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The Integrated Basin-Scale Opportunity Assessment Initiative, FY 2012 Year-End Summary of Activities

S Geerlofs, J Tagestad, K Ham, N Voisin, S Kallio

September 2012



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Pacific Northwest National Laboratory
Richland, Washington 99352

Abstract

This document reports on FY 2012 work carried out by Pacific Northwest National Laboratory for the Basin Scale Opportunity Assessment Initiative. Project partner, Oak Ridge National Laboratory is submitting a separate deliverable under a different cover. This progress report provides a brief summary of activities; final project results for the Deschutes Basin pilot assessment will be presented in January 2013.

Acronyms and Abbreviations

ANL	Argonne National Laboratory
BOR	Bureau of Reclamation
BSOA	Basin-Scale Opportunity Assessment
CADSWES	Center for Advanced Decision Support for Water and Environmental Systems
Corps	U.S. Army Corps of Engineers
DOE	U.S. Department of Energy
FY	fiscal year
NRCE	Natural Resources Consulting Engineers, Inc.
ORNL	Oak Ridge National Laboratory
OWRD	Oregon Water Resources Department
PNNL	Pacific Northwest National Laboratory
TNC	The Nature Conservancy
USGS	United States Geological Survey
VIC	Variable Infiltration Capacity (model)

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1.0 Introduction

Assessing hydropower and environmental performance at the scale of an entire river basin is intended to identify opportunities that rely upon integration across facilities and among management efforts. The benefits to energy and basin-wide environmental conditions that are possible from such a basin-level approach are almost certain to exceed those available from a location-specific approach. Shared resources reduce costs, and shared benefits encourage strong partnerships.

The U.S. Department of Energy's (DOE's) Wind and Water Power Program provided funding to Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL), and Argonne National Laboratory (ANL) (collectively referred to as the "project team") to develop an approach to basin-scale hydropower and environmental assessment that emphasizes sustainable, low-impact or small hydropower and related renewable energies within the context of basin-wide environmental protection/restoration. Called the Integrated Basin-Scale Opportunity Assessment Initiative (BSOA Initiative or "Initiative"), the assessment is one of seven action items of the March 24, 2010 Memorandum of Understanding (MOU) for Sustainable Hydropower between the U.S. Department of Energy (DOE), the Department of the Interior (through the Bureau of Reclamation), and the Department of the Army (through the U.S. Army Corps of Engineers).

The report describes Initiative activities from October 2011 through September 2012 focusing on work in progress to complete the Initiative's first pilot study in the Upper Deschutes/Crooked River in central Oregon. Final project results from the Deschutes Basin pilot study will be reported in January 2013.

1.1 Fiscal Year 2012 Work Plan and Objectives

Figure 1.1 depicts the overarching process for the initial two years of the BSOA Initiative. Work carried out in FY 10 and FY 11 was documented in last year's Preliminary Assessment Report, available at basin.pnnl.gov. In FY 12 PNNL and ORNL focused efforts and carrying out an analysis of opportunities for hydropower and environmental improvements in the Deschutes basin, as identified through stakeholder workshops, site visits, and literature review. Analysis activities focused on powering non-powered dams and Wickiup and Bowman dams, water management scenarios to improve peaking at value at Pelton-Round Butte, and adding new small hydro in irrigation canals and conduits. Environmental benefits associated with these activities focused largely on analysis of water management scenarios to enhance flow in areas identified by stakeholders as impaired during all or specific times of the year. Technical activities centered on improving operational modeling capabilities in the basin to move towards a daily time step RiverWare-based model to allow examination of proposed hydropower and stream flow enhancement scenarios, how opportunities relate to one another, and how opportunities impact other existing water users and values in the basin (primarily, risk to irrigation allocations).

This report details three aspects of PNNL's analysis activities:

1. Development of opportunity scenarios
2. Enhancement of hydrology and operational modeling in the basin

3. Development of a web-based platform to allow for collaborative exploration of modeling scenarios, modeling data, and other data to support opportunity assessment.

The focus of assessment activities was not to supply specific recommendations to basin stakeholders, but rather to provide a forum and tools to allow for visual and collaborative examination of the tension and opportunity space between opportunities, and where opportunities begin to impact other water uses in the basin. The intent of this is to inform ongoing stakeholder dialog around actions in the basin that could result in improved environmental conditions, new revenue sources from small hydropower, and support for healthy agricultural and municipal communities.

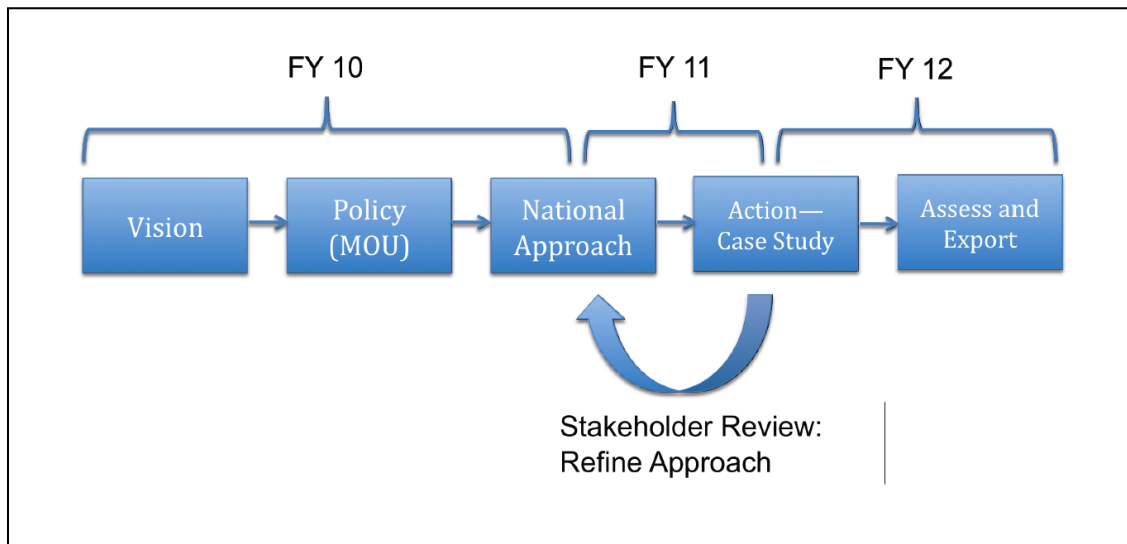


Figure 1.1. Overarching Process for First Two Years of the Integrated Basin-Scale Opportunity Assessment Initiative

1.2 Summary of FY 2012 Activities in the Deschutes Basin

In 2012, PNNL made significant progress in developing tools necessary to assess hydropower and environmental opportunities at the basin scale in the Upper Deschutes/Crooked River Basin. The project team had intended to complete Deschutes analysis activities by September 30, 2012, but due to late receipt of funds at both PNNL and ORNL, milestones and deliverables were shifted back by one quarter. Completion of the Deschutes pilot is on track for January, 2013.

By September 2012 the following tasks are completed or underway:

- Completed opportunity scenarios, in collaboration with basin stakeholders.

- Hosted a technical workshop at PNNL attended by ORNL, BOR, the Deschutes River Conservancy, and Oregon Department of Water Resources to assess the current status of modeling capabilities and tools in the basin and chart a path forward for modeling tools needed to answer questions associated with the opportunity assessment pilot.
- Hydrology and inflow modeling complete—Partnered with the BOR and basin stakeholders to update the basin’s existing MODSIM monthly operational model, as well as calculate inflows in the upper basin to improve modeling at the daily scale.
- Partnered with CADSWES and BOR to develop a daily RiverWare model for the basin in order to assess opportunity scenarios. By September 30th, this activity was 80% complete—improving rules-based simulation and ground water response continues into October, with the model runs expected by the end of the month.
- Designed the web-based visualization platform and opportunity dashboard and tradeoff analysis tool. Final coding of the visualization platform is underway as of October. Model runs will flow into the visualization platform and stakeholders will interact with data and scenarios at a planned January workshop in Bend OR.
- Interviewed small hydro developers and stakeholders to inform an descriptive analysis of the process by which in-conduit and small hydro projects move from identified opportunity to completed project. This analysis focuses on the interplay between environmental goals (conserve water projects and canal piping) and new revenue streams from small hydropower. This task will also be completed in January 2013.
- Met with stakeholders in the basin over webinar and one in-person meeting in Bend in order to refine our approach and select metrics for opportunity analysis scenarios.

The balance of this report describes scenarios, modeling, and visualization activities in greater detail.

2.0 Scenarios

2.1 Opportunities to Increase the Benefits Derived from Water Resources

Water resources in the upper Deschutes and Crooked River Basins have a history of intensive management to provide benefits to numerous stakeholders. One goal of the Basin Scale Opportunity Assessment (BSOA) is to identify opportunities to increase power, environmental, and other benefits of the available water resources. Key resources have been identified and mapped and strategic opportunities have been developed through analysis and from stakeholder input. In addition to opportunities such as powering non-powered dams, installing in-conduit and in-canal generation, and firming conventional hydropower, there are opportunities to be evaluated that improve environmental conditions for fish or improve the reliability of water for municipal or irrigation use. Models of the river system will be used to simulate how opportunities alter the system and the beneficial and adverse effects that accrue from that alteration. The results will help basin stakeholders visualize how opportunities interact and at what point changes in operations begin to affect other uses.

