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A Collaborative Model Process to Examine Temperature TMDL's and Related Remediation Strategies for the Willamette Basin

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Abstract

Water managers in the Willamette River Basin face a number of difficult and closely interrelated challenges associated with the Endangered Species Act (ESA), the Clean Water Act (CWA), and other associated concerns. For example, under the CWA, the Oregon Department of Environmental Quality (ODEQ) has recently released a total Maximum Daily Load (TMDL) for temperature in the Willamette Basin. Considerable public planning has already been accomplished in the basin with much of the assessment and planning phases for solving some of the basin's problems codified in the temperature TMDL. Some of the major factors impacting temperature in the Willamette include operation of the multiple reservoirs, permitted industrial and municipal discharges, land-use types, and irrigation practices. Possible mitigation strategies include changes in land-use to increase shading along streams, installations to cool or store point-source discharges, changes in how and when water is released from the reservoirs, installation of multi-port withdrawal structures on the reservoirs, and remediation of riparian and hyporheic zones. Each of these strategies comes with ecological, economic, and/or social costs and/or benefits that must be weighed and understood before meaningful dialogue about how to best manage the basin can occur. To address this problem a collaborative team from Sandia National Laboratories, the Institute for Water Resources, David Evans and Associates, and the Portland District of the Corps of Engineers have been working with stakeholders in the basin to design and collaboratively develop an integrated temperature model of the basin to examine the linkages between the various strategies and their tradeoffs. The model consists of a series of systems dynamics lumped parameter models that provides real-time feedback and scenario testing capabilities, as well as the ability to link disparate systems such as hydrology, ecosystem services, recreation, and economics. This presentation will describe the collaborative process in which the model was developed as well as demonstrate the model itself and how it is being used to influence and inform policy decisions in the basin.

Introduction

The Willamette River is the 13th largest river in the continental United States in terms of stream flow and produces more runoff per unit area of land than any of the 12 larger rivers. Water managers in the Willamette River Basin in Oregon face a number of difficult and closely interrelated challenges associated with the Endangered Species Act (ESA), Clean Water Act (CWA), and other associated concerns. Under the CWA, Oregon Department of Environmental Quality (ODEQ) has recently released a final Total Maximum Daily Load (TMDL) for the Willamette Basin. Considerable public planning has already been accomplished in the basin with much of the assessment and planning phases for solving some of the basin's problems codified in the TMDL. In response to the TMDL, many stakeholders in the basin will be required to undertake significant actions to address temperature loading and other water quality issues over the next few decades.

Between 1941 and 1969, the United States Army Corps of Engineers (USACE) built 13 water storage reservoirs on tributaries to the Willamette River to mainly provide flood control, with power generation and irrigation water serving as secondary benefits. Through the operation of its multiple reservoirs on the Willamette, the USACE is a major player in water management in the basin, with significant impacts on temperature loading and other ecological processes essential to the formation and maintenance of fish and wildlife habitats. Reservoir operations play a determining factor in the quantity and quality of water in the Willamette, and hence on the heat load that is permitted by other sources under the TMDL.

To engage in a discussion about management of the basin, modeling tools were needed that can link multiple factors such as water temperature, point source discharges, shading, fish habitat, and economic impacts at different locations throughout the basin. Leveraging funding from multiple sources, the Willamette Partnership, the USACE Institute for Water Resources (IWR), the USACE Portland District, Sandia National Laboratories (SNL), and David Evans and Associates have formed a Willamette Basin Collaborative Modeling project team to work with the basin stakeholders through the Willamette Partnership to collaboratively design and develop an integrated model of the Willamette System. The objective of the Willamette Basin Collaborative Modeling project is to facilitate a common understanding of the hydrology of the system and its linkages to temperature and other ecological concerns in the basin. The Collaborative Modeling project supports the Willamette Partnership's project to develop an ecosystem marketplace where water quality and conservation credits can be traded.

Although the hydrology serves as the backbone to the modeling effort, the collaboratively-developed model is broadly applicable to other management questions in the basin and includes modules to quantify site specific and basin wide biophysical and socioeconomic responses to various management alternatives in units of measure relevant to individual drivers (CWA, ESA, wetland mitigation, etc.). To fully address these questions, a systems dynamics approach has been adopted for the modeling to allow for the evaluation of the various delays and/or feedbacks that may impact the overall system.

