Center for Water and Environmental Sustainability (CWESt)
Annual Technical Report
FY 2006

Introduction

Oregonians are beginning to witness the difficulties caused by water limitations. Water quantity and quality issues in the Willamette and Klamath Basins are the Governor's top environmental priorities. This situation is paralleled around the world, and points toward a strong emerging area for growth in research, education, and outreach. OSU is ideally positioned to assume a leadership role in addressing water problems, with about 80 faculty in six colleges who teach and conduct research in areas related to water and watersheds. OSU is renowned for its landscape-scale ecosystems research and has just initiated five new graduate degree programs in Water Resources. These research and education efforts have all occurred without the benefit of programmatic coordination or strategic vision.

The Water and Watersheds Initiative developed by OSU in 2005 is designed to replace the Center for Water and Environmental Sustainability (CWEST) to better leverage OSU's existing excellence in water and watersheds by 1) providing coordination of water and watershed activities at OSU, 2) creating an innovative, place-based educational approach connecting a diverse student body with relevant issues across the state, 3) enabling capture of new, high-value opportunities for research, education, and outreach, 4) engaging OSU faculty and students with external stakeholders throughout the state, and 5) establishing a set of shared water and watershed collaboratories supporting research, teaching and outreach. This initiative will increase the diversity and quality of OSU students involved in water resource activities, and advance OSU's Strategic Plan and Land Grant mission.

Coordination and leadership are key to achieving these goals. The Initiative funded a search for a nationally prominent Director, leading to the hiring of Dr. Michael Campana, to pull faculty and resources together to tap the huge potential for new funding. This institute will catalyze and support the growth of academic programs; state of the art laboratories; enhanced outreach to Oregon's communities; and development of real solutions for Oregon's critical water resource issues. The WW Initiative is creating a physical and intellectual center for water at OSU that focuses faculty, students, facilities, and activities in a common location through four specific efforts: 1) a university-wide water services lab supported by a full-time technician that provides services to multiple researchers and teachers; 2) home offices for visiting scholars, fellows, and OSU faculty as necessary; 3) video-conferencing capacity for teaching, research, and outreach activities; and 4) co-location with the Institute of Natural Resources to provide links to policy, information, and research activities throughout the state of Oregon.

To create a diverse student population able to address complex water resources issues, the Initiative has funded the development of an innovative, multi-disciplinary learning environment through five specific mechanisms: 1) development of a place-based platform for learning in the Oak Creek watershed for integrating a water resources curriculum across multiple courses; 2) development of two new, interdisciplinary synthesis courses addressing relevant water resource issues in Oregon; 3) sponsorship of Diversity & Excellence scholarships to increase access and diversity in the water resources student population; 4) development of a common information repository integrating water resource courses, research activities and, outreach efforts designed to enhance student learning across multiple courses; and 5) support through a competitive funding process of activities designed to capture new, external resources focused on academic program innovation.

A central aspect of this Initiative is the development of new and innovative ways to engage stakeholders across the region: The Initiative has allowed OSU scientists and students to connect with diverse decision-makers at the federal, state and local levels to provide solutions to Oregon's water problems through three activities: 1) incorporation of stakeholder needs and experiences into the Water and Watershed curriculum; 2) sponsorship of a series of collaborative workshops held around the state with federal, state and local stakeholders to identify partnering opportunities for addressing high-profile issues in Oregon; and 3) establishment of a biennial conference, co-sponsored with the Governor's Natural Resources Office to engage the Oregon legislature and state and federal agencies, to identify critical water and watershed issues in the State and develop strategies to address these issues.

The Water and Watersheds Initiative is fundamentally elevating OSU's current capabilities in realizing new opportunities and attracting new funding sources while better serving the needs of students and the state. To date, the outcome has become a thriving academic engine built on current investments and existing excellence aligned with the OSU strategic plan - interdisciplinary collaboration; the land-grant mission; national and international dimensions; diversity; the environmental and economic health of the state, and will lead to a strong, self-sustaining unit that will continue to strategically leverage state investment to solve the water problems of the future.

Research Program

Evaluating the phosphorus dynamics in response to restoring historic hydrology at reclaimed wetlands along Upper Klamath Lake, OR.

Basic Information

Title:	Evaluating the phosphorus dynamics in response to restoring historic hydrology at reclaimed wetlands along Upper Klamath Lake, OR.
Project Number:	2006OR74B
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Congressional District:	2, 4
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Focus Category:	Water Quality, Agriculture, Groundwater
Descriptors:	None
Principal Investigators:	Desiree D. Tullos, Desiree D. Tullos

Publication

Evaluating the phosphorus dynamics in response to restoring historic hydrology at reclaimed wetlands along Upper Klamath Lake, Oregon

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EXECUTIVE SUMMARY

According to ODEQ's TMDL analysis (2002) and USFWS Sucker Recovery Plan (1993), elevated phosphorus levels are in part driving severe algal blooms in Upper Klamath Lake (UKL), causing pH and dissolved oxygen to reach toxic levels for fish. Historic lake-fringe wetlands likely played a key role in buffering external P loading to the lake and the draining and conversion of these wetlands to agriculture has had a profound influence on excess nutrient input to UKL (Snyder and Morace 1997; National Research Council 2004). Currently, millions of dollars are being directed toward wetland restoration of the reclaimed agricultural lands with the goals of habitat restoration and reduction of external nutrient input to ultimately improve water quality in the lake. However, the extent and mechanisms of nutrient retention for these restored wetlands actually retain nutrients is not well established (Fisher and Acreman 2004; Graham et al. 2005). Therefore, we developed a coupled laboratory and field study on the P dynamics of restored wetlands around UKL.

While we have no formal results to present from IWW/USGS funding, beneficial outcomes of this support include: (1) submission of three grant applications for additional support of students and sample analysis, (2) expanded study area and intensity, and (3) setup of the laboratory experiment. Laboratory experiments will begin in early July, 2007 to evaluate the patterns and processes associated with P release in four UKL restored wetlands through analysis of P and numerous other relevant properties of soil cores prior to, immediately following, and long after "flooding". The laboratory experiment will be followed by a field study of the sites as they flood during the winter of 2007.

This study design will inform an important management question (Are flooding regimes different with respect to minimizing soil P losses and are those differences significant?) by focusing on advancing the understanding of biotic and abiotic mechanisms of P release related to inundation timing and duration. Thus, the anticipated project benefits are to reduce uncertainties around wetland benefits and inform management decisions that minimize P loading to the lake.

PROJECT DESCRIPTION & RESULTS

This progress summary describes a laboratory and field study to elucidate the effects of timing and duration of restored wetland inundation on forms and concentrations of P. The goal of this study is to improve understanding on how restored wetlands can be managed to minimize P release into UKL by documenting P-source –sink relationships in wetlands restoration projects. The original objective of the IWW/USGS project was to document phosphorus dynamics associated with reflooding of the Williamson River Delta to address (a) whether reclaimed wetlands release phosphorus when reflooded for restoration? and (b) which mechanisms control phosphorus sequestration and release in reflooded wetland soils at UKL? We have expanded that original study scope to include a laboratory study (at the request of the IWW/USGS review committee) and three additional sites. This expanded scope will characterize the properties, including forms and concentrations of P, in water and soil cores collected across four wetland restoration study sites (Wood River Wetland, Agency Lake Ranch Wetland, Williamson River Delta, and South Marsh – **Fig. 1**) with different hydrologic regimes prior to and following (a) soil core inundation in a controlled laboratory study and (b) wetland inundation in a field study

Through these studies, we will evaluate two hypotheses:

1. The timing and duration of inundation does affect the concentrations and forms of P released in study wetlands.
2. The nature of P dynamics in the study wetlands releases primarily labile orthophosphorus (biologically available), as opposed to organically bound P.

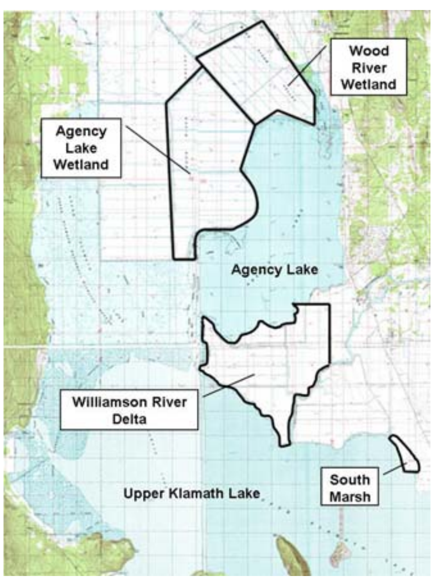


Figure 1– Locations of four study sites around UKL

Figure 2–Locations of soil core and surfacewater sampling locations within those sites

Through the proposed analyses, we will evaluate the four wetland restoration sites characterized by three different hydrologic management methods: (1) active management through mechanical pumping of an unconnected wetland (Agency Lake Ranch), (2) passive management with direct hydrologic connection (Williamson River Delta, South Marsh), and (3) passive management without direct hydrologic connection (Wood River Wetland). We hypothesize that the difference in timing of wetland filling and draining between these three management approaches will have significantly different outcomes on P forms and concentrations released to the lake, and that these outcomes are driven by differences in the bioavailability of P.

Goals and objectives.
The overarching goal of this project is to reduce uncertainties around wetland benefits and develop the understanding of how management of wetlands and agricultural lands can minimize external P loading to UKL. We will quantify how management of hydrology affects key response variables, including relevant soil properties and forms and concentrations of P in the soil and water. Specifically, we focus this limited research study on evaluating biotic and abiotic mechanisms of P release related to inundation timing and duration. We outline the following **objective** for the project:

(1) characterize the properties, including forms and concentrations of P, in soil cores collected from each of the wetlands prior to and following:

a. inundation in a controlled laboratory study
b. wetland inundation in a field study

This study design will inform an important management question: Are flooding regimes different with respect to minimizing soil P losses and are those differences significant?

To achieve the project objectives, the following general workflow has been defined:

1. General study design and preliminary soil P characterization- Initial collection and analysis of soil cores will be used to characterize variability in physical and chemical properties of the soil across each wetland to determine spatial patterns and distributions of P forms and concentrations. Sites were first classified according to wetland types (transitional wetland, emergent marsh, and deep water wetland) and sampling locations were selected from stratified (by wetland type), randomly sampled grid overlays (Fig 2). Three soil cores will be collected at four sampling locations within each of the wetland types for each analysis. Soil cores will be divided into two depths (0-2 cm and 2-15 cm) to evaluate the change in soil features with depth. These cores will be collected during the dry season (arbitrarily defined as the water table at or below the surface >3 weeks) and locations will be mapped with a GPS unit.