2.2 Scenarios

A scenario is defined as a compilation of opportunities to alter water management to provide a different mix of benefits to stakeholders. To fulfill the objectives of the BSOA, each scenario will include hydropower and environmental opportunities. Scenarios will also include other aspects of water use that are of interest to stakeholders or that are closely linked to the other objectives. Each scenario will define how the system is to be configured and an operational framework. By simulating the implementation of the alternate configuration and operation, each scenario can be compared with the baseline. The fundamental scenarios for this assessment include a baseline scenario, a scenario that captures the identified opportunities on the Deschutes River, and another that captures the identified opportunities on the Crooked River. Within each fundamental scenario, selected management actions are explored in greater detail through a process termed scoping. Scoping evaluates a range of possibilities for selected water management actions by simulating a number of levels within boundaries that extend slightly beyond the expected range of operations. Scoping is intended to identify the portion of the range where only moderate tradeoffs are required and benefits to multiple stakeholders accrue. Once the initial scoping is complete, scenarios will be refined and combined to achieve the basin-scale objectives.

2.2.1 Scenario 1: Baseline

This scenario assumes current water management practices are implemented. As such, it does not include any opportunities to change water management for increased benefits. This scenario will be simulated, used for model calibration, and will serve as the point of comparison for other scenarios. The entire upper Deschutes River Basin is included, but subsets will be used for comparison to the sub-basin scale scenarios.

2.2.2 Scenario 2: Deschutes River: Integrated

This scenario will focus on opportunities within the Deschutes River. The opportunities to be evaluated within this scenario revolve around adding hydropower generation at upstream reservoirs and in irrigation canals and conduits, improving generation at existing facilities, instream flow enhancements, water conservation, and potentially others. The primary opportunities are:

2.2.2.1 Hydropower

Adding Generation at

- Wickiup Dam
- Crane Prairie Dam
- Crescent Dam
- Multiple locations on irrigation canals or conduits
- Maintaining or increasing generation at Juniper Ridge (route North Unit ID water through COID diversion generator)
- Improving scheduling of Pelton Round Butte power generation to match daily peak power demand cycles in conjunction with timing upstream reservoir releases should be reviewed.

2.2.2.2 Environment

Approaching or meeting instream flow objectives in the upper Deschutes River through altering timing of releases at Wickiup Dam

This scenario element will be incorporated into the model by setting a range of flow targets to be evaluated within two reaches: 1) the Deschutes River between Wickiup Reservoir and the confluence with the Little Deschutes River, and 2) the Deschutes River between North Canal Dam and Lake Billy Chinook. The flow targets at specific locations (e.g., gage locations) will be inserted into the model as objectives. The model will then be run for the period of record, and the results will report whether or not the flow objectives could be met. The summary will include the percent of time that each flow objective was met over the period of record — including analyses of outcomes in dry, normal, wet years, and combinations of these water year types.

The flow targets to be modeled include:

1. The Deschutes River between Wickiup Reservoir and the confluence with the Little Deschutes River (WICO gage location)
 - a. An increase in discharge during the non-irrigation season (mid-October through late-March) from the baseline condition to 300 cfs in approximately 75 cfs increments, and

- b. A decrease in discharge during the irrigation season (late-March through mid-October) from the baseline condition – the magnitude of this decreased discharge is not specified, but will be reflected from the water conservation targets identified below
- 2. The Deschutes River between North Canal Dam and Lake Billy Chinook (DEBO gage location)
 - a. A decrease in discharge during the non-irrigation season (mid-October through late-March) from the baseline condition – the magnitude of this decreased discharge is not specified, but will be reflected from the water use changes identified below, and
 - b. An increase in discharge during the irrigation season (late-March through mid-October) from the baseline condition to 250 cfs in approximately 50 cfs increments

2.2.2.3 Water Use

Water can be conserved with efficiency improvements such as lining irrigation canals or installing piping. These activities are also potentially linked to the development of power in conduits or canals and to instream conservation programs that could help fund the improvements. Additional opportunities include exploring potential power and instream benefits of alternate irrigation water routing (such as described for Juniper Ridge above).

This scenario element will be incorporated into the model by setting a range of water conservation targets. These targets will be modeled by assuming a range of decreases in irrigation water demand from Wickiup Reservoir. The amount of storage required for irrigation demand will be reduced 20% from baseline condition in increments of 5%. The assumed water conservation reductions will be applied proportionally to the irrigation water supplied to each irrigation district.

2.2.2.4 Scoping

Within the framework defined by the opportunities listed above, there is still much flexibility in how benefits might be achieved. Scoping is a process by which the range of possible benefits from water management options will be explored. The objective is to identify natural breakpoints where tradeoffs intensify, and thereby identify ranges where only moderate tradeoffs arise. In this scenario, we foresee evaluating costs and benefits for instream flow objectives ranging from baseline to the instream water right and for a small number of levels of water efficiency improvements that might reasonably be available through canal lining or piping. Scoping may also evaluate other factors identified during further definition of the scenario.

2.2.3 Scenario 3: Crooked River Sub-basin: Integrated

This scenario will focus on opportunities within the Crooked River subbasin. The opportunities to be evaluated within this scenario revolve around adding hydropower generation at upstream reservoirs and in irrigation canals and conduits, improving generation at existing facilities, instream flow enhancements, and water conservation.

2.2.3.1 Hydropower

There are two primary opportunities.

1. Adding Generation at:
 - Bowman Dam (~5MW)
 - Ochoco Dam (?MW)
 - Locations on irrigation canals or conduits
2. Improving the scheduling of Pelton Round Butte power generation to match daily peak power demand cycles in conjunction with timing upstream reservoir releases should be reviewed. A portion of the increased revenue could support water conservation and habitat restoration projects in the basin

2.2.3.2 Environment

Approaching or meeting instream flow objectives in the Crooked River will be investigated through altering the timing of releases at Bowman and Ochoco Dam. Both anadromous fish and coldwater fish are expected to benefit. Movement toward these objectives would enhance flow through Smith Rocks Park and Wild and Scenic reaches of the Crooked River. Additional opportunity exists by using Ochoco ID water in place of Mackay Creek withdrawals to improve steelhead habitat.

This scenario element will be incorporated into the model by setting a range of flow targets to be evaluated in the Crooked River reach between the Crooked River Feed Canal (RM 56) and Highway 97 (RM 18). Flow targets in this reach will be set at the CKKO/CSRO gage. When modeling these flow targets as objectives, the existing baseline conditions and objectives for other water users will remain unchanged. These baseline objectives include water allocated to the City of Prineville, irrigation water supply, and existing reservoir water surface elevations for flood control and flatwater recreation. The flow targets to be modeled include an increase in discharge from the baseline condition to 140 cfs in approximately 20 cfs increments.

2.2.3.3 Water Use

The water use opportunities include conserving water through efficiency improvements such as lining irrigation canals or installing piping, while ensuring the reliability of irrigation and municipal water supply. Evaluating the release timing of unallocated water in Prineville reservoir may provide various benefits such as maintaining the reliability of irrigation water supply, instream flows, flatwater recreational opportunities, or hydropower generation.

This scenario element will be incorporated into the model by setting a range of water conservation targets. These targets will be modeled by assuming a range of decreases in irrigation water demand from Prineville Reservoir. The amount of storage required for irrigation demand will be reduced 20% from baseline condition in increments of 5%. The assumed water conservation reductions will be applied proportionally to the irrigation water supplied to each irrigation district.

2.2.3.4 Scoping

Within the framework defined by this scenario, there is still much flexibility in how benefits might be achieved. Scoping is a process by which the range of possible benefits from water management options will be explored. The objective is to identify natural breakpoints where tradeoffs intensify, and thereby identify ranges where only moderate tradeoffs arise. While there are other factors that may require scoping, the primary need is to evaluate the benefits of directing unallocated water within Prineville Reservoir to various uses. By simulating a range of possibilities, it should be possible to identify what tradeoffs arise and how often they are important. Scoping may also evaluate other factors identified during further definition of the scenario.

One possible result of the scoping process is the identification of one or more ranges of water management actions that have a favorable mix of costs and benefits. Those ranges would be used either to refine the main scenario, or to create alternate scenarios for comparison.

2.2.4 Scenario 4: Upper Deschutes River Basin

This scenario combines Scenarios 2 and 3 and integrates the opportunities and outcomes for a basin-scale result. The opportunities to be evaluated within this scenario will be based upon the results of simulation and scoping of the Deschutes and Crooked river sub-basins. While the basins are managed with relative independence, there may be some limitations or opportunities that are revealed in the combined scenario.

2.3 Remaining Work and Expected Outcomes

If scoping identifies more than one promising management approach within a scenario, those approaches will be split into alternate scenarios. Once a final set of scenarios has been developed, they will be simulated with the monthly and daily river models. The results of those simulations will be incorporated into visualization and decision support tools that allow stakeholders to understand, evaluate, and compare the management options and expected benefits of those scenarios. There will be a flexible set of tools for visualizing many aspects of the scenarios, including a “dashboard” of metrics defined by stakeholder interests. The dashboard metrics will distill the simulated results for each scenario into a few higher level representations of costs or benefits. Those interested in finer scale aspects of changes in water management will be able to drill down and compare specific results between scenarios. By comparing a scenario to the baseline or to another scenario, stakeholders should be able to identify scenarios that support their objectives and have some understanding of how other stakeholders are being affected.