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This paper describes the collaborative process in which the model was developed as well as the model itself, and how the model will be used to influence and inform policy decisions in the basin.

Modeling Objectives

The systems dynamics modeling tools are designed to provide screening level accuracy to test and evaluate various management scenarios. The tools provide real-time feedback through an easy to use interface that will allow for stakeholder interaction with the models. The models capture the important physics of the basin's heat and water budgets to help users better understand the linkages between hydrology and temperature as well as the impacts of different management strategies. Due to the importance of the temperature-flow interactions in the basin, the initial development of the modeling tools began by only addressing hydrology, temperature, and anthropogenic influences on the reservoirs and rivers. Later phases have added capabilities such as simulating changes to nutrient loading and carbon uptake due to riparian shading, economic costs of the various remediation efforts, power generation, and impacts on recreational opportunities and the corresponding economic addition to the region from those activities.

Plan and Framework

To establish the TMDL restrictions, the ODEQ contracted the development of a series of temperature and flow models using the CE-QUAL-W2 code [*Annear, et al.*, 2004; *Cole and Wells*, 2006]. The Willamette Basin TMDL model is actually a series of 9 separate models based on the major sub-basins (Clackamas, Coast Fork, Long Tom, Lower Willamette, McKenzie, Middle Willamette, North Santiam, South Santiam, and Upper Willamette). Where reservoirs exist in a sub-basin, they form the upper boundary condition for that CE-QUAL-W2 model. The systems levels models developed here are also based on the 9 major sub-basins but include temperature simulations and operation rule setss of the reservoirs. Algorithms describing the impact of different remediation efforts (riparian zone restoration, planting of streamside vegetation, etc.) are also be included.

For both the river and reservoir models, heat flows are simulated to be from gauged and un-gauged tributaries, municipal and industrial outfalls, rainfall, shortwave solar radiation, longwave radiation (in and out), convective heat loss, and evaporative heat loss. In many cases, the true impacts of restoration activities are not well quantified. In these cases, an assumption is made that the general understanding is good enough that we can at least compare one strategy against another (as opposed to predicting an exact impact). This is an agreement made by the stakeholder group.

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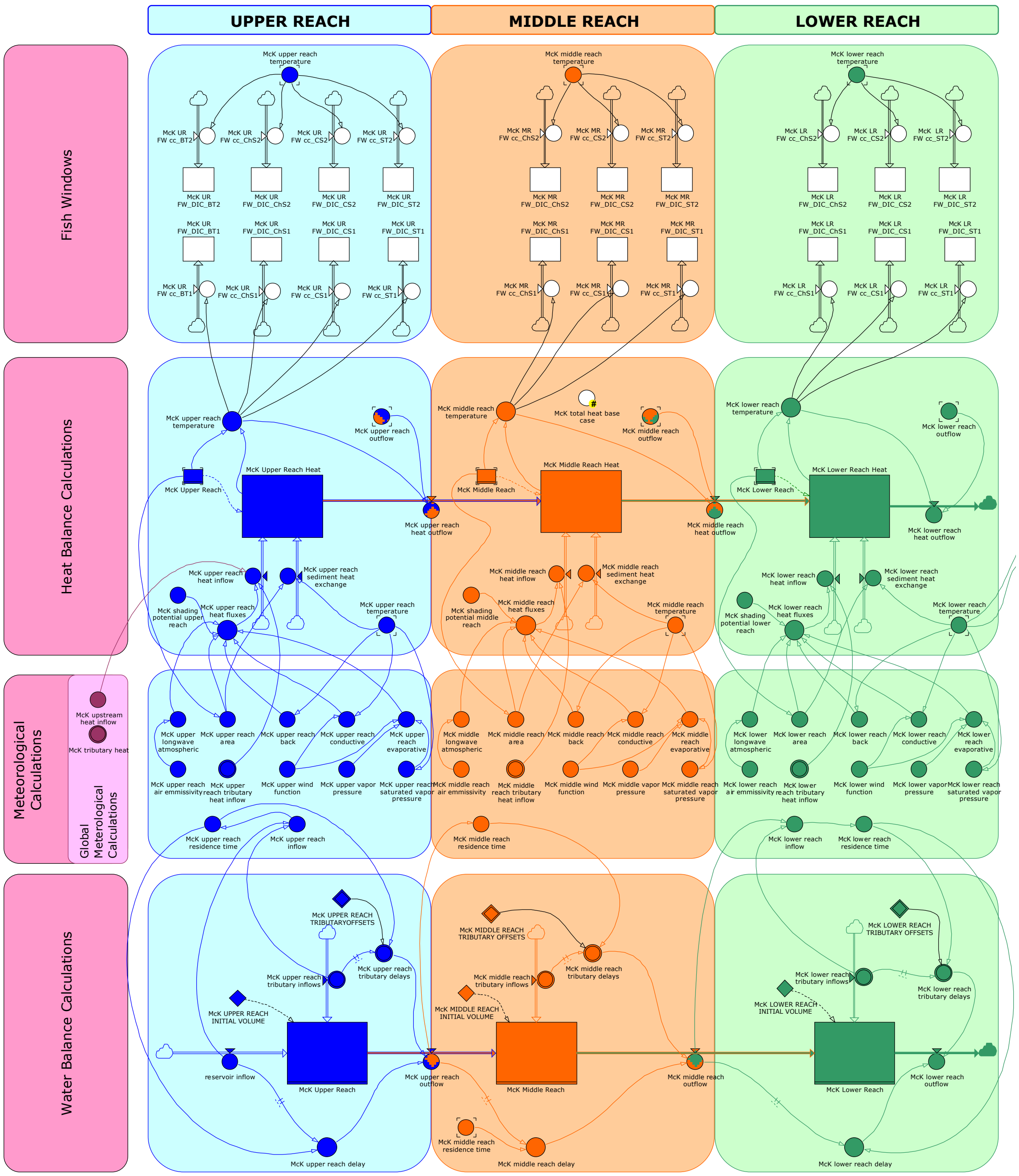

