conducted and published through 2012 were evaluated for model use and presentation of modeling quality metrics.

- A summary table of TMDLs, water quality parameters, and modeling data if applicable was developed. Table 1 presents a subset of this table with reports that presented quality metrics.
- Details of the quantitative model quality results are presented by the target water quality parameter in the quantitative results section of this report in Tables 2 through 9.
- TMDL studies that provided figures representing quality metrics are presented in Appendix B of this report.
- A collection of quantitative quality statistic tables from original reports are presented in Appendix C.

Some of the figures and tables in the appendices may reflect modeled variables that were not the focus of the TMDL, thus not listed in Table 1. Many studies also have more figures and tables presented than are presented in this report.

For the purposes of this report, a *model* is defined as any numerical or computational tool which simulates the aquatic system of interest and can be used to estimate changes to that system when inputs or outputs are altered or removed. One example is a computer model that simulates suspended sediment in a river, which is then used to predict altered suspended sediment levels when a known point source load is removed. This definition includes any statistical model presented in a TMDL report which presented some form of fit to known system values.

Quality metrics are broken into calibration and validation values. The scope of this study did not look into the practice and definition of calibration versus validation in modeling, but simply took quality values listed in the reports and cited as similarly as possible to the original report what the metric was based on and how it was used in the study. If the phrase *verification* or *confirmation* was used, this was taken to denote the same general process as validation, and is listed as validation in this report.

Description of Models Used

Models

Many different models are used by Ecology and contractors to conduct TMDL studies for Washington State. The dominant model used by Ecology in river and stream systems across the majority of TMDLs is QUAL2K, or some other version of that model. QUAL2K is a one dimensional model with steady state hydraulics. Heat budget and water quality kinetics are dynamically simulated in diel time scale (US EPA, 2013).

WASP, GEMSS, and CH3D are the models used in marine systems. In lakes CE-QUAL-W2 is used. HSPF is a watershed model that is used as input to lake or marine models (Ecology, 2013).

The most common type of TMDL analysis for fecal coliform or other bacteria is statistical rollback. This type of analysis uses the statistical characteristics of fecal coliform loads and basic dispersion and dilution assumptions to estimate a new population size after a reduction factor has been applied. This type of analysis does not provide quality metrics and is not discussed further in this report.

Model Quality

Model quality was presented quantitatively in TMDL reports using a variety of metrics.

The most common metric cited was root mean square error (RMSE). The RMSE is the square root of the average of squared residual errors between modeled and measured values. Tables 2-9 present the average RMSE values for the models. If additional metrics were presented in table format in the original report, these are included in their entirety in Appendix C.

In a few cases, the coefficient of variation (CV) was referenced as the quality metric. This metric is sometimes expressed as a percent and called the percent relative standard deviation (%RSD). This metric represents the dispersion in the model and is the standard deviation divided by the mean.

Standard error and r^2 quality metrics are presented in a few cases where a regression type model was used. Another metric cited in TMDLs is the Nash-Sutcliffe coefficient.

For specifics on calculations of these metrics as calculated for the TMDL reports cited here, please see the original report text.

Results

Temperature

Temperature is the most commonly modeled water quality parameter in TMDL studies. There are 23 studies that utilized modeling for temperature analysis. QUAL2KW and related versions of this model were the dominant models used. Other models used included QUAL2E, GEMSS, SNTemp, rTEMP, CE-QUAL-W2, and CORMIX. The other models used were either only used once or did not provide similar quality metrics, thus there is no basis for comparison.

Table 2 shows a summary of all TMDL studies that evaluated temperature and subsequent summary statistics provided in the analysis. Separate lines for the same study indicate calibration versus validation data, which is noted in the table.

In some cases it was unclear what the quality metric was relative to, which makes comparison between models and at different drainages difficult. The most common metric is the 7-day average of daily maximum temperature during the hottest summer week. The average RMSE for studies that used this metric for QUAL2K calibration was 0.67 °C with a standard deviation of 0.17 (n=8).

In many of the available cases for comparison between calibration and validation, the quality metric was relative to a different unit of time. For example, calibration was sometimes completed with a 7-day average of daily maximum temperatures then validated with only one day of data. However, for the QUAL2KW simulations reviewed in this study, the 7-day average is most commonly a simulation of a repeating diel variation.

Taking this into account, the average RMSE of QUAL2K temperature calibration was 0.56 °C, with 0.20 standard deviation (n=7). The average RMSE of validation was 0.75 °C, with 0.16 standard deviation (n=10). This comparison looked at the same studies for calibration and validation, but some studies included multiple validation quality metrics, thus a difference in n values. The maximum RMSE calibration error for QUAL2K was 0.85 °C, and the maximum RMSE validation error was 1°C.

Dissolved Oxygen

Dissolved oxygen as a water quality parameter has been modeled and presented with quality metrics second in abundance to temperature. Table 3 lists these TMDL studies, which use several different quality metrics, making the comparison of modeling results more difficult. Pooling the metrics, the values for variability in oxygen modeling range from 0.001 to 2.2 mg/L with a mean of 0.60 mg/L and standard deviation of 0.59 mg/L.

DO TMDL studies often calibrate to secondary variables, such as nutrients and chlorophyll-*a*. Quality metrics for nutrients are presented for several studies. These results had a variety of metrics and are shown in Table 4.

Other TMDL Parameters

All other modeled water quality parameters listed in Table 1 – bacteria, toxics, sediment, nutrients, and total dissolved gas – are represented by fewer than five TMDL studies. Tables 5 through 9 summarize the TMDL studies for these other parameters that included modeling with quality metric information.

The quality metrics can be summarized:

- pH had RMSE values for four models that varied from 0.2 to 0.58 standard units.
- Total dissolved gas has standard error values for four regressions of gas pressure that varied from 6.78 to 15.95 mm Hg.
- Sediment modeling had Nash-Sutcliffe values that varied from 0.36 to 0.98 for multiple locations.
- Other water quality parameters had few studies with a variety of metrics and are not summarized here.

Conclusions and Recommendations

This study demonstrates the variability in accuracy and precision of water quality models. The review also found that studies provided a variety of modeling quality metrics and methods of presentation. This magnitude of variability will depend on the constituent of interest, the system being studied, the model being used, and the metric chosen. Although improvements to models and data collection equipment may reduce some of this variance, model uncertainty will always exist.

Based on this review of TMDL studies, the consistency of describing model design and resulting accuracy and precision could be improved. When quality metrics were presented, it was often unclear how they were calculated and how they related to water quality regulations. Often information was not clearly presented in tables. It was also unclear in some reports if values being reported were from in situ data or modeling results.

Clearer and more consistent reporting procedures for quality metrics are recommended to reduce these kinds of problems. Authors and peer reviewers should consider the following questions in evaluating the reporting of quality metrics:

- Are the methods for calculating model quality metrics clearly described and explained?
- Are the quality metrics presented clearly in tables or graphs?
- Are the quality results interpreted with narrative that puts them in context and explains their significance?

Presentation of findings varied widely between text, tables, and figures. Development of a set combination of presentation methods is recommended.

The relevance of these recommendations will vary between water quality parameters, but they should be attainable for relatively common and simple parameters such as temperature. Defining a clear format to act as a template for dissemination of model results could improve modeling, especially with water quality variables that are less frequently modeled.

References

Annear, R., S. Wells, and C. Berger. 2005. Upper Spokane River Model in Idaho: Boundary Conditions and Model Setup and Calibration for 2001 and 2004. Portland State University. http://pdxscholar.library.pdx.edu/cengin_fac/160/

Annear, R., C. Berger, and S. Wells. 2006. Pend Oreille River, Box Canyon Model: Model Development and Calibration. Washington State Department of Ecology. http://pdxscholar.library.pdx.edu/cengin_fac/155/

Baldwin, K. and P. Pickett. 2011. Pend Oreille River Temperature Total Maximum Daily Load - Water Quality Improvement Report. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/1010065.html

Breithaupt, S. and T. Khangaonkar. 2007. Temperature Modeling of the Pend Oreille River, Boundary Hydroelectric Project CE-QUAL-W2 Model Calibration Report. Battelle Pacific Northwest Division. www.ecy.wa.gov/programs/wq/tmdl/pendoreille/SCL-BoundaryRes-CalibRptFINALSept07.pdf

Brock, S. 2008. Upper Naches River Temperature Total Maximum Daily Load - Vol. 1 Water Quality Study Findings. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0803036.html

Brock, S. and A. Stohr. 2002. Little Klickitat River Watershed Temperature Total Maximum Daily Load. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0203031.html

Butkus, S., M. Wills, and S. Hood. 2000. Johnson Creek Watershed Total Maximum Daily Load. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0010033.html

Carroll, J., S. O'Neal, and S. Golding. 2006. Wenatchee River Basin Dissolved Oxygen, pH, and Phosphorus Total Maximum Daily Load Study. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0603018.html

Coffin, C., S. Lee, and C. DeGasperi. 2011. Green River Temperature Total Maximum Daily Load - Water Quality Improvement Report. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/1110046.html

Cusimano, R. 1995. Snohomish River Estuary Dry Season TMDL Study - Phase 1 - Water Quality Model Calibration. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/95338.html

Ecology. 2001. Upper Chehalis River Basin Temperature Total Maximum Daily Load. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/9952.html

Ecology. 2013. Models for Total Maximum Daily Load Studies. http://www.ecy.wa.gov/programs/eap/models.html

Hood, S., N. Cristea, and A. Stohr. 2011. Whatcom, Squalicum, and Padden Creeks Temperature Total Maximum Daily Load - Water Quality Improvement Report. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/1110019.html

Irle, P. 2001. Teanaway Temperature Total Maximum Daily Load - Submittal Report. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0110019.html

Johnson, A., B. Era-Miller, R. Coots, and S. Golding. 2004. A Total Maximum Daily Load Evaluation for Chlorinated Pesticides and PBCs in the Walla Walla River. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0403032.html

Joy, J. 1994. Snoqualmie River Total Maximum Daily Load Study. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/9471.html

Joy, J. 2002. Upper Yakima River Basin Suspended Sediment and Organochlorine Pesticide Total Maximum Daily Load Evaluation. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0203012.html

Joy, J. and B. Patterson. 1997. A Suspended Sediment and DDT Total Maximum Daily Load Evaluation Report for the Yakima River. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/97321.html

Joy, J. and J. Jones. 2012. Little Spokane River Watershed Fecal Coliform Bacteria, Temperature, and Turbidity Total Maximum Daily Load - Water Quality Improvement Report. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/1110075.html

Joy, J., G. Pelletier, and K. Baldwin. 2007. Walla Walla River Basin pH and Dissolved Oxygen Total Maximum Daily Load - Water Quality Improvement Report. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0703010.html

Joy, J., R. Noll, and E. Snouwaert. 2009. Hangman (Latah) Creek Watershed Fecal Coliform, Temperature, and Turbidity Total Maximum Daily Load - Water Quality Improvement Report. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0910030.html

Lee, S., D. Garland, and J. Burkey. 2011. Newaukum Creek Temperature Total Maximum Daily Load - Water Quality Improvement Report and Implementation Plan. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/1110047.html

Mohamedali, T. and S. Lee. 2008. Bear-Evans Watershed Temperature and Dissolved Oxygen Total Maximum Daily Load - Water Quality Improvement Report. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/SummaryPages/0810058.html

Pelletier, G. 2002. Wind River Watershed Temperature Total Maximum Daily Load. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0203010.html

Pelletier, G. and D. Bilhimer. 2004. Stillaguamish River Watershed Temperature Total Maximum Daily Load Study. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0403010.html

Pelletier, G. and K. Seiders. 2000. Grays Harbor Fecal Coliform Total Maximum Daily Load Study. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0003020.html

Pickett, P. 1994. Upper Chehalis River Dry Season Total Maximum Daily Load Study. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/94126.html

Pickett, P. 1997. Lower Skagit River Total Maximum Daily Load Water Quality Study. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/97326a.html

Pickett, P. and R. Harding. 2002. Total Maximum Daily Load (TMDL) for Lower Columbia River Total Dissolved Gas. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0203004.html

Pickett, P. and S. Hood. 2008a. Lake Whatcom Watershed Total Phosphorus and Bacteria Total Maximum Daily Loads - Vol. 1 Water Quality Study Findings. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0803024.html

Pickett, P. and S. Hood. 2008b. Lake Whatcom Watershed Total Phosphorus and Bacteria Total Maximum Daily Loads - Vol. 1 Water Quality Study Findings - Appendices B-F. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0803024AppBF.html

Roberts, M. 2003. South Prairie Creek Temperature and Bacteria Total Maximum Daily Loads. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0303021.html

Roberts, M., A. Ahmed, G. Pelletier, and D. Osterberg. 2012a. Deschutes River, Capitol Lake, and Budd Inlet Temperature, Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Fine Sediment Total Maximum Daily Load Technical Report - Water Quality Study Findings. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/1203008.html

Roberts, M., A. Ahmed, G. Pelletier, and D. Osterberg. 2012b. Deschutes River, Capitol Lake, and Budd Inlet Temperature, Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Fine Sediment Total Maximum Daily Load Technical Report - Water Quality Study Findings – Appendix G-H. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/1203008.html

Sargeant, D., B. Carey, M. Roberts, and S. Brock. 2006. Henderson Inlet Watershed Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Temperature Total Maximum Daily Load Study. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0603012.html

Serdar, D. and B. Era-Miller. 2004. DDT Contamination and Transport in the Lower Mission Creek Basin, Chelan County - Total Maximum Daily Load Assessment. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0403043.html

Stohr, A. 2004. Willapa River Watershed Temperature Total Maximum Daily Load Study. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0403024.html

Stohr, A., M. LeMoine, and G. Pelletier. 2007. Walla Walla River Tributaries Temperature Total Maximum Daily Load Study. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0703014.html

The Cadmus Group, Inc., and CDM. 2007. Final Model Report for Lake Whatcom Watershed TMDL Model Project. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0910010.html

US EPA. 2013. QUAL2KW CREM Knowledge Base Summary. http://cfpub.epa.gov/crem/knowledge_base/crem_report.cfm?deid=83126&view=PDF

Whiley, A.J. 2004. Cottage Lake Total Phosphorus Total Maximum Daily Load. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0310085.html

Whiley, A.J. and K. Baldwin. 2005. Colville National Forest Temperature, Bacteria, pH, and Dissolved Oxygen Total Maximum Daily Load (Water Cleanup Plan) - Submittal Report. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0510047.html

Whiley, A.J. and K. Merrill. 2007. Newman Lake - Total Phosphorus Total Maximum Daily Load - Water Quality Improvement Report. Washington State Department of Ecology. https://fortress.wa.gov/ecy/publications/summarypages/0610045.html

Tables

Table 1. Summary of TMDL studies that used modeling and provided model quality metrics

TMDL parameters are marked if quality metrics for modeling were provided TMDL parameters denoted by X_a only have qualitative figures in Appendix B of this report.

Waterbody	**References**	**TMDL Water Quality Parameters**							
		Total Dissolved Gas	**Oxygen**	**pH**	**Temperature**	**Bacteria**	**Toxics**	**Sediment**	**Nutrients**
Bear-Evans Creek - Bear Creek	Mohamedali and Lee, 2008		X		X				
Bear-Evans Creek - Cottage Lake Creek	Mohamedali and Lee, 2008		X		X				
Bear-Evans Creek - Evans Creek	Mohamedali and Lee, 2008		X		X				
Chehalis River Basin-Grays Harbor	Pelletier and Seiders, 2000					X			
Chehalis River Basin-Upper Chehalis River	Pickett, 1994; Ecology, 2001		X		X				
Cottage Lake	Whiley, 2004								X
Deschutes River	Roberts *et al., 2012a; 2012b*		X	X	X				
Deschutes River - Budd Inlet	Roberts *et al., 2012a; 2012b*		X						X
Deschutes River - Capitol Lake	Roberts *et al., 2012a; 2012b*		X		X				X
Green River	Coffin *et al*., 2011				X				
Hangman (Latah) Creek	Joy *et al., 2009*				X	X_a		X	
Henderson Inlet	Sargeant *et al*., 2006		X		X				

Waterbody	References	TMDL Water Quality Parameters							
		Total Dissolved Gas	Oxygen	pH	Temperature	Bacteria	Toxics	Sediment	Nutrients
Lake Whatcom	Pickett and Hood, 2008a; 2008b; The Cadmus Group Inc and CDM, 2007		X						X
Little Klickitat	Brock and Stohr, 2002				X				
Little Spokane	Joy and Jones, 2012				X			X	
Lower Columbia River (Bonneville)	Pickett and Harding, 2002	X_a							
Lower Columbia River (Dalles)	Pickett and Harding, 2002	X							
Lower Columbia River (John Day 1996-97)	Pickett and Harding, 2002	X							
Lower Columbia River (John Day 1998)	Pickett and Harding, 2002	X							
Lower Columbia River (McNary)	Pickett and Harding, 2002	X							
Lower Yakima River	Joy and Patterson, 1997						X_a		
Mission Creek	Serdar and Era-Miller, 2004						X		
Newaukum Creek	Lee *et al.*, 2011				X				
Newman Lake	Whiley and Merrill, 2007								X
Pend Oreille River	Annear *et al.*, 2006; Baldwin and Pickett, 2011; Breithaupt and Khangaonkar, 2007				X				
Skagit River and Bay	Pickett, 1997		X						
Snohomish Estuary	Cusimano, 1995		X						

Waterbody	References	TMDL Water Quality Parameters							
		Total Dissolved Gas	Oxygen	pH	Temperature	Bacteria	Toxics	Sediment	Nutrients
Snoqualmie River	Joy, 1994		X		X	X			X
South Prairie Creek	Roberts, 2003				X				
Spokane River	Annear *et al.*, 2005		X		X[a]				
Stillaguamish River	Pelletier and Bilhimer, 2004		X[a]		X				
Teanaway River	Irle, 2001				X				
Upper Naches River	Brock, 2008				X				
Upper Yakima River	Joy, 2002							X	
Walla Walla River	Johnson *et al.*, 2004						X[a]		
Walla Walla River - Mill and Yellowhawk Creeks	Joy *et al.*, 2007; Stohr *et al.*, 2007		X	X	X				
Walla Walla River - Touchet River	Joy *et al.*, 2007; Stohr *et al.*, 2007		X	X	X				
Wenatchee River	Carroll *et al.*, 2006		X	X	X				
Whatcom Creek	Hood *et al.*, 2011				X				
Willapa River	Stohr, 2004				X	X[a]			
Wind River	Pelletier, 2002				X				

Table 2. Summary of temperature TMDL studies with modeling framework and associated water quality metrics.

Waterbody	Model Framework	Quality Metric	Quality Metric Value (°C)	Quality Relative to	Calibration or Validation
Pend Oreille River	CE-QUAL-W2	Average RMSE	0.41	1997-1998, 2004 (Box Canyon)	Calibration
Pend Oreille River	CE-QUAL-W2	Average RMSE	0.41	2004-2005 (Boundary)	Calibration
Deschutes River - Capitol Lake	GEMSS	Average RMSE	1.6	Entire Water Column	Calibration
Deschutes River - Capitol Lake	GEMSS	Mean Residual	0.66	Entire Water Column	Calibration
Deschutes River - Capitol Lake	GEMSS	Mean Residual	0.14	Entire Water Column	Validation
Snoqualmie River	QUAL2E	Average RMSE	0.05	Sept 1991	Calibration
Bear-Evans Creek - Bear Creek	QUAL2K	Average RMSE	0.41	7 Day Max	Calibration
Bear-Evans Creek - Evans Creek	QUAL2K	Average RMSE	0.59	7 Day Max	Calibration
Bear-Evans Creek - Cottage Lake Creek	QUAL2K	Average RMSE	0.67	7 Day Max	Calibration
Deschutes River	QUAL2K	Average RMSE	0.85	7 Day Max	Calibration
Green River	QUAL2K	Average RMSE	0.54	2-Aug-06	Calibration
Henderson Inlet	QUAL2K	Average RMSE	0.521	Sept 2003	Calibration
Little Spokane	QUAL2K	Average RMSE	0.58	7 Day Max	Calibration
Newaukum Creek	QUAL2K	Average RMSE	0.37	2-Aug-06	Calibration
South Prairie Creek	QUAL2K	Average RMSE	0.54	7 Day Max/Min 9-Aug-2001 to 15-Aug-2001	Calibration

Waterbody	Model Framework	Quality Metric	Quality Metric Value (°C)	Quality Relative to	Calibration or Validation
Stillaguamish River	QUAL2K	Average RMSE	0.7	Aug 9-15, 2001	Calibration
Upper Naches River	QUAL2K	Average RMSE	0.73	7 Day Max	Calibration
Walla Walla River - Mill and Yellowhawk Creeks	QUAL2K	Average RMSE	0.65	31-Aug to 1-Sept-2004	Calibration
Walla Walla River - Touchet River	QUAL2K	Average RMSE	0.62	July 11-17, 2002 Maximum	Calibration
Walla Walla River - Touchet River	QUAL2K	Average RMSE	0.5	Sept 2002	Calibration
Wenatchee River	QUAL2K	Average RMSE	0.47	Aug-Sept 2002	Calibration
Whatcom Creek	QUAL2K	Average RMSE	0.28	July 11-17, 2002 Max	Calibration
Willapa River	QUAL2K	Average RMSE	0.51	Aug 8-14, 2001 Max	Calibration
Wind River	QUAL2K	Average RMSE	0.6	Daily Max	Calibration
Green River	QUAL2K	Mean Residual	-0.37	2-Aug-06	Calibration
Deschutes River	QUAL2K	Average RMSE	0.9	7 Day Max	Validation
Green River	QUAL2K	Average RMSE	0.77	23-Jul-06	Validation
Green River	QUAL2K	Average RMSE	0.78	7-Aug-06	Validation
Green River	QUAL2K	Average RMSE	0.72	18-Aug-06	Validation
Newaukum Creek	QUAL2K	Average RMSE	0.58	20-Aug-06	Validation
South Prairie Creek	QUAL2K	Average RMSE	0.64	7 Day Max/Min 29-Jul-2000 to 4-Aug-2000	Validation
South Prairie Creek	QUAL2K	Average RMSE	0.91	7 Day Max/Min 1-Aug-2001 to 7-Aug-2001	Validation
Teanaway River	QUAL2K	Average RMSE	0.7	Sept 7-8,2001	Validation
Upper Naches River	QUAL2K	Average RMSE	0.45	7 Day Max	Validation
Whatcom Creek	QUAL2K	Average RMSE	0.73	August 5-7, 2002 Max	Validation
Wind River	QUAL2K	Average RMSE	1	Daily Max	Validation

Waterbody	Model Framework	Quality Metric	Quality Metric Value (°C)	Quality Relative to	Calibration or Validation
Little Klickitat	rTEMP	Average RMSE	0.85	7 Day Max, July 29-Aug 4, 2000	Calibration
Hangman (Latah) Creek	rTEMP	within	0.7	7 Day Max	Calibration
Little Klickitat	rTEMP	Average RMSE	1.23	7 Day Max, Aug 21-Aug 27, 2000	Validation
Chehalis River Basin-Upper Chehalis River	SNTemp	Average RMSE	3.2	Aug 1992	Calibration
Hangman (Latah) Creek	SNTemp	Average RMSE	1	Most weeks and sites	Calibration
Chehalis River Basin-Upper Chehalis River	SNTemp	Median Abs Deviation	1.4	Aug 1991	Calibration
Chehalis River Basin-Upper Chehalis River	SNTemp	Average RMSE	3.2	Aug 1991	Validation
Chehalis River Basin-Upper Chehalis River	SNTemp	Median Abs Deviation	1.5	Aug 1992	Validation

Table 3. Summary of oxygen TMDL studies with modeling framework and associated water quality metrics.

Waterbody	Model Framework	Quality Metric	Quality Metric Value (mg/L)	Quality Relative to	Calibration or Validation
Lake Whatcom	CE-QUAL-W2	Average Mean Error	0.12	Average	Calibration
Lake Whatcom	CE-QUAL-W2	Average RMSE	0.84	Average	Calibration
Spokane River	CE-QUAL-W2	Average RMSE	0.74	2001	Calibration
Spokane River	CE-QUAL-W2	Average RMSE	0.3	2004	Calibration
Spokane River	CE-QUAL-W2	Mean Error	0.17	2001	Calibration
Spokane River	CE-QUAL-W2	Mean Error	0.18	2004	Calibration
Deschutes River - Capitol Lake	GEMSS	Average RMSE	2.2	Entire Water Column	Calibration
Deschutes River - Budd Inlet	GEMSS	Average RMSE	2	Entire Water Column	Calibration
Deschutes River - Capitol Lake	GEMSS	Mean Residual	0.29	Entire Water Column	Calibration
Deschutes River - Budd Inlet	GEMSS	Mean Residual	-0.65	Entire Water Column	Calibration
Deschutes River - Capitol Lake	GEMSS	Average RMSE	3.5	Entire Water Column	Validation
Deschutes River - Capitol Lake	GEMSS	Mean Residual	3.3	Entire Water Column	Validation
Skagit River and Bay	MULTISMP	CV	< 4%	Sept 1995	Calibration
Skagit River and Bay	MULTISMP	CV	< 2%	Oct 1995	Validation
Snoqualmie River	QUAL2E	Average RMSE	0.7	Sep-91	Calibration
Bear-Evans Creek - Bear Creek	QUAL2K	Average RMSE	0.12	7 Day Max	Calibration
Bear-Evans Creek - Evans Creek	QUAL2K	Average RMSE	0.99	7 Day Max	Calibration
Bear-Evans Creek - Cottage Lake Creek	QUAL2K	Average RMSE	0.001	7 Day Max	Calibration
Deschutes River	QUAL2K	Average RMSE	0.64	Min	Calibration

Waterbody	Model Framework	Quality Metric	Quality Metric Value (mg/L)	Quality Relative to	Calibration or Validation
Henderson Inlet	QUAL2K	Average RMSE	0.559	Sep-03	Calibration
Walla Walla River - Touchet River	QUAL2K	Average RMSE	0.3	Sep-02	Calibration
Walla Walla River - Mill and Yellowhawk Creeks	QUAL2K	Average RMSE	0.46	31-Aug-04 to 1-Sept-04	Calibration
Wenatchee River	QUAL2K	Average RMSE	0.2	Aug to Sept 2002	Calibration
Chehalis River Basin-Upper Chehalis River	WASP	Average RMSE	1.8	July 1992 Max	Calibration
Snohomish Estuary	WASP	Average RMSE	0.23	-	Calibration

Table 4. Summary of nutrients TMDL studies with modeling framework and associated water quality metrics

Waterbody	Model Framework	Quality Metric	Quality Metric Value	Quality Relative to	Calibration or Validation
Lake Whatcom – Total Phosphorus - (mg/L)	CE-QUAL-W2	Average Mean Error	0	Average	Calibration
Lake Whatcom – Total Phosphorus - (mg/L)	CE-QUAL-W2	Average RMSE	0.004	Average	Calibration
Deschutes River - Budd Inlet - DIN (mgN/L)	GEMSS	Average RMSE	0.086	Entire water column	Calibration
Deschutes River - Budd Inlet - Nitrate/Nitrite (mgN/L)	GEMSS	Average RMSE	0.067	Entire water column	Calibration
Deschutes River - Budd Inlet - Ammonium (mgN/L)	GEMSS	Average RMSE	0.04	Entire water column	Calibration
Deschutes River - Capitol Lake - PO_4 (mgP/L)	GEMSS	Average RMSE	0.011	Entire water column	Calibration

Waterbody	Model Framework	Quality Metric	Quality Metric Value	Quality Relative to	Calibration or Validation
Deschutes River - Capitol Lake - DIN (mgN/L)	GEMSS	Average RMSE	0.17	Entire water column	Calibration
Deschutes River - Budd Inlet - DIN (mgN/L)	GEMSS	Mean Residual	-0.005	Entire water column	Calibration
Deschutes River - Budd Inlet - Nitrate/Nitrite (mgN/L)	GEMSS	Mean Residual	-0.004	Entire water column	Calibration
Deschutes River - Budd Inlet - Ammonium (mgN/L)	GEMSS	Mean Residual	0.002	Entire water column	Calibration
Deschutes River - Capitol Lake - PO_4 (mgP/L)	GEMSS	Mean Residual	-0.007	Entire water column	Calibration
Deschutes River - Capitol Lake - DIN (mgN/L)	GEMSS	Mean Residual	0.054	Entire water column	Calibration
Deschutes River - Capitol Lake - PO_4 (mgP/L)	GEMSS	Average RMSE	0.007	Entire water column	Validation
Deschutes River - Capitol Lake - DIN (mgN/L)	GEMSS	Average RMSE	0.13	Entire water column	Validation
Deschutes River - Capitol Lake - PO_4 (mgP/L)	GEMSS	Mean Residual	-0.003	Entire water column	Validation
Deschutes River - Capitol Lake - DIN (mgN/L)	GEMSS	Mean Residual	-0.087	Entire water column	Validation
Cottage Lake – Total Phosphorus (ug/L)	Mass Balance	Average RMSE	1.6	Epilimnion Summer	Calibration
Cottage Lake – Total Phosphorus (ug/L)	Mass Balance	Average RMSE	33.2	Hypolimnion Summer	Calibration
Snoqualmie River - Total N	QUAL2E	Average RMSE	44.745	Sep-91	Calibration
Newman Lake – Total Phosphorus (ug/L)	Vollenweider	r^2	0.94	Annual	-

Table 5. Summary of pH TMDL studies with modeling framework and associated water quality metrics.