2. Lab experiments to determine breakthrough curves, timing of P cycle and release

This lab study will “flood” soil cores in a controlled environment to analyze the change in several physical properties of the soil (e.g. phosphorus forms, redox potential, bulk density, organic matter, pH, total N) and water (e.g. temperature, DO, specific conductivity, pH, TP, SRP, CO_2 emission, redox potential) over the current flood season of each of the sites. For each sampling location within each site, three cores will be pulled for: (1) analysis prior to “flooding”, (2) analysis immediately after “flooding”, and (3) analysis following the “flood” season. To isolate flooding treatments from responses due to soil properties, the experiment will replicate all flooding regimes with all soils (i.e. individual Agency Lake Ranch wetland cores will be treated with flooding regimes from each of the four sites) for a combination of 16 cores per wetland type. In a two factorial design, cores will be inundated and changes in physical and P soil properties will be analyzed by ANOVA. Further, breakthrough curves (Fig. 3) of P release into the surfacewater will be developed for the soil cores.

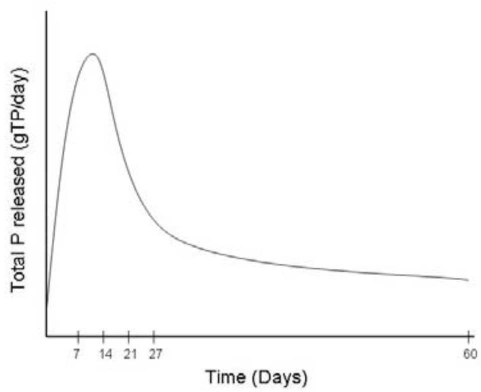


Figure 3 – Theoretical breakthrough curves for increase of P in surface water of cores following inundation

The key differences between the hydrology of the sites that we will simulate in the laboratory study are the timing and duration of flooding. The cores will remain flooded for the same duration that soils are flooded at each of the sites or until soil leaching of P stabilizes. The timing of inundation will be simulated through the following two steps:
(1) pulling all of the cores at the same time of year
(2) controlling temperature, through refrigeration, of the cores to correspond to the time of year that the soils are flooded in the field. Through this approach, we can evaluate patterns of biotic activity in mobilizing organically-bound P and the role of inundation timing in P release at the wetlands

All soil cores will be flooded with the same, well-mixed water drawn from UKL, which will be analyzed for TP and SRP concentrations prior to application on soil cores. Light will be held constant throughout the lab study. Vegetation will be removed from the cores.

3. *Collection and analysis of field samples* **-** To compare findings of controlled laboratory experiments with soil P dynamics at the sites, soil cores will be collected from permanent sampling locations (1) shortly before flooding occurs at each site in coordination with management agencies at dates specific to each site, (2) immediately after wetlands are flooded, and (3) prior to draining. Soil cores will be sent to the OSU soil laboratory for analysis. Basic analysis of water quality (e.g., temperature, dissolved oxygen, specific conductivity, pH, redox potential) will be performed at the time of soil coring.

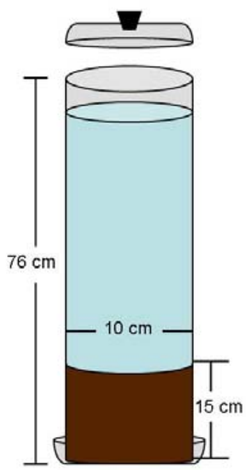
Progress to date.

Additional support

It was necessary to delay the field study proposed to IWW/USGS due to a delay in construction. Thus, substantial efforts were directed towards securing additional funding to replicate the study at several sites at UKL. Three additional proposals were submitted:

1. submitted to the US Fish and Wildlife Ecosystem Restoration Office in Klamath Falls and the PI was recently notified that this proposal has been recommended for funding to support sample analyses and the GRA for year 2. ($58,594)
2. submitted to the Oregon Agricultural Research Foundation to support additional soil and water samples as well as an undergraduate research assistant to help with analysis of soil and water samples. Reviews of these proposals will become available late June, 2007. ($11,840)
3. submitted to the US Bureau of Reclamation in Klamath Falls in partnership with The Nature Conservancy. Funding will support the collection and analysis of additional soil cores at the Williamson River Delta site, including support for an undergraduate research assistant. ($30,000)

Laboratory Experiments



Elevation GIS data layers were obtained and used to determine water depths throughout the summer. Water depths were used to estimate wetland vegetation and classify areas as transitional wetland and emergent marsh. Four sampling locations were then randomly selected from grid overlays within these stratifications (Fig. 2). The lab experiments will be performed in the Klamath Tribes' water quality labs in Chiloquin and setup of these experiments is nearly complete. Cores for the laboratory experiments will be pulled from all four sites and flooded (Fig. 4) during July 2007

Figure 4 – Schematic of experimental setup for laboratory analysis of core inundation.

Timeline

In light of the expanded scope of the project, a new timeline of activities has been developed (Table 2).

Table 2 – Timeline and schedule of proposed activities.

Activity	date of completion
initial core samples pulled	june 2007
permanent sampling locations defined	july 2007
laboratory experiment set-up	august 2007
laboratory experiment completed	september 2007
field sampling for soil dynamics during flooding	august 2007 to may 2008
analysis and reporting	may 2008

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Modeling Effects of Channel Complexity and Hyporheic Flow on Stream Temperatures

Basic Information

Title:	Modeling Effects of Channel Complexity and Hyporheic Flow on Stream Temperatures
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Descriptors:	None
Principal Investigators:	Scott A. Wells

Publication

Modeling Effects of Channel Complexity and Hyporheic Flow on Stream Temperatures

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ABSTRACT
Stream temperatures are affected by multiple forcing functions, including surface heat exchange (including solar radiation, evaporation, conduction, and net long wave radiation) and hyporheic flows. Each of these forcing functions is directly influenced by the level of channel complexity in the stream channel and riparian shading. The interrelationship between channel complexity, hyporheic flow and stream temperature is highly complex, and efforts to manage for habitat diversity by managing channel complexity could result in unintended consequences on stream temperature. When planning modifications to stream channel complexity, consideration should be given to the effects such moderations could have on stream temperatures.

Urbanization has impacted many steams due to the construction of bank protections, levees, vegetation removal, etc. Such activities have eliminated side channels and reduced stream braiding, thereby reducing the overall channel complexity. Hulse et al. (2002) developed maps showing the channel configurations of the Willamette River in Oregon, USA in the years 1850 and 1995. These maps show a significant reduction in channel complexity in the intervening years. More complex stream channels provide greater habitat diversity and thus, are generally more desirable from a wildlife management perspective. Therefore, management of streams for increased channel complexity is gaining in popularity.

Knowing that stream channel complexity has diminished over time, an important question to consider is 'what were stream temperatures before we altered the natural channels?' This is an important issue in determining what natural conditions were and how we have strayed from these so-called 'natural' conditions as a result of channelization, dam building, and changes to the riparian vegetation and deforestation. Current Total Maximum Daily Load's (TMDL) rely on determining a 'natural' condition. In order to develop an understanding of what that is, a hydrodynamic and water quality computer simulation model has been applied to Oregon's Willamette River with several levels of channel complexity and varying rates of hyporheic flows. Adapting the model used to develop TMDL's for temperature in the Willamette River, the effects of present and past channel complexity on water temperatures was determined. The model used to develop the TMDL was the U. S. Army Corps of Engineers dynamic 2-D model CE-QUAL-W2, which consists of directly coupled hydrodynamic and water quality transport models and simulates parameters such as temperature, algae concentration, dissolved oxygen concentration, pH, nutrient concentrations and residence time. The model also incorporates a dynamic shading algorithm for both vegetative and topographic shading on water bodies.

KEYWORDS
Temperature Modeling, Hyporheic Flow, CE-QUAL-W2, Willamette River

INTRODUCTION

The State of Oregon Department of Environmental Quality (DEQ) developed a river basin temperature model for the Willamette River basin. The study area included the Willamette River and all major tributaries. The model was used by DEQ to set temperature limits on point source dischargers and to evaluate the impact of management strategies on river temperatures to improve fish habitat. Stream temperatures directly influence habitat suitability for salmonids and other aquatic life by directly affecting metabolic rates, food requirements, growth rates, digestion rates, development rates, life-cycle timing, disease and parasite incidence, and predator-prey and competitor interactions (Lewis et al., 2000). The interrelationship between channel complexity, hyporheic flow and stream temperature is highly complex, and efforts to manage for habitat diversity by managing channel complexity could result in unintended consequences on stream temperature. When considering modifications to stream channel complexity, consideration should be given to the affects such moderations could have on stream temperatures.

Urbanization has impacted many streams due to the construction of bank protections, levees, vegetation removal, etc. Such activities have eliminated side channels and reduced stream braiding, thereby reducing the overall channel complexity. Hulse et al. (2002) developed maps showing the channel configurations of the Willamette River in Oregon, USA in the years 1850 and 1995. These maps (Figure 1 and Figure 2) show a significant reduction in channel complexity in the intervening years. More complex stream channels provide greater habitat diversity and thus, are generally more desirable from a wildlife management perspective. Therefore, management of streams for increased channel complexity is gaining in popularity.

The research goal is to investigate the extent which channel complexity and hyporheic flows can influence stream temperatures. Simulations will determine the relative difference observed in stream temperatures between the more- and less-complex channel systems with varying amounts of hyporheic flow and shade. Analysis will also evaluate critical densities and heights of streamside vegetation necessary to provide a net reduction in stream temperatures. From this work an assessment of ‘natural’ conditions for temperature in this section of the Willamette will be developed and compared to the ‘natural’ condition of the DEQ TMDL model.

MODEL DEVELOPMENT

Stream temperatures are influenced by processes that are external to the stream and by processes that occur within the stream system and the associated riparian zone. Most prominent of these forcing functions include incidence of solar radiation, topographic shade, vegetative shade, air temperature, relative humidity, wind speed and direction, precipitation, phreatic flows, and hyporheic flows (Poole & Berman 2000). Channel complexity is directly related to nearly all of these forcing functions. Broader streams have more surface area and thus have greater exposure to solar radiation. Deeply incised streams and narrow streams are likely to have more shading (on a percentage basis) from streamside vegetation. Stream channels located in deep, sharply cut or narrow valleys, as opposed to broad alluvial valleys, are likely to experience more shading from surrounding topographic features. Streams located in deeply cut valleys are likely to have winds directed along the axis of the valley, thus greater wind exposure is possible, while broad alluvial valleys may experience less wind funneling, and thus have less exposure to winds. While riparian vegetation can provide shade, it can also trap cool or warm air in the stream corridor or provide shelter from prevailing winds.