Figure 1 - Screen shot of river hydrologic module built in the Powersim environment.

The integrated systems dynamics tool has been developed in the Powersim framework (Figure 1), which allows for greater flexibility in modeling additional systems (e.g. economics, demographics, reservoir operation rules, etc.) as well as provides a means for developing user-friendly interfaces that can provide real-time feedback to the user (Figure 2). The final users of the tool are non-modelers who will interact and use the models under the guidance of the model developers.

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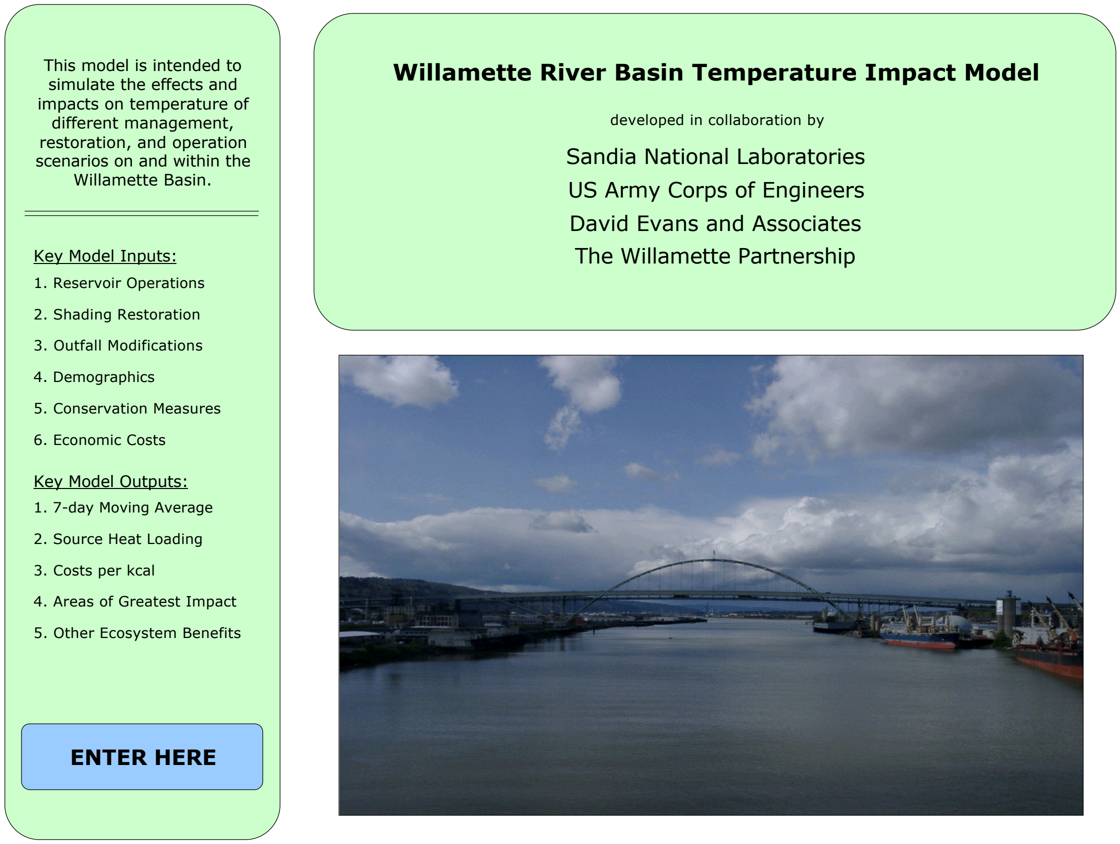