Waterbody	Model Framework	Quality Metric	Quality Metric Value (SU)	Quality Relative to	Calibration or Validation
Deschutes River	QUAL2K	RMSE	0.58	Maximum	Calibration
Walla Walla River - Touchet River	QUAL2K	RMSE	0.2	Sep-02	Calibration
Walla Walla River - Mill and Yellowhawk Creeks	QUAL2K	RMSE	0.23	31-Aug-04 to 1-Sept-04	Calibration
Wenatchee River	QUAL2K	RMSE	0.2	Aug-Sept 2002	Calibration

Table 6. Summary of dissolved gas TMDL studies with modeling framework and associated water quality metrics.

Waterbody	Model Framework	Quality Metric	Quality Metric Value (pressure, mm Hg)	Quality Relative to	Calibration or Validation
Lower Columbia River (Dalles)	Regression	St Err, r2	7.34, 0.735	1997 spill	-
Lower Columbia River (John Day 1996-97)	Regression	St Err, r2	15.95, 0.94	1996-97 spill	-
Lower Columbia River (John Day 1998)	Regression	St Err, r2	6.78, 0.84	1998 spill	-
Lower Columbia River (McNary)	Regression	St Err, r2	9.25, 0.97	1997 spill	-

Table 7. Summary of bacteria TMDL studies with modeling framework and associated water quality metrics.

Waterbody	Model Framework	Quality Metric	Quality Metric Value	Quality Relative to	Calibration or Validation
Snoqualmie River (cfu/100 mL)	QUAL2E	RMSE	1.22	Sep-91	Calibration
Chehalis River Basin-Grays Harbor	WASP	RMSE	34%	Comparison between geometric means and 90th percentiles	Calibration

Table 8. Summary of toxics TMDL studies with modeling framework and associated water quality metrics.

Waterbody	Model Framework	Quality Metric	Quality Metric Value (unitless)	Quality Relative to	Calibration or Validation
Walla Walla River	Systat	r^2	0.83	-	-
Mission Creek - DDT	Systat	r^2	0.03	2000 and 2003 samples	-

Table 9. Summary of suspended sediment TMDL studies with modeling framework and associated water quality metrics.

Waterbody	Model Framework	Quality Metric	Quality Metric Value (unitless)	Quality Relative to	Calibration or Validation
Hangman (Latah) Creek	Regression	Nash-Sutcliffe coefficient	0.8	Stream Flow	-
Little Spokane - TSS	Regression	Nash-Sutcliffe coefficient	0.36 to 0.98	Multiple locations	Calibration
Upper Yakima	Regression	r^2	0.956	1994 and 1995, TSS/Turbidity	-
Hangman (Latah) Creek	WARMF	Nash-Sutcliffe coefficient	0.58	Stream Flow	-

Appendix A: Glossary, Acronyms, and Abbreviations

Glossary

CE-QUAL-W2: A water quality modeling framework.

CH3D: A water quality modeling framework.

Colony forming units: The measurement unit for quantifying bacteria concentrations.

CORMIX: A water quality mixing zone modeling framework.

Diel: Of, or pertaining to, a 24-hour period.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Fecal coliform: A category of bacteria regulated by Washington's Water Quality Standards rules.

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10 to 10,000 fold over a given period. The calculation is performed by either: (1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

GEMSS: A water quality modeling framework.

HSPF: A hydrologic and water quality modeling framework.

Hyporheic: The area beneath and adjacent to a stream where surface water and groundwater intermix.

Millimeters of mercury: A unit of measurement for gas pressure.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Parameter: Water quality constituent being measured (also called the *water quality variable*). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

QUAL2K: A water quality modeling framework. Other versions include QUAL2E and QUAL2kw.

rTemp: A water temperature modeling framework.

SNTemp: A water temperature modeling framework.

Standard Units: Units used for reporting pH.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Turbidity: The cloudiness or haziness of a fluid caused by individual particles (total suspended or dissolved solids).

WARMF: A water quality modeling framework.

WASP: A water quality modeling framework.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report. For acronyms and abbreviations in Appendix B and C, refer to the original report.

%RSD	Percent Relative Percent Difference
4.4'-DDE	Dichlorodiphenyldichloroethylene, a break-down product of DDT
cfu/100 mL	Colony forming units per 100 milliliters
CV	Coefficient of Variation
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
mm Hg	Millimeters of mercury
n	Number of values
r^2	Coefficient of determination
RM	River mile
RMSE	Root mean square error
RPD	Relative percent difference
RSD	Relative standard deviation
SU	Standard Units
t-DDT	Dichlorodiphenyltrichloroethane
TMDL	(See Glossary above)
TSS	Total suspended solids

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
deg C	degrees centigrade
cms	cubic meters per second, a unit of flow
kg	kilograms, a unit of mass equal to 1,000 grams
km	kilometer, a unit of length equal to 1,000 meters
mg/L	milligrams per liter (parts per million)
ng/L	nanograms per liter (parts per trillion)
ug/L	micrograms per liter (parts per billion)

Appendix B: Figures Representing Quality Metrics

Qualitative results are presented below by modeled water quality parameter and sorted alphabetically. Qualitative results are original graphs from TMDL reports. The figure captions in this report note the original figure caption in the reference from Table 1, and page number where the original figure may be found.

Temperature

Bear-Evans

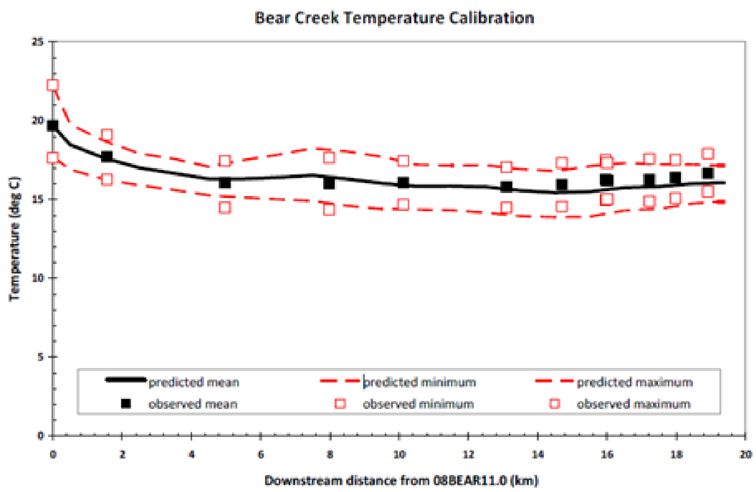

Figure B-1. Comparison of predicted and observed temperatures for Bear Creek on July 18-19, 2006. Mohamedali and Lee (2008), page 72.

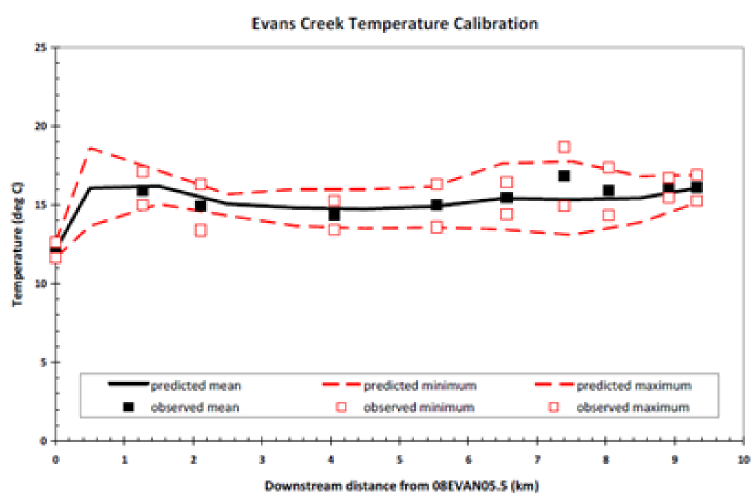

Figure B-2. Comparison of predicted and observed temperatures for Evans Creek on July 18-19, 2006. Mohamedali and Lee (2008), page 72.

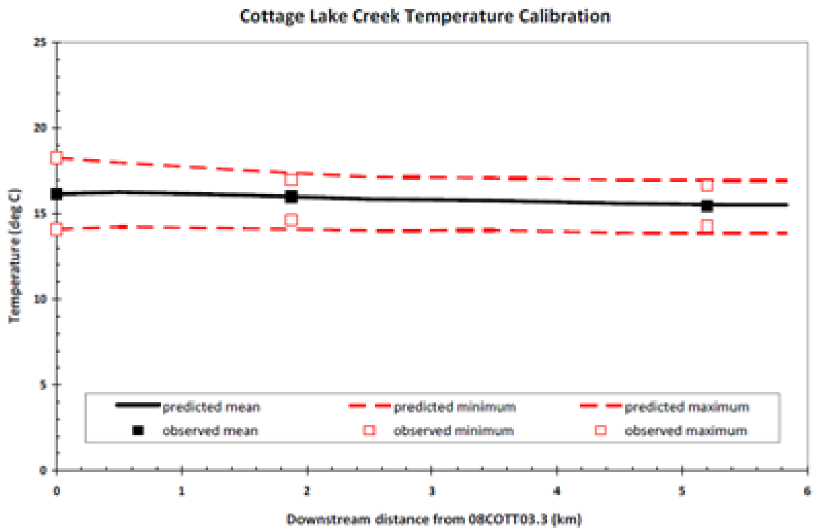

Figure B-3. Comparison of predicted and observed temperatures for Cottage Lake Creek on July 18-19, 2006. Mohamedali and Lee (2008), page 72.

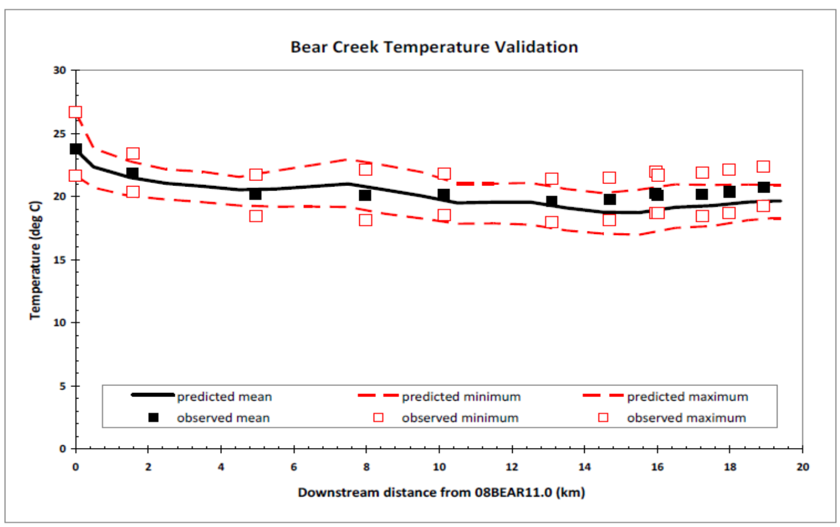

Figure 21. Comparison of predicted and observed temperatures for Bear Creek on July 21-27, 2006.

Figure B-4. Comparison of predicted and observed temperatures for Bear Creek on July 21-27, 2006. Mohamedali and Lee (2008), page 76.

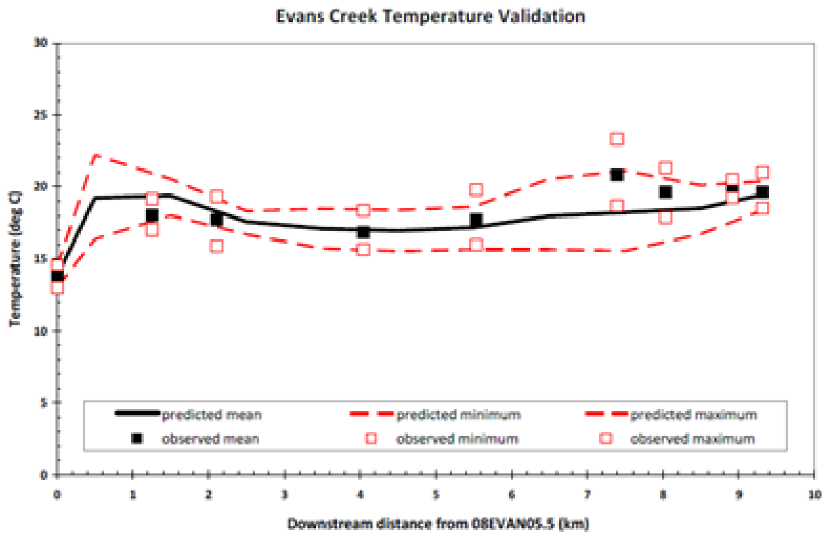

Figure B-5. Comparison of predicted and observed temperatures for Evans Creek on July 21-27, 2006. Mohamedali and Lee (2008), page 77.

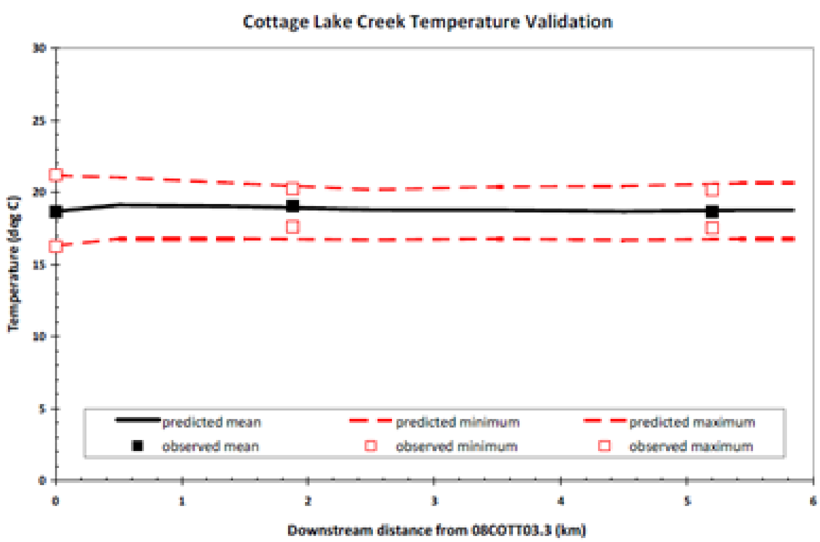

Figure B-6. Comparison of predicted and observed temperatures for Cottage Lake Creek on July 21-27, 2006. Mohamedali and Lee (2008), page 77.

Deschutes River

This TMDL had many other figures and tables in the report text and appendices. Please see Roberts *et al.* (2012a; 2012b) for additional information.

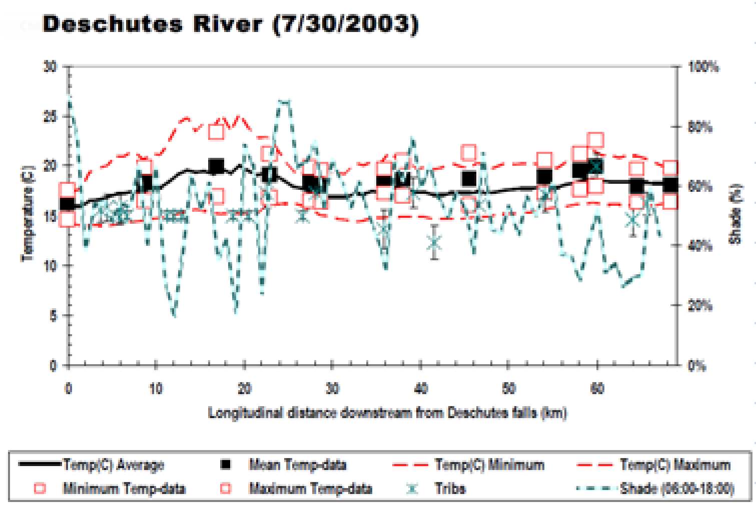

Figure B-7. QUAL2K model run results for the July 27 to August 2, 2003, validation period (peak daily max surface water temperature). Roberts *et al.* (2012b), page 118.

Green River

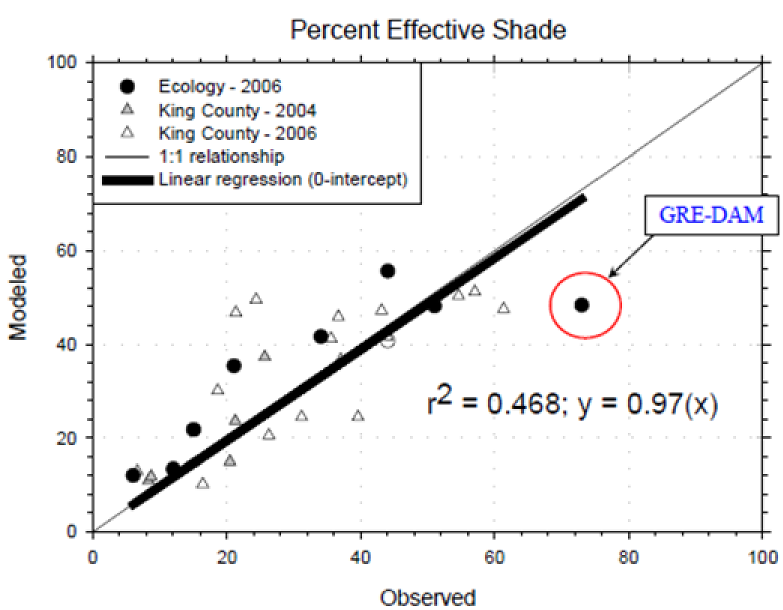

Figure B-8. Comparison of predicted and observed Effective Shade, August 2, 2006. The outlier identified by the red circle represents the comparison for Station GRE-DAM just below the Tacoma Public Utilities diversion. Coffin *et al.* (2011), page 43.

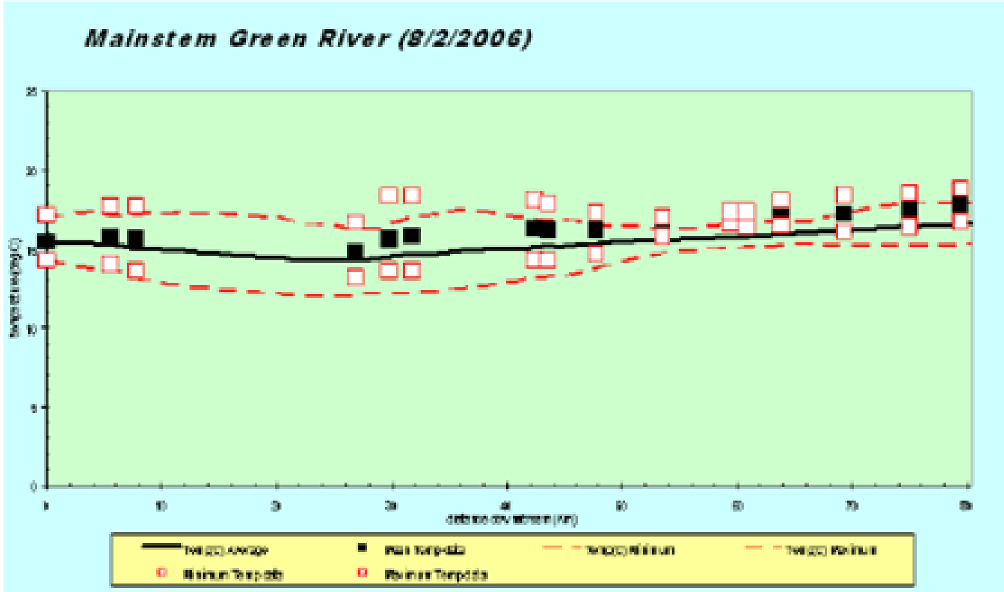

Figure B-9. QUAL2Kw predicted Green River temperature for August 2, 2006, based on calculated solar radiation. Coffin *et al.* (2011), page 58.

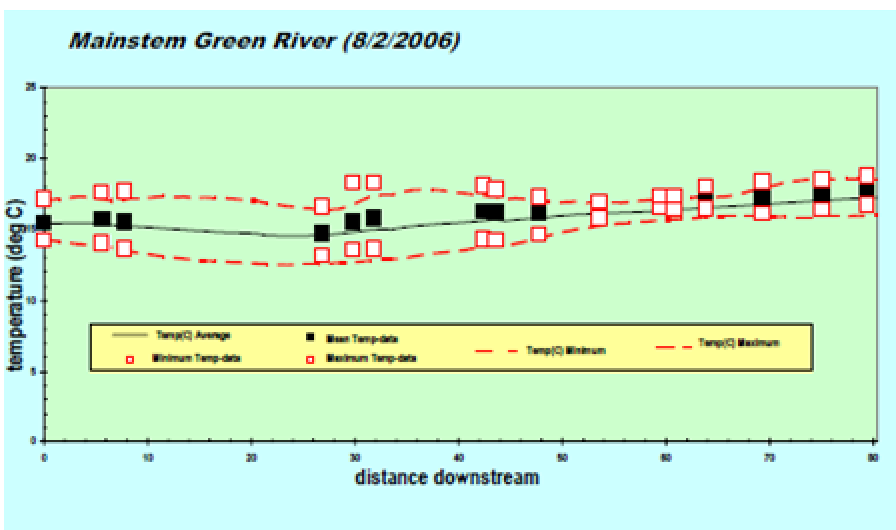

Figure B-10. QUAL2Kw predicted Green River temperature for August 2, 2006, based on observed solar radiation. Coffin *et al.* (2011), page 58.

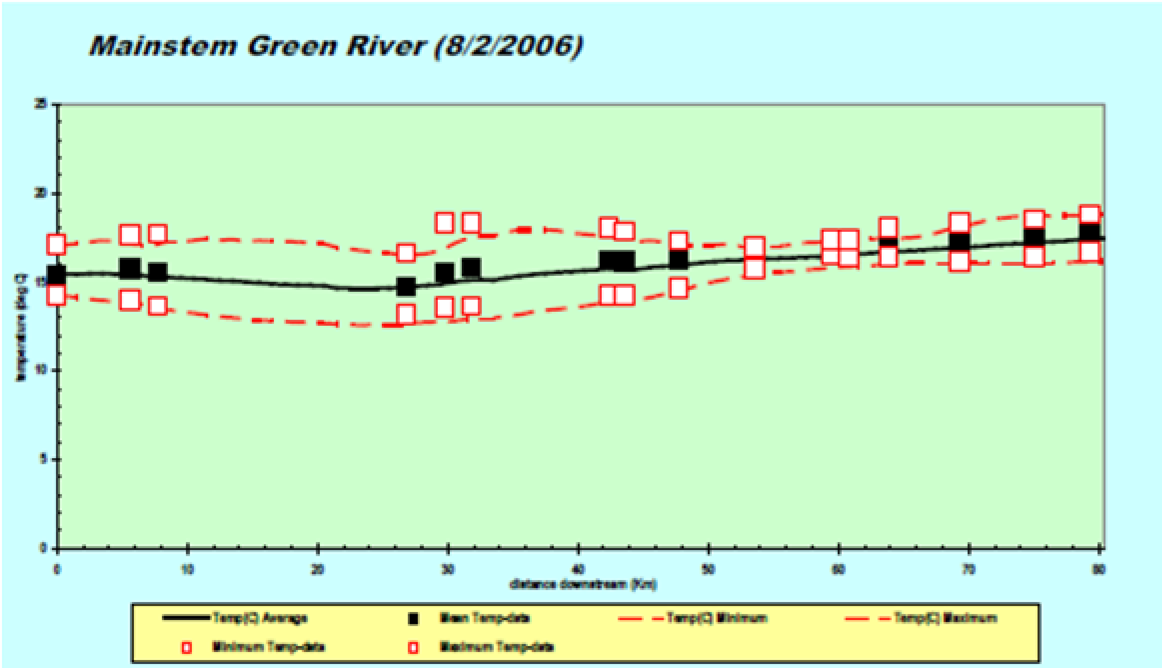

Figure B-11. QUAL2Kw predicted Green River temperature for August 2, 2006, based on observed solar radiation and longwave cloud cover coefficient of 0.22. Coffin *et al.* (2011), page 61.