Evaluating the Deschutes and the Crooked Rivers in separate scenarios facilitates making progress and interacting with stakeholder groups. Evaluating them in combination in Scenario 4 will ensure that these scenarios represent a basin-scale enhancement and that there is no conflict between the two.

Once again, it is important to note that analysis and scoping of scenarios is not intended to recommend an optimal course of action for the Deschutes basin. It is the intent of this project to enhance existing tools and analyze alternative management options as a means to provide added value to ongoing and future dialog in the basin around water planning decisions.

3.0 Improved Hydrology Modeling to Account for Water in the System

3.1 Description

Potential hydropower generation and environmental improvements are linked to the hydrology of the basin. It is essential for opportunity scenarios to fully account for changes in flow and hydrology in order to understand how hydropower and environmental scenarios affect other water uses. A key outcome of the Deschutes Basin Stakeholder Workshop held in Bend in July of 2011 was the stated need for an improved hydrology model in the basin to allow for accurate and transparent tracking of water.

The overall approach to hydrology and operational modeling activities in the Deschutes Basin in FY 12 consisted of performing a first assessment of existing water resources modeling capabilities in the order to support the initial screening of potential opportunities. Next, a modeling workshop was organized (hosted by PNNL in Seattle, Washington in January 2012) in order to go into further details of the different tools and assess how much we could leverage from the existing modeling capabilities to address the defined opportunities with the proper spatial and temporal scales, and accuracy.

Understanding the hydrology in the Deschutes Basin requires an understanding of both surface water and ground water flows, as well as reservoir operations and water consumptive uses. The end product is an improved understanding of the hydrology in the basin and in particular, human impact on the hydrology and the basin ecosystem. This model serves as a foundational resource for the Basin Scale Opportunity Assessment Pilot project, enabling analysis of opportunity tradeoffs.

In the following sections the modeling tools are described: current status of the hydrology and water resources management modeling of the basin, followed by the development of additional and enhanced modeling capabilities in order to assess hydropower and environmental opportunities.

3.2 Technical Approach

To the extent possible, the technical approach builds on existing models in the basin modified to meet the specific needs of this Opportunity Assessment. The modeling chain includes observed and adjusted or simulated river flow forcing a water resources management model simulating water regulation, transfers and consumptive uses of the system.

3.2.1 Existing Modeling of Water Resources

In January 2012 a modeling workshop was organized by PNNL in Seattle in order to discuss the modeling status of the water resources in the basin and discuss potential improvements and brain storm necessary improvement in the modeling for the BSOA project.

Deschutes MODSIM Development

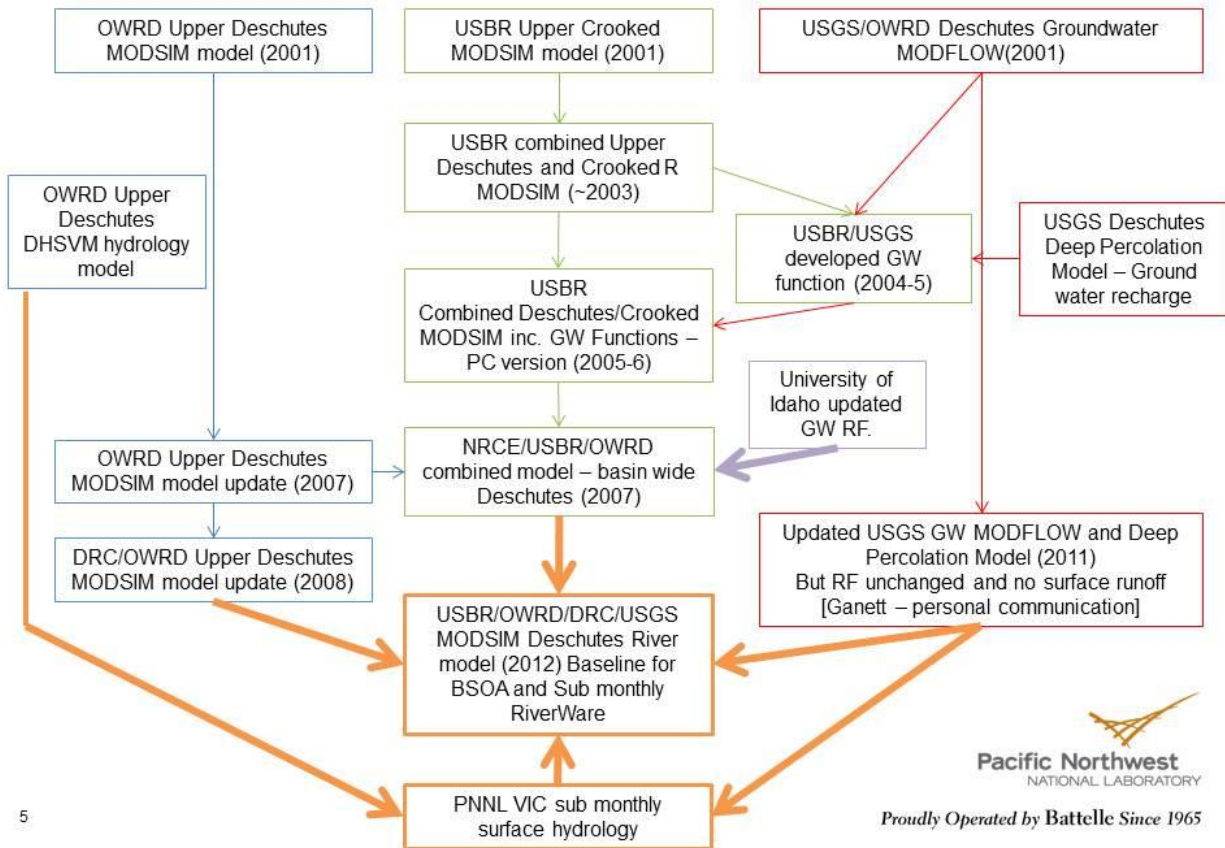


Figure 3.1. Status of the MODSIM set up over the Deschutes River Basin, OR. The orange arrows are the modeling development tasks for BSOA. From MODSIM modeling workshop

The existing operational water resource management is based on model simulations performed using a software called MODSIM (Schafer and Labadie 1979; Labadie 1995). This MODSIM model set up over the entire Deschutes River Basin has been jointly developed as a collaborative effort that has been led by the Confederated Tribes of the Warm Springs Indian Reservation (CTWS), through their consultant Natural Resources Consulting Engineers, Inc., (NRCE), and the sponsorship of Warm Springs Power Enterprises (WSPE) in association with the U.S. Bureau of Reclamation (BOR), the Oregon Department of Water Resources (OWRD), and the U.S. Geological Survey (USGS). This model has been developed for use in planning future water use, development, and potential management strategies in the Deschutes River Basin. It simulates the monthly streamflows and the effects of reservoir operations, irrigation and municipal diversions, and groundwater pumping on the flows of the major streams (Figure 3.1).

The OWRD has developed the initial upper Deschutes model (La Marche 2001) and made some improvements in the model. The USGS developed a MODFLOW model of the basin and has provided oversight for the development of the groundwater response functions in the MODSIM model. BOR developed the groundwater response functions, the initial Crooked River model, and modified and improved the OWRD model. The groundwater response functions were developed by applying stresses in the top layers in the USGS/OWRD MODFLOW model set up over the basin. The response functions represent the groundwater stress mostly due to irrigation practices and canal leakage. The irrigation

extraction from the observed monthly flow and the return flow are already taken into account in the monthly modified flow generated by BOR. The National Resources Consulting Engineers Inc. (NRCE 2007) developed the demands and undepleted flows inputs, and integrated, expanded, and improved existing models into the new MODSIM model (combined Upper Deschutes and Crooked River). They calibrated and verified the model and developed a baseline and a groundwater withdrawal scenario.

In real time mode, the modified observed flow (reconstructed naturalized flow based on observed flow and diversions) and observed reservoir storage are used to initialize the monthly water resource model MODSIM. A simplified ground water model (groundwater response functions) isolates and anticipates the effects of irrigation practices and leaking from canals into downstream water resources. The deep groundwater pumping is assumed to have a long enough response time before reaching equilibrium and is not taken into account in the current MODSIM groundwater module. The MODSIM model, operated by the Bureau of Reclamation, presently allows for water rights accounting, environmental metrics monitoring, and managing diversions amounts.

3.2.2 Modeling Enhancement

Assessing hydropower and environmental scenarios involves a multi-faceted approach built upon the existing integrated modeling tools (Figure 3.2). More importantly, this requires building a sub-monthly time-step appropriate for performing simulations of hydropower scenarios. A system-wide water-balance must first be achieved to ensure that all instances of water flow, water usage, and reservoir storage changes are appropriately accounted for. This also acts as a validation process for the data through which any discrepancies and errors in the data can be appropriately handled. This effort helps establish a level of confidence in the framework of the operation of the system from which simulations are performed. Monthly water balances will be achieved with an existing setup using MODSIM. Existing rules and constraints in the model define monthly operations. Since hydropower production varies in relation to day and week-time peak electrical demands and reservoir control, a daily or even hourly time step will be required. A daily time-step constrained by the existing monthly model will allow flow scenarios to account for both environmental and hydropower values within the constraints of existing monthly water uses. In the future, exploration of flow-shaping to increase hydropower generation at peak value or demand periods may require an hourly time-step. While an hourly time-step may be outside of the time and budget constraints of this initiative, the daily model will be designed so that moving to an hourly time-step in the future can be easily achieved.