To maintain consistency and avoid redundancy with past efforts, we used the CE-QUAL-W2 models that were developed for establishing the ODEQ TMDL requirements as the foundation for the systems level models [*Annear, et al.*, 2004; *Cole and Wells*, 2006]. Several important differences between the systems level approach and the CE-QUAL-W2 models are:

Figure 2 – Example screen-shot of the Willamette Basin systems dynamics tool opening page.

1. The systems level models utilize POWERSIM as the development environment.
2. The systems level models include upstream reservoirs as part of the calculations. The CE-QUAL-W2 TMDL models use the outflow from the reservoirs as the upper boundary condition for each tributary.
3. The systems level models are lumped parameter models, meaning that each water body is represented as a single volume of water. The CE-QUAL-W2 TMDL model of the McKenzie River has over 400 separate reaches.
4. The systems level reservoir models are 1-dimensional in the vertical direction meaning lateral and longitudinal variations are assumed to be negligible. The CE-QUAL-W2 TMDL models do not include the reservoirs.
5. The systems level reservoir model incorporate reservoir operation rule-sets as part of the input parameter set to simulate USACE operations on the system.
6. The systems level models include processes and inputs that reflect the impact of different restoration and remediation efforts.
7. The systems level model includes mechanisms for evaluating the plausibility and usefulness of an ecosystem market place and provides a basis for the design of the market place if it is deemed feasible.

For the project, we have identified three tiers of models that were used. Each tier has been identified based on its level of resolution (both spatially and temporally), what questions they can answer, and the level of expertise needed to run the models. The tiers have been structured to become progressively more detailed and to have the ability to link with the models in other tiers.

- *Tier I – Conceptual Model.* The conceptual model describes how different elements of the Willamette affect each other in qualitative terms, how the collaborative process engages stakeholders, and serves as a framework for developing the systems dynamics models (Tier II). The original intent was to develop the conceptual models collaboratively to engage stakeholders to specify their objectives for Willamette management and increase their understanding of how the different elements of the Willamette system interact with the stakeholders. After an initial workshop with stakeholders on conceptual model development, further input from the stakeholders was assigned to an independent Technical Advisory Group (TAG). Made up of modeling experts from the region that are familiar with the Willamette basin, the TAG's main responsibility is to review the modeling process to ensure that technical information, understanding, and relevant questions are incorporated in the more detailed models (Tiers II and III). Periodic (semi-annual) workshops with the full stakeholder group were also conducted to elicit input on alternative development and evaluation by engaging stakeholders with the models using "what-if" scenarios.

- *Tier II – Systems Level Planning Model.* The Tier II model includes the systems level models discussed and quantifies the linkages identified in the Tier I conceptual model to provide information that is relevant to the needs of the decision makers. Final versions of the Tier II model includes a graphical user interface for both data input and visualizing output, as well as linkages to the higher resolution Tier III models. The Tier II model will be used to develop management strategies and policy options, evaluate the usefulness and plausibility of the ecosystem market place, and to simulate impacts due to changes in reservoir operations. The TAG's have supported the development of the Tier II models by guiding the core modeling team with regards to sourcing data, giving advice on processes important to the Willamette Basin, and reviewing the models themselves.