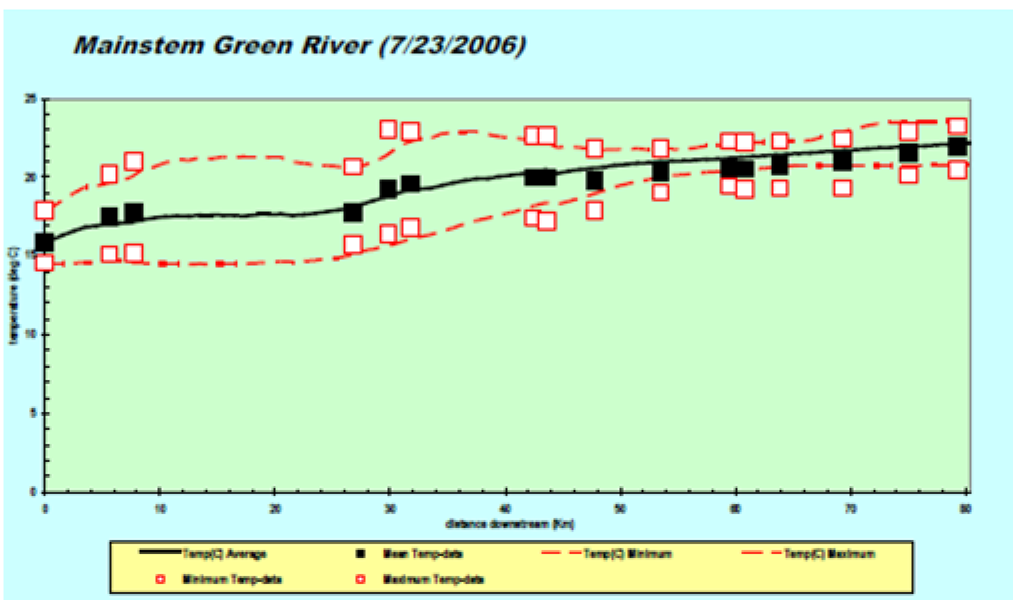

Figure B-12. QUAL2Kw predicted Green River temperature for July 23, 2006, based on observed solar radiation and longwave cloud cover coefficient of 0.22. Coffin *et al.* (2011), page 62.

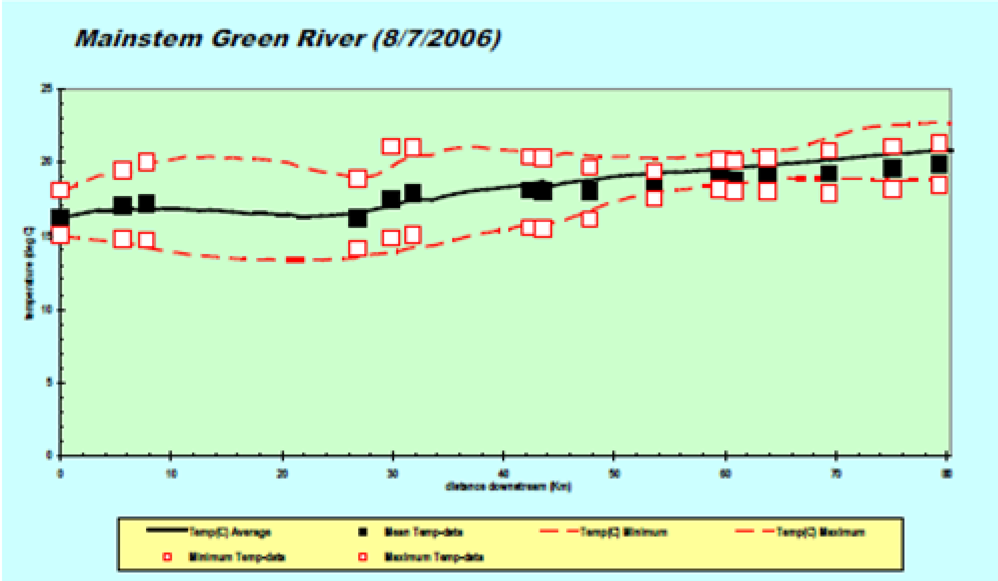

Figure B-13. QUAL2Kw predicted Green River temperature for August 7, 2006, based on observed solar radiation and longwave cloud cover coefficient of 0.22. Coffin *et al.* (2011), page 63.

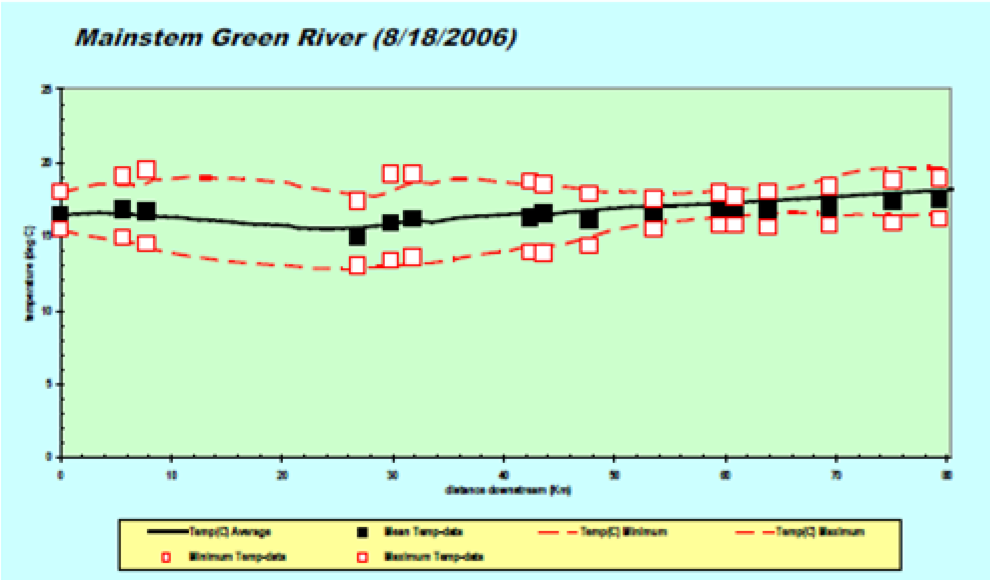

Figure B-14. QUAL2Kw predicted Green River temperature for August 18, 2006, based on observed solar radiation and longwave cloud cover coefficient of 0.22. Coffin *et al.* (2011), page 63.

Hangman Creek

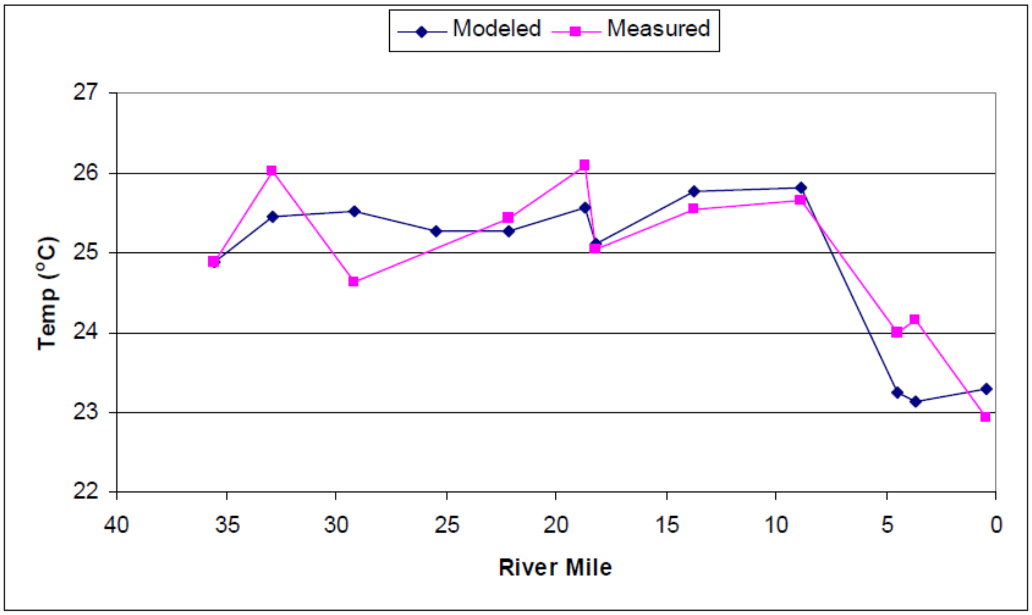

Figure B-15. Weekly average stream temperatures measured and modeled at several sites along Hangman Creek for week 28 in July 2002 (Hardin and Davis, 2003). Joy *et al.* (2009), page 98.

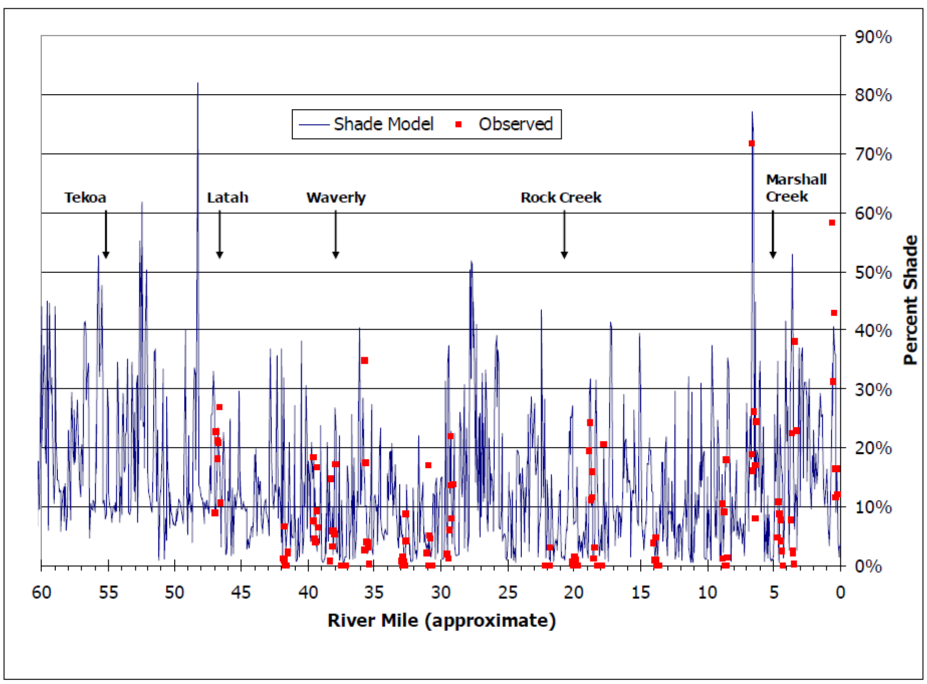

Figure B-16. Current shade along Hangman Creek. Comparing shade model results to canopy closure measurements taken by the SCCD with densitometer transects at selected locations. Joy *et al.* (2009), page 102.

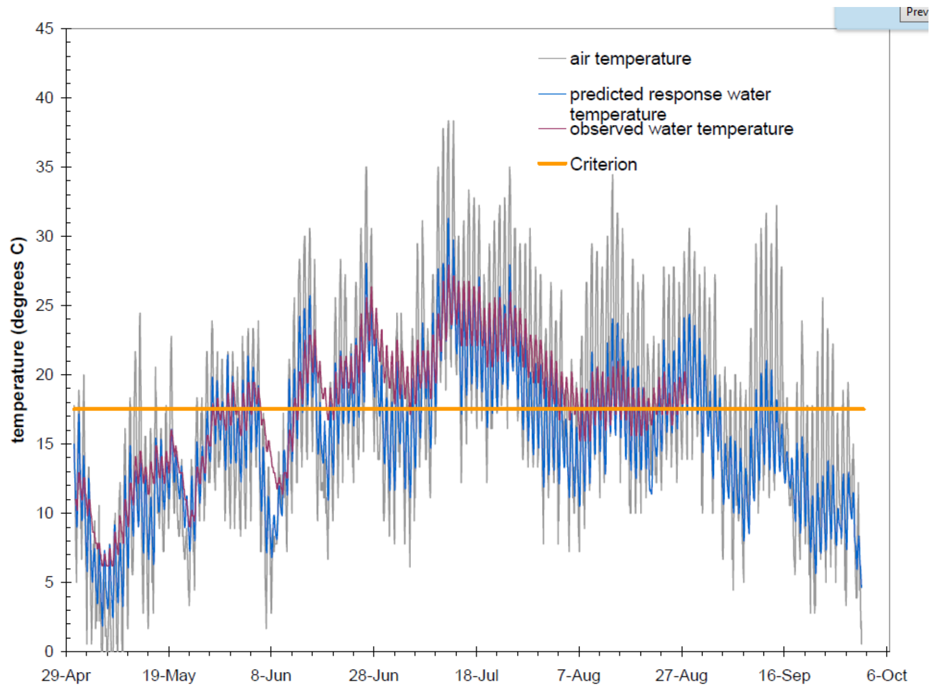

Figure B-17. Hangman Creek water temperature at Tekoa. From the rTemp model compared to observed local water temperatures and air temperatures recorded at the Spokane Airport from April to October 2002. Joy *et al.* (2009), page 103.

Little Klickitat

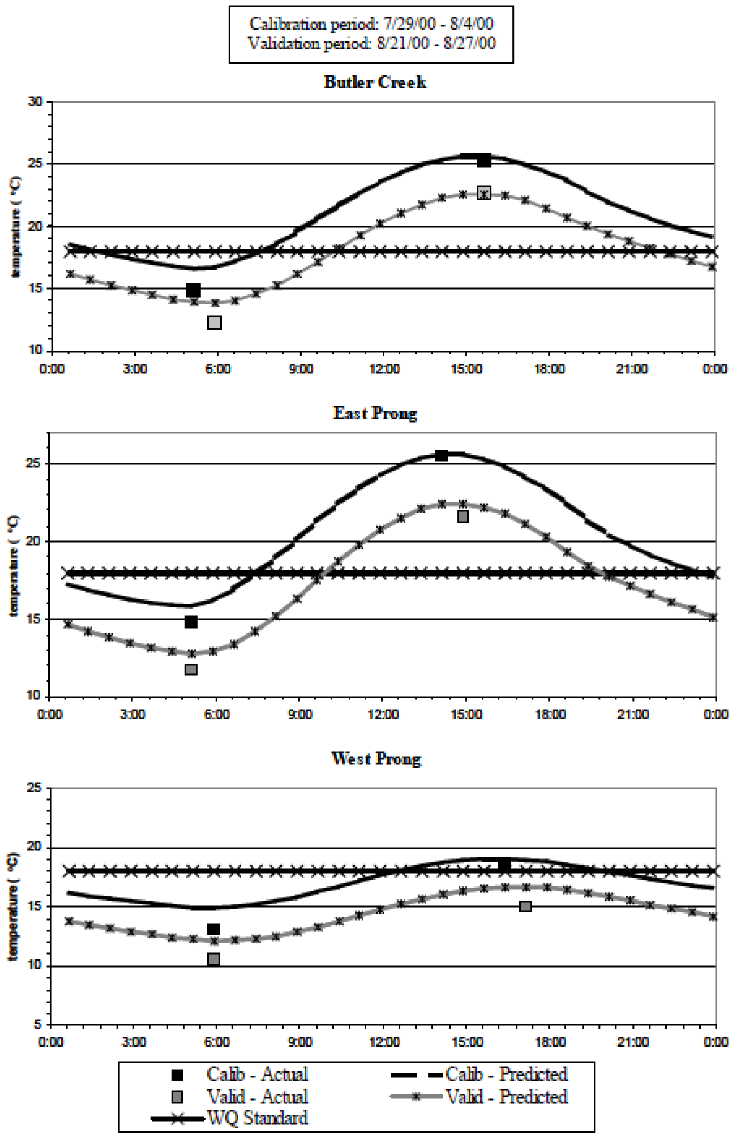

Figure B-18. Comparison of predicted and measured temperatures for the calibration and verification periods for Butler Creek, East Prong, and West Prong. Brock and Stohr (2002), page 48.

Little Spokane

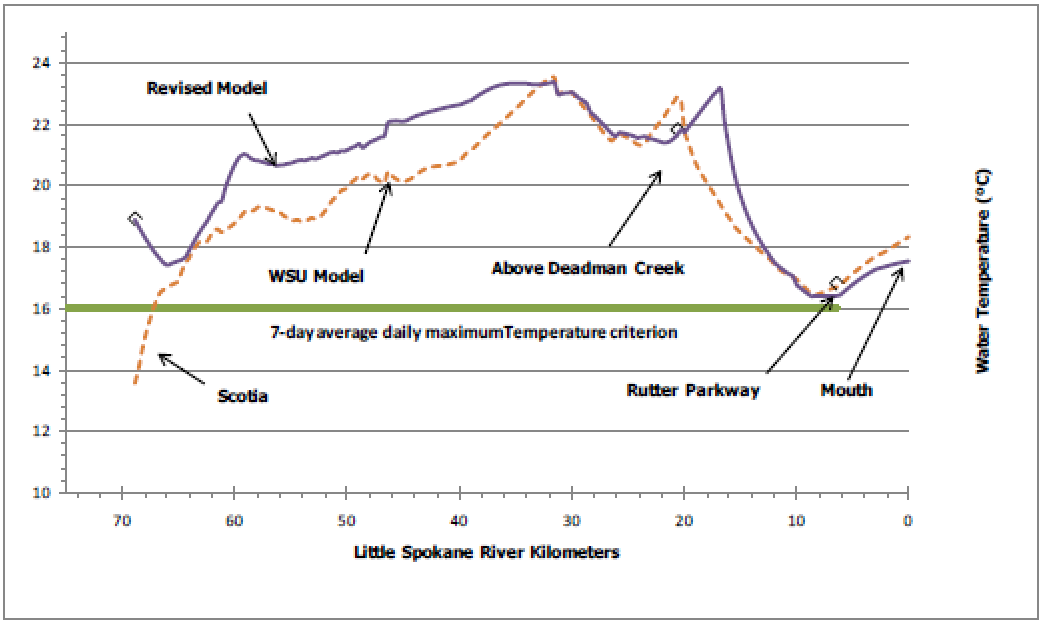

Figure B-19. Maximum water temperature estimated for August 9, 2005, in the Little Spokane River by two QUAL2K models calibrated by WSU/WWRC (Barber *et al.*, 2007) and revised by Ecology. Joy and Jones (2012), page 81.

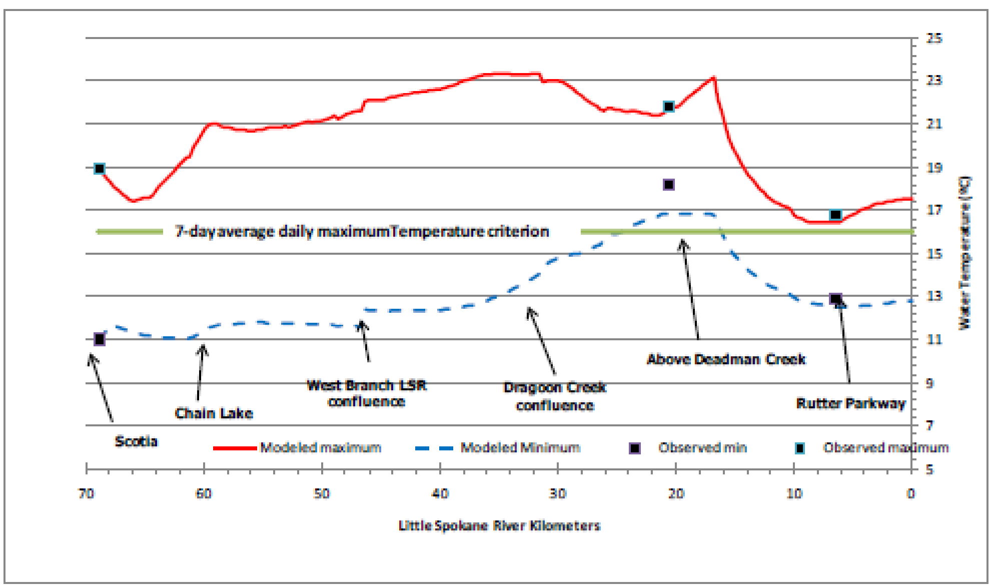

Figure B-20. Calibrated QUAL2K model results of maximum and minimum daily temperatures along the Little Spokane River for August 9, 2005. Joy and Jones (2012), page 82.

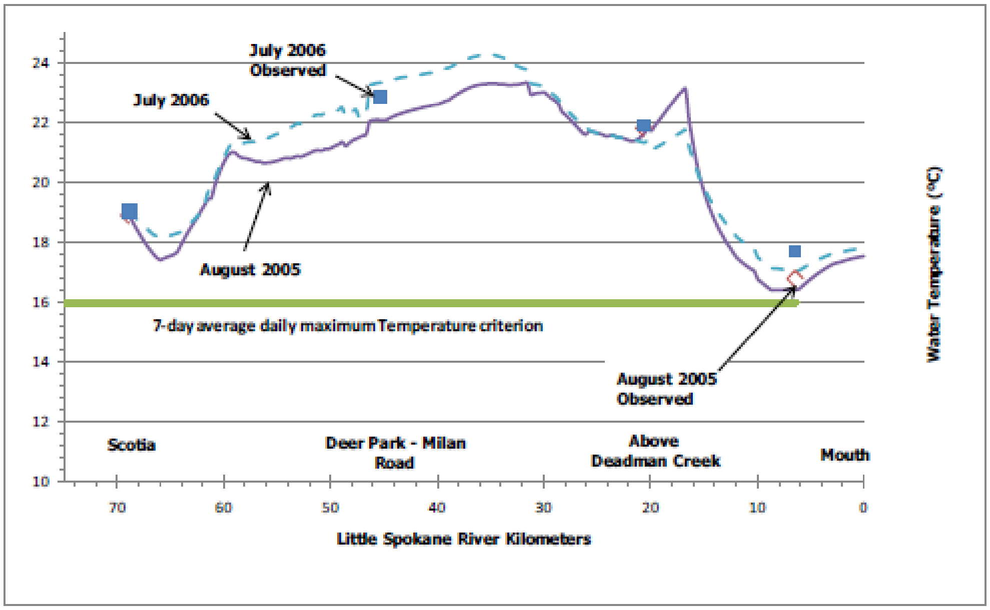

Figure B-21. Results of QUAL2K model calibrated for August 2005 (solid line) and run under July 2006 (dashed line) conditions. Joy and Jones (2012), page 82.

Newaukum Creek

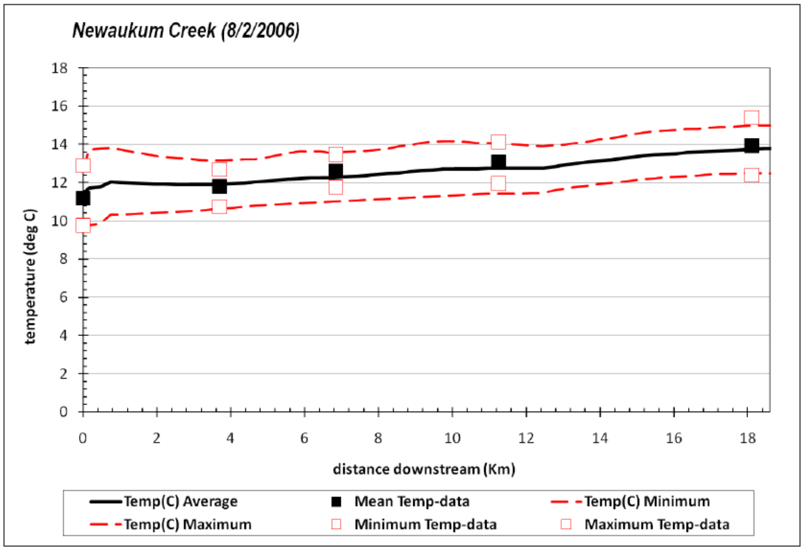

Figure B-22. Longitudinal profile for water temperature on August 2, 2006. Average stream temperatures gradually increased moving downstream from 11 to 14 degrees C. Lee *et al.* (2011), page 47.

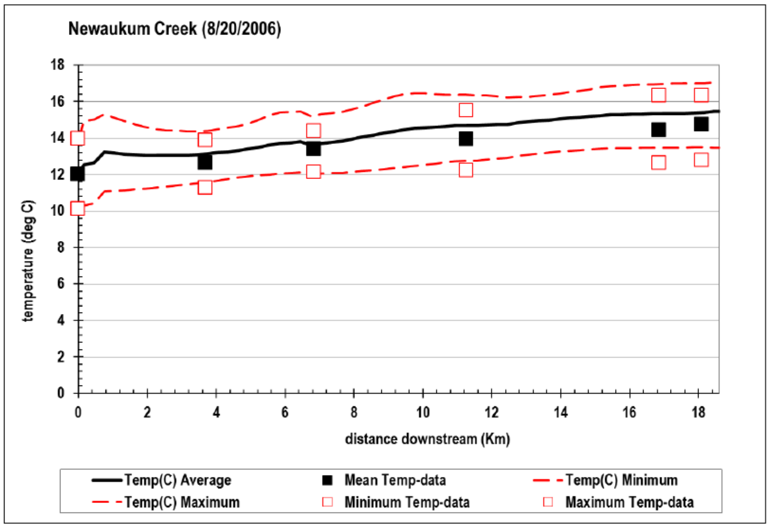

Figure B-23. Water temperature longitudinal profile validation run for August 20, 2006. August 20 was the hottest day of the season for 2006. RMSE = 0.58 degrees Celsius (includes all diel data for all reaches with observed data). Lee *et al.* (2011), page 49.

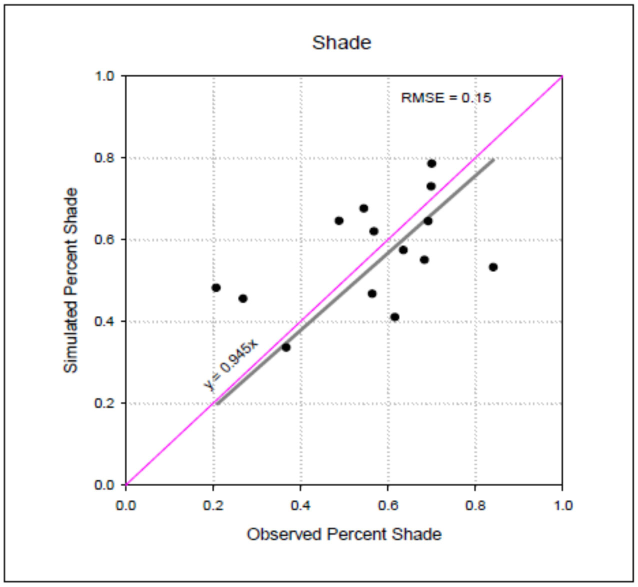

Figure B-24. Scatterplot of simulated versus observed shade. Red line is a reference line representing a 1:1 relationship (i.e. perfect model). Black line is a representation of the slope coefficient for the linear regression between observed and simulated (0.94), with an RMSE = 0.15. Lee *et al.* (2011), page C-123.