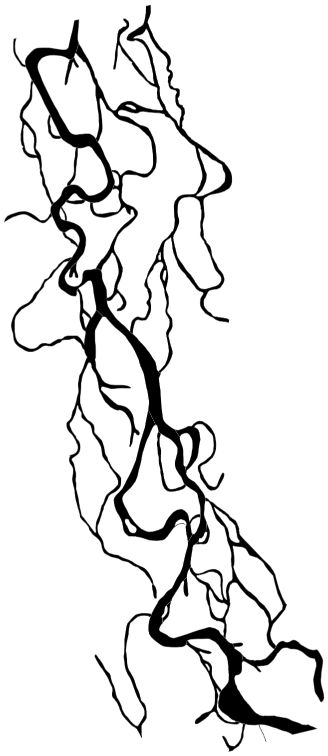

Figure 1. Willamette River channel configuration as it appears to have existed in 1850. This six-mile reach of the river is located a few miles north of Eugene, Oregon (Hulse et al., 2002)

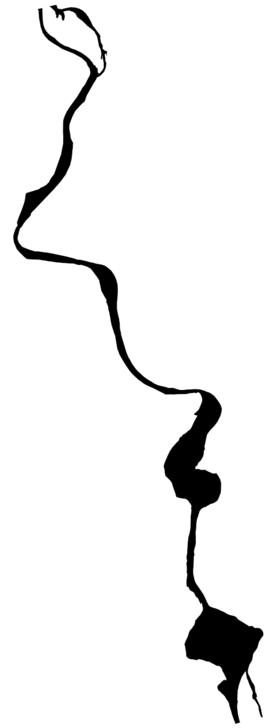

Figure 2. Willamette River channel configuration as it appeared in 1995. This is the same six-mile river reach shown in Figure 2. Urbanization has resulted in a dramatic reduction in channel complexity (Hulse et al., 2002).

Models developed to predict stream temperatures typically simulate the heat exchange functions given flow, meteorological, and stream channel configurations. CE-QUAL-W2 is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality computer simulation model developed by the US Army Corps of Engineers (Cole and Wells 2006). This model includes a compartmentalized heat exchange function based on the following:

$$H_n = H_s + H_a + H_e + H_c - (H_{sr} + H_{ar} + H_{br})$$

where H_n = the net rate of heat exchange across the water surface; H_s = incident short wave solar radiation; H_a = incident long wave radiation; H_e = evaporative heat loss; H_c = heat conduction; H_{sr} = reflected short wave solar radiation; H_{ar} = reflected long wave solar radiation; and H_{br} = back radiation from the water surface. Each of the above compartments is solved individually to predict stream temperatures throughout the model's domain and over the time period of interest.

CE-QUAL-W2 simulates the hydrodynamics of the system by simultaneous solution of the continuity and momentum equations. The results of the hydrodynamics are used in the solution of the energy continuity compartment. The hydrodynamic calculations affect the travel time and depth of flow through the river channel and thus can affect heat transfer processes significantly.

The governing equations in CE-QUAL-W2 include the x-momentum equation, the continuity equation, the free water surface equation, and the constituent transport equation. The six governing equations were derived from three-dimensional, turbulent and time averaged equations. A discussion of their derivation is supplied in Edinger and Buchak (1978) and Wells (1997). The six unknowns are pressure, P; horizontal velocity, U; vertical velocity, W; constituent concentration, Φ; density, ρ_v; and free water surface elevation, η. If macrophytes are modeled, porosity ϕ is the ratio of plant volume in a model cell to total wetted cell volume. Conservation of mass is governed by the continuity equation:

$$\frac{\partial}{\partial x}(U\phi B)+\frac{\partial}{\partial z}(W\phi B)=q\phi B$$

where B is the channel width and q is the lateral inflow/outflow per unit volume. Assumptions implicit in the equation's derivation include a width-averaged channel and constant fluid density.

Conservation of fluid momentum in the horizontal direction is governed by the x-momentum equation:

$$\frac{\partial}{\partial t}(U\phi B)+\frac{\partial}{\partial x}(UU\phi B)+\frac{\partial}{\partial z}(WU\phi B)=$$
$$-\frac{\phi B}{\rho_w}\frac{\partial p}{\partial x}+\frac{1}{\rho_w}\frac{\partial}{\partial x}(\phi B\tau_{xx})+\frac{1}{\rho_w}\frac{\partial}{\partial z}(\phi B\tau_{xz})$$

τ_{x} is the turbulent shear stress acting in the x-direction on the x-face of the control volume and τ_{x} is the turbulent shear stress acting in the x-direction on the z-face of the control volume.

The vertical momentum equation simplifies to the hydrostatic equation by assuming that vertical velocities are very low compared to horizontal velocities ($U >> W$) :

$$\frac{1}{\rho_w}\frac{\partial p}{\partial z}=g$$

The free water surface equation is obtained by integrating the continuity equation over depth:

$$\frac{\partial}{\partial t}\left(\phi B_\eta \eta\right) = \frac{\partial}{\partial x}\int_\eta^h U\phi B dz - \int_\eta^h q\phi B dz$$

where B_η is the surface width, η is the free water surface elevation and h is the bottom elevation. In CE-QUAL-W2 the free water surface elevation is integrated over all the layers in a segment.

Constituent transport is governed by the constituent transport equation:

$$\frac{\partial}{\partial t}(\phi B\Phi) + \frac{\partial}{\partial x}(U\phi B\Phi) + \frac{\partial}{\partial z}(W\phi B\Phi) - \frac{\partial}{\partial x}\left(\phi BD_x \frac{\partial \Phi}{\partial x}\right) - \frac{\partial}{\partial z}\left(\phi BD_z \frac{\partial \Phi}{\partial z}\right) =$$
$$q_\phi \phi B + S_K \phi B$$

where D_x and D_z the longitudinal and vertical temperature and constituent dispersion coefficients, respectively. q_ϕ is the lateral inflow of constituent per unit volume and S_K is the kinetics source/sink term for constituent concentration.

Water density is governed by the equation of state and is a function of temperature T_w, total dissolved solids concentration Φ_{TDS}, and suspended solids concentration Φ_{SS}:

$$\rho_w = f\left(T_w, \Phi_{TDS}, \Phi_{SS}\right)$$

An algorithm which simulates hyporheic flow through the alluvial aquifer is being added to the CE-QUAL-W2 model code. The model will be able to capture the transient storage effects of hyporheic flow and the transfer of water across the river bed and banks. A conceptualized hyporheic flow zone is shown in Figure 3.

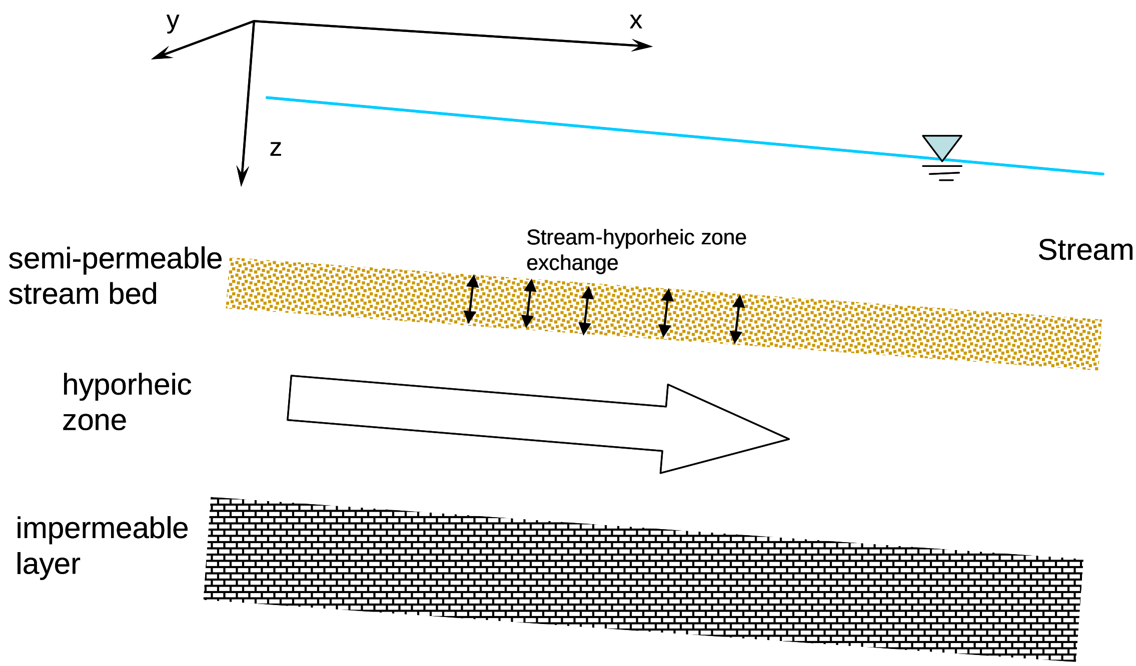

Figure 3. Illustration showing stream, semi-permeable stream bed, hyporheic zone, and the impermeable layer below the hyporheic zone.

Darcy's law is being used to estimate flow through the hyporheic zone. The head ϕ [L] and hyporheic flow velocity $\vec{q}$ [L/T] are functions of x, y, and z such that

$$\phi = \phi(x, y, z)$$

and

$$\vec{q} = \{q_x, q_y, q_z\}$$

Applying Darcy's law and assuming the conductivity $k = k_x = k_y = k_z$ [L/T] is constant,

$$\vec{q} = -k\nabla\phi$$

or

$$\vec{q} = -k\left(\frac{\partial\phi}{\partial x}\vec{i} + \frac{\partial\phi}{\partial y}\vec{j} + \frac{\partial\phi}{\partial z}\vec{k}\right)$$

Assuming $\frac{\partial\phi}{\partial y} = 0$ and that $q_z = -k\frac{\partial\phi}{\partial z} \approx 0$ within the hyporheic zone, then

$$\vec{q} = -k\frac{\partial\phi}{\partial x}\vec{i}$$

and

$$q_x = -k\frac{\partial \phi}{\partial x}$$

The governing equation for hyporheic flow is derived using a control volume of length Δx, depth B(thickness of hyporheic zone) and width $\Delta y$and assuming flow is only in the x-direction (Figure 4). The inflow is

$$Q_{\text{in}} = -kB\frac{\partial \phi}{\partial x}\Delta y$$

Whereas flow rate out is

$$Q_{\text{out}} = \left(-kB\frac{\partial \phi}{\partial x} - \Delta x\frac{\partial}{\partial x}kB\frac{\partial \phi}{\partial x}\right)\Delta y$$

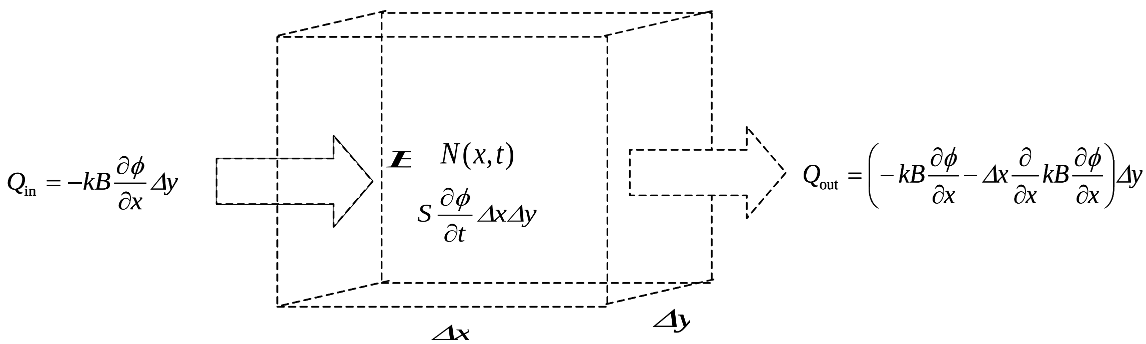

Figure 4. Control volume with length Δx, depth B and width Δy.