- *Tier III – Detailed Numerical Models.* The development of an integrated, collaborative planning model (Tier II) does not obviate the need for a more detailed analysis of components of the system. In many cases detailed numerical (Tier III) models of components of the Willamette already exist (e.g. CE-QUAL-W2, HEC ResSim). Instead, the Tier II planning models will make use of the existing analyses either directly, or in a reduced form, as needed by the analysis. The integrated, Tier II models are able to test the sensitivity of the stakeholder objectives and performance metrics to various model components and help focus efforts on those components where a high-level of precision is most important. Development of detailed numerical models of the Willamette, have not been the focus of this effort.

Work Group Participation

To facilitate the development of the water quality modeling tools that serve as the backbone to the integrated modeling process, an initial water quality TAG has been formed that consists of local experts who have experience in modeling temperature dynamics on the Willamette. The TAG serves in an advisory role to guide and help the core modeling team (CMT) during the model development process, as well as to review the finished models to ensure that they meet the intended goals of the project in a scientifically defensible manner. This review process has built a level of confidence with the stakeholders that the models can be trusted for their intended use. In addition, the TAG may direct the CMT on where to source data for the project, as well as provide background information regarding past studies and investigations that could be important to this work. The TAG frequently interacted with the CMT on a regular basis via conference calls and/or web-based meetings.

Results

The simulation time encompasses the entire year of 2001, which corresponds to the CE-QUAL-W2 TMDL modeling timeframe (The CE-QUAL-W2 TMDL models simulated May-October for 2001 and 2002, while the timeframe of this effort is January-December for 2001). The reservoir models were calibrated to temperature outflow from either USGS gauging stations immediately downstream of the reservoirs or USACE data at the reservoir, as well as to vertical profile data for the reservoirs where those data exist. Calibration plots for Foster, Green Peter, and Cougar reservoirs are shown in Figure 3 (Foster and Green Peter reservoirs are on the South Santiam River, Cougar is on the McKenzie River). Rivers are modeled as 2 to 3 lumped parameter reaches ranging from 5 to 30 river miles long. The rivers are calibrated to the 7-day average daily maximum temperature (7dADM) output from the CE-QUAL-W2 TMDL models at the point

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furthest downstream in the model. Calibration plots for the South Santiam and McKenzie rivers are shown in Figure 4. Example output from the reservoir recreation module is shown in Figure 5.