Pend Oreille

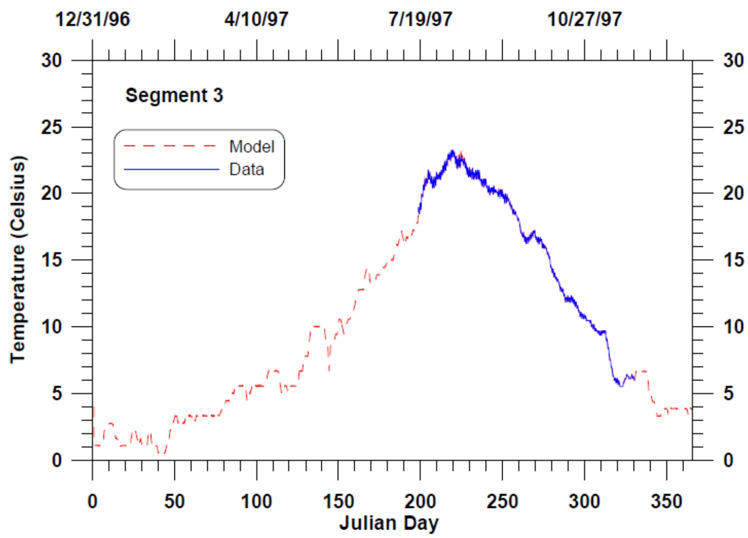

Figure B-25. Model prediction and 1997 continuous temperature data measured at segment 3 (site POALB). Annear *et al.* (2006), page 72. *Many more figures like this are presented in the original report.*

South Prairie Creek

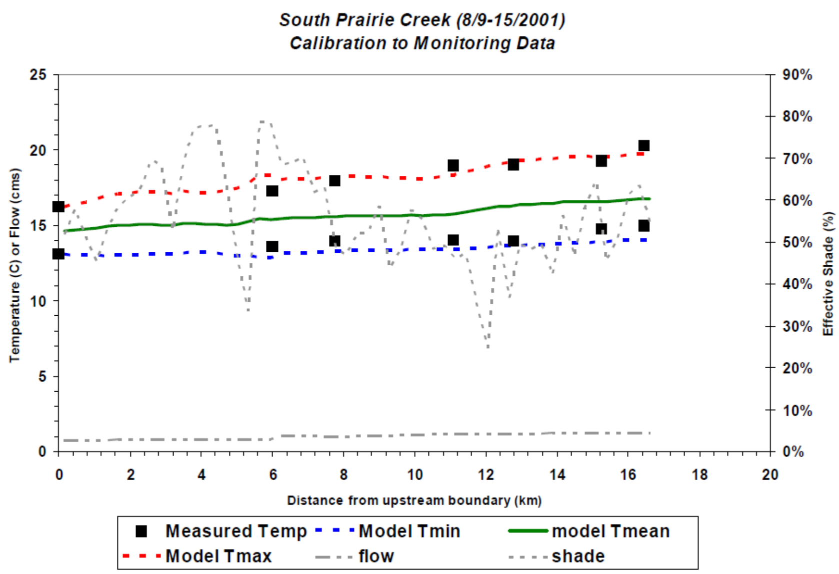

Figure B-26. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the calibration period August 9 through 15, 2001. (RMSE = 0.54°C). Roberts (2003), page 40.

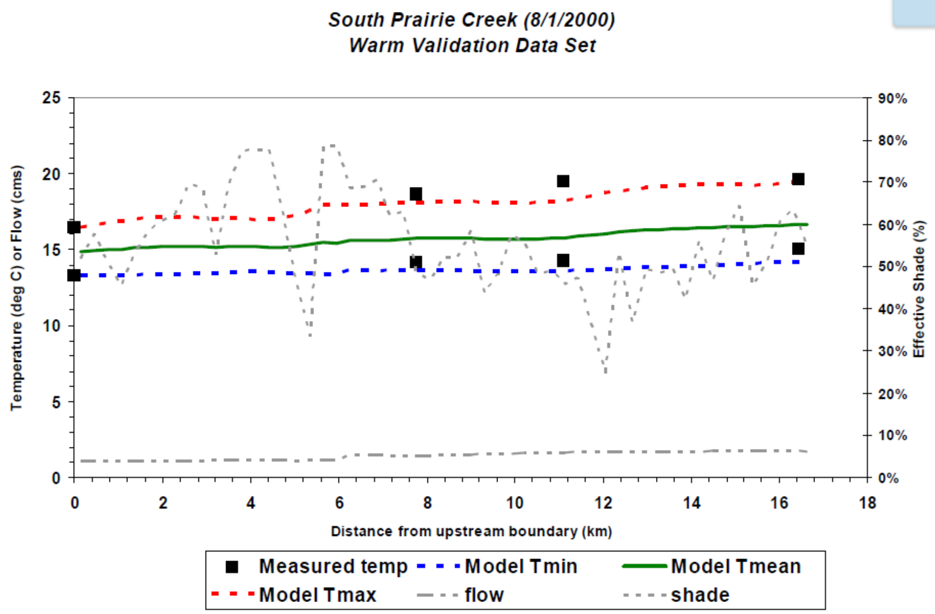

Figure B-27. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the warm validation period of July 29 through August 4, 2000. (RMSE = 0.64°C). Roberts (2003), page 41.

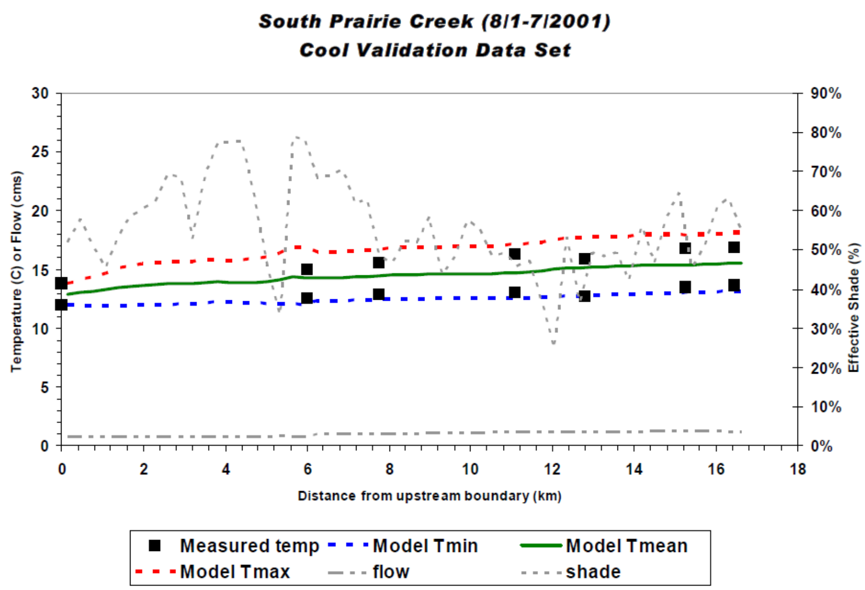

Figure B-28. Comparison of predicted and observed minimum and maximum temperatures for South Prairie Creek for the cool validation period of August 1 through August 7, 2001. (RMSE = 0.91°C). Roberts (2003), page 42.

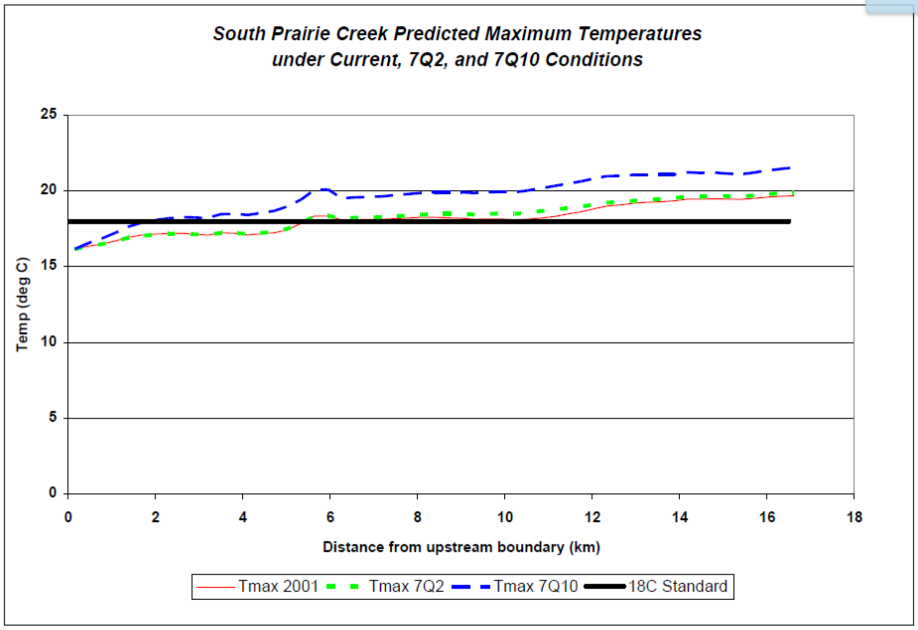

Figure B-29. Predicted temperatures in South Prairie Creek under current, typical (7Q2), and extreme (7Q10). Roberts (2003), page 43.

Spokane River

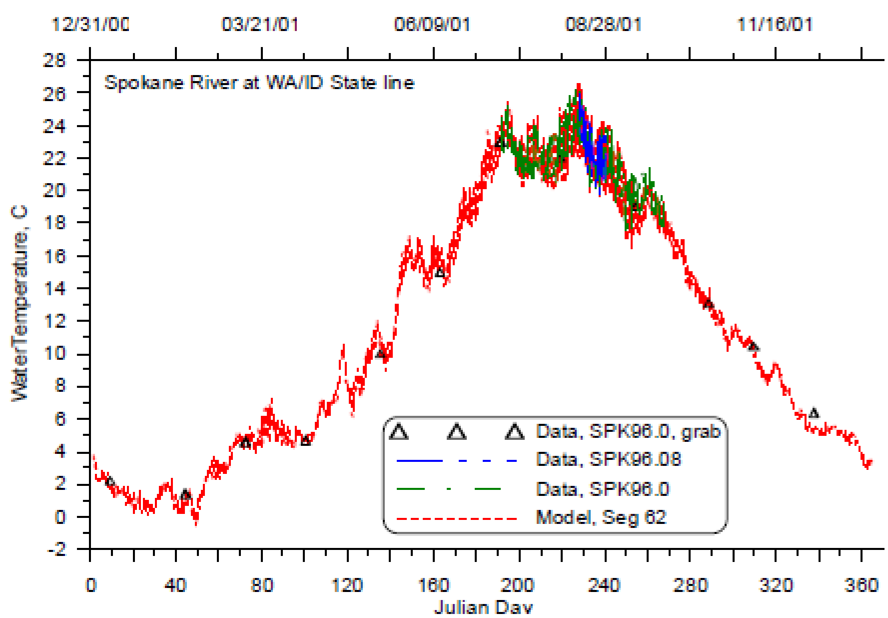

Figure B-30. Model-data water temperature comparison at State Line, 2001. Annear *et al.* (2005), page 106.

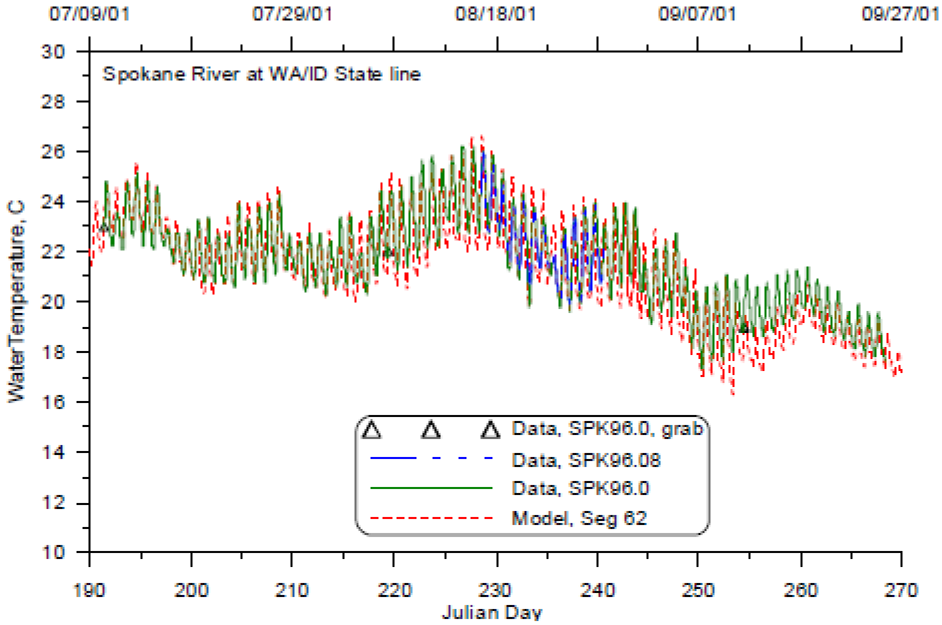

Figure B-31. Model-data water temperature comparison at State Line from July 9 to September 27, 2001. Annear *et al.* (2005), page 106.

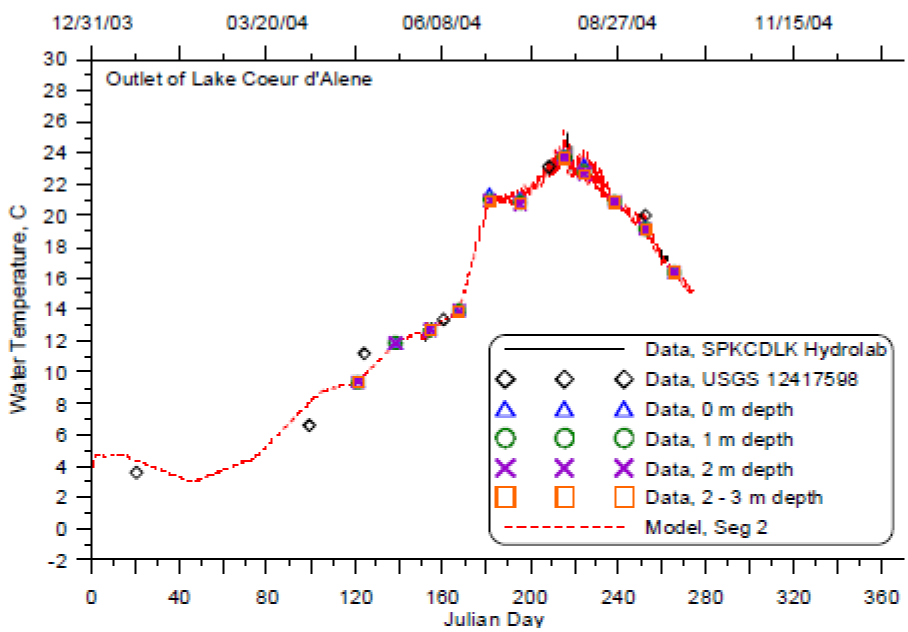

Figure B-32. Model-data water temperature comparison at outlet to Lake Coeur d'Alene, 2004. Annear *et al.* (2005), page 107.

Upper Naches River

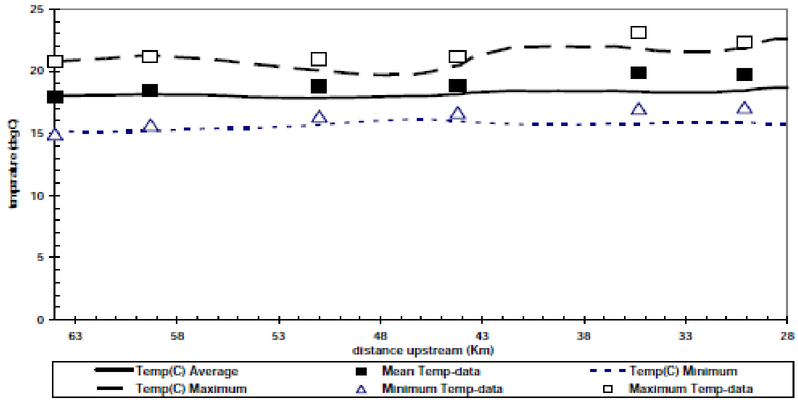

Figure B-33. Modeled and observed instream temperatures for the calibration period (July 28-August 3, 2003) for the upper Naches River. Brock (2008), page 90.

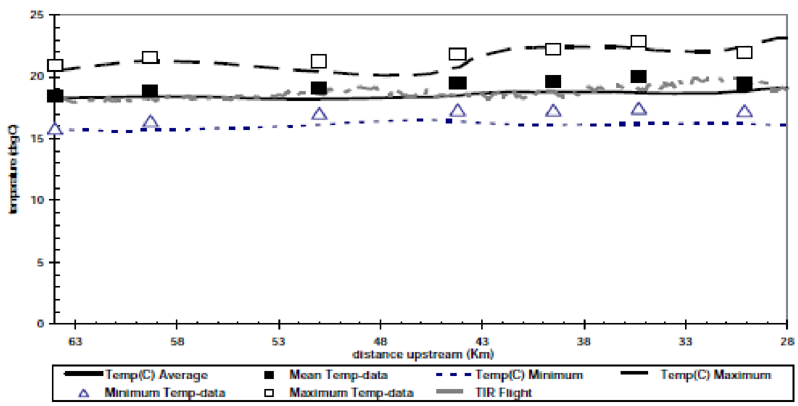

Figure B-34. Modeled and observed instream temperatures for the verification period (August 11-17, 2004) for the upper Naches River. Brock (2008), page 90.

Whatcom Creek

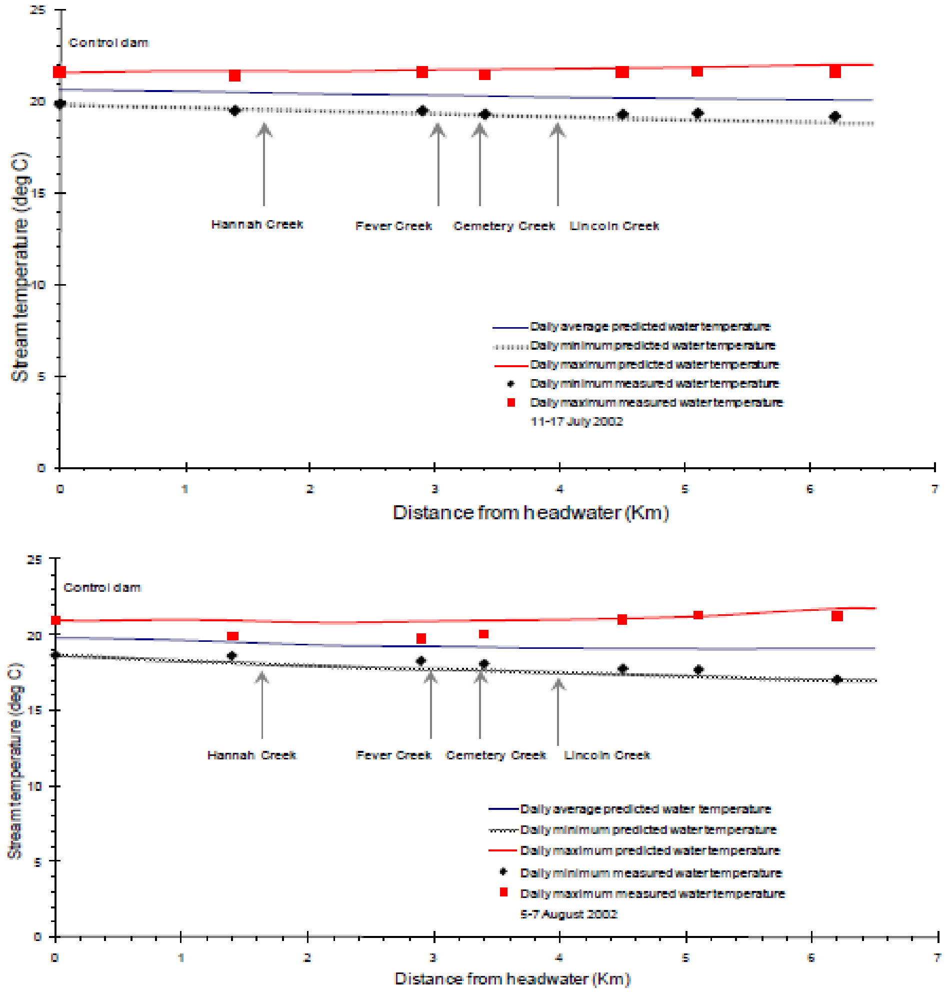

Figure B-35. Predicted and observed water temperatures in Whatcom Creek at model calibration (July 11-17, 2002) and model confirmation (August 5-7, 2002). Hood *et al.* (2011), page 54.

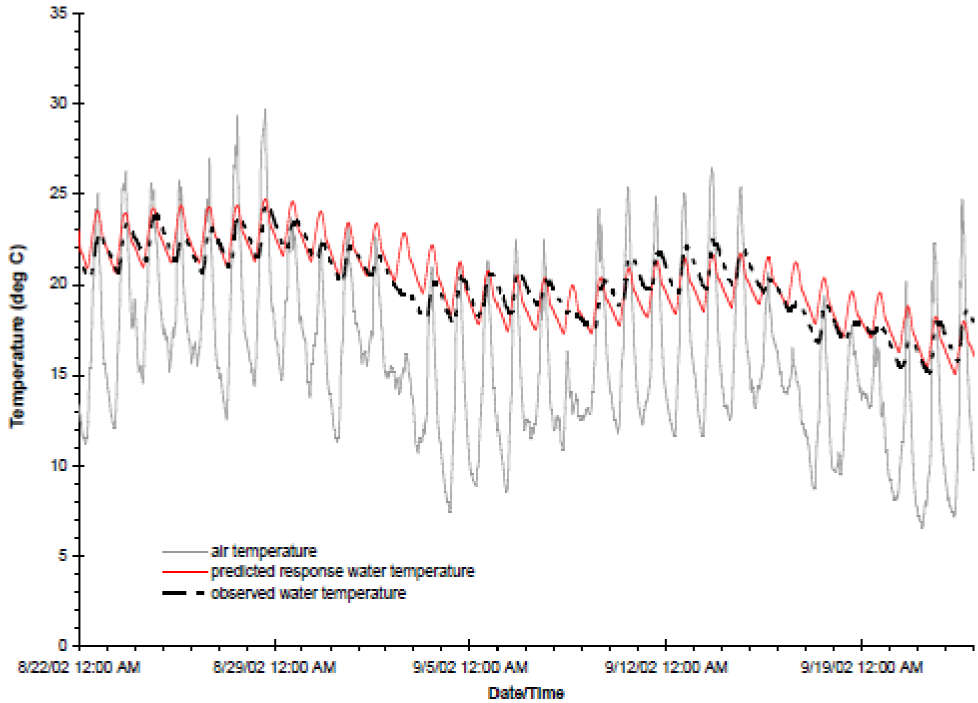

Figure B-36. Predicted and observed water temperatures in Whatcom Creek from August 22 to September 22, 2002, at the Control Dam station. Hood *et al.* (2011), page 55.

Willapa River

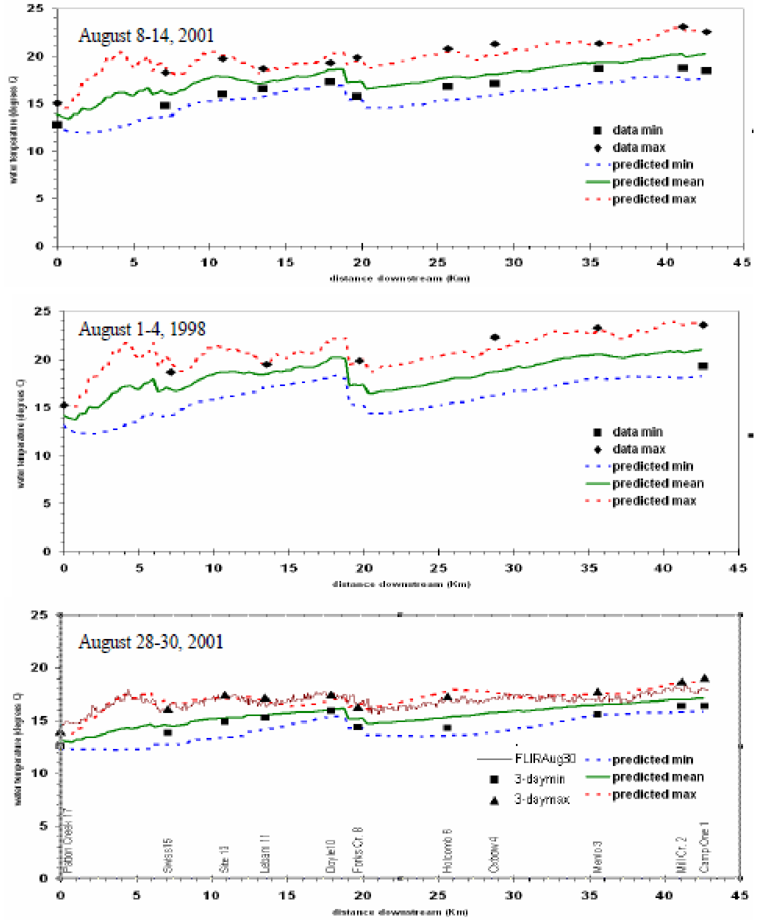

Figure B-37. Predicted and observed water temperatures in the Willapa River for calibration (August 8-14 and 28-30, 2001) and verification (August 1-4, 1998) periods. Stohr (2004), page 56.

Wind River

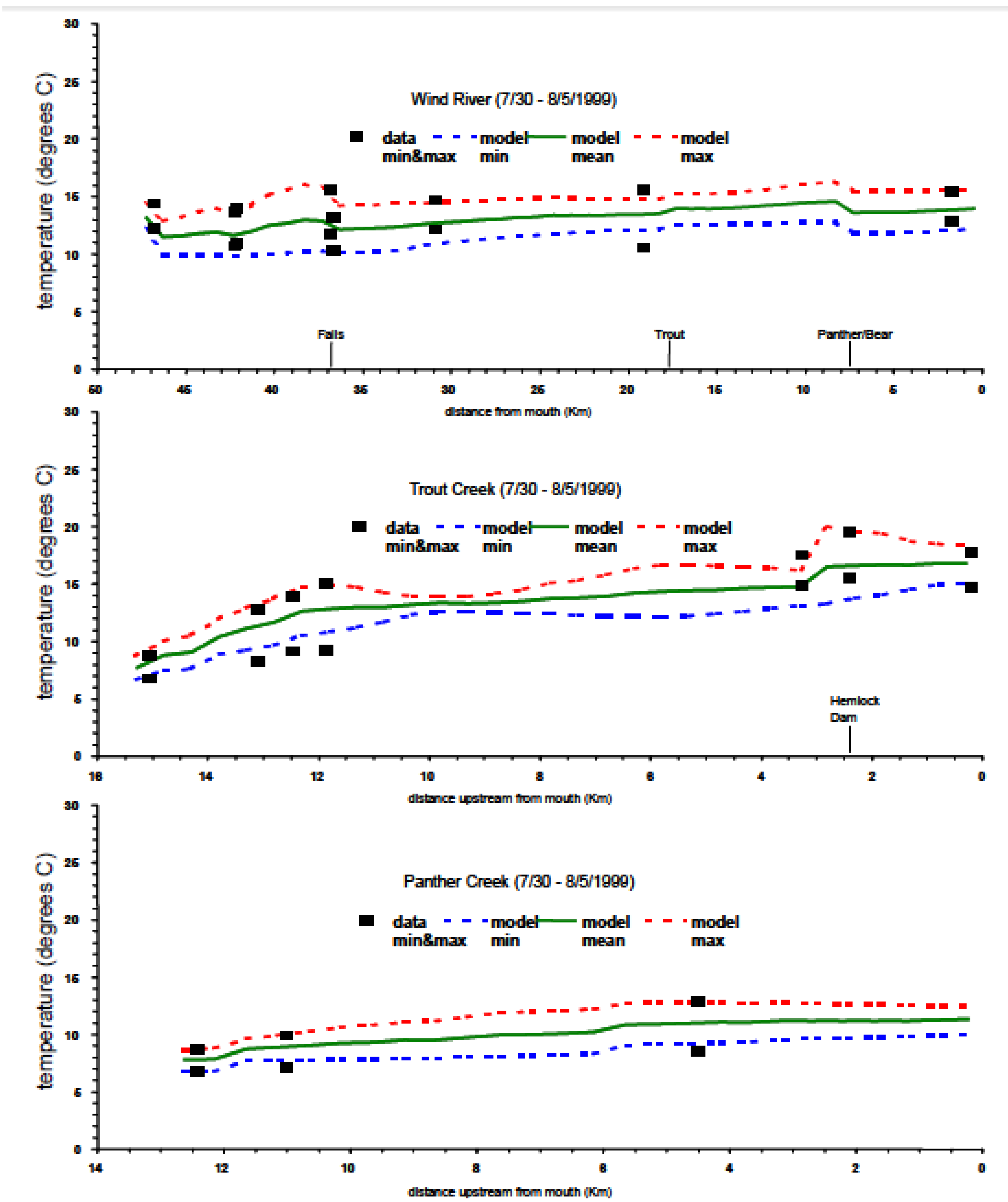

Figure B-38. Comparison of predicted and observed minimum and maximum temperatures for the Wind River, Trout Creek, and Panther Creek for the period of July 30 through August 5, 1999. Pelletier, 2002, page 37.