A flow balance can be constructed giving

$$\underbrace{S\frac{\partial \phi}{\partial t}\Delta x\Delta y}_{\text{change in fluid volume per unit time}} = \underbrace{-kB\frac{\partial \phi}{\partial x}\Delta y}_{\text{flow in}} - \underbrace{\left(-kB\frac{\partial \phi}{\partial x} - \Delta x\frac{\partial}{\partial x}kB\frac{\partial \phi}{\partial x}\right)\Delta y}_{\text{flow out}} + \underbrace{N(x,t)}_{\text{sources/sinks}}$$

where the dimensionless parameter S is the storativity and $N(x,t)$ [L^3/T] is the net flow rate of sources and sinks. Simplifying gives

$$S\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial x}kB\frac{\partial \phi}{\partial x} + \frac{N(x,t)}{\Delta x\Delta y}$$

Letting $\frac{N(x,t)}{\Delta x\Delta y} = \varepsilon(x,t)$

$$S\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial x}kB\frac{\partial \phi}{\partial x} + \varepsilon(x,t)$$

The source/sink term $\varepsilon(x,t)$ [L/T] represents flow across the stream bed between the hyporheic zone and the stream:

$$\varepsilon(x,t) = \frac{k'}{b'}(\phi_{\circ} - \phi)$$

where
$\phi_{\circ}$=water level in stream [L]
k'=conductivity through stream bed [L/T]
b'=thickness of streambed [L]

Substituting for $\varepsilon(x,t)$ gives the following governing equation:

$$S\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial x} kB \frac{\partial \phi}{\partial x} + \frac{k'}{b'}(\phi_{\circ} - \phi)$$

which can be solved to calculate the head ς in the hyporheic zone.

The control volume approach is also used to derive the governing equations for constituent transport. It is assumed that flow and variation in concentration occur only in the x-direction. Given the mass dispersive flux m_x [M/L²-T] the rate of change in mass in the control volume can be expressed as:

$$\underbrace{\frac{\partial C}{\partial t}\Delta x \Delta y B}_{\text{Rate of change in constituent mass}} = \underbrace{Cq_x B\Delta y}_{\text{advected mass flux in}} - \underbrace{\left(q_x C + \Delta x \frac{\partial C q_x}{\partial x}\right) B\Delta y}_{\text{Advected flux out}} + \underbrace{m_x B\Delta y}_{\text{mass dispersive flux in}} - \underbrace{\left(m_x C + \Delta x \frac{\partial m_x}{\partial x}\right) B\Delta y}_{\text{mass dispersive flux out}} + \underbrace{r\Delta x \Delta y B}_{\text{mass source/sinks}}$$

The mass dispersive flux is:

$$m_x = -D_x \frac{\partial c}{\partial x}$$

where D_x [L²/T] is the coefficient of dispersion. Figure 5 shows the control volume for constituent transport.

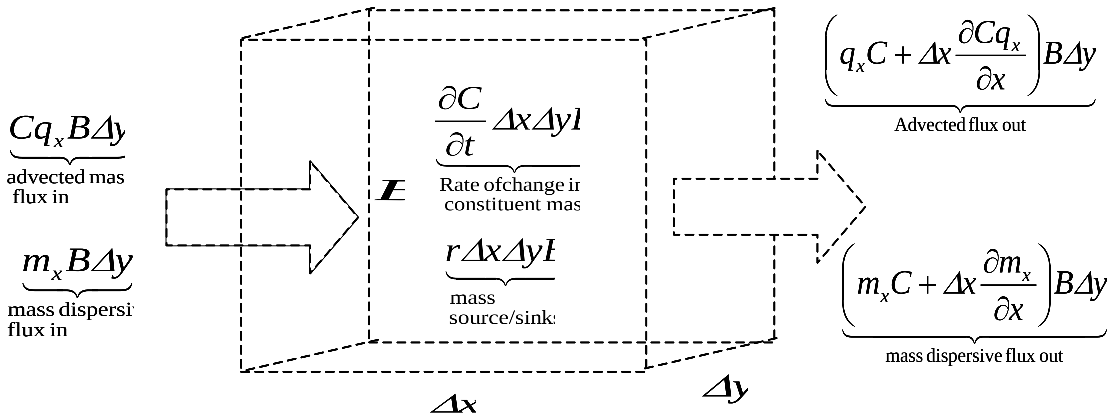

Figure 5. Control volume for constituent transport.

Simplifying and substituting for m_x gives

$$\frac{\partial C}{\partial t} + \frac{\partial C q_x}{\partial x} = \frac{\partial}{\partial x} D_x \frac{\partial C}{\partial x} + r$$

Constituent transport between the hyporheic zone and the stream is modeled using the source/sink term r.

NUMERICAL SOLUTION SCHEME FOR CALCULATING HYPORHEIC HEAD

The head in the hyporheic zone was calculated using the governing equation

$$S\frac{\partial \phi}{\partial t} - \frac{\partial}{\partial x}\left(kB_T \frac{\partial \phi}{\partial x}\right) - \frac{k'}{b'}\left(\phi_w - \phi\right) = 0$$

Where

ϕ=head [L]

S=storativity

B=width [L]

k= conductivity [L/T]

ϕ_w=water level in stream [L]

k'=conductivity through stream bed [L/T]

b'=thickness of streambed [L]

Once the head ϕ is determined, the velocity q_x can be estimated using

$$q_x = -k\frac{\partial \phi}{\partial x}$$

The head ϕ will be calculated at the center of a model cell. Figure 6 shows a sample grid.

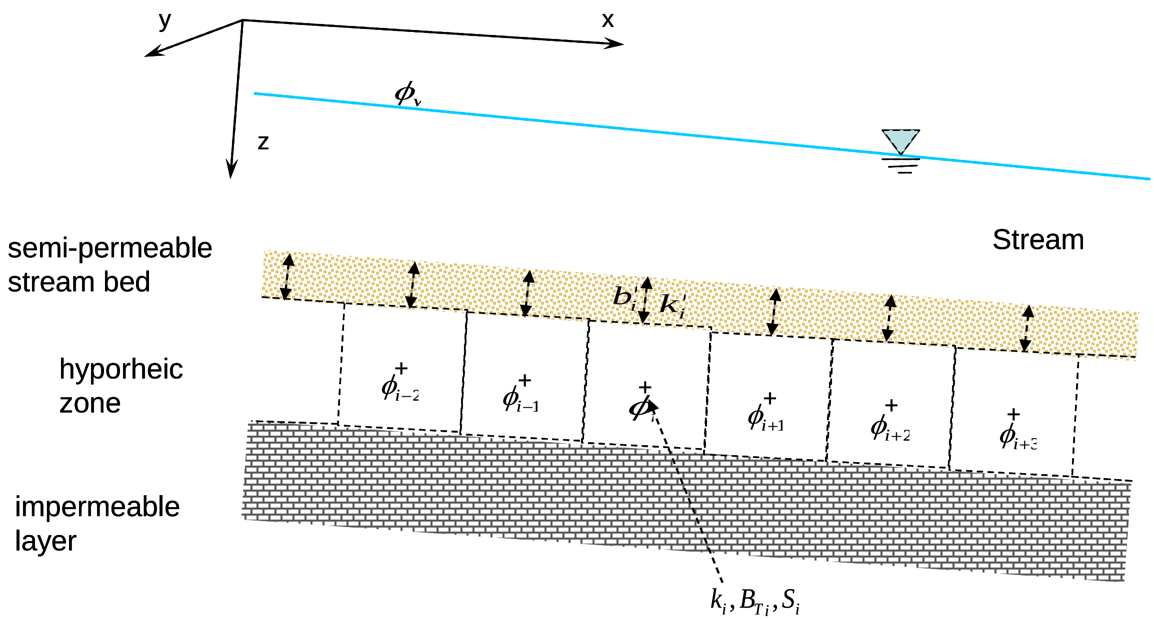

Figure 6. Example grid used for hyporheic zone.

To determine the head in the hyporheic zone, an implicit finite difference scheme was applied where the time derivative was expressed as

$$\frac{\partial \phi}{\partial t} \approx \frac{\phi_i^{n+1} - \phi_i^n}{\Delta t}$$

and the spatial derivatives were

$$\frac{\partial^2 \phi}{\partial x^2} \approx \theta \frac{\phi_{i+1}^{n+1} - 2\phi_i^{n+1} + \phi_{i-1}^{n+1}}{\Delta x^2} + (1-\theta)\frac{\phi_{i+1}^n - 2\phi_i^n + \phi_{i-1}^n}{\Delta x^2}$$

and

$$\frac{\partial \phi}{\partial x} \approx \theta \frac{\phi_{i+1}^{n+1} - \phi_{i-1}^{n+1}}{2\Delta x} + (1-\theta)\frac{\phi_{i+1}^n - \phi_{i-1}^n}{2\Delta x}$$

where θ is the time-weighting factor. A value of $\theta = 0$ indicates a fully implicit scheme, whereas a value of $\theta = 1$ is fully explicit. Substituting into the governing equation gives

$$\frac{\phi_i^{n+1} - \phi_i^n}{\Delta t} - \frac{\theta}{S_i \Delta x}\left(kB_T\big|_{i+1/2} \frac{\phi_{i+1}^{n+1} - \phi_i^{n+1}}{\Delta x} - kB_T\big|_{i-1/2} \frac{\phi_i^{n+1} - \phi_{i-1}^{n+1}}{\Delta x} \right) -$$

$$\frac{(1-\theta)}{S_i \Delta x}\left(kB_T\big|_{i+1/2} \frac{\phi_{i+1}^n - \phi_i^n}{\Delta x} - kB_T\big|_{i-1/2} \frac{\phi_i^n - \phi_{i-1}^n}{\Delta x} \right) + \theta \frac{k_i'}{S_i b_i'} \phi_i^{n+1} + (1-\theta)\frac{k_i'}{S_i b_i'} \phi_i^n - \frac{k_i'}{S_i b_i'} \phi_w = 0$$