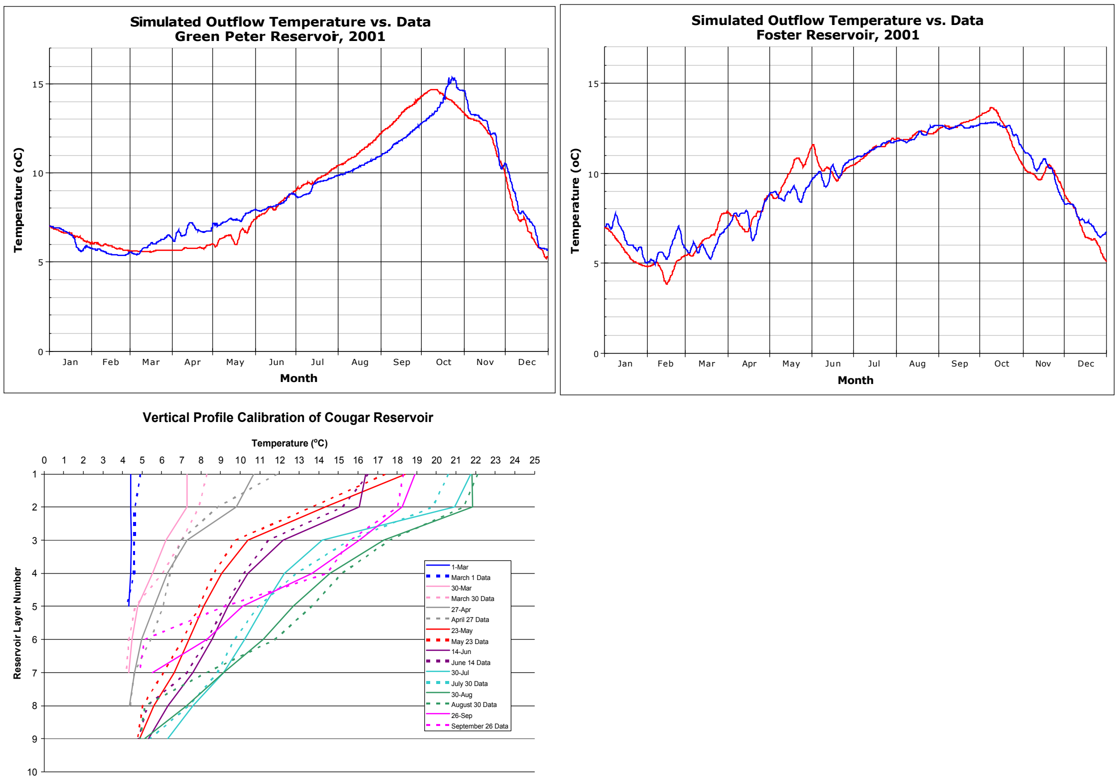

Figure 3 - Calibration plots for outflow temperature from Foster and Green Peter Reservoirs, and for vertical temperature profiles from Cougar Reservoir.

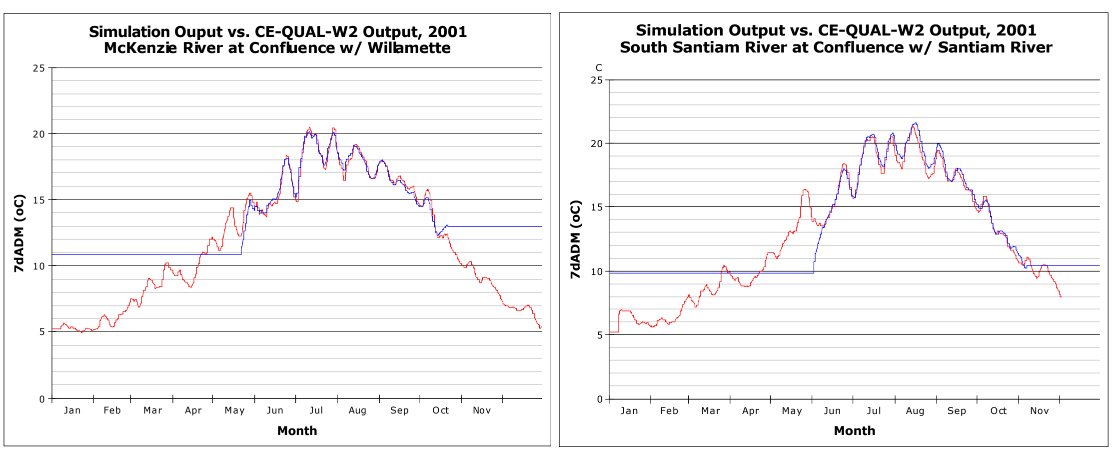

Figure 4 - Calibration plots for 7dADM for McKenzie and South Santiam Rivers.

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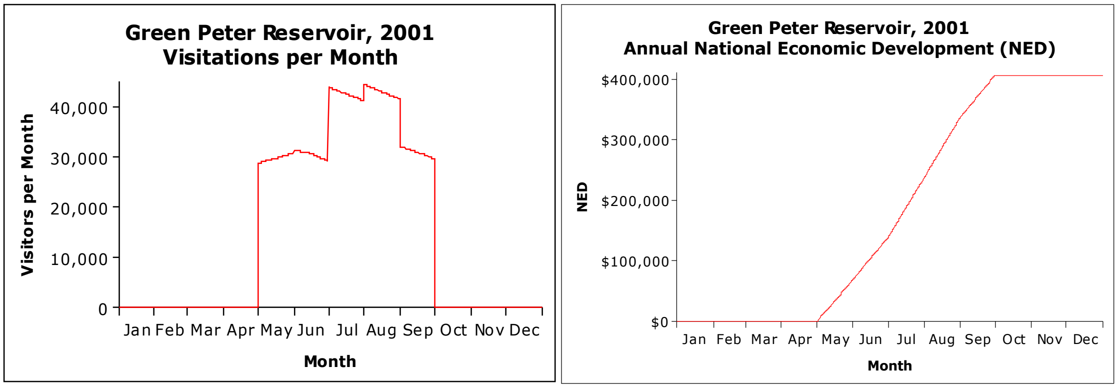

Figure 5 - Visitations per month and the resulting national economic development (NED) for Green Peter Reservoir in 2001. Reservoir visitations are calculated from May through September.

References:

Annear, R., M. McKillip, S. J. Khan, C. Berger, and S. A. Wells (2004), Willamette River Basin Temperature TMDL Model: Boundary Conditions and Model Setup, 553 pp, Portland State University.

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