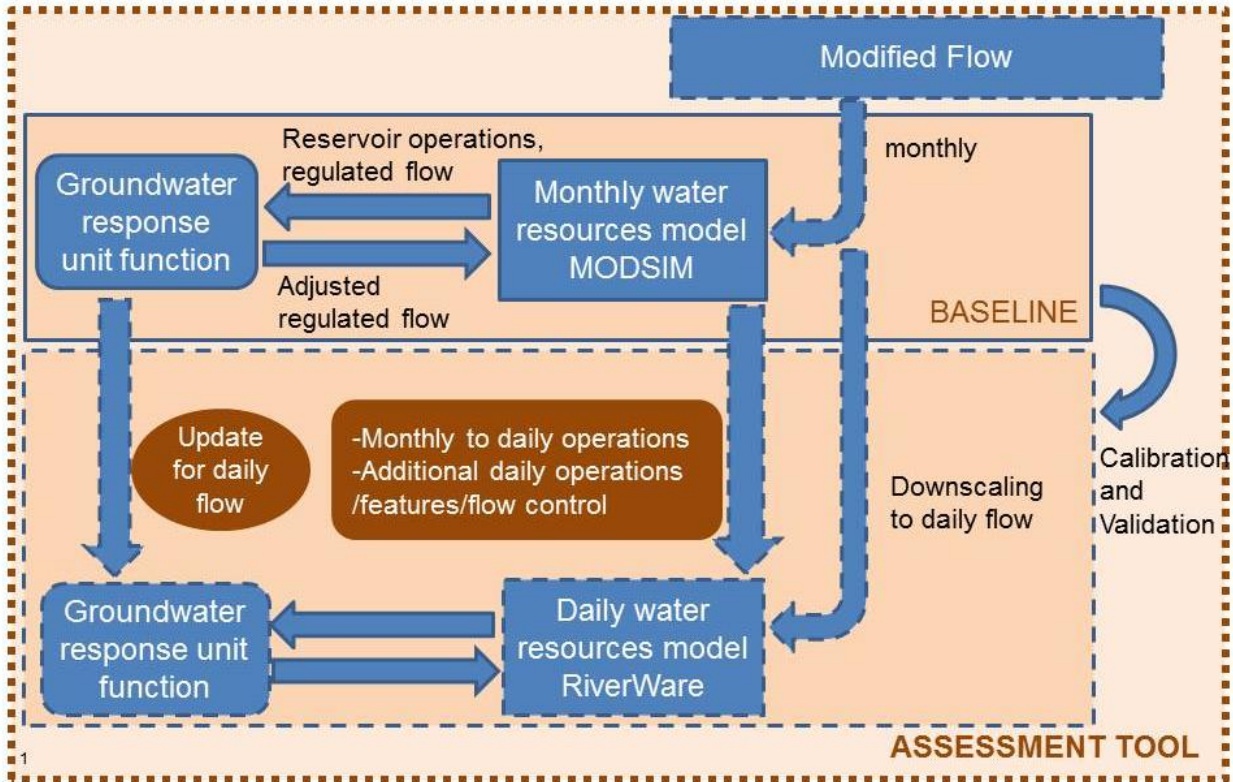


Figure 3.2. Integration of the existing model at monthly time step into a daily time step model

The following modeling activities were performed in order to build this sub-monthly basin wide water-balance model.

3.2.2.1 Hydrology Modeling

The BOR modified flow is available at a monthly time step only. A spatially distributed hydrology model is needed in order to simulate sub monthly naturalized surface flow. The hydrology of the Deschutes River Basin is complex, being controlled mostly by groundwater then snowmelt over the Deschutes reach, and mostly snowmelt on the Crooked River reach. A number of spatially distributed groundwater models (MODFLOW) and surface water models (DHSVM, VIC, Deep Percolation) have been set up in diverse parts of the basin. As part of the “rapid assessment” approach we opted for an existing set up of the variable infiltration capacity (VIC) hydrology model (Liang et al. 1994) at 1/16th degree spatial resolution (about 6km) and daily time step associated with an existing 1/16th degree daily gridded meteorological observation dataset (Maurer et al. 2002) spanning the 1915-2006 period. Both are available over the entire contiguous US, and are being used for seasonal flow forecasts and drought monitoring systems, as well as for climate change assessments. This is also the same hydrology model used in another on-going Department of Energy funded project for hydropower enhancement (Water Use Optimization Toolset Project). The set up was recently used for an analysis of climate change impacts on the water resources of the Deschutes River OR lead by BOR in collaboration with the University of Washington (BOR 2010). The model was initially calibrated at a monthly time scale with respect to BOR modified flow. Given the lack of coupling with a groundwater model, the VIC simulations had to go

through an extended bias correction procedure at the monthly time scale in this analysis. There is also an inherent uncertainty in the daily meteorological forcing.

The Variable Infiltration Capacity model developed by the University of Washington and Princeton University (Liang et al. 1994) is a semi distributed macroscale hydrology model solving for water and energy balances. Each grid cell allows for varying infiltration patterns, displays a mosaic of vegetation covers distributed over elevation bands in order to take into account the effects of vegetation and elevation on the energy and water balances. Three soil layers are simulated, which allows for an improved representation of evapotranspiration and distribution of flow into a fast flow and slow flow components. The model has been applied and validated extensively over spatial scales and diverse hydrometeorological conditions over medium to large river basins throughout the globe, and over global energy and water balance studies.

Because of the groundwater-surface water interaction in the basin affecting the monthly performance of the hydrology model, the daily variability of the simulated daily flow was used in order to temporally downscale the USBR monthly modified flow and incremental flows. Daily flows for the 1928-2006 period were derived for 8 locations upstream of Pelton-Round-Butte (Figure 3.3). Incremental flows were derived by delineating the incremental contributing grid cells in the unit hydrograph convolution scheme. The temporal downscaling simply consists of adjusting the daily 1928-2005 simulated daily flow with the ratio of the corresponding monthly modified flow over the monthly simulated flow (Figure 3.4). The daily simulated flow was derived from a 1915-2005 VIC simulation allowing for ample warm up of the initial conditions of the hydrological state in 1928. The 1928-2005 time series of monthly flow can drive to disparities in the daily flow when month changes. The sensitivity of the water resources management model to this will be evaluated.