And rearranging results in

$$\frac{\theta}{S_i \Delta x^2}\left(-kB_T\big|_{i-1/2}\right)\phi_{i-1}^{n+1} + \left(\frac{1}{\Delta t} + \theta\frac{kB_T\big|_{i-1/2}}{S_i \Delta x^2} + \theta\frac{kB_T\big|_{i+1/2}}{S_i \Delta x^2} + \theta\frac{k_i'}{S_i b_i'}\right)\phi_i^{n+1}$$

$$+\frac{\theta}{S_i \Delta x^2}\left(-kB_T\big|_{i+1/2}\right)\phi_{i+1}^{n+1} = \left(\frac{1-\theta}{S_i \Delta x^2}\right)kB_T\big|_{i-1/2}\phi_{i-1}^{n}$$

$$+\left(\frac{1}{\Delta t} - (1-\theta)\frac{k_i'}{S_i b_i'} - (1-\theta)\frac{1}{S_i \Delta x^2}\left(kB_T\big|_{i+1/2} + kB_T\big|_{i-1/2}\right)\right)\phi_i^n + \left(\frac{1-\theta}{S_i \Delta x^2}\right)kB_T\big|_{i+1/2}\phi_{i+1}^n + \frac{k_i'}{S_i b_i'}\phi_w$$

or

$$-\theta\frac{kB_T\big|_{i-1/2}}{S_i \Delta x^2}\phi_{i-1}^{n+1} + \left(\frac{1}{\Delta t} + \theta\frac{kB_T\big|_{i-1/2}}{S_i \Delta x^2} + \theta\frac{kB_T\big|_{i+1/2}}{S_i \Delta x^2} + \theta\frac{k_i'}{S_i b_i'}\right)\phi_i^{n+1}$$

$$-\theta\frac{kB_T\big|_{i+1/2}}{S_i \Delta x^2}\phi_{i+1}^{n+1} = (1-\theta)\frac{kB_T\big|_{i-1/2}}{S_i \Delta x^2}\phi_{i-1}^{n} + \left(\frac{1}{\Delta t} - (1-\theta)\frac{k_i'}{S_i b_i'} - (1-\theta)\left(\frac{kB_T\big|_{i+1/2}}{S_i \Delta x^2} + \frac{kB_T\big|_{i-1/2}}{S_i \Delta x^2}\right)\right)\phi_i^n +$$

$$(1-\theta)\frac{kB_T\big|_{i+1/2}}{S_i \Delta x^2}\phi_{i+1}^n + \frac{k_i'}{S_i b_i'}\phi_w$$

This equation was solved using a tri-diagonal matrix solver pre-existing in the CE-QUAL-W2 source code to determine the head ϕ in the hyporheic flow zone.

STEADY STATE HEAD TEST

The hyporheic flow module was initially tested separately from CE-QUAL-W2 by simulating steady state conditions with fixed head boundary conditions and leakage between an aquifer and a overlying body of water (Figure 7). The governing equation for the steady state system is

$$\frac{\partial}{\partial x}\left(kB_T\frac{\partial \phi}{\partial x}\right) + \frac{k'}{b'}(\phi_w - \phi) = 0$$

since $\frac{\partial \phi}{\partial t} = 0$. If $kB_T = 0$ the governing equation simplifies to

$$kB_T\frac{\partial^2 \phi}{\partial x^2} + \frac{k'}{b'}(\phi_w - \phi) = 0$$

with fixed head boundary conditions $\phi(x=0) = \phi_\circ$ and $\phi(x=L) = \phi_L$ where L is the distance to the downstream boundary condition. To solve, the governing equation can be rewrote

$$kB_T \frac{\partial^2(\phi-\phi_w)}{\partial x^2} - \frac{k'}{b'}(\phi-\phi_w) = 0$$

and letting $f(x) = \phi(x) - \phi_w$ such that

$$kB_T \frac{\partial^2 f}{\partial x^2} - \frac{k'}{b'} f = 0$$

where $f(x=0) = \phi_\circ - \phi_w$ and $\phi(x=L) = \phi_L - \phi_w$. If $\lambda = \sqrt{\frac{k'}{kB_T b'}}$ the governing equation can be written

$$\frac{\partial^2 f}{\partial x^2} - \lambda f = 0$$

The solution for f has the form

$$f(x) = c_1 e^{-\lambda x} + c_2 e^{\lambda x}$$

where c_1 and c_2 are constants. At $x = 0$, the boundary condition is

$$f(0) = \phi_\circ - \phi_w = c_1 + c_2$$

giving $c_2 = \phi_\circ - \phi_w - c_1$.

At $x = L$, the boundary condition is

$$f(L) = \phi_L - \phi_w = c_1 e^{-\lambda L} + c_2 e^{\lambda L} = c_1 e^{-\lambda L} + (\phi_\circ - \phi_w - c_1)e^{\lambda L}$$

resulting in

$$c_1 = \frac{\phi_L + \phi_w(e^{\lambda L} - 1) - e^{\lambda L}\phi_\circ}{e^{-\lambda L} - e^{\lambda L}}$$

and

$$c_2 = \phi_\circ - \phi_w - \frac{\phi_L + \phi_w(e^{\lambda L} - 1) - e^{\lambda L}\phi_\circ}{e^{-\lambda L} - e^{\lambda L}}$$

The solution for $\phi(x)$ is thus

$$\phi(x) = c_1 e^{-\lambda x} + c_2 e^{\lambda x} + \phi_w$$

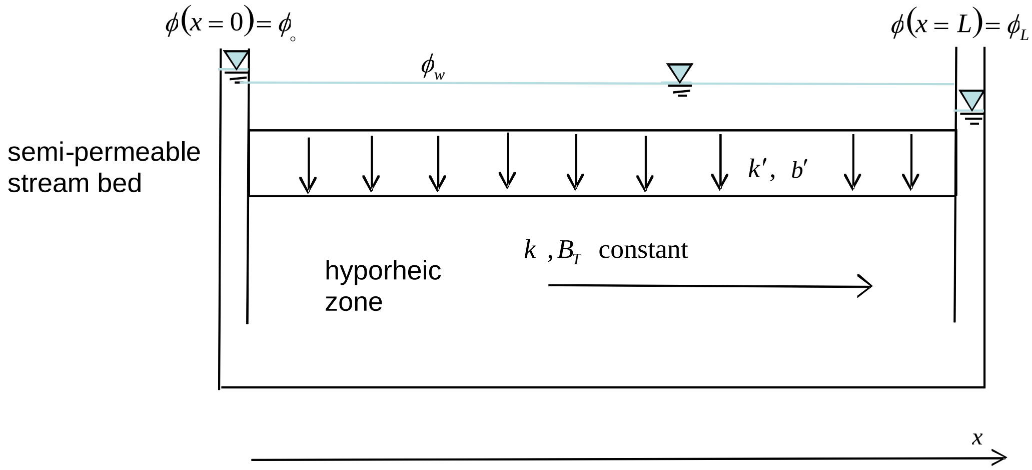

Figure 7. Hyporheic flow test case where condtions are steady-state, the upstream and downstream head boundary conditions are fixed, and leakage occurs between aquifer and overlying water body.

Five simulations were conducted with varying parameter values.
Table 1 lists the coefficients used in the different test simulations. The model grid consisted of 12 model segments, each 10 m long (Δx=10 m). The storativity, hyporheic zone conductivity, stream bed conductivity, and stream bed thickness were assumed to be constant. The comparisons between the analytical solution and model predictions for head were shown in Figure 8. Error statistics, including mean error, absolute mean error, and root mean square error were listed in Table 2. The average absolute mean error for all the steady-state test cases was 0.003 m. Source code used for the steady state head test is shown in Appendix.

Table 1. Coefficient values used model test of steady-state conditions with leakage.

Test #	*Upstream Head (m)* ϕ_o	*Downstream Head (m)* ϕ_L	*Overlying Head (m)* ϕ_w	*Stora-tivity* S	*Hyporheic zone cond. (m/s)* k	*Hyorheic zone thick. (m)* B_T	*Stream bed cond. (m/s)* k'	*Stream bed thick. (m)* b'
1	3.0	2.5	2.75	0.0001	0.004	10.0	0.00004	0.2
2	4.0	3.0	3.9	0.0002	0.001	1.0	0.00001	0.4
3	3.0	4.0	3.5	0.0001	0.004	5.0	0.00002	0.4
4	2.0	1.0	2.5	0.0001	0.006	5.0	0.0004	0.3
5	3.0	1.0	2.0	0.0001	0.008	10.0	0.00001	2.0

Figure 8. Comparison of model predictions with analytical solution for steady state test cases with leakage to hyporheic zone.

Table 2. Error statistics of model predictions with analytical solutions for steady state test cases with leakage to hyporheic zone.

Test #	*Mean Error (m)*	*Absolute Mean Error (m)*	*Root Mean Square Error (m)*
1	0.000	0.001	0.001
2	0.003	0.004	0.008
3	0.000	0.001	0.001
4	0.009	0.009	0.018
5	0.000	0.000	0.000
Average	0.002	0.003	0.006

CONSTITUENT TRANSPORT TEST

Another test case was used to compare model predictions of constituent transport in the hyporheic zone with an analytical solution. Model predictions were made using a CE-QUAL-W2 test code which included the hyporheic flow module. Constituent transport in the hyporheic zone is modeled using the following governing equation:

$$\frac{\partial C}{\partial t} + \frac{\partial C q_x}{\partial x} = \frac{\partial}{\partial x} D_x \frac{\partial C}{\partial x} + r$$

The solution of to the constituent transport equation was determined using an advective-diffusion solution scheme pre-existing in CE-QUAL-W2. For the test case transport across the stream bed was assumed to be zero ($r = 0$). The horizontal velocity q_x and dispersion D_x were assumed to be constant giving

$$\frac{\partial C}{\partial t} + q_x \frac{\partial C}{\partial x} = D_x \frac{\partial^2 C}{\partial^2 x}$$

The initial concentration in the hyporheic zone was set to zero and the concentration at the left hand boundary $x = 0$ was C_o. The initial condition and boundary conditions were thus

$$C(0,t) = C_o \quad , \quad 0 < t < \infty$$
$$C(x,0) = 0 \quad , \quad 0 < x < \infty$$

The analytical solution to this equation is

$$C(x,t) = \frac{C_o}{2}\left[erfc\left(\frac{x - q_x t}{\sqrt{4Dt}} \right) + erfc\left(\frac{x + q_x t}{\sqrt{4Dt}} \right) \exp\left(\frac{q_x x}{D} \right) \right]$$

The test case was diagrammed in Figure 9. With increasing time the constituent front travels to the right due to advection while also spreading out because of dispersion. The coefficient parameters used in the test cases were listed in Table 3. The concentration at the left hand boundary C_o was assumed to be 100 mg/l. The model grid consisted of 100 segments, each 10 m long ($\Delta x = 100$ m). Model predictions are compared with the analytical solution in Figure 10. The mean error, absolute mean error, and root mean square error of the test cases were listed in Table 4.