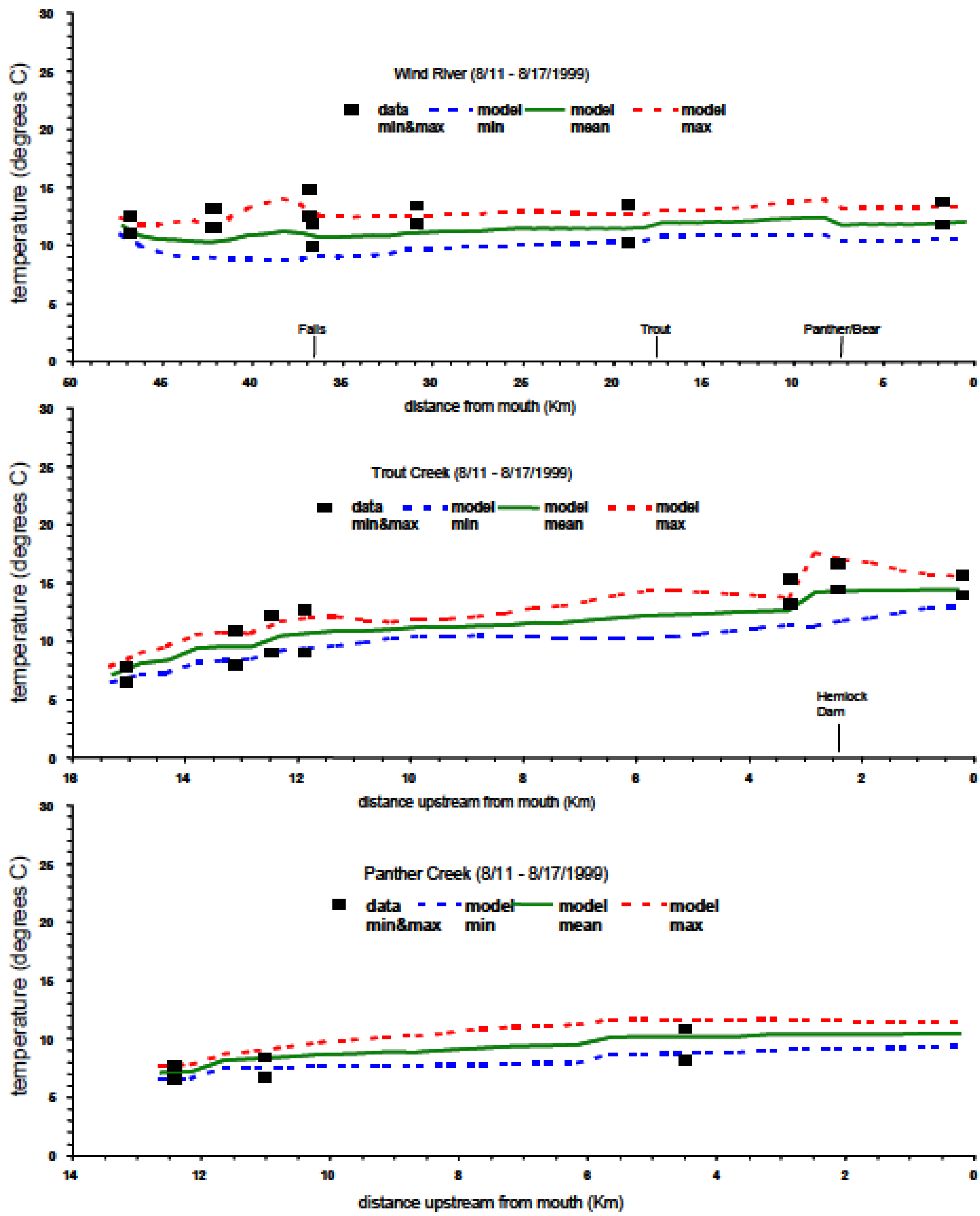

Figure B-39. Comparison of predicted and observed minimum and maximum temperatures for the Wind River, Trout Creek, and Panther Creek for the period of August 11 through August 17, 1999. Pelletier (2002), page 38.

Oxygen

Bear Creek

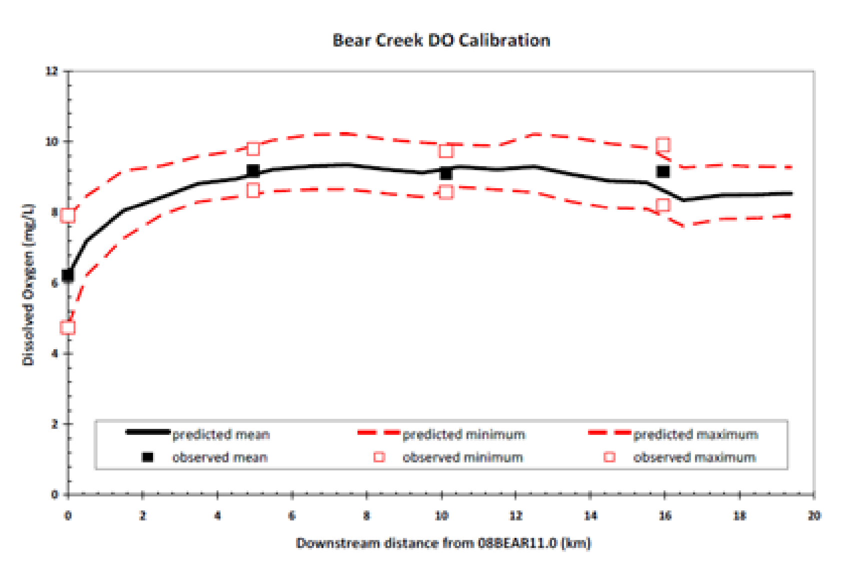

Figure B-40. Comparison of predicted and observed DO for Bear Creek on July 18-19, 2006. Mohamedali and Lee (2008), page 74.

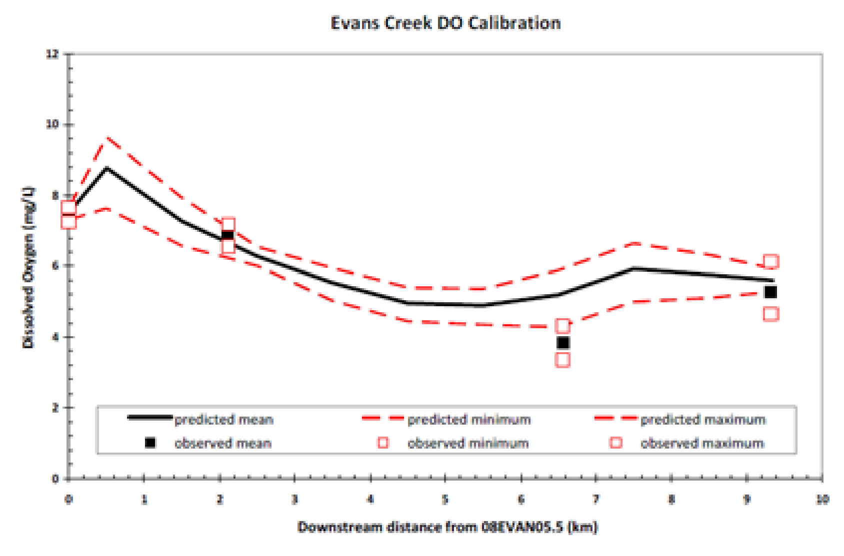

Figure B-41. Comparison of predicted and observed DO for Evans Creek on July 18-19, 2006. Mohamedali and Lee (2008), page 75.

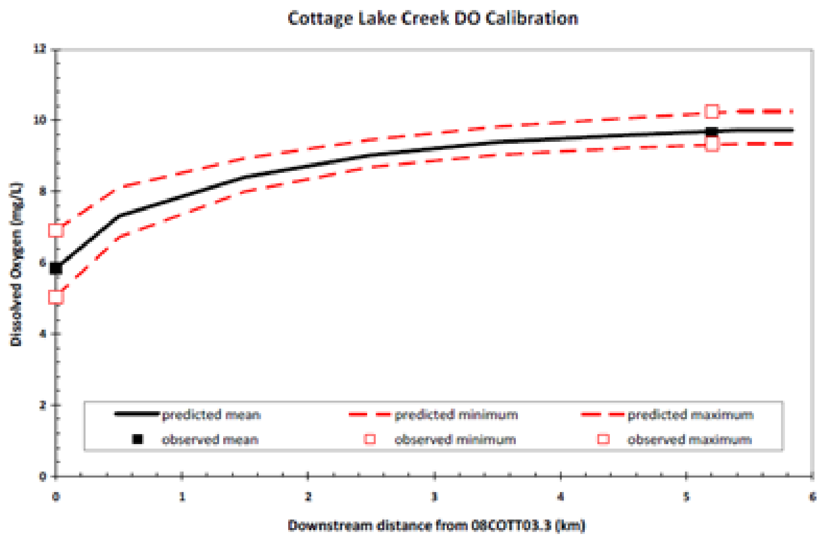

Figure B-42. Comparison of predicted and observed DO for Cottage Lake Creek on July 18-19, 2006. Mohamedali and Lee (2008), page 75.

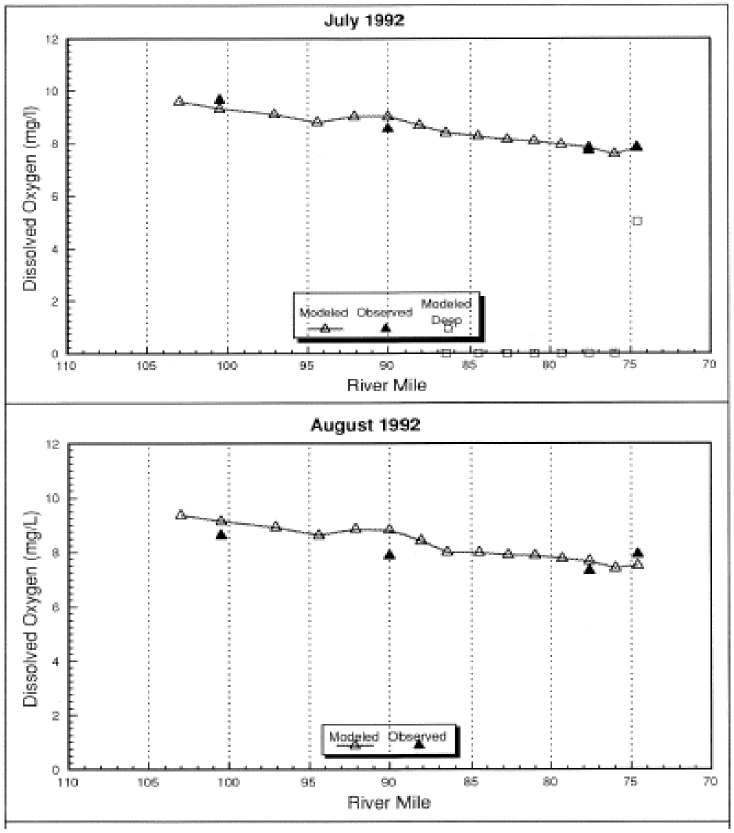

Figure B-43. Dissolved Oxygen Calibration Results - Upper Study Area. Pickett, 1994, page 57.

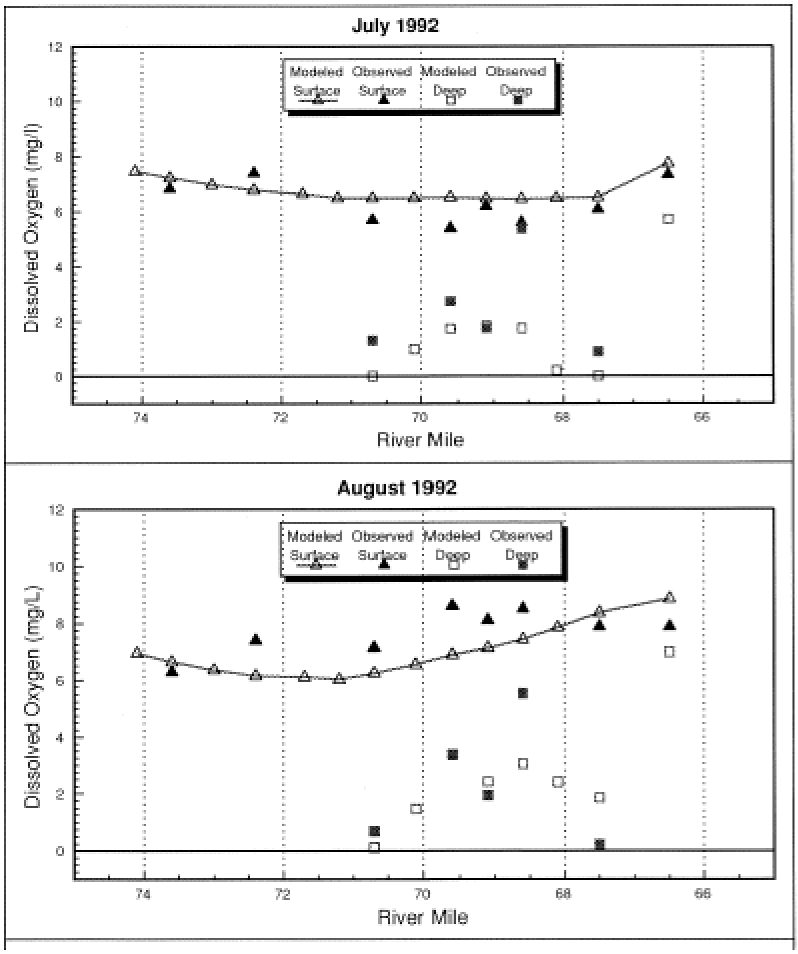

Figure B-44. Dissolved Oxygen Calibration Results – Centralia Reach. Pickett, 1994, page 58.

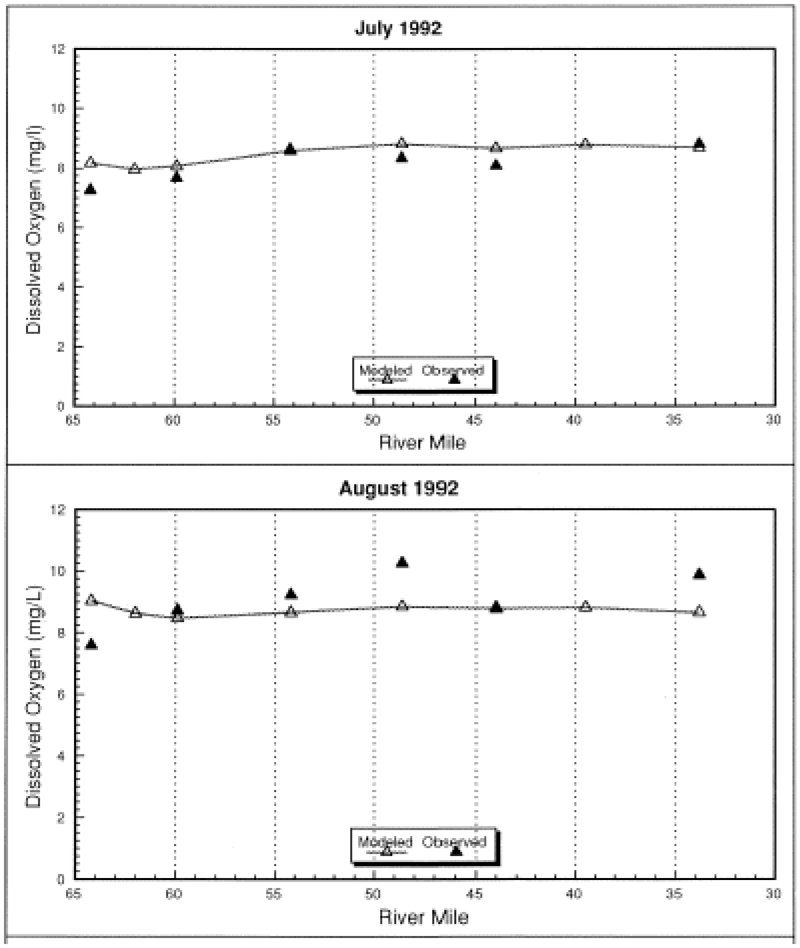

Figure B-45. Dissolved Oxygen Calibration Results – Lower Study Area. Pickett, 1994, page 58.

Spokane River

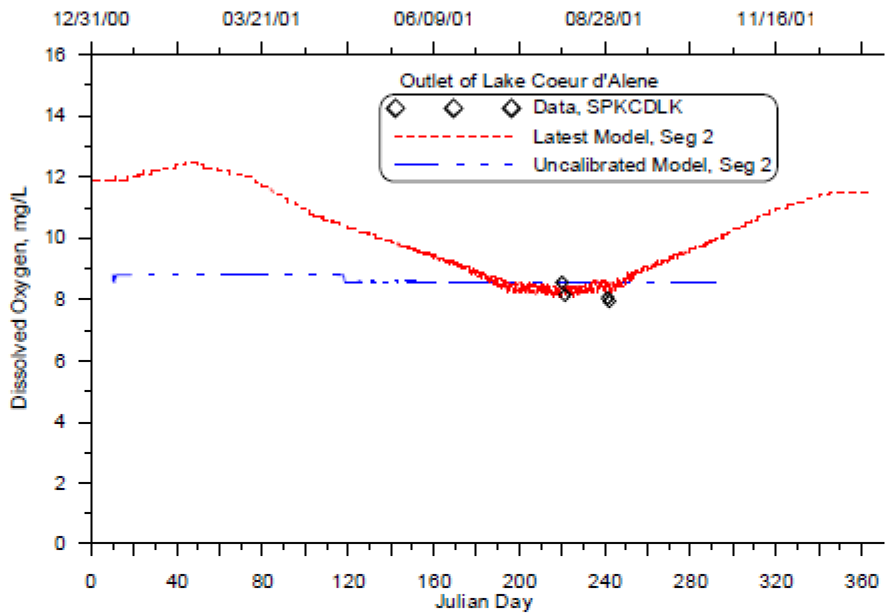

Figure B-46. Model-data dissolved oxygen concentration comparison, at the Lake Coeur d'Alene outlet, 2001. Annear *et al.* (2005), page 126.

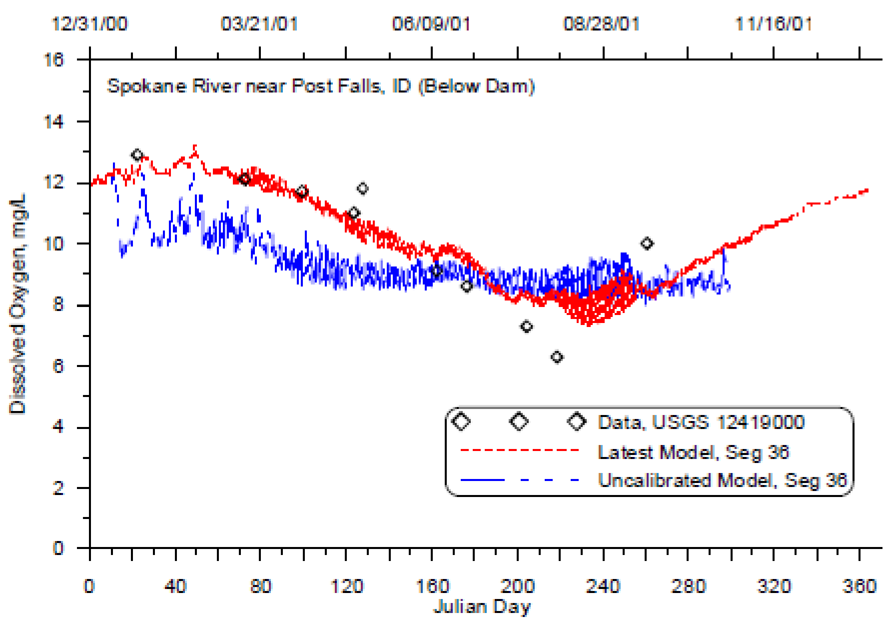

Figure B-47. Model-data of dissolved oxygen concentration comparison, 0.8 mi downstream of the Post Falls Dam, 2001. Annear *et al.* (2005), page 126.

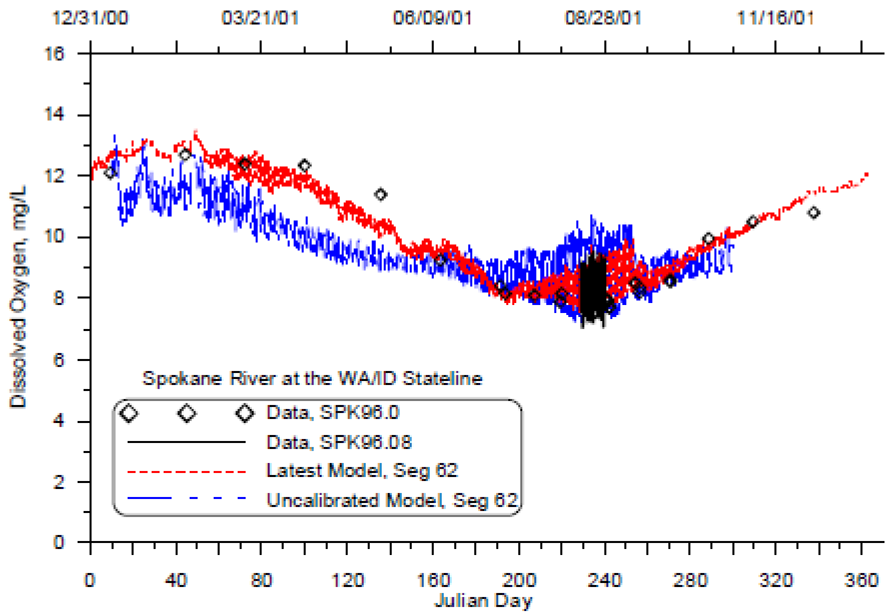

Figure B-48. Model-data dissolved oxygen comparison at the WA/ID State Line, 2001. Annear *et al.* (2005), page 127.

Stillaguamish River

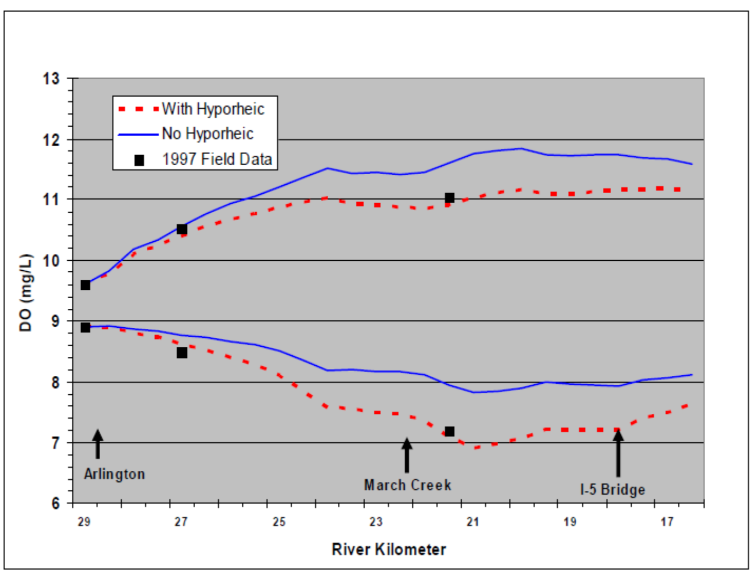

Figure B-49. QUAL2Kw simulations of maximum and minimum dissolved oxygen (DO) profiles in the mainstem Stillaguamish River compared to diel DO data collected by Earth Tech in August 2007. The effect of simulating hyporheic respiration in QUAL2Kw is demonstrated in the dashed lines. Pelletier and Bilhimer, 2004, page 76.