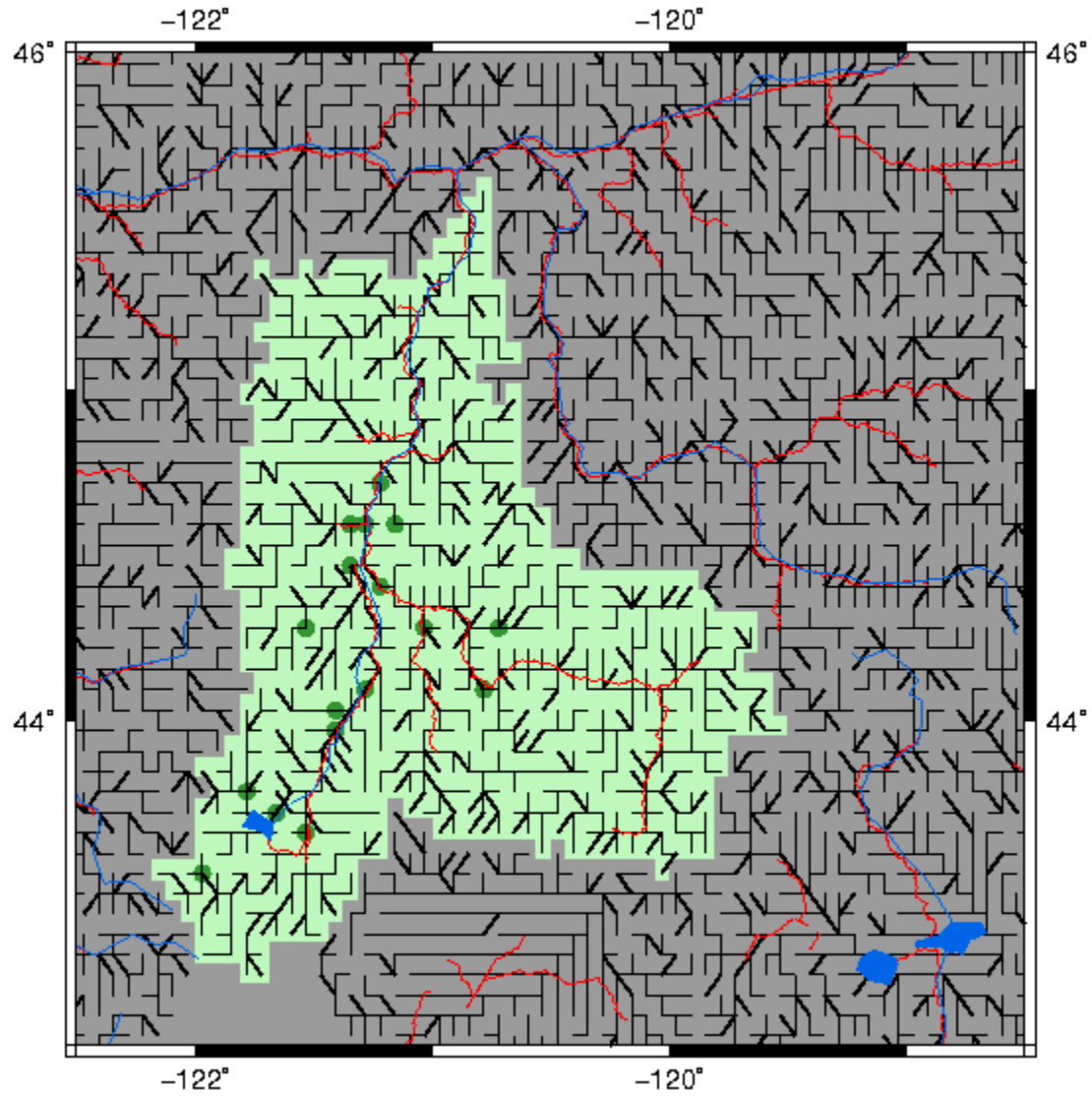


Figure 3.3. Flow direction file of the Deschutes River Basin with location of the simulated flow and incremental flow for input into the water resources model

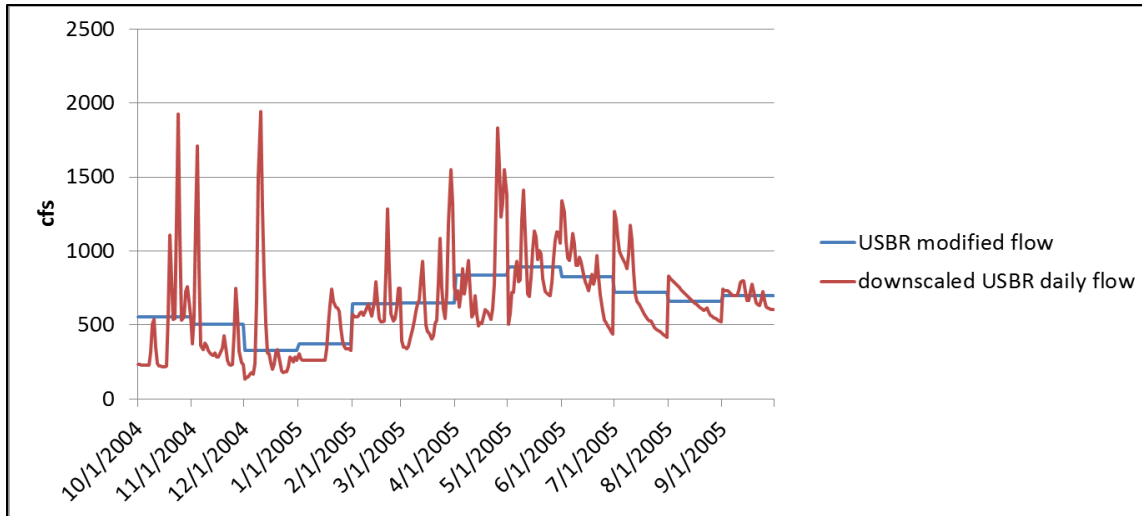


Figure 3.4. Downscaled daily flow at Wickiup reservoir

3.2.2.2 Monthly Water Resources Management Model MODSIM

Following the January modeling workshop, PNNL engaged the Bureau of Reclamation, Oregon State Water Resources Department and the Nature Conservancy to merge the different MODSIM set ups into an enhanced model along with an improved and documented derivation of groundwater response unit function. The Bureau took the lead of this effort and provided in June of 2012 an enhanced MODSIM set up over the Deschutes River Basin, which constitute the reference for BSOA modeling efforts' validation.

Current operations define the constraints for running the scenarios at a monthly time scale. Note that the daily model is required for assessing performance metrics related to environmental and energy questions. Some other performance metrics, in particular water rights accounting, are kept at a monthly time step for simplicity. For simplicity, the groundwater inflow into the reaches in the daily water resources model is derived from the monthly MODSIM groundwater flow using the updated groundwater unit response functions (Figure 3.5 and 3.6).

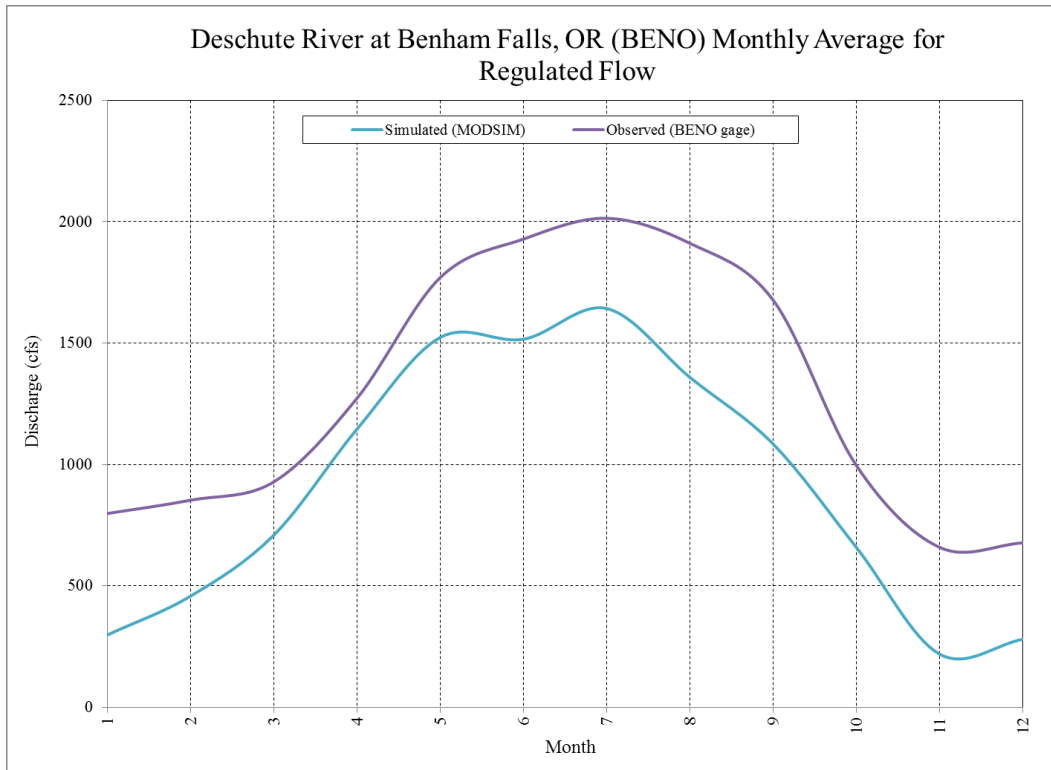


Figure 3.5. Monthly average regulated flow from MODSIM (simulated) and at the Deschutes River at Benham Falls, Oregon gage (observed)

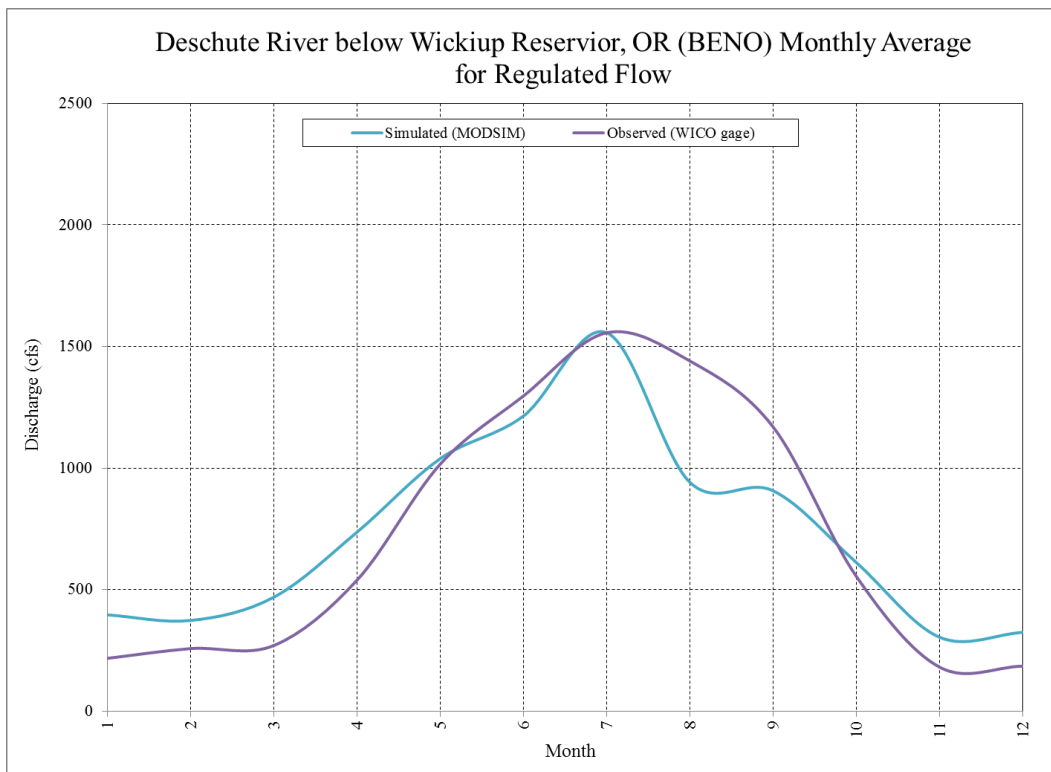


Figure 3.6. Monthly average regulated flow from MODSIM (simulated) and at the Deschutes River below Wickiup Reservoir, Oregon gage (observed)

3.2.2.3 Daily water resources management model: RiverWare

In order to assess environmental and energy related questions; a sub monthly basin scale water resources model is needed. Three software packages are widely used nationwide and could potentially meet the goals of the basin scale assessment approach:

- RiverWare (Zagona 2005): Widely used nationwide for daily and sub daily time steps and offers optimization capabilities.
- MODSIM: offers the advantage of being already set up at the monthly time step, However stakeholders shared reservations with the current set up having bugs when going to sub monthly time steps. MODSIM also does not offer an optimization option.
- HEC-RESsim: is being used by the Corps of Engineer along the main stem of the Columbia River. There is no present set up over the Deschutes, and does not allow for optimization.