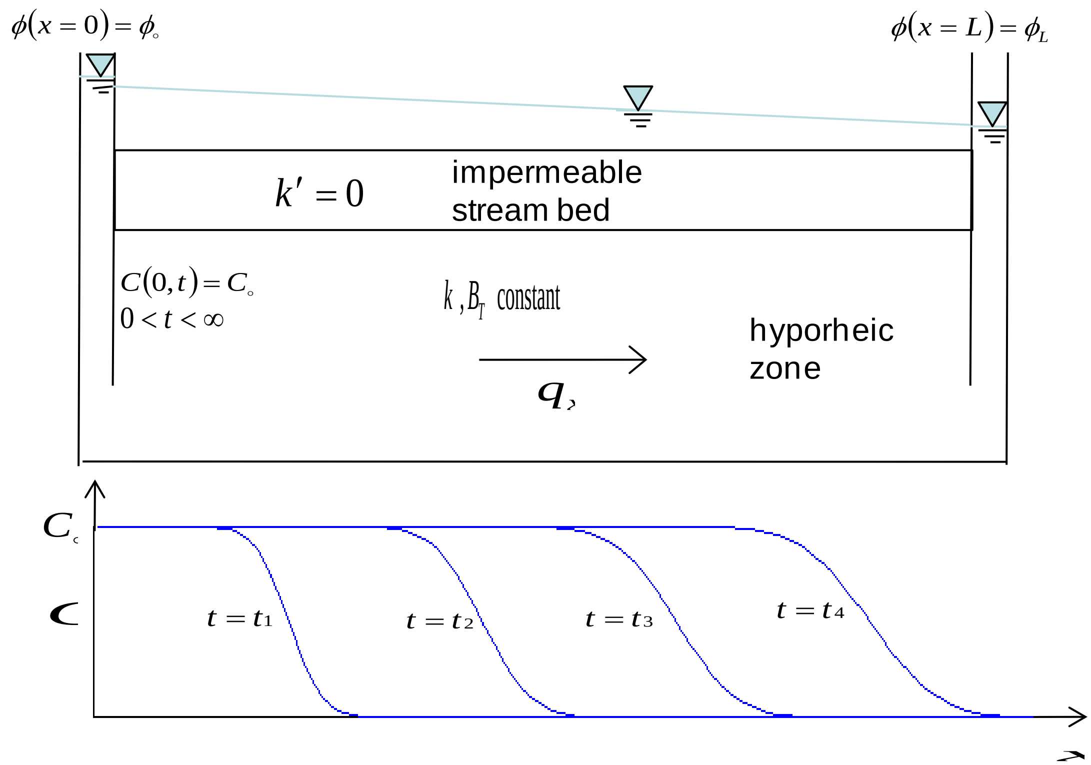

Figure 9. The constituent transport test case where a constituent of concentration C_o is released continuously at the location $x = 0$ starting at time $t = 0$

Table 3. Coefficient values used model constituent transport test.

Test #	*Upstream Head (m)* ϕ_o	*Downstream Head (m)* ϕ_L	*Dispersion (m^2/s)* D_x	*Storativity* S	*Hyporheic zone cond. (m/s)* k	*Hyorheic zone thick. (m)* B_T	*Stream bed cond. (m/s)* k'	*Stream bed thick. (m)* b'
6	3.0	2.5	0.02	0.0001	0.020	10.0	0.0	0.2
7	3.0	2.5	0.001	0.0001	0.100	1.0	0.0	0.2
8	3.0	2.5	0.020	0.0001	0.020	5.0	0.0	0.2

Table 4. Error statistics of model predictions with analytical solutions for constituent transport test.

Test #	*Mean Error(mg/l)*	*Absolute Mean Error(mg/l)*	*Root Mean Square Error(mg/l)*
6	-2.0	2.0	3.3
7	-0.2	0.2	0.6
8	-1.0	1.0	1.8
Average	-1.1	1.1	1.9

Figure 10. Comparisons of model predictions with analytical solution for constituent transport test cases.

INTEGRATION WITH CE-QUAL-W2

A specialized input file was created to input hyporheic coefficients. Table 1 lists the coefficients in the input file “hyporheic.npt”.

Table 5. List of coefficients used in hyporheic.npt input file.

Variable Name	*Equation Variable*	*Description*
THETAH	θ	Time weighting factor. $\theta = 0$ indicates a fully implicit scheme, whereas a value of $\theta = 1$ is fully explicit
THI	-	Initial temperature in hyporheic zone (Celsius)
UHH	-	Upstream branch boundary condition. UHH=0 for no-flux boundary, UHH=-1 for head boundary
DHH	-	Downstream branch boundary condition. DHH=0 for no-flux boundary, DHH=-1 for

Variable Name	*Equation Variable*	*Description*
		head boundary
STOR	S	Storativity (-)
KC	K	Hyporheic zone conductivity (m/s)
BT	B_1	Hyorheic zone thickness (m)
WHP	Δy	Stream bed width (m)
KP	k'	Stream bed conductivity (m/s)
BP	b'	Stream bed thickness (m)
DXH	D_x	Dispersion in groundwater (m^2/s)

An example file is shown below. The columns are eight spaces wide. This example file corresponds to a model consisting of a single branch, with 20 segments.

```
hyporheic input file: hyporheic.npt

          THETAH     THI
            0.55    12.0

             UHH     DHH
    br1       -1       0

     SEG    STOR      KC      BT     WHP      KP      BP     DXH
       1  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
       2  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
       3  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
       4  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
       5  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
       6  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
       7  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
       8  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
       9  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
      10  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
      11  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
      12  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
      13  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
      14  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
      15  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
      16  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
      17  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
      18  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
      19  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
      20  0.0001   0.500     2.0    15.0  0.1000     0.2   0.001
```

MODEL APPLICATION

Initially, the CE-QUAL-W2 model is being applied to an idealized riverine system consisting of a single main channel and then to the same idealized system, but with the addition of side channels. Assumptions used in the model development, for both systems, includes 15-meter tall dense streamside vegetation, diurnal air temperature fluctuations (7^{o}C to 21^{o}C) based on current meteorological data, constant flow rates and inflow stream temperatures, 44^{o} north latitude, no wind, a domain length of one mile, and with and without hyporheic flows. Also, changes in channel geometry is being explored in the main channel and the side channels. The results of the two models will be compared to evaluate differences in predicted temperature regimes between these two idealized systems.

The CE-QUAL-W2 model is being developed for the two Willamette River channel configurations shown in Figure 1 and Figure 2. The temperature regimes predicted for the two channel configurations are being compared. A sensitivity analysis is being performed to determine the dominant forcing functions affecting stream temperatures and evaluate critical levels for these forcing functions.

CONCLUSION

A model has been developed for simulating hyporheic flow in rivers. The hyporheic flow model is one-dimensional and based on Darcy's groundwater flow equation. Flow exchange between the stream and hyporheic zone is simulated across a semi-permeable stream bed. Constituent transport in the hyporheic zone is being modeled using the one-dimensional advective-diffusion equation. The hyporheic flow model has been coupled to the hydrodynamic and water quality model CE-QUAL-W2 and has been tested. The hyporheic flow model has been shown to reproduce analytical solutions. The combined impact of multiple stream channels and hyporheic flow will be evaluated. It will also be used to model to temperatures in the Willamette River, Oregon. Past and present channel configurations are being simulated in order to determine the impact of channelization on stream temperatures. Model predictions will be compared with data to validate the model's suitability for simulating present conditions.

When the project is complete a tool will be available that can model flow and constituent transport in the hyporheic zone of streams. This hyporheic flow feature will be part of future versions of CE-QUAL-W2. The prediction of pre-development or natural condition stream temperatures often necessary in TMDL studies will be made easier with a tool simulating the combined effect of hyporheic flow and channel complexity.