Walla Walla River – Mill and Yellowhawk Creeks

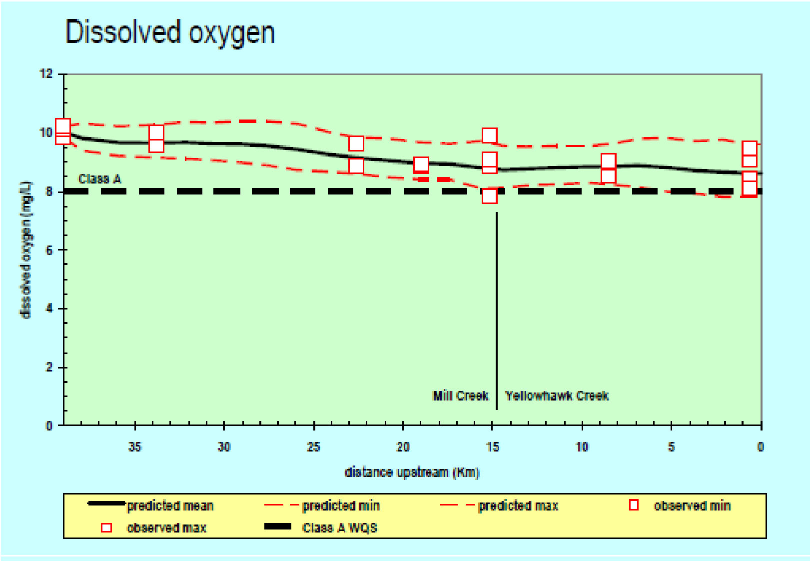

Figure B-50. Predicted and observed dissolved oxygen on August 31 through September 1, 2004, in Mill Creek above the diversion dam and in Yellowhawk Creek. Joy *et al.* (2007), page 94.

pH

Walla Walla River – Mill and Yellowhawk Creeks

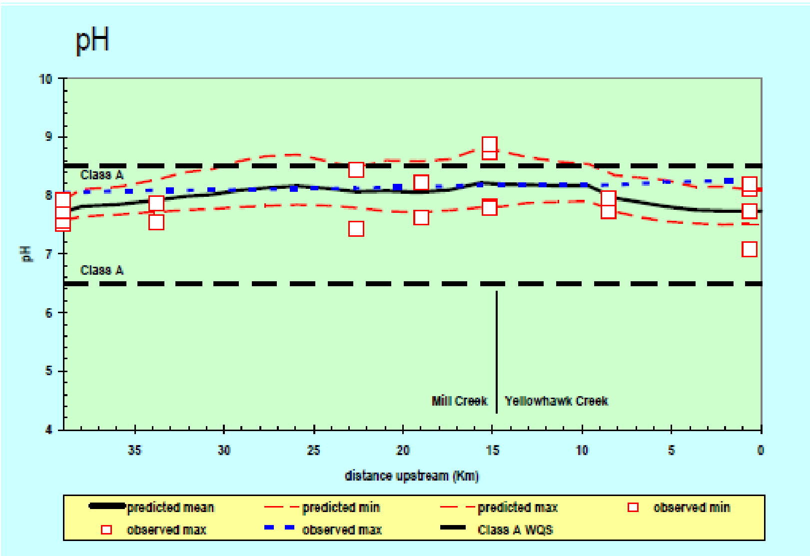

Figure B-51. Predicted and observed pH on August 31 through September 1, 2004, in Mill Creek above the diversion dam and in Yellowhawk Creek. Joy *et al.* (2007), page 94.

Dissolved Gas

Lower Columbia River – McNary

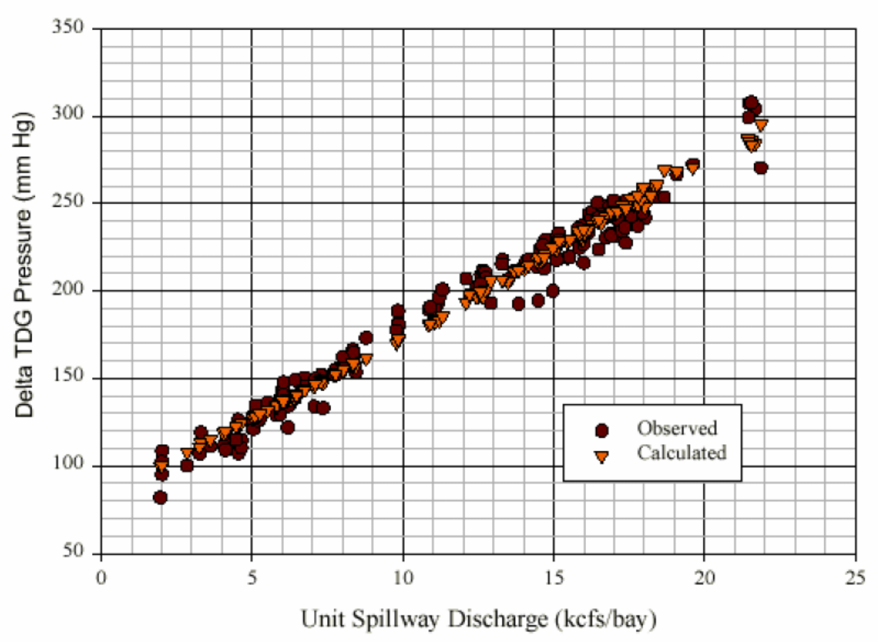

Figure B-52. Unit Spillway Discharge versus TDG Pressure Above Barometric Pressure at McNary Dam, 1997. Pickett and Harding (2002), page 38.

Lower Columbia River – John Day 1998

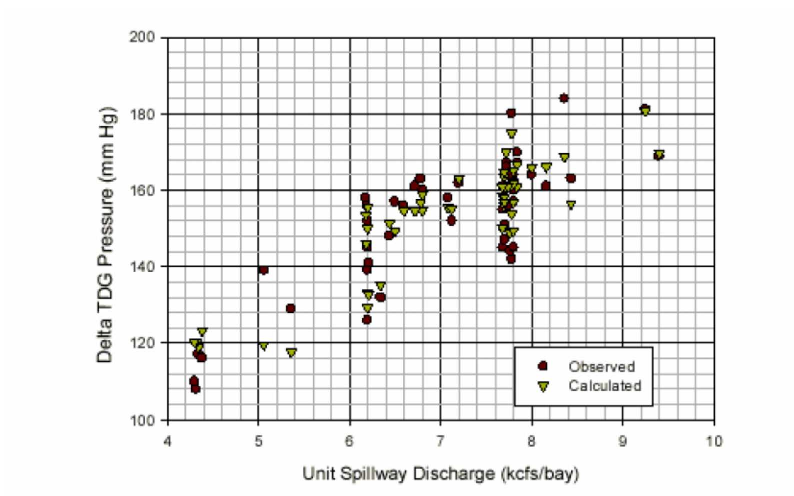

Figure B-53. Unit Spillway Discharge versus TDG Pressure Above Barometric Pressure at John Day Dam, 1998. Pickett and Harding (2002), page 44.

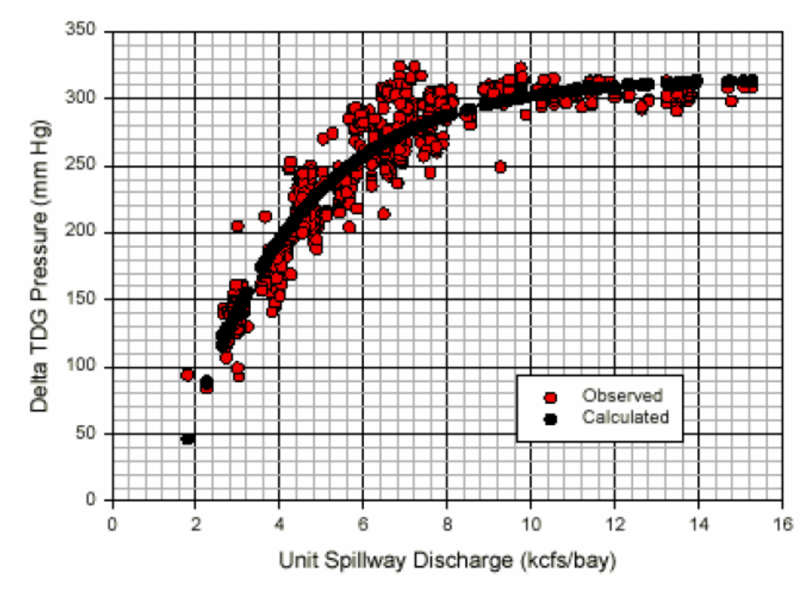

Figure B-54. Observed and Calculated Delta TDG pressure at John Day Dam (Standard Spillway – no Deflector). Pickett and Harding (2002), page 47.

Lower Columbia River – Dalles

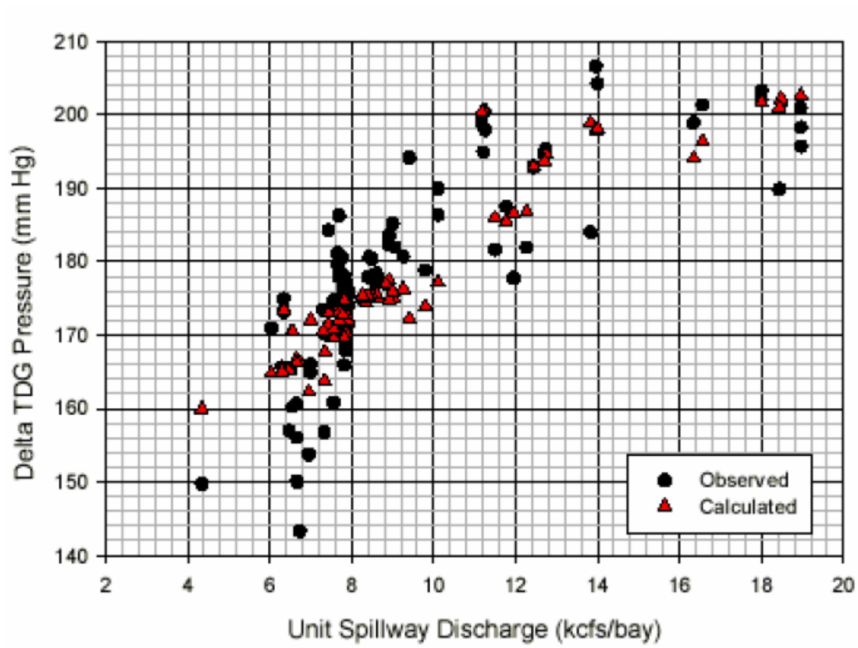

Figure B-55. Unit Spillway Discharge versus TDG Pressure Above Barometric Pressure at The Dalles Dam, 1997. Pickett and Harding (2002), page 50.

Lower Columbia River – Bonneville

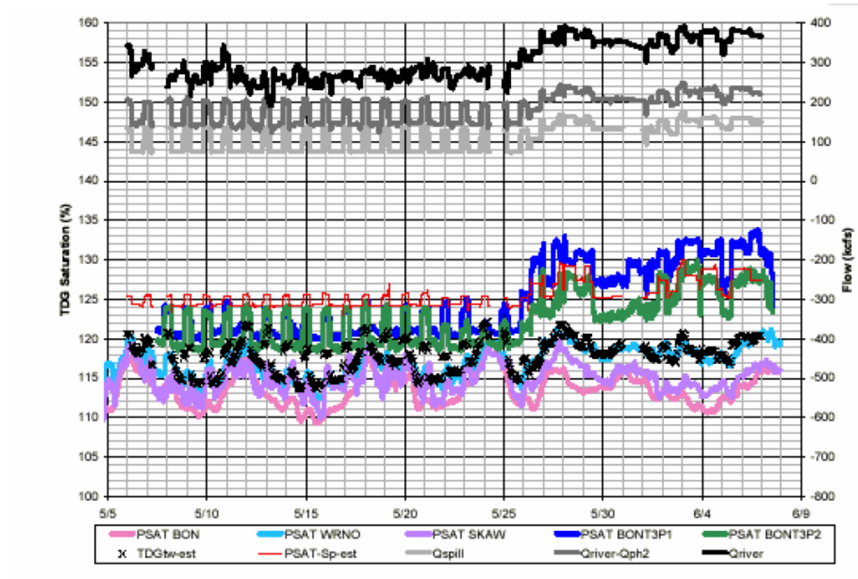

Figure B-56. Observed and Estimated TDG Saturation Below Bonneville Spillway During Spill Season, May 5 through June 8, 1999. Pickett and Harding (2002), page 57.

Bacteria

Chehalis River Basin – Grays Harbor

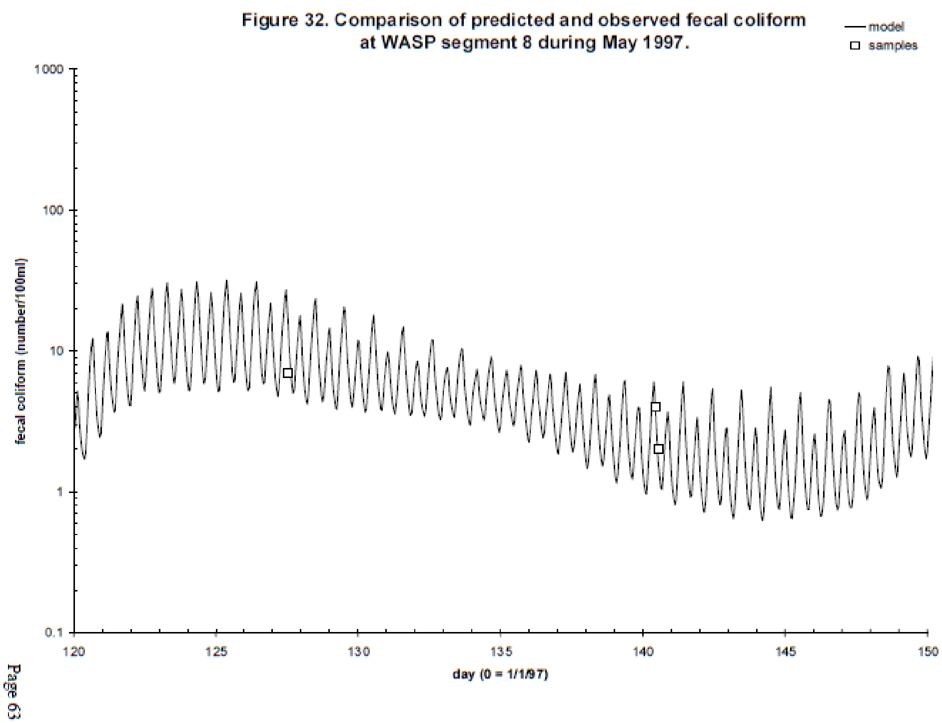

Figure B-57. Comparison of predicted and observed fecal coliform at WASP segment 8 during May 1997 on July 18-19, 2006. Pelletier and Seiders (2000), page 63.

Hangman Creek

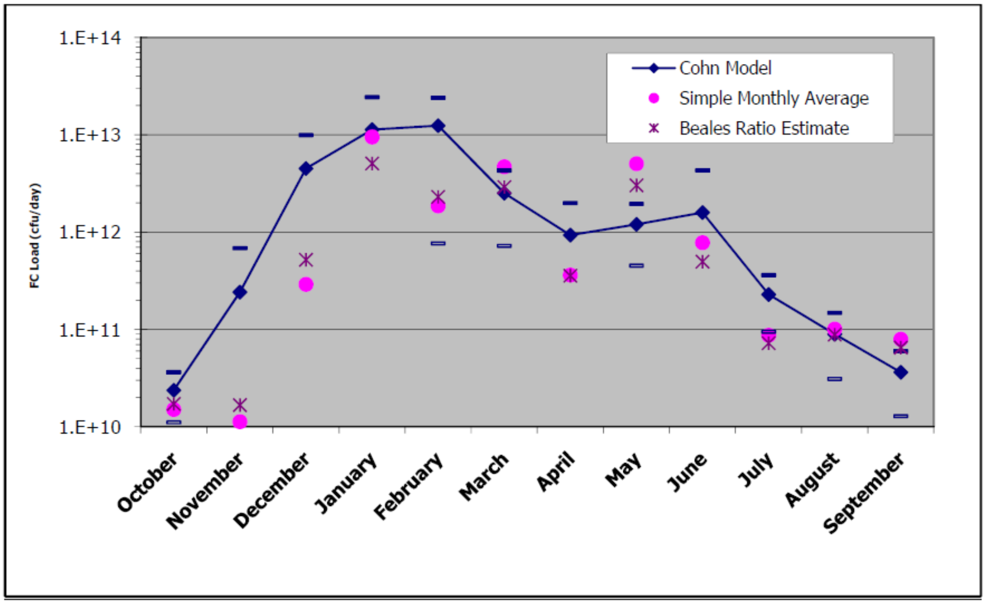

Figure B-58. A comparison of monthly fecal coliform average loads. At the mouth of Hangman Creek from October 1989 to September 2005 (Ecology Site 56A070). Joy *et al.* (2009), page 89.

Willapa River

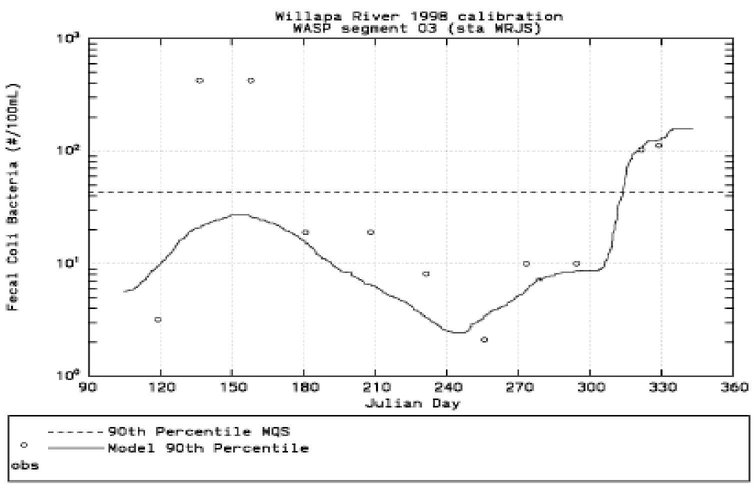

Figure B-59. Willapa River FC bacteria calibration, station WRJS (90^{th} percentile). Stohr (2004), Appendix A. *See additional figures in the original report.*

Toxics

Walla Walla River

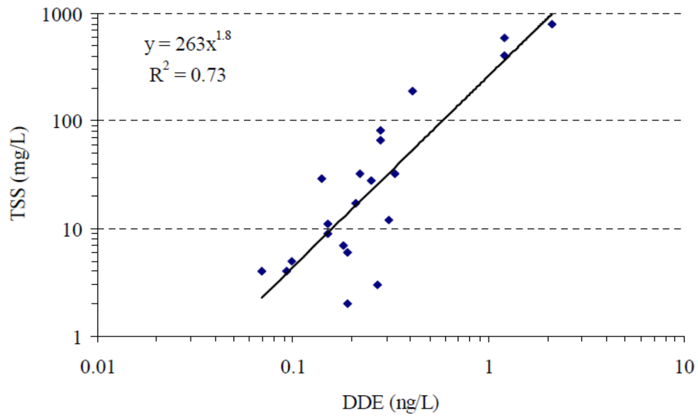

Figure B-60. Relationship between TSS and 4.4'-DDE in the Mainstem Walla Walla River. Johnson *et al.* (2004), page 84.

Lower Yakima River

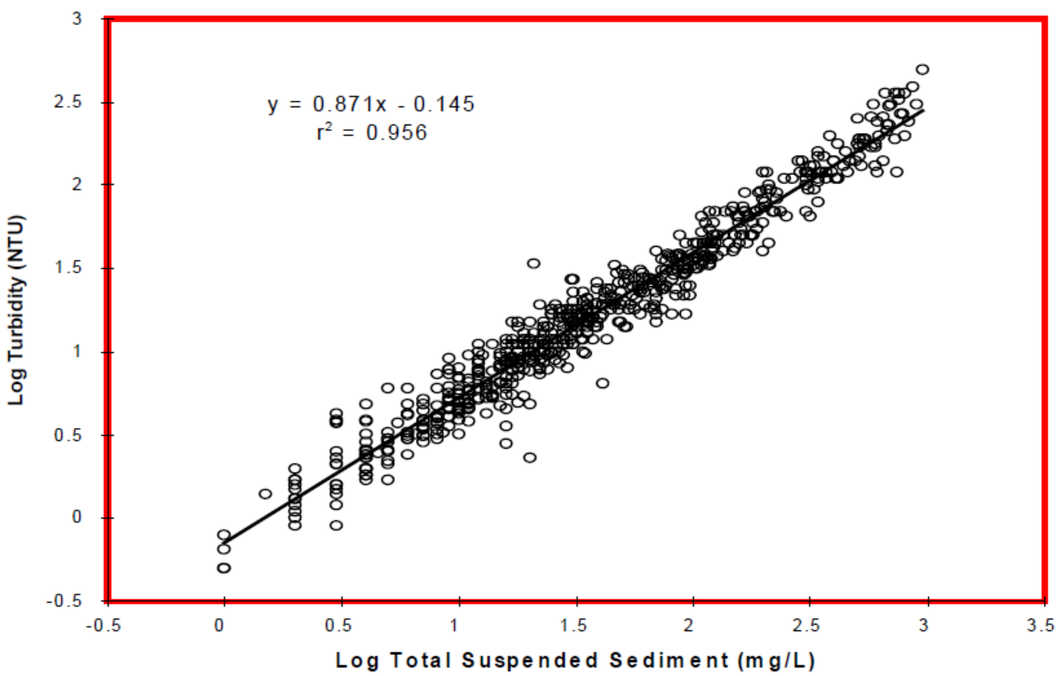

Figure B-61. TSS and turbidity regression developed using TMDL data collected 1994 and 1995. Joy and Patterson (1997), page 64.

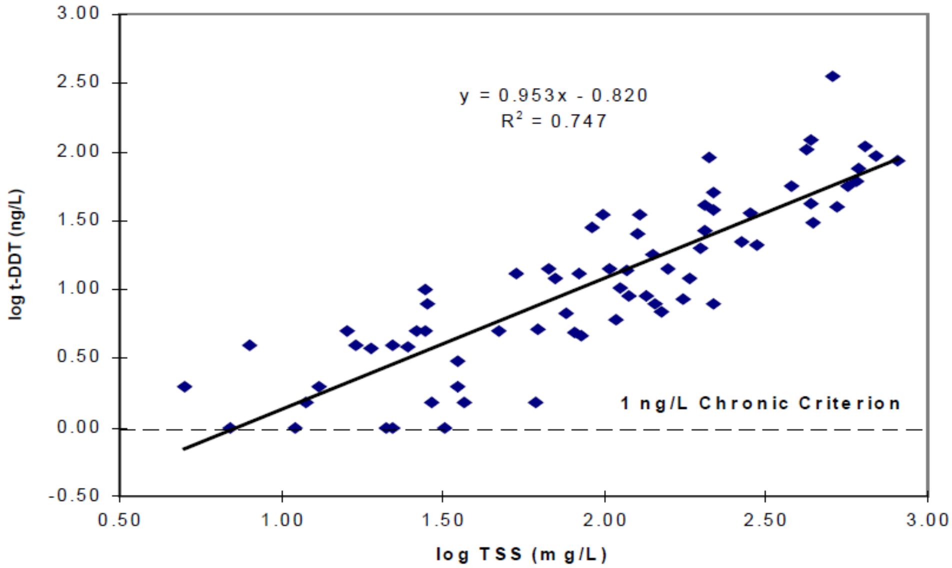

Figure B-62. Regression of t-DDT as a function of TSS for water samples collected from the lower Yakima River basin canals, tributaries, drains, and main stem river. Joy and Patterson (1997), page 73.

Suspended Sediment

Hangman Creek

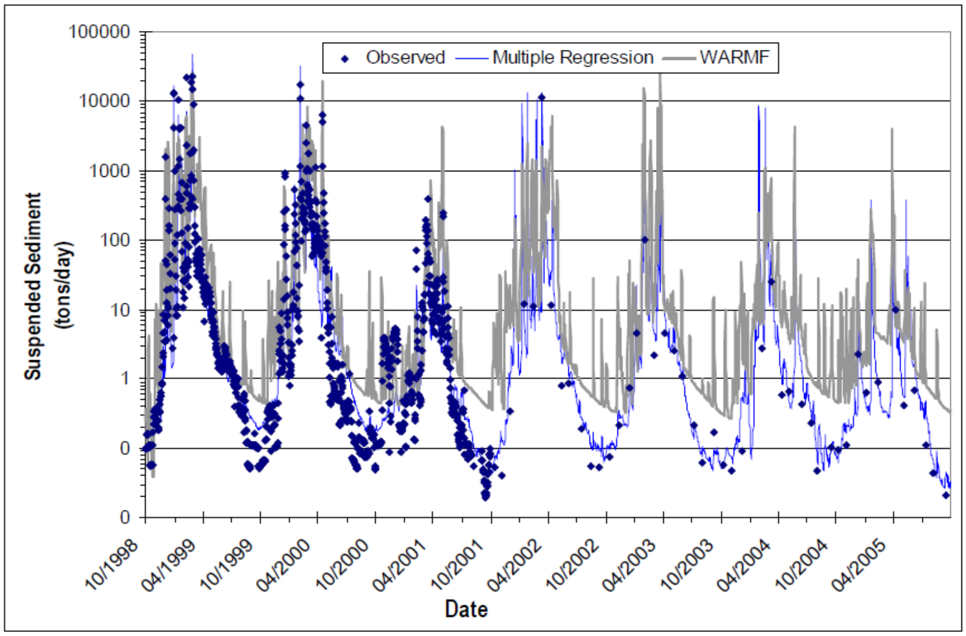

Figure B-63. A comparison of suspended sediment loads. From WARMF and the multiple-regression models output, and observed instantaneous loads for the mouth of Hangman Creek. Joy *et al.* (2009), page 133.

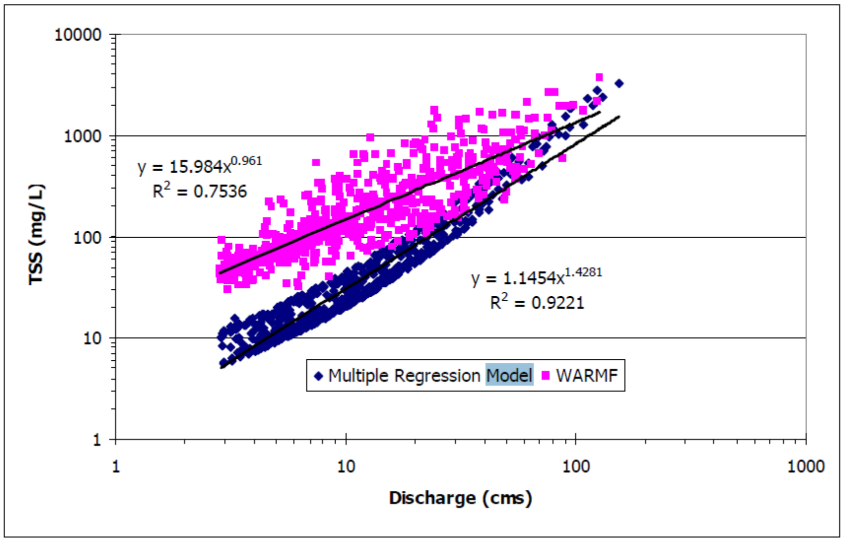

Figure B-64. Hangman Creek at the mouth. Correlation between discharge and suspended sediment concentration estimated by two models for discharge greater than 2.83 cms or 100 cfs. Joy *et al.* (2009), page 134.