RiverWare had already been chosen by the BOR and as such was the primary choice for the BSOA Deschutes pilot. In addition, it offers this optimization module in which many stakeholders are interested in its use in future applications.

For any of these software packages, the present inputs are necessary:

- Daily naturalized flow: complete
- Disaggregate monthly to daily operating rules and constraints: completed
- Current monthly operating rules with a wet, dry and average year patterns: implemented
- Define the day the diversion starts each year: benefit from the BOR work in progress.
- Daily groundwater model interaction: conversations with modeling experts in the basin from the USGS, BOR, and ODWR have suggested that the existing groundwater response unit functions are sufficient for opportunity assessment activities
- Enhance the MODSIM connectivity for transfer into RiverWare by increasing the number of nodes for computational stability required for the shorter time step.

The current MODSIM layout was transferred to RiverWare with many of the features from MODSIM being replicated (i.e., monthly demands from water users, basic reservoir attributes, etc.). MODSIM is restricted to monthly water demand simulation, where RiverWare on the contrary, has the capability to be driven by as fine as hourly water demand, reservoir operations, or basin power objectives. The RiverWare model currently being built for the Deschutes is able to accurately simulate daily operational flows from 1928 to 2006 through the Deschutes and Crooked Rivers. To achieve water balance on a sub-monthly

basis without major issues (such as assessing possibilities of spurious data causing unnatural results), the model must ensure consistent transformation of monthly to daily constraints within a reasonable and accepted manner. This water balance was achieved by a flow calibration of the model that consisted of routing observed daily reservoir outflows and comparing downstream simulated flows with daily observed gage discharge. Water demands have been kept to a monthly request from the MODSIM model and have been added to the river system appropriately throughout both reaches. Figures 3.7 and 3.8 display the current configuration in RiverWare of the Deschutes and Crooked Rivers.

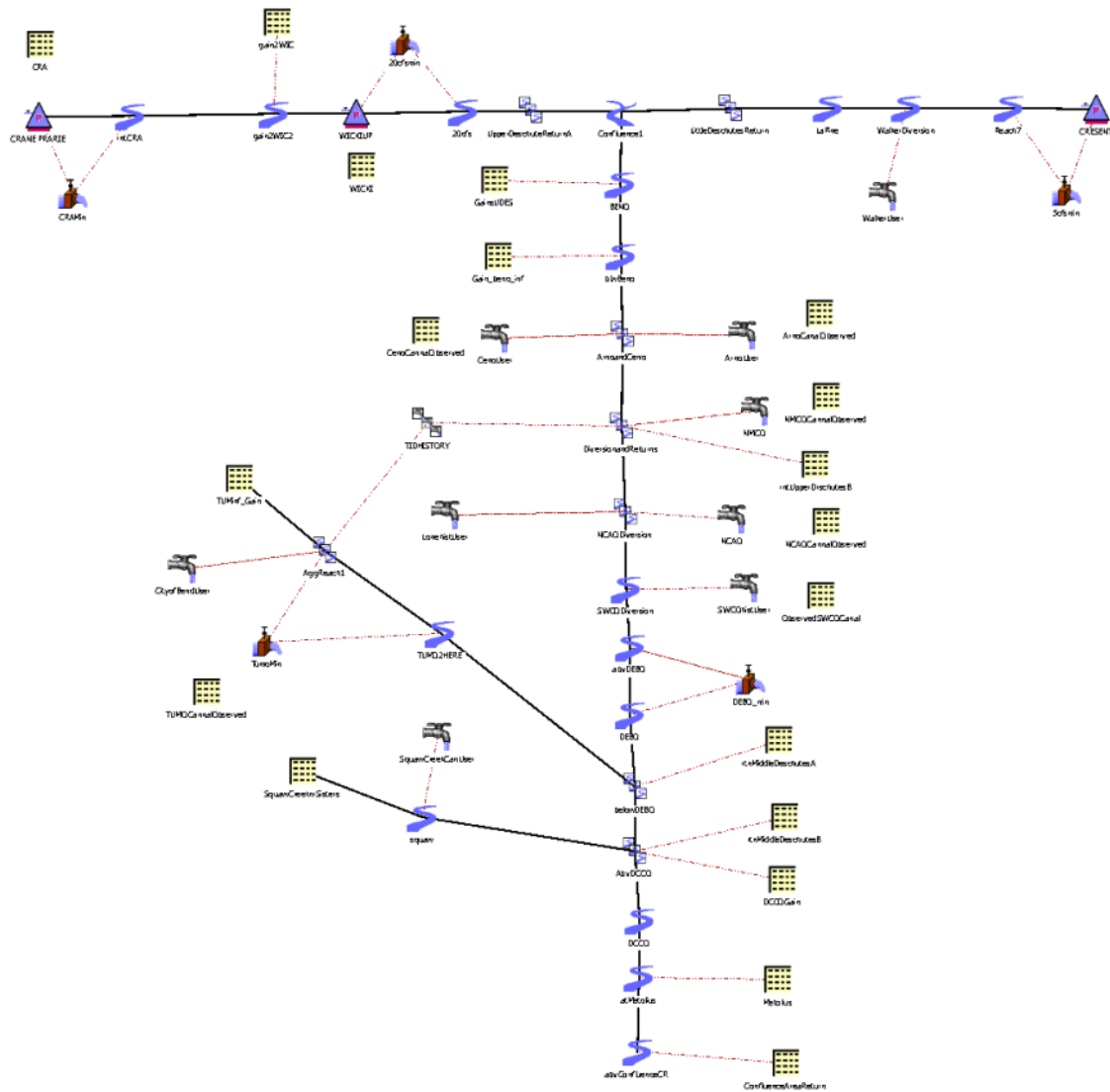


Figure 3.7. Deschutes River side of the Deschutes Basin RiverWare model

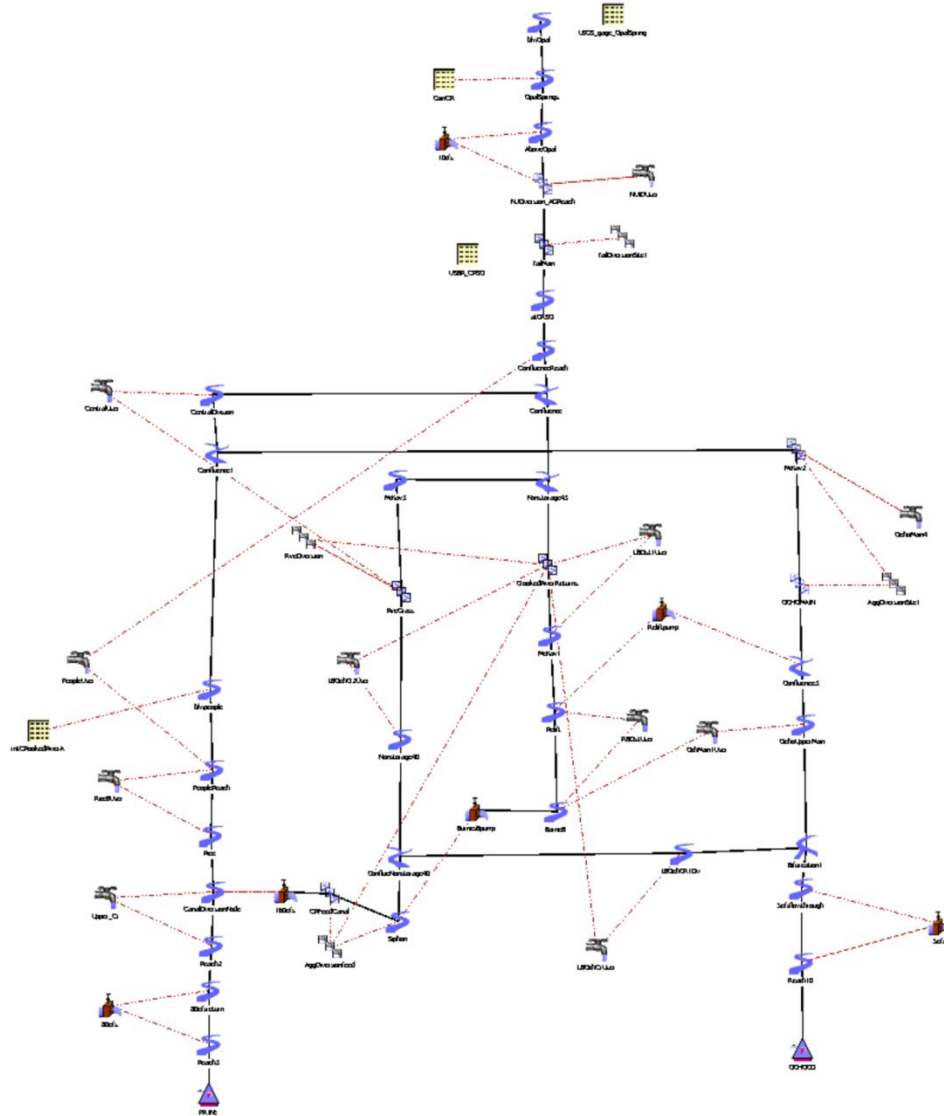


Figure 3.8. Crooked River side of the Deschutes Basin RiverWare model

The following objectives are currently being implemented in the RiverWare model:

- Working with CADSWES (software developers) to cultivate a strategy of taking the monthly groundwater response functions to a daily routing application.
- Constructing a “Rule Based and Water Allocation simulation” to allow RiverWare to prioritize water demand, power generation, and/or reservoir operations.

Models setup will allow for exploration of various hydropower and environmental variables and scenarios. A visualization scheme described in Section 4 will allow for an efficient communication of the multiple metrics derived from running the different scenarios (described in Section 2) though this modeling set up.

3.3 Remaining Work and Expected Outcomes

Observed records of streamflows, diversions, groundwater withdrawals, reservoir specification; i.e. hydraulic capacity, storage area and volume, and water rights data were obtained from the Oregon Water Resources Department, the U.S. Geological Survey, and the U.S. Bureau of Reclamation. As described earlier, there will be uncertainties in the daily meteorological forcing, the surface hydrology model and groundwater components as most of the observation do not exist at the daily time step or without regulation for calibration and validation purposes.

The modeling set up will be able to provide performance metrics directly for water rights accounting, environmental flow at specific locations and energy. Some of the output from the modeling scheme will be used for further analysis (HeatSource) evaluation, and in particular for environmental performances outside of the specific nodes described in the model, and for visualization.

ORNL is currently working to assess hydropower engineering specification at sites identified in the opportunity scenarios. RiverWare flow data will be run through these engineering specifications to assess on-peak and off-peak generation under the various flow scenarios examined in the assessment.

4.0 Data Visualization

The basin scale visualization system is a web-based interface developed to provide the user with an intuitive means of assessing the opportunities and trade-offs between various power development and environmental conservation strategies, in the context of existing water uses.

The data visualization tools have been developed to facilitate the exploration of modeling scenarios via value-based metrics computed from model outputs. These metrics represent the goals of various interests within the basin (hydropower, environmental and water users). For the Deschutes River case study, daily river operational flow data (via RiverWare model) are the primary inputs to the visualization interface.

4.1 Three Levels of Data

The interface consists of three main components: (1) an interactive map, (2) opportunity evaluation tools, and (3) scenario exploration tools. The interactive map allows the user to tailor the map with customizable GIS overlays. The opportunity evaluation tool includes site cards showing the location and details on hydropower and environmental opportunities. The site-specific descriptions provide a jumping-off point into model data exploration. The system architecture consists of a relational database containing metadata for individual model nodes (diversion points, reaches, etc.) and their associated model outputs (flow, reservoir level, etc.). The model output data is queried via interface control and metrics (Table 4.1). There are three levels of data available for user interaction and drill down: value-based metrics, summaries and tabular raw data. Value-based metrics are based on the raw data synthesized into the form of value statements, for general categories of stakeholders. For example, power generation stakeholders may be interested in model outputs expressed in terms of amount of power generated or percent of peak demand power generation. Similarly, water users may be interested in model outputs expressed in terms of the likelihood that irrigation water will not be prorated, or environmental stakeholders may want to visualize the likelihood of maintaining biologically important flow levels during a critical period for fish habitat.

Table 4.1. Example of value-based metrics

Metric Categories	Example Metric Description
Power Generation	Percent of generation during peak demand
	Percent of plant capacity that can be generated under the scenario
Environmental	Percentage of years that August/September flow maintains at least 150 cfs
	Proportion of winter days (Nov-Feb) that minimum flow exceed 200 cfs
Water User	Percent likelihood that irrigation water will not be prorated
	Proportion of summer (Jun-Aug) days that reservoir level will remain between 1250 and 1255 feet

Summaries are tabular or graphical statistical derivatives of raw model outputs. The raw data is the information from which summaries and metrics are derived, exported from the database for a particular model node. The system will present the highest order elements (derived metrics) foremost and for an anticipated majority of users, no further exploration will be necessary. However, if a user is interested in a more detailed view, they can drill down multiple levels to view hydrologic summaries and if desired, download a data package.

The illustrations below represent example results of model output using 5 different flow cases and 3 different conservation targets (15 model runs). Flow case refers to a model setting wherein a particular reach has a goal of some minimal flow (25 cfs, 100 cfs, 175 cfs, etc.) under 3 different conservation targets: no conservation, 10% conservation and 25% conservation. When viewing the value-based metrics, the user has three different options for displaying metric data. To compare different metrics under a particular flow case and conservation target, we can view all metrics stacked together (panel A in Figure 4.1). In this view, the user can toggle between the different flow cases and conservation target settings to see the effect of such actions on the different metrics. While comparing different metrics under a selected flow case is useful, it may also be desirable to see how an individual metric may change under the entire suite of flow cases. The second panel view (panel B in Figure 4.1) allows the user to select the metric of interest to visualize the effect on that goal, under all the flow cases for a specific conservation target. The user can toggle between metrics and conservation targets.

To better understand tradeoffs and impacts to different stakeholder interests, the third option allows the user to selectively compare any combination of two metrics (panel C in Figure 4.1). The ability to view trade-offs between opposing metrics, for selected locations in the basin, under varying operational scenarios, different climatic conditions and targeted conservation goals, is a key function of the visualization interface and provides a rapid means of exploring which operational scenarios would be the most beneficial to the most stakeholders.

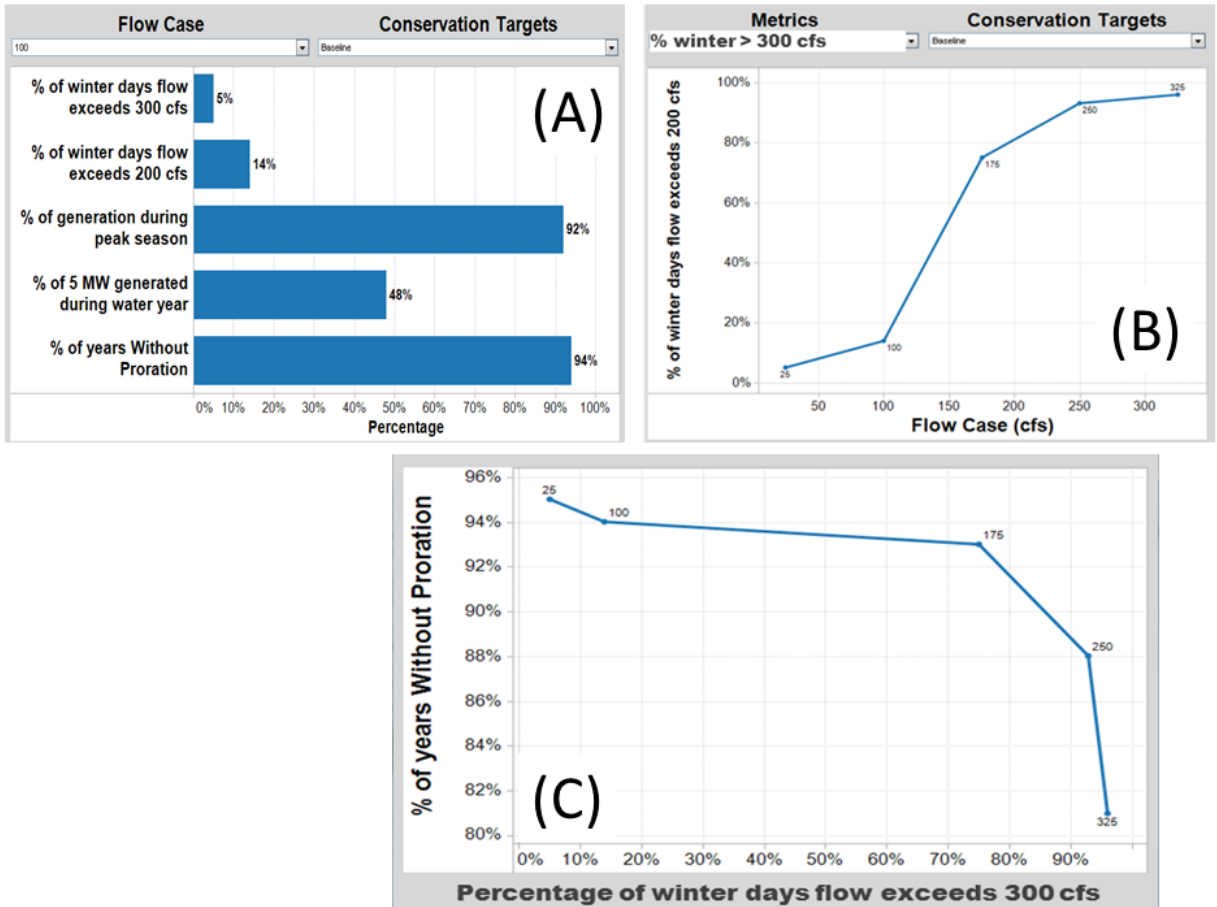


Figure 4.1. The three primary views of value-based metrics. Panel A shows all metrics for a single model (flow) case, panel B shows the results of a single metric for all the model cases

4.2 Dashboard View

The visualization charts and views can be arranged in a dashboard view designed for quick and intuitive interpretation of the information. The default metrics can be arranged in the dashboard to personalize the viewing interface and highlight the metrics of highest interest. The dashboard will initially contain a set of default metrics developed through consultation with stakeholders in the basin. Since metrics are computed via database query, the system architecture can support the development of user-created metrics, if required in future deployments (Figure 4.2).