ACKNOWLEDGEMENTS

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Appendix

The code used in the CE-QUAL-W2 model is written in Fortran 90/95. This appendix contains the test codes used to verify the hyporehic flow algorithms in the CE-QUAL-W2 model.

```
! Head test program

  parameter(imx=12,kmx=5,nbr=1,nwb=1,tmend=86400.0)

  real thetah
  real head1(imx), stor(imx),kc(imx),bt(imx),whp(imx),kp(imx)
  real bp(imx),dxh(imx),kcb(imx),kpb(imx),porh(imx)
  real uhy(imx),qh(imx), qhf(kmx),qb(imx),elws(imx),dlx(imx),volh(imx)
  real aa(imx),vv(imx),cc(imx),dd(imx)
  integer us(nbr),ds(nbr),bs(nwb),be(nwb),cus(nbr),uhh(nbr),dhh(nbr)
  logical uhyp_external(nbr),dhyp_external(nbr)
  double precision c1,c2,ush,dsh,head2(imx),lambda,headm(imx),dist(imx)

  open(1,file="uhout.dat",status='unknown')
  open(2,file="qout.dat",status='unknown')
  open(3,file="headout.dat",status='unknown')
  open(4,file="volhout.dat",status='unknown')

  us(1)=2;ds(1)=11;bs(1)=1;be(1)=1

! dlx = segment length, dlt=time step
  dlx=10.0
  dlt=10.0
  tconv=86400.0

! ush= upstream head, dsh=downstream head
  ush=3.0
  dsh=2.5
  delth=ush-dsh

  iu=us(1)
  id=ds(1)

! elws= water surface elevation of overlying water body
  elws(1)=ush
  elws(imx)=dsh
  do i=iu,id
!    elws(i)=ush - delth*real(i-2)/real(imx-3)
    elws(i)=2.75
  end do

! read coefficients

  open (712, file='hyporheic.npt',status='old')
  read (712,'(///(8x,f8.0))')thetah
  read (712,'(//(8x,2i8))')      (uhh(jb),  dhh(jb), jb=1,nbr)
  read (712,'(/)')
  do i=1,imx
    read                                (712,'(8x,8f8.0)')
stor(i),kc(i),bt(i),whp(i),kp(i),bp(i),dxh(i),porh(i)
```

```
  end do
  close(712)

! head conditions
  do jb=1,nbr
    uhyp_external(jb) = uhh(jb)  == -1;dhyp_external(jb) = dhh(jb)  == -1
  end do

! hyporheic geometry and constants
  do jw=1,nwb
    do jb=bs(jw),be(jw)
      iu=us(jb)
      id=ds(jb)
      stor(iu-1)=stor(iu)
      stor(id+1)=stor(id)
      kc(iu-1)=kc(iu)
      kc(id+1)=kc(id)
      bt(iu-1)=bt(iu)
      bt(id+1)=bt(id)
      kp(iu-1)=kp(iu)
      kp(id+1)=kp(id)
      bp(iu-1)=bp(iu)
      bp(id+1)=bp(id)
      do i=iu-1,id
        kcb(i)=(kc(i)*bt(i)+kc(i+1)*bt(i+1))/2.0
        kpb(i)=kp(i)/bp(i)
      end do
      kcb(id+1)=kcb(id)
      kpb(id+1)=kpb(id)
    end do
  end do

  do i=iu,id
    volh(i)=dlx(i)*whp(i)*bt(i)*porh(i)
  end do

  head1=elws
  head2=head1
  time=0.0

  do while (time<=tmend)
    time=time+dlt

    do jw=1,nwb
      do jb=bs(jw),be(jw)
        cus(jb)=us(jb)
        iu=cus(jb)
        id=ds(jb)
        aa = 0.0; cc = 0.0; vv = 0.0; dd = 0.0
        aa(iu)=0.0
        cc(iu)=-thetah*kcb(iu)/(stor(iu)*dlx(iu)**2)
        if(uhyp_external(jb))then
          vv(iu)=1/dlt+thetah*(kcb(iu-1)+kcb(iu))/(stor(iu)*dlx(iu)**2)+
          thetah*kpb(iu)/stor(iu)        &
          dd(iu)=(1-thetah)*(kcb(iu-1)/(stor(iu)*dlx(iu)**2))*head2(iu-1)+
&
```

```
               (1/dlt-(1.0-thetah)*kpb(iu)/stor(iu)-(1.0-
thetah)*(kcb(iu)+kcb(iu-1))/  &
               (stor(iu)*dlx(iu)**2))*head2(iu)+    &
               (1-thetah)*(kcb(iu)/(stor(iu)*dlx(iu)**2))*head2(iu+1) +   &
               kpb(iu)/stor(iu)*elws(iu) +         &
               thetah*kcb(iu-1)/(stor(iu)*dlx(iu)**2) * head2(iu-1)
        else

vv(iu)=1/dlt+thetah*kcb(iu)/(stor(id)*dlx(id)**2)+thetah*kpb(iu)/stor(iu)
          dd(iu)=(1/dlt-(1.0-thetah)*kpb(iu)/stor(iu)-(1.0-thetah)*   &
          kcb(iu)/(stor(iu)*dlx(iu)**2))*head2(iu)+    &
               (1-thetah)*(kcb(iu)/(stor(iu)*dlx(iu)**2))*head2(iu+1)        +
&
                 kpb(iu)/stor(iu)*elws(iu)
        end if
        do i=iu+1,id-1
          aa(i)=-thetah*kcb(i-1)/(stor(i)*dlx(i)**2)
          vv(i)=1/dlt+thetah*(kcb(i-
1)+kcb(i))/(stor(i)*dlx(i)**2)+thetah*kpb(i)/stor(i)
          cc(i)=-thetah*kcb(i)/(stor(i)*dlx(i)**2)
          dd(i)=(1-thetah)*(kcb(i-1)/(stor(i)*dlx(i)**2))*head2(i-1)         +
&
                 (1/dlt-(1.0-thetah)*kpb(i)/stor(i)-(1.0-thetah)*(kcb(i)+
&
                 kcb(i-1))/(stor(i)*dlx(i)**2))*head2(i) +   &
                 (1-thetah)*(kcb(i)/(stor(i)*dlx(i)**2))*head2(i+1)          +
kpb(i)/stor(i)*elws(i)
        end do
        cc(id)=0.0
        aa(id)=-thetah*kcb(id-1)/(stor(id)*dlx(id)**2)
        if(dhyp_external(jb))then
          vv(id)=1/dlt+thetah*(kcb(id-
1)+kcb(id))/(stor(id)*dlx(id)**2)+thetah*kpb(id)/stor(id)
          dd(id)=(1-thetah)*(kcb(id-1)/(stor(id)*dlx(id)**2))*head2(id-1)    +
&
              (1/dlt-(1.0-thetah)*kpb(id)/stor(id)-(1.0-thetah)*(kcb(id-1)+
&
              kcb(id))/(stor(id)*dlx(id)**2))*head2(id) +   &
              (1-thetah)*(kcb(id)/(stor(id)*dlx(id)**2))*head2(id+1)         +
&
              kpb(id)/stor(id)*elws(id)  +  &
              thetah*kcb(id)/(stor(id)*dlx(id)**2) * head2(id+1)
        else
          vv(id)=1/dlt+thetah*kcb(id)/(stor(id)*dlx(id)**2)+thetah*kcb(id-1)/
&
          (stor(id)*dlx(id)**2)+thetah*kpb(id)/stor(id)
          dd(id)=(1-thetah)*(kcb(id-1)/(stor(id)*dlx(id)**2))*head2(id-1)    +
&
            (1/dlt-(1.0-thetah)*kpb(id)/stor(id)-(1.0-thetah)*kcb(id-1)/
&
                   (stor(id)*dlx(id)**2))*head2(id) +   &
              (1-thetah)*(kcb(id)/(stor(id)*dlx(id)**2))*head2(id+1)         +
kpb(id)/stor(id)*elws(id)
        end if
        call tridiag(aa,vv,cc,dd,iu,id,imx,head1)
! calculating hyporheic velocity and flow rate between cells - assuming no
flux boundaries at branch ends
```

```
        do i=iu,id-1
          uhy(i)=kcb(i)*(head1(i)-head1(i+1))
          qh(i)=uhy(i)*(bt(i)*whp(i)+bt(i+1)*whp(i+1))/2.0
        end do
        if(uhyp_external(jb))then
           uhy(iu-1)=kcb(iu)*(head1(iu-1)-head1(iu))
           qh(iu-1)=uhy(iu-1)*bt(iu)*whp(iu)
        end if
        if(dhyp_external(jb))then
          uhy(id)=kcb(id)*(head1(id)-head1(id+1))
          qh(id)=uhy(id)*bt(id)*whp(id)
        end if
! correcting flows so that volume balances...
        do i=iu,id
         qb(i)=whp(i)*dlx(i)* kpb(i) * (elws(i)-head1(i))
         qh(i)=qh(i-1)+qb(i)
        end do
        head2=head1
      end do
    end do

    write(1,55)time/tconv,uhy
    write(2,55)time/tconv,qh
    write(3,55)time/tconv,head2
    write(4,55)time/tconv,volh

55  format(g10.4,<imx>(2x,f12.5))

  end do

  open(14,file='head_end.dat',status='unknown')
  write(14,'("       X    model     eqn")')
  dist(1)=0.0
  do i=2,imx
    dist(i)=dist(i-1)+dlx(i-1)/2.0+dlx(i)/2.0
  end do

! calculating analytical solution
! assuming constant kp,bt,kc and bp
  lambda=sqrt(kp(2)/(kc(2)*bt(2)*bp(2)))
    c1=(dsh+elws(2)*(exp(lambda*dist(imx))-1.0)-exp(lambda*dist(imx))*ush)/
&
       (exp(-lambda*dist(imx))-exp(lambda*dist(imx)))
  c2=ush-elws(2)-c1
  do i=1,imx
    headm(i)=c1*exp(-lambda*dist(i)) + c2*exp(lambda*dist(i)) + elws(2)
  end do

  do i=1,imx
    write(14,'(f8.2,2f8.3)')dist(i),head2(i),headm(i)
  end do


  stop

  end
```

```
!*****************************************************************************
******************
!*                                              S U B R O U T I N E   T R I
D I A G
!*****************************************************************************
******************

SUBROUTINE TRIDIAG(A,V,C,D,S,E,N,U)
  INTEGER, PARAMETER :: I2=SELECTED_INT_KIND (3)
  INTEGER, PARAMETER :: R8=SELECTED_REAL_KIND(15)
  INTEGER,                            INTENT(IN)  :: S, E, N
  REAL    ,              DIMENSION(:), INTENT(IN)  :: A(E),V(E),C(E),D(E)
  REAL,                  DIMENSION(:), INTENT(OUT) :: U(N)
  REAL, ALLOCATABLE, DIMENSION(:)              :: BTA, GMA
  ALLOCATE (BTA(N),GMA(N))

  BTA(S) = V(S)
  GMA(S) = D(S)
  DO I=S+1,E
    BTA(I) = V(I)-A(I)/BTA(I-1)*C(I-1)
    GMA(I) = D(I)-A(I)/BTA(I-1)*GMA(I-1)
  END DO
  U(E) = GMA(E)/BTA(E)
  DO I=E-1,S,-1
    U(I) = (GMA(I)-C(I)*U(I+1))/BTA(I)
  END DO
  Deallocate (BTA, GMA)
END SUBROUTINE TRIDIAG
```

Information Transfer Program

Building Capacity to Manage Conflict and Change through Oregon's Water Governance Structures

Basic Information

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Building Capacity to Manage Conflict and Change through Oregon's Water Governance Structures

Mini-Grant Final Report

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EXECUTIVE SUMMARY

Competing interests and values in water management have created contentious situations that traditional water governance structures have increasingly found difficult to resolve. Oregon has been a leader in developing innovative, place-based structures to complement the agencies and institutions responsible for water resources management. Our project (1) teased out lessons about working with conflict from Oregon's local partnerships in managing and restoring water quality and watershed health; (2) created a curriculum that was taught Spring 2007 as the capstone course for the graduate certificate in water conflict management and transformation; (3) will use parts of the curriculum in a workshop for practitioners and stakeholders in New Mexico on conflict transformation later this summer; and (4) through the Water Governance Practicum (June 17-22) in northeastern Oregon and a site-visit to Rio Jemez in conjunction with the New Mexico workshop, will cycle back to watershed councils to discuss, cross-check, and deepen our understanding of the capacities and resources needed by local governance structures to develop stable solutions for local water problems.

Through these activities, we experienced new and more holistic ways that people were framing, understanding, and addressing their challenges and opportunities, and how these create a ripple of change from the individual to society. These open up collaborative and less confrontational approaches that build community rather than disrupt it.

The project overall contributes insights and practices for transformation from the individual to the societal level that appear to be contributing to a more sustainable future for Oregon's water resources and watersheds. This project also explores the transferability of these findings to other parts of the West.

PROJECT DESCRIPTION

Oregon has been a leader in water governance innovation. This arose from the recognition that agency-developed programs and regulations have reached their limits when it comes to nonpoint source pollution control, and endangered fish and watershed restoration. Oregon empowered diverse local groups to work collaboratively on water quality and watershed health restoration. Other state and federal resource management agencies also connect with and often do their work with these watershed councils.

We began our efforts to learn more about Oregon's water governance innovations by visiting five watershed councils across the state to conduct listening sessions. We visited the Walla Walla, a transboundary watershed between Oregon and Washington; the Grande Ronde Watershed Program, one of the oldest watershed councils in Oregon; Wallowa Resources, a non-profit group which has broadened its watershed focus to intentionally include its local economy and community needs; and the Coquille Watershed Council, and the Coos Watershed Council, two neighboring councils with dramatically different approaches, landowner patterns, and council structures. We chose councils representing diversity in annual precipitation, water and land uses/ownership, council membership and leadership, and geographic size and location. (See map in Appendix 1.) All were dealing with water quantity/water quality problems, urban growth, endangered species, habitat restoration, and economic and global market pressures that are changing local economies and land uses.

We probed with questions about what has worked; what hasn't; what was critical to positive change; what made a difference with diverse people working together; what were they able to accomplish; how did they work; what had they learned; what would they recommend; and what did they think belonged in a graduate level curriculum about Oregon's water governance innovations. Interviews were also conducted with participants in the Calapooia Watershed Council, the Sprague Watershed Working Group within the Klamath Basin, and The Deschutes River Conservancy, as well as state officials from multiple state agencies, the Governor's Office, several federal officials, academics who were studying and participating in councils, and non-profits such as The Nature Conservancy and National Fish and Wildlife Foundation. (See attached summary of the listening sessions – Appendix 2.)

Our scoping for our curriculum and gathering of lessons was furthered by attending the Oregon Watershed Enhancement Board's biennial conference, both to attend scheduled presentations as well as to informally visit with representatives of state agencies from Oregon and Washington, federal agency officials, OWEB staff, and a broad array of stakeholders participating in watershed councils. Several of the individuals and the themes and recommendations are recorded in Appendix 3.