Upper Yakima River

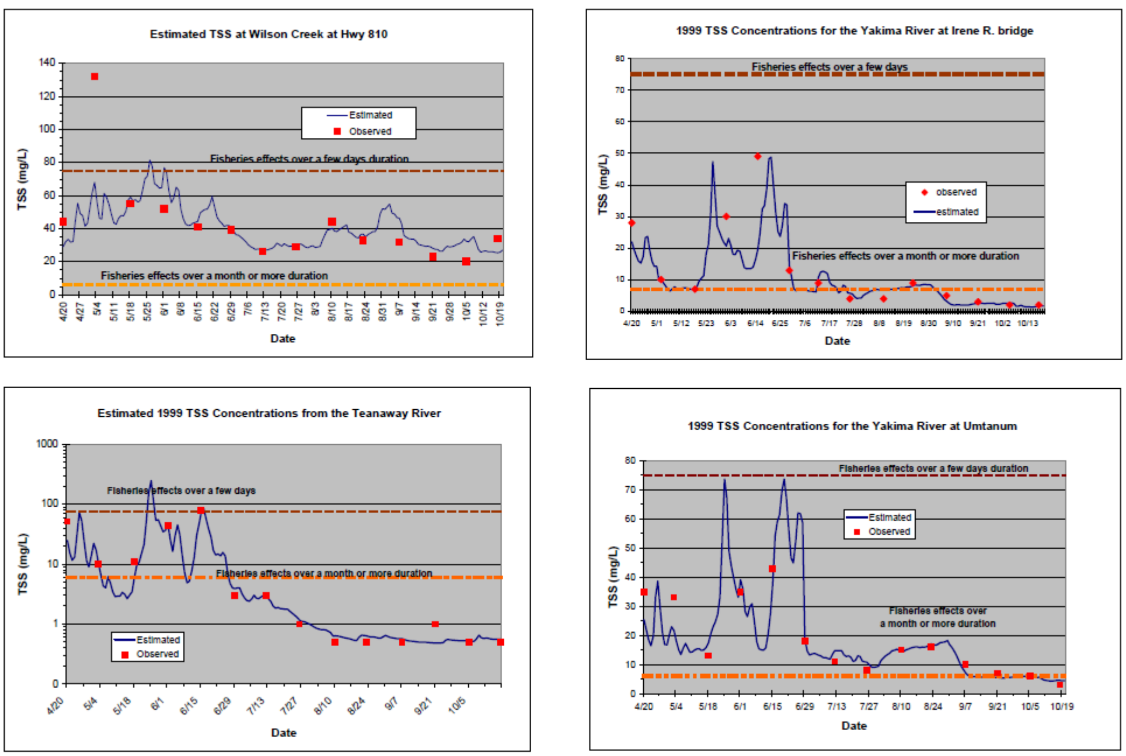

Figure B-65. Estimated TSS concentrations from regression equations compared to field data collected at three sites in the upper Yakima River. Results are compared to fisheries effect threshold concentrations suggested by Newcombe (1996). Joy (2002), page 39.

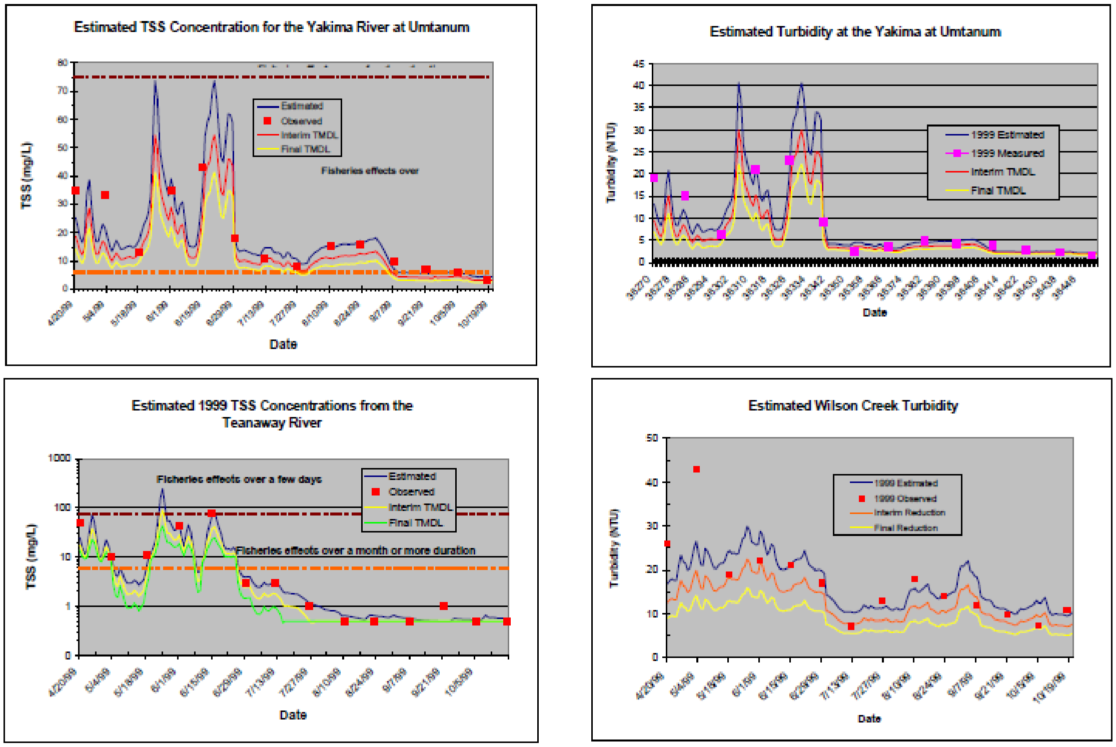

Figure B-66. 1999 data and estimated levels of TSS and turbidity at two sites in the upper Yakima River relative to fisheries effect levels. Estimated TMDL load reduction effects are also shown. Joy (2002), page 60.

Little Spokane River

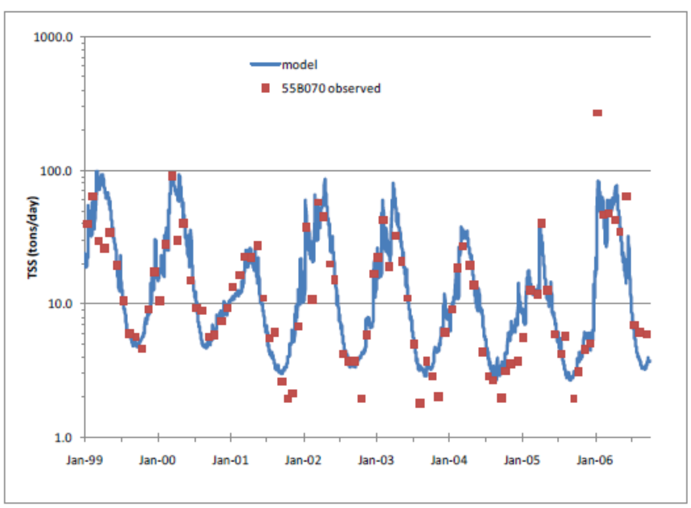

Figure B-67. A comparison of daily total suspended solids (TSS) load estimates at the mouth of the Little Spokane River (55B070) from a multiple regression model (model) and instantaneous sample collection (observed). Joy and Jones (2012), page 96.

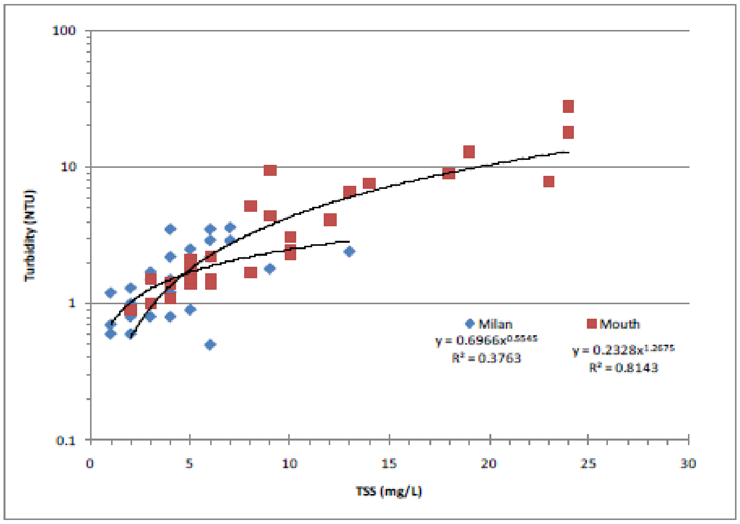

Figure B-68. Relationships between total suspended solids (TSS) concentrations and turbidity values for samples collected at two sites along the Little Spokane River. Joy and Jones (2012), page 91.

Nutrients

Cottage Lake

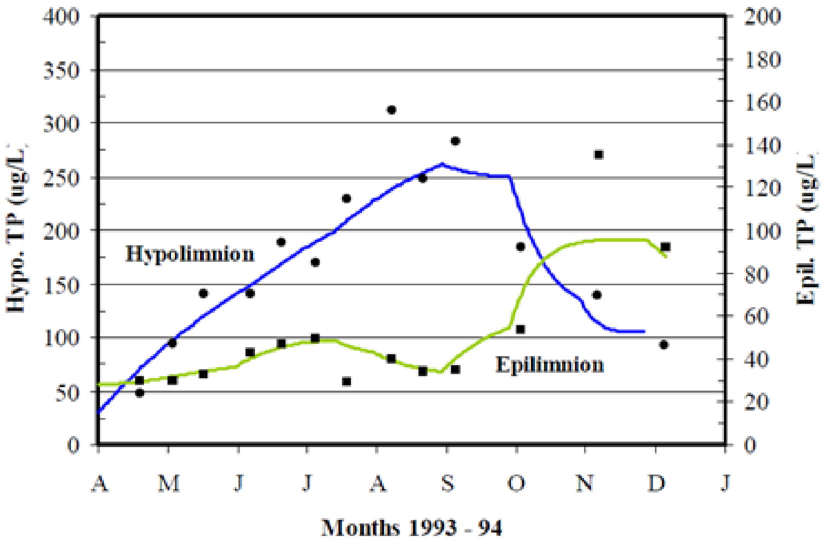

Figure B-69. Results of model calibration for the epilimnion and hypolimnion layers of the mass-balance model. Model predictions are represented by lines and observed data represented by points (hypolimnion) and squares (epilimnion). Whiley (2004), page 26.

Newman Lake

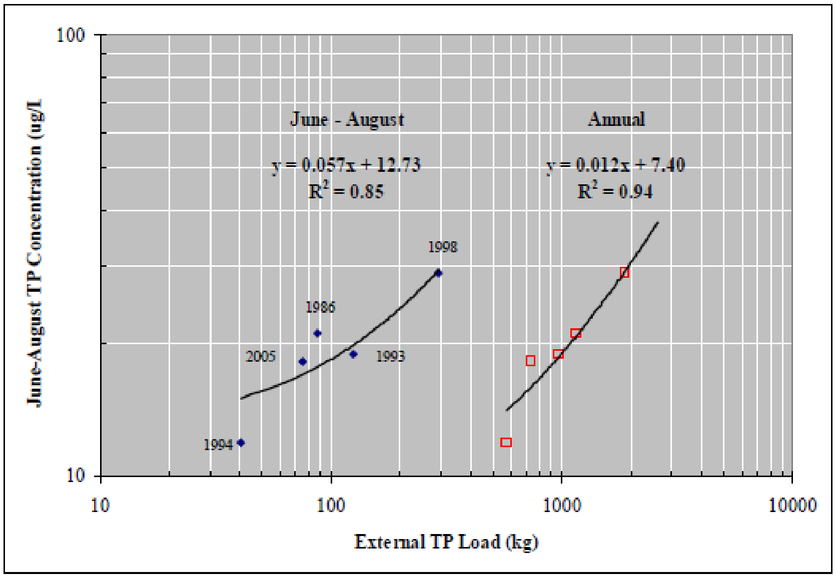

Figure B-70. The relationship between the summer period (June-August) epilimnion TP concentrations (ug/L) and the summer and annual external TP loads (kg). Whiley and Merrill (2007), page 57.

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Appendix C: Model Quality Summary Tables

This appendix presents some of the original model quality summary tables from reports. Many model quality summary tables from original TMDL reports are inclusive of all modeled water quality parameters, thus this section is organized alphabetically by water body with a listing of the modeled parameters presented in the tables. The table captions in this report are the original table captions from the original report, reference from Table 1, and page number where the original table may be found.

Bear Creek – Temperature and Dissolved Oxygen

Table C-1. Summary of root mean square error (RMSE) of difference between predicted and observed temperature and DO from calibration and validation runs. Mohamedali and Lee (2008), page 78.

	Bear Creek	Evans Creek	Cottage Lake Creek
Temperature Calibration			
RMSE of Min & Max	0.59 °C	0.67 °C	0.53 °C
RMSE of Max	0.41 °C	0.59 °C	0.67 °C
RMSE of Min	0.74 °C	0.75 °C	0.33 °C
Temperature Validation			
RMSE of Min & Max	0.98 °C	0.73 °C	0.63 °C
RMSE of Max	0.99 °C	0.93 °C	0.40 °C
RMSE of Min	0.96 °C	0.73 °C	0.79 °C
Dissolved Oxygen Calibration			
RMSE of Min & Max	0.13 mg/L	0.86 mg/L	0.001 mg/L
RMSE of Max	0.12 mg/L	0.99 mg/L	0.001 mg/L
RMSE of Min	0.15 mg/L	0.72 mg/L	0.001 mg/L

Chehalis River Basin – Upper Chehalis River – Temperature

Table C-2. Performance of the Upper Chehalis River Network Stream Temperature Model in Predicting Maximum Daily Temperature. Ecology (2001), page 14.

Location	Calibration – August 1991			Validation - August 1992		
	Measured (°C)	Predicted (°C)	Delta (°C)	Measured (°C)	Predicted (°C)	Delta (°C)
Chehalis River Mile 106.3	15.3	16.0	0.7	18.1	15.6	-2.5
Chehalis River Mile 88.3	18.1	20.1	2.0	18.1	19.7	1.6
Chehalis River Mile 75.4	23.4	22.7	-0.7	23.4	22.2	-1.2
Chehalis River Mile 74.7	23.0	22.1	-0.9	21.7	21.8	0.1
Chehalis River Mile 69.4	19.2	22.1	2.9	20.1	21.3	1.2
Chehalis River Mile 67.0	21.7	21.7	0.0	22.6	20.9	-1.7
Chehalis River Mile 61.9	22.6	22.8	0.2	22.9	22.5	-0.4
Chehalis River Mile 55.2	21.3	20.9	-0.4	20.8	21.6	0.8
Chehalis River Mile 47.0	22.1	21.9	-0.2	19.5	21.9	2.4
Chehalis River Mile 33.8	19.8	21.7	1.9	21.2	21.6	0.4
South Fork Chehalis Mouth	21.2	21.1	-0.1	20.0	20.1	0.1
Newaukum River Mouth	17.7	20.9	3.2	20.5	20.5	0.0
Dillenbaugh Creek Mouth	18.8	21.0	2.2	18.6	20.4	1.8
Salzer Creek Mouth	19.2	19.3	0.1	18.2	20.1	1.9
Skookumchuck River Mouth	20.4	18.7	-1.7	18.7	18.9	0.2
Lincoln Creek Mouth	19.0	21.8	2.8	16.2	21.4	5.2
Scatter Creek Mouth	20.9	20.7	-0.2	21.1	20.2	-0.9
Black River Mouth	21.0	20.1	-0.9	18.7	20.5	1.8
Statistics						
Median Absolute Deviation	1.4°C			1.5°C		
Median Scaled Residual	0.5%			1.6%		
Root Mean Square Error	3.2°C			3.2°C		
Relative Error	16%			16%		

Deschutes River – Capitol Lake – Dissolved Oxygen, Temperature, Nutrients

This TMDL had many other figures and tables in the report text and appendices. See Roberts *et al.* (2012a; 2012b) for additional information.

Table C-3. Overall error statistics. Roberts *et al.* (2012a), page 24.

Variable	n	RMSE	Mean residual	Standard deviation of residuals
Dissolved Oxygen (DO)	567	2.2	0.29	2.17
Orthophosphate (PO4)	23	0.011	-0.007	0.009
Dissolved Inorganic Nitrogen (DIN)	23	0.17	0.054	0.17
Temperature	571	1.6	0.66	1.4
Total Chlorophyll	12	27	5.56	27.5

Table C-4. Overall error statistics during the verification period (2001). Roberts *et al.* (2012a), page 47.

Variable	n	RMSE	Mean	Standard deviation
Dissolved Oxygen (DO)	32	3.5	3.3	1
Orthophosphate (PO4)	39	0.007	-0.003	0.006
Dissolved Inorganic Nitrogen (DIN)	24	0.13	-0.087	0.096
Temperature	57	0.99	0.14	0.986
Total Chlorophyll	24	13.8	9.8	9.9

Deschutes River – Budd Inlet – Dissolved Oxygen and Nutrients

This TMDL had many other figures and tables in the report text and appendices. Please see Roberts *et al.* (2012a; 2012b) for additional information.

Table C-5. Summary of overall goodness-of-fit statistics. Roberts *et al.* (2012a), page 23.

Parameter	N[1]	RMSE	RMSE relative to the mean observed value (% of mean)	Mean residual (bias)	Standard deviation of residual (bias)
Bottom DO (mg/L)[2]	678	1.3	16%	-0.02	1.3
Surface DO (mg/L)[2]	1994	2.2	23%	-0.86	2.0
All DO (mg/L)	2672	2.0	22%	-0.65	1.9
Total chlorophyll a (μg/L)	2562	12.7	88%	-1.92	12.6
DIN (mgN/L)	916	0.086	48%	-0.005	0.086
Nitrate+Nitrite (mgN/L)	916	0.067	50%	-0.004	0.067
Ammonium (mgN/L)	916	0.040	97%	0.002	0.040

[1] Number of comparisons.
[2] Bottom and surface DO statistics were calculated for lower half and upper half of the water column, respectively.

Green River – Temperature

Table C-6. Summary of temperature model bias, absolute mean error (AME), and root mean square error (RMSE) for calibration and model testing runs. Coffin *et al.* (2011), page 61.

Date	Bias	AME	RMSE
7/23/2006	0.28	0.62	0.77
8/2/2006	-0.37	0.45	0.54
8/7/2006	0.41	0.67	0.78
8/18/2006	0.50	0.59	0.72

Hangman Creek – Sediment

Table C-7. Three estimates of annual suspended sediment load. Compared to annual average discharge at the mouth of Hangman Creek for the water years 1998-2005. Joy *et al.* (2009), page 134.

Water Year	USGS (tons)	Multiple Regression Model (tons)	WARMF Model (tons)	Annual Average Discharge (cfs)
1999	175,000	188,252	190,787	315
2000	83,000	90,677	139,855	273
2001	3,430	1,604	19,824	84
2002	-	73,770	72,687	229
2003	-	16,503	180,869	139
2004	-	30,605	19,543	124
2005	-	2,832	13,147	73.5

Henderson Inlet – Temperature, Dissolved Oxygen, pH, Nutrients

Table C-8. Overall performance of calibration and confirmation models using RMSE and CV. Sargeant *et al.* (2006), Appendices, page 99.

Parameter	RMSE of calibration model (Sept 2003)	% CV of calibration model RMSE (Sept 2003)	RMSE of confirmation model (Aug 2003)	% CV of confirmation model RMSE (Aug 2003)
Temperature (° C)	0.521	5%	0.796	7%
Dissolved Oxygen (mg/L)	.559	6%	0.623	7%
Conductivity (µmhos)	10.3	7%	13.2	10%
pH (SU)	0.122	2%	0.148	2%
Ammonia Nitrogen (µmhos) *	32.8	5%	21.9	34%
Nitrate+nitrite Nitrogen (µmhos)	109.4	7%	111.3	6%
Organic Nitrogen (µmhos) *	109.7	48%	56.2	211%
Dissolved Phosphorus (µmhos)	7.32	12%	4.88	8%
Organic Phosphorus (µmhos) *	9.65	83%	5.95	47%

* Values for ammonia nitrogen, organic nitrogen, and organic phosphorus were at or close to detection limits. At levels close to the method detection limit, a greater % CV is expected.

Lake Whatcom – Temperature, Dissolved Oxygen, Nutrients

Table C-9. Water level error statistics (in meters). Pickett and Hood (2008b), page 97.

Mean Error	Absolute Mean Error	Root Mean Square Error
0.00	0.01	0.01

Table C-10. Temperature profile error statistics. Pickett and Hood (2008b), page 97.

Site	Model Segment #	Mean Error (Celsius)	Absolute Mean Error (Celsius)	Root Mean Square Error (Celsius)
LW1	61	-0.11	0.69	0.79
LW2	52	0.14	0.57	0.67
LW3	25	-0.08	0.42	0.53
LW4	11	-0.11	0.52	0.62
Intake	54	-0.04	0.45	0.50
	Average	-0.04	0.53	0.62

Table C-11. Model-data error statistics for orthophosphorus. Pickett and Hood (2008b), page 102.

Site ID	Model Segment #	Mean Error (mg/l)	Mean Absolute Error (mg/l)	Root Mean Square Error (mg/l)
LW1	61	0.003	0.005	0.006
LW2	52	0.001	0.003	0.003
LW3	25	0.001	0.002	0.002
LW4	11	0.001	0.002	0.002
INTAKE	54	-0.001	0.002	0.002
Average		0.001	0.003	0.003

Table C-12. Model-data error statistics for ammonia nitrogen. Pickett and Hood (2008b), page 102.

Site ID	Model Segment #	Mean Error (mg/l)	Mean Absolute Error (mg/l)	Root Mean Square Error (mg/l)
LW1	61	-0.005	0.030	0.037
LW2	52	-0.002	0.020	0.030
LW3	25	0.002	0.005	0.006
LW4	11	0.001	0.004	0.005
INTAKE	54	0.006	0.007	0.007
Average		0.000	0.013	0.017

Table C-13. Model-data error statistics for nitrite-nitrate. Pickett and Hood (2008b), page 102.

Site ID	Model Segment #	Mean Error (mg/l)	Mean Absolute Error (mg/l)	Root Mean Square Error (mg/l)
LW1	61	0.09	0.11	0.12
LW2	52	0.02	0.05	0.05
LW3	25	0.00	0.04	0.04
LW4	11	-0.01	0.04	0.04
INTAKE	54	0.02	0.05	0.05
Average		0.02	0.06	0.06

Table C-14. Model-data error statistics for dissolved oxygen. Pickett and Hood (2008b), page 102.

Site ID	Model Segment #	Mean Error (mg/l)	Mean Absolute Error (mg/l)	Root Mean Square Error (mg/l)
LW1	61	0.35	1.00	1.32
LW2	52	-0.12	0.68	0.77
LW3	25	0.15	0.58	0.68
LW4	11	0.26	0.68	0.75
INTAKE	54	-0.02	0.66	0.69
Average		0.12	0.72	0.84

Table C-15. Model-data error statistics for total phosphorus. Pickett and Hood (2008b), page 103.

Site ID	Model Segment #	Mean Error (mg/l)	Mean Absolute Error (mg/l)	Root Mean Square Error (mg/l)
LW1	61	0.001	0.005	0.007
LW2	52	0.000	0.004	0.004
LW3	25	0.000	0.003	0.004
LW4	11	0.001	0.003	0.004
INTAKE	54	0.000	0.003	0.003
Average		0.000	0.004	0.004

Little Klickitat – Temperature

Table C-16. Comparison of calculated and measured effective shade. Breithaupt and Khangaonkar (2007), page 30.

Station/ Tributary	Distance downstream from headwater (km)	Calculated Effective Shade (%)	Measured Effective Shade (%) by vegetation only	Calculated Effective Shade (%) by topography only
Butler (trib)		55.0	47.5	4.6
East Prong (trib)		62.3	45.7	4.6
West Prong (trib)		77.5	60.8	4.6
Rimrock	14.1	60.0	49.0	1.4
Tom Miller	19.1	46.4	35.0	0.0
Olson	27.2	30.0	38.1	0.0
Mouth	42.9	48.1	45.2	2.9

Table C-17. Calibration and verification statistics. Brock and Stohr (2002), page 50.

	Calibration Period - 7/29 to 8/4/00					Validation Period - 8/21 to 8/27/00				
	Max Temp		Min Temp		Overall	Max Temp		Min Temp		Overall
	RMSE	Δ Ave	RMSE	Δ Ave	RMSE	RMSE	Δ Ave	RMSE	Δ Ave	RMSE
Little Klickitat	0.85	0.69	1.32	1.1	1.11	1.23	0.96	0.78	0.66	1.03
Butler Creek	0.36	0.25	1.28	0.91	0.94	0.22	0.15	1.12	0.79	0.81
East Prong	0.14	0.1	0.77	0.55	0.56	0.62	0.43	0.77	0.54	0.7
West Prong	0.33	0.24	1.34	0.94	0.97	1.25	0.88	1.21	0.85	1.23

Little Spokane – Sediment

Table C-18. A comparison of recommended total suspended solids (TSS) load reductions at three sites where both multiple regression equations and Water Quality Index (WQI) analysis methods were used. Joy and Jones (2012), page 95.

Site	Multiple Regression TSS	WQI TSS and Turbidity
LSR at Mouth	75%	70%
LSR at Deer Park Milan	25%	20%
Deadman Creek at Mouth	70%	65%

Lower Columbia River – McNary – Dissolved Gas

Table C-19. Statistical summary of Regression Variables for McNary Dam. Pickett and Harding (2002), page 37.

	Delta Pressure ΔP (mm/Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	173	173	173
Minimum	81.9	2.0	30.8
Maximum	307.6	21.9	40.5
Average	191.6	11.7	35.0
Standard Deviation	53.0	5.4	2.2

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-29

Table C-20. Statistical summary of Nonlinear Regression at McNary 1997 Spill Season. Pickett and Harding (2002), page 39.

$$\Delta P = D_{tw}^{c1} q_s^{c2} + c3$$

Number of Observations n=173

$r^2 = 0.97$

Std Error = 9.26 mm Hg

Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
C_1	0.647	0.0693	12.71	<0.0001
C_2	0.969	0.0762	9.35	<0.0001
C_3	82.14	5.89	14.08	<0.0001

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-29

Lower Columbia River – John Day 1998 – Dissolved Gas

Table C-21. Statistical Summary of Regression Variables. Pickett and Harding (2002), page 42.

	Delta Pressure ΔP (mm/Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	52	52	52
Minimum	108.0	4.3	33.8
Maximum	184.0	9.4	42.4
Average	152.7	7.1	38.7
Standard Deviation	16.7	1.2	1.9

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-31

Table C-22. Statistical Summary of Nonlinear Regression at John Day 1998 Spill Season (Bays 2 through 19 With Flow Deflectors). Pickett and Harding (2002), page 43.

$$\Delta P_{tw} = C_1 * D_{tw} * (1 - \exp(C_2 * q_s))$$

Number of observations n=51

$r^2 = 0.84$

Std. Error=6.78 mm Hg

Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
C_1	4.969	0.192	25.908	<0.0001
C_2	-0.2278	0.0221	10.3069	<0.0001

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-32

Lower Columbia River – John Day 1996-1997 – Dissolved Gas

Table C-23. Statistical Summary of Nonlinear Regression at John Day 1996-1997 Spill Season. Pickett and Harding (2002), page 47.

$\Delta P_{tw} = C_1 - C_2 * (\exp(C_3 * q_s))$ Number of observations = 1137 $r^2 = 0.94$ Std. Error = 15.95 mm Hg				
Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
C_1	315.29	1.647	191.48	<0.0001
C_2	-519.09	10.3867	-49.975	<0.0001
C_3	-0.3649	0.0084	-43.38	<0.0001

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-34

Lower Columbia River – The Dalles – Dissolved Gas

Table C-24. Statistical Summary of Nonlinear Regression at The Dalles 1997 Spill Season. Pickett and Harding (2002), page 49.