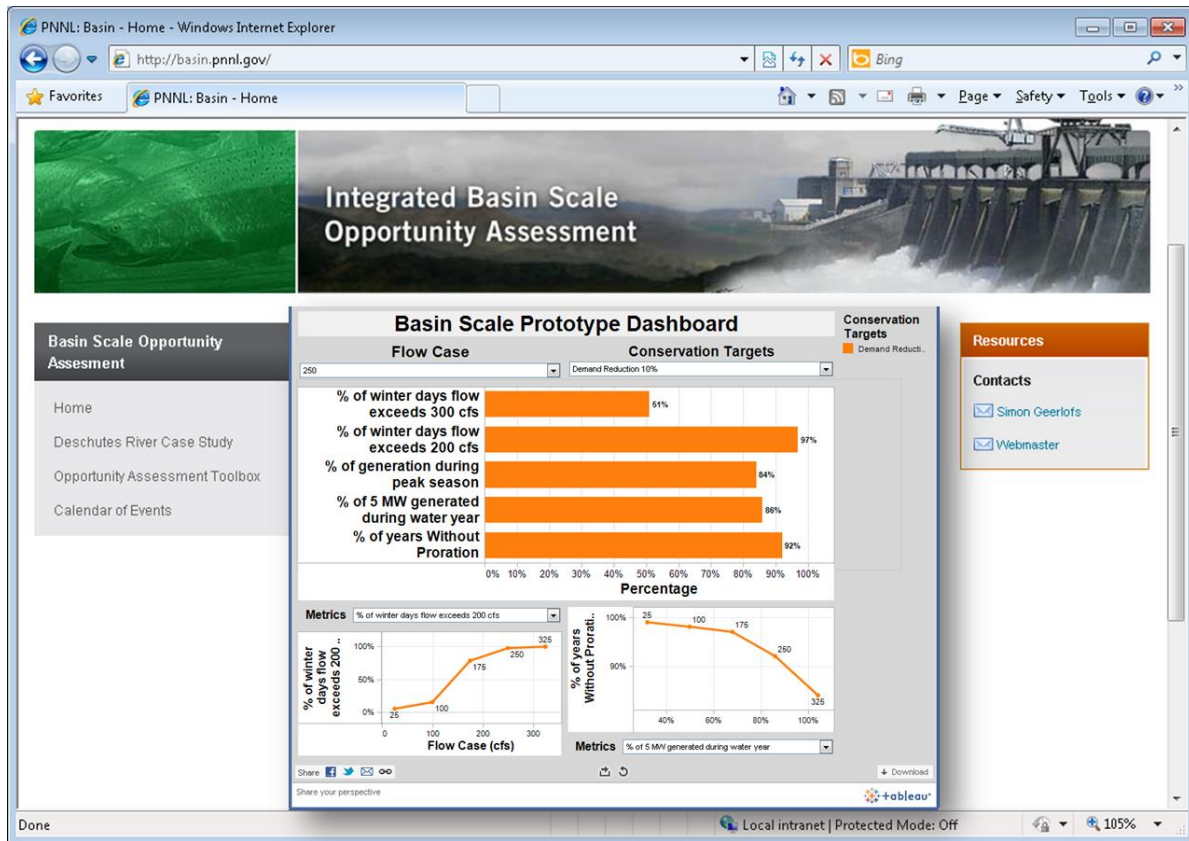


Figure 4.2. Visualization dashboard prototype showing relationship between metrics (top panel), the effect on a specific metric for all flow cases (bottom left panel), and trade-off between selected metrics for all flow cases; under a 10% conservation scenario (bottom right panel)

4.3 Remaining Work and Expected Outcomes

During this year we mapped stakeholder concerns and interests and determined how to represent concern in terms of resource availability at specific locations in the basin. These concerns have been codified into metrics/value statements derived from model output. We have constructed an interface and architecture to map and visualize these metrics.

Tasks remaining include:

1. Completion of the visualization dashboard to portray historical baseline and variation
2. Publish visualization interface to the web
3. Stakeholder review of visualization system

5.0 Conclusions and Next Steps

This report summarizes major activities under the BSOA for FY 12 focused around analysis of hydropower and environmental opportunities in the Deschutes Basin. Figure 5.1 describes the process taken to date in the Deschutes basin: Phase 3 has been the primary focus of FY 12, with Phase 4 to follow in Q1 of FY 13.

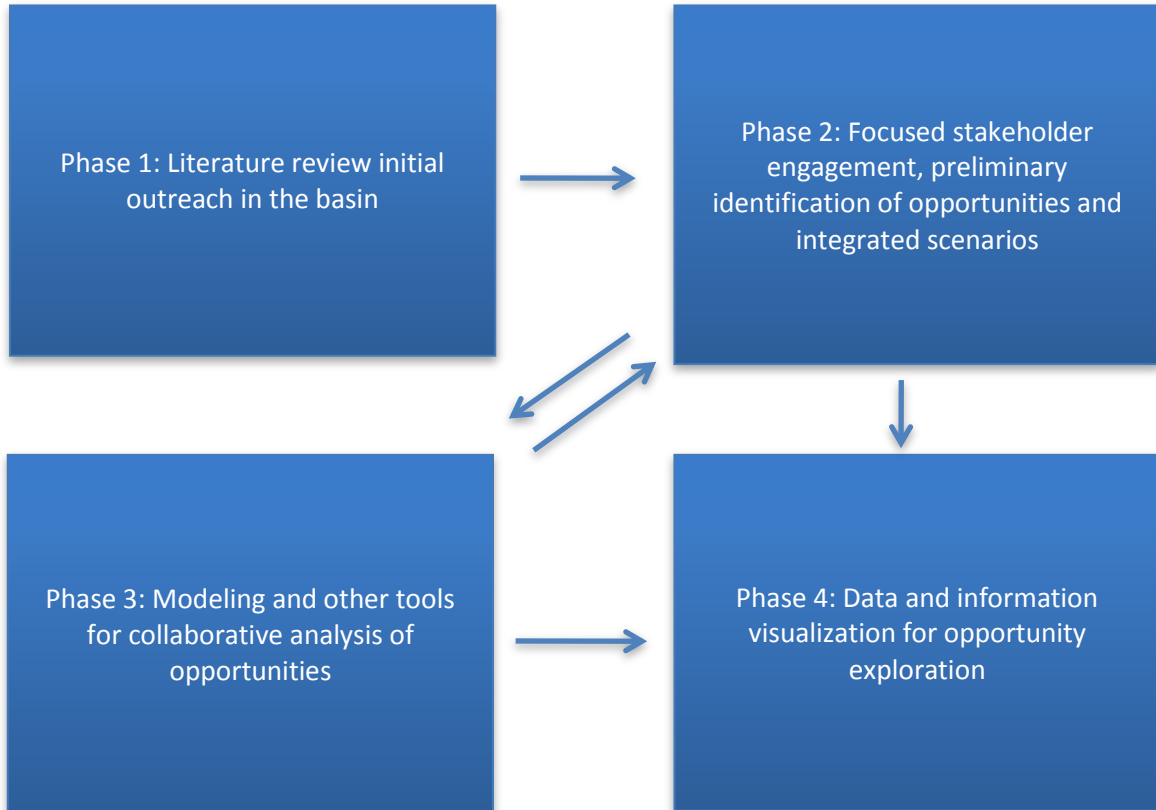


Figure 5.1. Four Phases of the Deschutes Pilot Study

We expect to complete the Deschutes pilot and report on assessment results in January 2013. The Deschutes pilot will conclude with a stakeholder workshop that will be organized by PNNL and ORNL in January; stakeholders will have an opportunity to collaboratively explore model results and scenarios through the visualization platform. Following completion of the Deschutes pilot, PNNL and ORNL will shift activities towards high-level screening of opportunities in three additional basins. However, it is expected that some level of engagement with the Deschutes will continue, should that be desired by stakeholders. PNNL has budgeted a small amount of FY 13 funds to go towards this continued engagement and refinement (scoping) of scenarios in the Deschutes.

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