$\Delta P_{tw} = D_{tw}^{C_1} q_s^{C_2} + C_3$ Number of observations = 87 $r^2 = 0.735$ Std. Error = 7.34 mm Hg				
Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
C_1	1.02	0.12	2.69	<0.0086
C_2	0.33	0.12	8.72	<0.0001
C_3	145.9	2.21	66.11	<0.0001

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-36

Mission Creek – Sediment, Toxics

Table C-25. Simple Linear Models for Relationships Between TSS (mg/L) and t-DDT (ng/L). Serdar and Era-Miller (2004), page 35.

Stream	n	Linear model	F-ratio	R^2	P
Mission	10	t-DDT = $e^{(0.21 \times \ln TSS) + 0.96}$	0.24	0.03	0.639
Brender	10	t-DDT = $e^{(0.55 \times \ln TSS) + 1.09}$	5.07	0.39	0.054
Yaksum	10	t-DDT = $e^{(0.58 \times \ln TSS) + 2.38}$	22.0	0.73	0.002

Pend Oreille – Temperature

Table C-26. Year 1997 error statistics for continuous temperature data. Annear *et al.* (2006), page 61.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
POALB	3	3165	0.00	0.01	0.01
INDA	59	3070	-0.06	0.14	0.17
SKMA	112	2461	-0.06	0.28	0.36
TACOA	152	2497	0.04	0.33	0.41
Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
CCAA	155	2728	0.00	0.24	0.31
MILA	208	2711	0.17	0.33	0.42
LCLA	219	2650	-0.06	0.32	0.40
BMATOP	333	3146	-0.10	0.35	0.43
Average			-0.01	0.25	0.31

Table C-27. Year 1998 error statistics for continuous temperature data. Annear *et al.* (2006), page 62.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
POALB	3	3647	-0.08	0.42	0.54
SKMA	112	5858	-0.07	0.46	0.57
CCAA	155	1306	0.03	0.58	0.69
MILA	208	3647	0.19	0.45	0.60
BMABOT	333	4657	-0.19	0.45	0.57
FORB	358	4667	0.00	0.40	0.53
Average			-0.02	0.46	0.58

Table C-28. Year 2004 error statistics for continuous temperature data. Annear *et al.* (2006), page 62.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
1010	17	4069	-0.02	0.11	0.14
1020	38	5588	-0.15	0.20	0.27
1040	57	2035	-0.11	0.22	0.36
1060	83	5589	-0.16	0.23	0.31
1070	102	5589	-0.15	0.32	0.42
1080	131	5843	-0.19	0.28	0.35
1110	150	4204	-0.13	0.34	0.42
1140	217	5548	-0.11	0.31	0.39
1160	232	5548	-0.07	0.31	0.39
1180	264	4921	-0.14	0.32	0.39
1190	334	5542	-0.16	0.34	0.42
1220	358	3589	0.01	0.31	0.38
Average			-0.11	0.27	0.35

Table C-29. Year 2004 error statistics for vertical profile data. Annear *et al.* (2006), page 62.

Site ID	Model Segment	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
1010	17	0.22	0.30	0.30
1020	38	-0.11	0.14	0.15
Site ID	Model Segment	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
1040	57	-0.04	0.11	0.12
1060	83	-0.06	0.14	0.15
1070	102	0.01	0.19	0.20
1080	131	-0.17	0.18	0.19
1110	150	-0.20	0.26	0.26
1125	187	-0.22	0.22	0.23
1130	204	-0.25	0.39	0.40
1140	217	-0.10	0.24	0.26
1160	232	-0.07	0.15	0.16
1180	264	0.01	0.15	0.16
1185	300	-0.33	0.33	0.34
1190	334	-0.12	0.36	0.38
1220	358	-0.47	0.47	0.47
Average		-0.13	0.24	0.25

Table C-30. Year 1997 error statistics for maximum daily temperature. Annear *et al.* (2006), page 63.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
POALB	3	132	0.01	0.01	0.01
INDA	59	128	-0.02	0.11	0.14
SKMA	112	103	0.07	0.24	0.30
TACOA	152	104	-0.03	0.31	0.40
CCAA	155	113	0.10	0.25	0.33
MILA	208	113	0.05	0.26	0.33
LCLA	219	111	-0.08	0.29	0.37
BMATOP	333	131	0.01	0.40	0.46
Average			0.01	0.23	0.29

Table C-31. Year 1998 error statistics for maximum daily temperature. Annear *et al.* (2006), page 63.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
POALB	3	152	-0.30	0.50	0.62
SKMA	112	245	0.02	0.43	0.54
CCAA	155	54	0.03	0.53	0.64
MILA	208	152	0.04	0.36	0.47
BMABOT	333	194	-0.11	0.40	0.52
FORB	358	195	0.08	0.39	0.53
Average			-0.04	0.43	0.55

Table C-32. Year 2004 error statistics for maximum daily temperature. Annear *et al.* (2006), page 64.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
1010	17	85	0.15	0.16	0.22
1020	38	116	-0.03	0.16	0.25
1040	57	42	-0.04	0.21	0.32
1060	83	116	-0.24	0.27	0.34
1070	102	116	-0.15	0.31	0.39
1080	131	94	-0.05	0.24	0.35
1110	150	87	0.00	0.28	0.35
1140	217	115	-0.08	0.26	0.32
1160	232	115	-0.06	0.32	0.39
1180	264	102	-0.05	0.31	0.38
1190	334	115	-0.09	0.30	0.38
1220	358	80	0.09	0.33	0.40
Average			-0.05	0.26	0.34

Table C-33. Calibration Error Analysis for Temperature Time Series in the Boundary Reservoir and Boundary Tailrace. Breithaupt and Khangaonkar (2007), page 3.5.

Station	Depth (ft)	ME (°C)	AME (°C)	RMS (°C)	N
T2. Metaline Pool	3.28 (1 m)	-0.268	0.299	0.368	14,537
	10.49 (3.2 m)	-0.189	0.244	0.317	14,536
	17.17 (5.4 m)	-0.257	0.278	0.340	14,537
	24.94 (7.6 m)	-0.249	0.272	0.336	14,538
	32.15 (9.8 m)	-0.218	0.264	0.345	14,538
T6. Slate Pool	3.28 (1 m)	-0.155	0.306	0.397	21,081
	36.09 (11 m)	-0.172	0.291	0.369	21,081
	68.90 (21 m)	-0.179	0.281	0.376	21,080
	101.7 (31 m)	-0.258	0.278	0.356	20,931
T7. Boundary Intake	16.41 (5 m)	-0.110	0.304	0.381	26,719
	36.09 (11 m)	-0.204	0.301	0.373	33,865
	55.78 (17 m)	-0.102	0.234	0.303	34,624
	75.46 (23 m)	-0.136	0.235	0.310	34,626
	95.15 (29 m)	-0.113	0.168	0.212	19,071
T8. Boundary Dam Tailwater	-	-0.051	0.436	0.790	32,844
Overall Averages		-0.163	0.284	0.409	338,608

AME = Absolute mean error; ME = mean error; RMS = Root mean square error.

Table C-34. Calibration Error Analysis for Maximum Daily Temperature Time Series in the Boundary Reservoir and Boundary Tailrace. Breithaupt and Khangaonkar (2007), page 3.5.

Station	Depth (ft)	ME (°C)	AME (°C)	RMS (°C)	N
T2. Metaline Pool	3.28 (1 m)	-0.194	0.279	0.337	203
	10.49 (3.2 m)	-0.092	0.220	0.274	203
	17.17 (5.4 m)	-0.144	0.231	0.280	203
	24.94 (7.6 m)	-0.129	0.223	0.273	203
	32.15 (9.8 m)	-0.104	0.238	0.292	203
T6. Slate Pool	3.28 (1 m)	-0.126	0.298	0.395	295
	36.09 (11 m)	-0.074	0.259	0.327	295
	68.90 (21 m)	-0.095	0.254	0.329	295
	101.7 (31 m)	-0.226	0.252	0.322	293
T7. Boundary Intake	16.41 (5 m)	-0.168	0.342	0.436	424
	36.09 (11 m)	-0.022	0.311	0.381	203
	55.78 (17 m)	-0.082	0.224	0.290	481
	75.46 (23 m)	-0.117	0.214	0.291	481
	95.15 (29 m)	-0.096	0.146	0.184	265
T8. Boundary Dam Tailwater	-	-0.057	0.450	0.803	461
Overall Averages	-	-0.113	0.271	0.401	4,508

AME = Absolute mean error; ME = mean error; RMS = Root mean square error.

Table C-35. Calibration Error Analysis for Temperature Profiles in the Boundary Reservoir. Breithaupt and Khangaonkar (2007), page 3.6.

Station	ME (°C)	AME (°C)	RMS (°C)	N
V1. Wolf Creek	0.000	0.095	0.144	101
V2. Metaline Old	-0.074	0.122	0.190	114
V3. Pend Oreille Mine	-0.201	0.212	0.247	70
V4. Slate Creek	-0.075	0.228	0.249	99
V5. Everett Creek	-0.138	0.282	0.364	82
V6. Boundary Reservoir	-0.167	0.307	0.417	94
Overall Averages	-0.102	0.201	0.280	560

AME = Absolute mean error; ME = mean error; RMS = Root mean square error.

Skagit River and Bay – Temperature, Nutrients

Table C-36. Lower Skagit River DO Model Calibration and Verification. Pickett (1997), page 16.

	Calibration					Verification				
	DO			Ammonia-N		DO			Ammonia-N	
RM	Predict.	Observ.	CV	Predict.	Observ.	Predict.	Observ.	CV	Predict.	Observ.
Mainstem River Skagit										
19.0	10.3	10.2	0.9%	0.005	< 0.01	10.4	10.2	1.3%	0.007	0.01
15.8	10.3	9.8	3.8%	0.009	< 0.01	10.4	10.1	1.9%	0.01	≤ 0.01
12.1	10.2	10.3	0.5%	0.008	< 0.01	10.4	10.3	0.5%	0.009	< 0.01
8.7	10.2	10.3	0.9%	0.013	0.014	10.4	10.5	0.9%	0.013	0.012
South Fork Skagit River										
4.4										
24-hr avg	10.0	10.1	0.4%	0.023	0.025	10.3	10.2	0.8%	0.027	0.03
Minimum	8.8	9.3	3.6%			9.1	9.0	0.9%		

Snohomish Estuary – Dissolved Oxygen, Nutrients

Table C-37. Root mean square error (RMSE) between model predicted (P) and observed (O) values for salinity, dissolved oxygen, chlorophyll a, ammonia, and phosphorus. Cusimano (1995), page 54.

Parameter	n (number of pairs)	RMSE $[\sqrt{\Sigma(P_i - O_i)^2/n}]$	Range Observed
Salinity (‰)	38	2.18[a]	0.0 - 27.3
Dissolved Oxygen (mg/L)	52	0.23	6.6 - 10.2
Chlorophyll *a* (μg/L)	26	1.55[b]	1.4 - 7.4
Ammonia (mg/L)	52	0.0167	0.005[c] - 0.140
Phosphorus (mg/L)	52	0.0050	0.005[c] - 0.049

[a] For salinity values ≤ 3 ppt RMSE is 0.53.

[b] RMSE is 0.76 μg/L excluding two sites in Ebey Slough associated with water quality model segments 60 and 67.

[c] Minimum value is one-half the detection limit.

Snoqualmie River – Dissolved Oxygen, Temperature, Nutrients

Table C-38. Root mean square error values for QUAL2E model results compared to field data collected from the Snoqualmie River, 9/91. Number of comparisons (field stations) for each group are inside (). Joy (1994), Appendix B, page 1.

	CHLORIDE	DO(log)	D.O.	SRP	Total N	FC (log)	Temp	NH3	log SRP
RMSE FOR ALL STATIONS (19	0.034	0.029	0.696	0.684	44.745	1.219	0.048	12.237	0.041
MEAN RESPONSE	1.35	1.0085	10.20	4.35	235.01	1.6758	14.60	15.66	0.61
% MEAN RESPONSE	2.6%	2.9%	6.8%	15.7%	19.0%	72.8%	0.1%	78.1%	6.7%
RMSE: S.F. TO TOLT R.(12)	0.012	0.009	0.212	0.774	2.226	1.408	0.122	0.710	0.072
MEAN RESPONSE	1.30	1.01820	10.43	5.24	229.83	1.53	13.35	10.61	0.68665
% MEAN RESPONSE	0.9%	0.9%	2.0%	14.8%	1.0%	92.1%	0.9%	6.7%	10.5%
RMSE: TOLT R. TO MOUTH (7	0.042	0.037	0.869	0.113	70.804	0.165	0.080	19.231	0.027
MEAN RESPONSE	1.39	1.00012	10.00	3.59	239.45	1.80	15.67	19.99	0.53642
% MEAN RESPONSE	3.0%	3.7%	8.7%	3.2%	29.6%	9.2%	0.5%	96.2%	5.0%

Spokane River – Temperature, Dissolved Oxygen, Nutrients, Sediment, pH

Table C-39. Summary of model-data error statistics at the WA/ID State Line, 2001 and 2004. Annear *et al.* (2005), page 182.

Table 26: Summary of model-data error statistics at the WA/ID State Line, 2001 and 2004

	2001				2004			
	Number of Comparisons	Mean Error	Absolute ME	RMS Error	Number of Comparisons	Mean Error	Absolute ME	RMS Error
Flow, cms	34943	-78.03	78.03	117.66	272	-146.80	146.80	191.71
Temperature, C	3704	-0.41	0.79	0.98	369	-0.19	0.40	0.60
pH	607	0.01	0.50	0.64	369	0.55	0.56	0.58
Conductivity, umhos/cm	615	7.37	7.60	7.79	369	0.19	0.69	0.96
DO, mg/L	611	0.17	0.61	0.74	342	0.18	0.22	0.30
NH3, mg/L	13	0.012	0.016	0.025	20	-0.048	0.065	0.127
TKN, mg/L	16	-0.198	0.198	0.249				
TPN, mg/L	12	0.041	0.051	0.065	20	0.033	0.080	0.103
Nox, mg/L	21	0.015	0.047	0.074	20	0.032	0.051	0.073
SRP, mg/L	23	-0.001	0.003	0.004	20	0.000	0.002	0.003
TP, mg/L	30	-0.008	0.008	0.009	20	0.001	0.006	0.008
CBODU, mg/L	11	0.376	0.656	0.723	11	0.096	0.463	0.547
TDS, mg/L	18	15.27	16.97	22.98				
TSS mg/L		-2.127	2.127	3.299	9	-0.94	0.94	1.22
DOC, mg/L	27	-0.67	0.70	0.86				
TOC mg/L	27	-0.39	0.45	0.65				
ALK mg/L	18	-2.14	2.31	2.65				
Chl a ug/L	10	-0.62	1.12	1.46	11	0.57	0.87	1.37

Stillaguamish River – Temperature

Table C-40. Summary of RMSE of differences between the predicted and observed daily maximum temperatures in the Stillaguamish River basin. Pelletier and Bilhimer, 2004, page 58.

Watercourse	RMSE for the calibration period of August 9-15, 2001 (deg C)	RMSE for the verification period of September 7-8, 2001 (deg C)
Mainstem Stillaguamish River	0.6	0.3
South Fork Stillaguamish River	0.6	1.3
North Fork Stillaguamish River	1.1	1.3
Deer Creek	0.4	0.0
Pilchuck Creek	0.9	0.8

Upper Naches River – Temperature

Table C-41. Summary root mean square error (RMSE) of differences between the predicted and observed daily maximum temperatures and combined maximum and minimum temperatures in the upper Naches River (RM 38.8 to 17.6). Brock (2008), page 91.

Watercourse	Statistic	RMSE for July 28–Aug 3, 2004 (°C)	RMSE for Aug 11–17, 2004 (°C)
Upper Naches River	Maximum	0.73	0.45
Upper Naches River	Total (max + min)	0.78	0.55

Walla Walla River – Mill and Yellowhawk Creeks – Temperature, Dissolved Oxygen, Nutrients, pH

Table C-42. Summary of root mean square errors (RMSE) of QUAL2Kw calibration predictions of the August 31 to September 1, 2004, synoptic survey of Mill-Yellowhawk Creeks. Joy *et al.* (2007), page 185.

Variable	RMSE	RMSE/ Mean
Temperature (deg C)	0.65	4%
Conductivity (um/cm)	2.9	3%
Dissolved oxygen, all (mg/L)	0.46	5%
Dissolved oxygen, grabs (mg/L)	0.52	6%
Dissolved oxygen, Hydrolab (mg/L)	0.23	2%
Organic nitrogen (ugN/L)	21	60%
Ammonia nitrogen (ugN/L)	2.6	40%
Nitrate + nitrite N (ugN/L)	18	20%
Organic phosphorus (ugP/L)	5.1	120%
Soluble reactive P (ugP/L)	1.58	4%
Alkalinity (mgCaCO3/L)	0.97	2%
pH, all data	0.23	3%
pH, grabs	0.24	3%
pH, Hydrolab	0.23	3%
Periphyton (mgA/m2)	22	62%
Total nitrogen (ugN/L)	21	15%
Total phosphorus (ugP/L)	5.2	13%
Ultimate CBOD (mg/L)	0.63	28%
Total organic carbon (mgC/L)	0.24	29%

Walla Walla River – Touchet River – Temperature, Dissolved Oxygen, Nutrients, pH

Table C-43. Summary of root mean square errors (RMSE) and Nash- Sutcliffe coefficients for QUAL2Kw calibration predictions for the September 2022 survey of the Touchet River. Joy *et al.* (2007), page 185.

Variable	RMSE	RMSE/ Mean	Nash-Sutcliffe	Nash-Sutcliffe*
Temperature (deg C)	0.5	2%	0.98	
Conductivity (um/cm)	6.4	6%	0.88	
Dissolved oxygen, all (mg/L)	0.3	3%	0.95	
Total nitrogen (ugN/L)	68.9	26%	0.58	
Dissolved Inorganic N (ug/L)	17.8	14%	0.97	
Ammonia nitrogen (ugN/L)	6.7	75%	-1.5	
Nitrate + nitrite N (ugN/L)	17.1	15%	0.98	
Total phosphorus (ugP/L)	7.4	9%	-0.5*	0.97
Soluble reactive P (ugP/L)	7.2	12%	0.06*	0.93
Alkalinity (mgCaCO3/L)	8.6	14%	0.2	
pH, all data	0.2	3%	0.78	
Total organic carbon (mgC/L)	1.7	85%	-26	

* Effect on Nash-Sutcliffe coefficient by eliminating one 'errant' data point

Table C-44. Summary root mean square error (RMSE) of differences between the predicted and observed daily maximum temperatures and combined maximum and minimum temperatures in the Touchet River. Stohr *et al.* (2007), page 68.

Watercourse	Statistic	RMSE for July 11-17, 2002 (°C)	RMSE for August 9-15, 2002 (°C)	RMSE for July 22-28, 1998 (°C)
Touchet mainstem	Maximum	0.62	0.72	0.73
Touchet mainstem	Total (max + min)	0.55	0.69	0.67

Table C-45. Summary root mean square error (RMSE) of differences between the predicted and observed daily maximum temperatures for the upper Touchet River forks. Stohr *et al.* (2007), page 69.

Watercourse	Statistic	RMSE for July 11-17, 2002 (°C)	RMSE for the TIR period tidbits August 7-9, 2002 (°C)	RMSE for all TIR segments August 7-9, 2002 (°C)
North Fork Touchet RM 7.7 to 4.9	Maximum	0.16	0.02	0.55
Wolf Fork Touchet RM 4.5 to 1.7	Maximum	0.00	0.06	0.19

Whatcom Creek – Temperature

Table C-46. Summary of RMSE (deg C) of differences between the predicted and observed daily maximum and minimum temperatures in Whatcom Creek. Hood *et al.* (2011), page 53.

Watercourse	Model Calibration		Model Confirmation	
Whatcom Creek	Minimum 0.22	July 11-17, 2002	Minimum 0.37	Aug 5-7, 2002
	Maximum 0.28		Maximum 0.73	

Willapa River – Temperature

Table C-45. Summary root mean square error (RMSE) of differences between the predicted and observed daily maximum temperatures and combined maximum and minimum temperatures in the Willapa River basin. Stohr (2004), page 55.

Watercourse	Statistic	RMSE		
		August 8-14, 2001 (°C)	August 28-30, 2001 (°C)	August 1-4, 1998 (°C)
Willapa mainstem	Maximum	0.51	0.42	0.69
	Total (max + min)	0.70	0.62	0.74
Fork Creek	Maximum	0.56	0.14	NA
	Total (max + min)	0.61	0.22	NA

Upper Yakima River – Sediment

Table C-46. Goodness-of-fit measures for daily estimates of suspended sediment and turbidity based on discharge to TSS correlations and TSS to turbidity correlations. Joy (2002), Appendix A.

Site	Total Suspended Solids		Turbidity	
	RMSE - cv	Nash – Sutcliffe R^2	RMSE - cv	Nash – Sutcliffe R^2
Yakima River at Nelson	43%	0.57	27%	0.7
Teanaway River	24%	0.90	21%	0.95
Yakima River at Thorp	37%	0.73	31%	0.75
Taneum Creek	36%	0.88	--	--
Manastash Creek	34%	0.83	24%	0.73
Yakima River at Irene Rinehart Park	24%	0.59	--	--
Sorenson Creek	45%	0.17	44%	0.07
Wilson Creek	21%	0.45	21%	0.53
Yakima River at Umtanum	18%	0.85	19%	0.87
Yakima River at Harrison Bridge	13%	0.95	25%	0.75

Table C-47. 1999 water balance and TSS load balances for the upper Yakima River Study area. Relative percent difference is between calculated water volume or load at the mainstem site and sum of the upstream inputs and diversions. Joy (2002), page 40.

1999 Water Balance

Site	Q 4/20-10/18 cfs season	Q 4/20-6/30 cfs early	Q 7/1-10/18 cfs late	Sum of Inputs and Diversion / Relative % Difference		
Yakima at Nelson Rd	**752**	**1235**	**441**			
Cle Elum River	1453	1357	1522			
Crystal Creek	2.2	4.8	1.3			
Cle Elum WWTP	0.8					
Teanaway River	706	1573	144			
Swauk Creek	70.5	156	15			
Westside Canal	-85	-91	-82			
Taneum Creek	64	136	17			
Yakima River at Thorp	**2909**	**4013**	**2194**	2964	4371	2058
Town Canal	-111	-115	-108	-1.9%	-8.5%	6.4%
Cascade Canal	-84	-77	-89			
Dry Creek	20					
Packwood Ditch	50	51	50			
Yakima River at KOA	**3056**	**4448**	**2145**	2784	3872	2047
Manastash Creek	56	119	15	9.3%	13.8%	4.7%
Ellensburg WWTP	5.5					
Reecer Creek	30	29	31			
Yakima River at Irene R.	**3131**	**4522**	**2240**	3148	4596	2191
Fogerty/Sorenson	44	51	39	-0.5%	-1.6%	2.2%
Wilson/Cherry	537	788	380			
Yakima at Umtanum	**3500**	**4877**	**2636**	3712	5361	2659
Roza Canal	-1615	-1830	-1475	-5.9%	-9.5%	-0.9%
Wenas Creek	25	60	3.3			
Yakima at Harrison Bridge	**1900**	3100	1134	1910	3107	1164
				-0.5%	-0.2%	-2.6%

1999 TSS Load Balance Using Beales Estimator Values

Site	TSS 4/20-10/20 Tons/day season	TSS 4/20-6/29 Tons/day early	TSS 7/1-10/20 Tons/day late	Sum of Inputs and Diversion / Relative % Difference		
Yakima at Nelson Rd	**14**	**28**	**3**			
Cle Elum River	5.8	7.5	4.8			
Crystal Creek	0.03	0.06	0.04			
Cle Elum WWTP	0.12					
Teanaway River	77	188	0.9			
Swauk Creek	6.4	15	0.07			
Westside Canal	-2.7	-5.9	-0.8			
Taneum Creek	4	10	0.2			
Yakima River at Thorp	**132**	**278**	**24**	105	243	8
Town Canal	-3.6	-7.1	-1.1	23%	14%	98%
Cascade Canal	-2.7	-5	-0.9			
Dry Creek	0.11					
Packwood Ditch	1.2	1	1.2			
Yakima River at KOA	**164**	**340**	**35**	127	267	23
Manastash Creek	4.4	10	0.4	25%	24%	41%
Ellensburg WWTP	0.05					
Reecer Creek	0.5	0.7	0.3			
Yakima River at Irene R.	**145**	**288**	**37**	169	351	36
Fogerty/Sorenson	3.2	6	1.1	-15%	-20%	4%
Wilson/Cherry	71	132	31			
Yakima at Umtanum	**215**	**399**	**79**	219	426	69
Roza Canal	-88	-160	-47	-1.9%	-6.5%	13.4%
Wenas Creek	3.9	10	0.05			
Yakima at Harrison Bridge	**131**	**271**	**27**	131	249	32
				0.1%	8.5%	-17.1%

1999 TSS Load Balance Using Average Regression Values

Site	TSS 4/20-10/20 Tons/day season	TSS 4/20-6/29 Tons/day early	TSS 7/1-10/20 Tons/day late	Sum of Inputs and Diversion / Relative % Difference		
Yakima at Nelson Rd	**20**	**47**	**2.2**			
Cle Elum River	4.9	6.3	3.9			
Crystal Creek	0.021	0.048	0.003			
Cle Elum WWTP	0.12					
Teanaway River	69	173	0.8			
Swauk Creek	4.9	12	0.1			
Westside Canal	-2.8	-6.0	-0.7			
Taneum Creek	5.5	14	0.2			
Yakima River at Thorp	**157**	**370**	**21**	101	247	7
Town Canal	-3.8	-8.3	-0.9	43%	40%	103%
Cascade Canal	-2.5	-5.2	-0.7			
Dry Creek	0.1	0.1	0.1			
Packwood Ditch	1.2	1.2	1.2			
Yakima River at KOA	**209**	**478**	**34**	152	358	20
Manastash Creek	3.5	8.4	0.4	31%	29%	51%
Ellensburg WWTP	0.05					
Reecer Creek	0.5	0.7	0.3			
Yakima River at Irene R.	**134**	**281**	**40**	213	487	35
Fogerty/Sorenson	2.7	4.1	1.6	-46%	-54%	14%
Wilson/Cherry	68	117	37			
Yakima at Umtanum	**240**	**486**	**89**	205	402	78
Roza Canal	-90	-160	-48	15.9%	19.0%	12.8%
Wenas Creek	2.8	7.5	0.05			
Yakima at Harrison Bridge	**120**	**261**	**29**	153	334	41
				-24.0%	-24.4%	-34.4%