The input we got from our visits and interviews, coupled with our own experiences and literature about the forces and themes we were hearing about led to the creation of WPM 599: Water Governance and Conflict Management. This graduate course was taught

Spring 2007. (See attached syllabus under Appendix 4.) Thirteen students enrolled for a three credit course that was taught once a week for three hours.

Prof. Denise Lach, Prof. Aaron Wolf, and Julia Doermann co-taught the course. Five guest speakers participated as well, bringing a richness of perspective, history, insight, and inspiration to the class. The speakers were Geoff Huntington (former Director of OWEB and former Deputy Director of OWRD), Ken Bierly (Deputy Director of OWEB), Prof. Kathleen Dean Moore, James Honey (Sustainable Northwest), and Bruce Aylward (The Deschutes River Conservancy).

We are now about to embark on a journey back to where we began – northeastern Oregon. An intersession class of seven students and three instructors will return to the Grande Ronde Watershed and the Wallowas to take what we've learned back out to the field and deepen it, check it, and grow it further as we visit projects, players, and the landscape. (See Appendix 5 for class syllabus.)

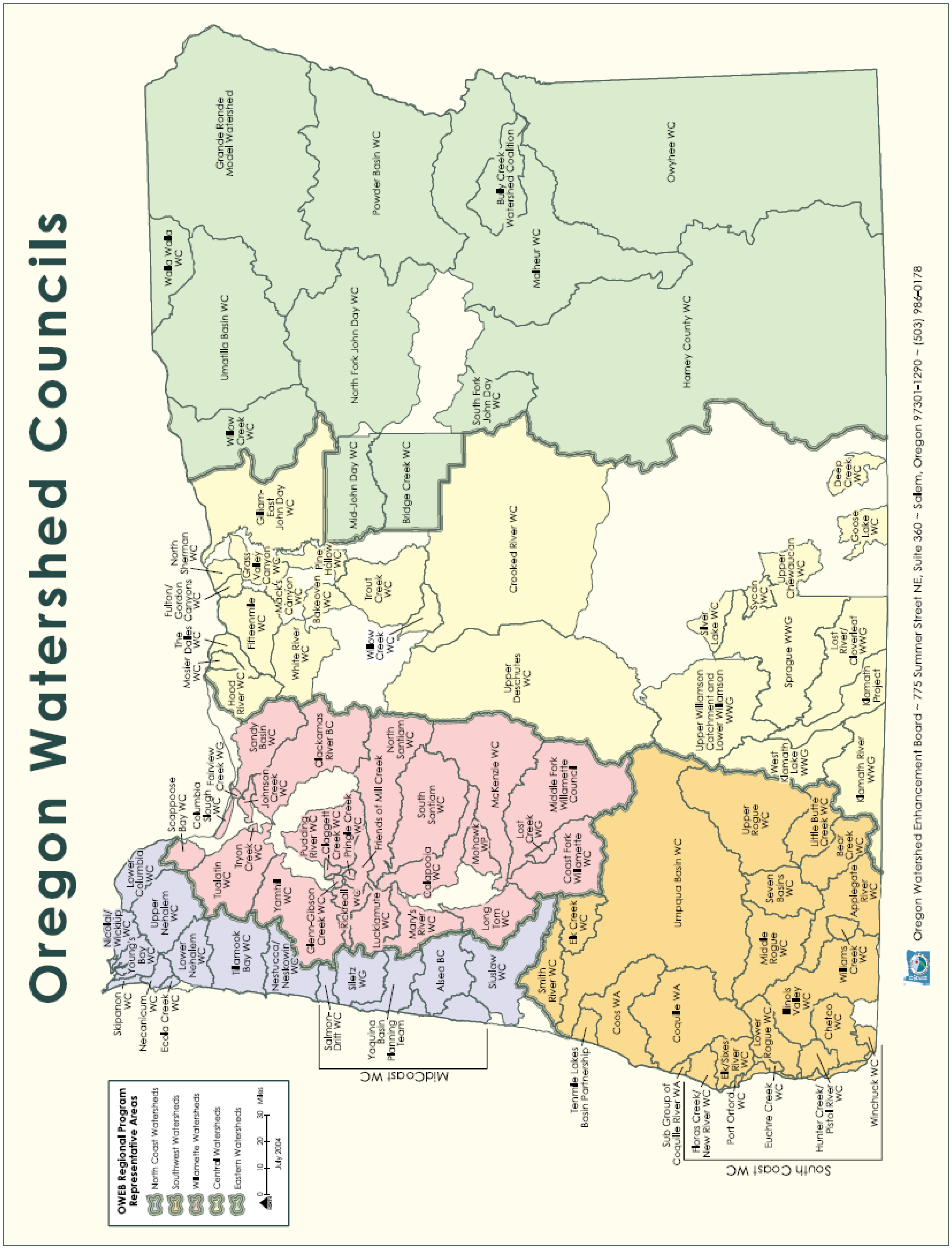
We will also take some of the core ideas and practices we taught in the Spring term, and learn about their transferability to New Mexico. Working with the Utton Transboundary Resources Center at the University of New Mexico School of Law and two of its associates who work on intercultural relations and tribal issues, we will weave our ideas and experiential exercises together and test them with an audience of practitioners and stakeholders. We also plan a site visit to the Rio Jemez to learn about an innovative watershed agreement as part of an ongoing federal water adjudication.

FINDINGS

Though watershed councils are still relatively new and growing in their capacity, these place-based, networked structures offer an example of 21st Century governance structures that can operate and be a place to integrate many of the 20th Century laws and institutions. They are increasingly able to simultaneously hold multiple, often-competing elements of a community and its sense of place – its environment, economic interests, and social needs, and offer a community structure for making resource decisions that benefit the entire watershed and its inhabitants.

John Paul Lederach's Conflict Transformation helps us understand how unusual and visionary this is. He says that conflict transformation requires real change in our current ways of relating that includes and goes beyond the resolution of a specific problem towards a clear and important vision; and in the process, builds healthy relationships and communities, locally to globally. We discovered that this transformation transforms us, too. With as much evidence that our laws and institutions are running up against limits, Oregon's water governance structures offer a model, important lessons, inspiration and insights for the challenges we are facing in the 21st Century.

Appendix 1


Oregon Watershed Councils
OWEB Regional Program Representative Areas
North Coast Watersheds
Southwest Watersheds
Willamette Watersheds
Central Watersheds
Eastern Watersheds
0 10 20 30 Miles
July 2004
Grande Ronde Model Watershed
Powder Basin WC
Owyhee WC
Bully Creek Watershed Coalition
Walla Walla WC
Umatilla Basin WC
North Fork John Day WC
Malheur WC
Harney County WC
South Fork John Day WC
Willow Creek WC
Gilliam-East John Day WC
Mid-John Day WC
Bridge Creek WC
Crooked River WC
North Sherman WC
Fulton/Gordon Canyons WC
The Dalles WC
Mosier WC
Hood River WC
Fifteenmile WC
Grass Valley Canyon WC
Macks Canyon WC
Bakeoven WC
Pine Hollow WC
Trout Creek WC
White River WC
Willow Creek WC
Upper Deschutes WC
Deep Creek WC
Goose Lake WC
Upper Chewaucan WC
Sycan WC
Silver Lake WC
Sprague WWG
Lost River/Cloverleaf WWG
Klamath Project
Upper Williamson Catchment and Lower Williamson WWG
West Klamath Lake WWG
Klamath River WWG
Scappoose Bay WC
Columbia Slough WC
Fairview Creek WG
Sandy Basin WC
Clackamas River BC
Johnson Creek WC
North Santiam WC
South Santiam WC
McKenzie WC
Middle Fork Willamette Council
Friends of Mill Creek
Pringle Creek WC
Claggett Creek WC
Pudding River WC
Tryon Creek WC
Tualatin WC
Yamhill WC
Glenn-Gibson Creek WC
Rickreall WC
Luckiamute WC
Calapooia WC
Mohawk WP
Lost Creek WG
Coast Fork Willamette WC
Mary's River WC
Long Tom WC
Lower Columbia WC
Upper Nehalem WC
Necanicum WC
Nicolai/Wickiup WC
Young's Bay WC
Skipanon WC
Ecola Creek WC
Lower Nehalem WC
Tillamook Bay WC
Nestucca/Neskowin WC
Salmon-Drift WC
Siletz WG
Yaquina Basin Planning Team
Alsea BC
Siuslaw WC
MidCoast WC
Smith River WC
Elk Creek WC
Umpqua Basin WC
Tenmile Lakes Basin Partnership
Coos WA
Coquille WA
Sub Group of Coquille River WA
Floras Creek/New River WC
Elk/Sixes River WC
Port Orford WC
Lower Rogue WC
Euchre Creek WC
Hunter Creek/Pistol River WC
Winchuck WC
Chetco WC
Illinois Valley WC
Williams Creek WC
Applegate River WC
Middle Rogue WC
Seven Basins WC
Bear Creek WC
Little Butte Creek WC
Upper Rogue WC
South Coast WC
Oregon Watershed Enhancement Board ~ 775 Summer Street NE, Suite 360 ~ Salem, Oregon 97301-1290 ~ (503) 986-0178

Appendix 2

Lessons from Listening Sessions with Oregon Watershed Councils

Background

Oregon is in its second decade of experimenting with a new kind of water governance. The primary motivation for innovation was the recognition that traditional government programs and regulations have significant limitations when it comes to addressing nonpoint source pollution control, and restoring endangered fish and watersheds involving private lands. Working at the watershed scale with landowners offers unique possibilities for progress on multiple resource management objectives simultaneously including water quantity issues.

Oregon now empowers diverse local groups to work collaboratively on water quality and watershed health restoration through 92 watershed councils and 45 Soil and Water Conservation Districts with funding for on-the-ground projects, monitoring, council support and technical assistance; common assessment and monitoring protocol and equipment; formal recognition; scientific review and advice from independent, multidisciplinary scientists about complex, systemic questions; and government participation in a watershed context. For example, state and federal resource management agencies connect with and often do their work through or coordinated with these councils. Though watershed councils are still relatively new, they offer a structure for making resource decisions that benefit the entire watershed and its inhabitants, and a place to try and learn from innovative restoration practices.

The structures are still evolving to nest across multiple scales of decision-making in order to harmonize activities -- from local to national. However, Oregon is demonstrating that this collaborative place-based approach can make incremental, adaptive progress in overall watershed health and species recovery while building community rather than disrupting it. It fosters sustained, long-term environmental stewardship connecting people with their environment and their communities, and connecting communities and more centralized institutions in productive ways.

Gathering Lessons

In an effort to capture some of the lessons learned by watershed councils, a team from Oregon State University (OSU) toured several watersheds with stakeholders and held listening sessions to learn about what works, what doesn't, and what should be part of a masters level curriculum. OSU team members visited the Walla Walla watershed -- a transboundary watershed between eastern Oregon and eastern Washington, the Grande Ronde Model Watershed and Wallowa Resources in Wallowa County, Oregon, and the Coquille and Coos Watershed Councils in western Oregon. All are dealing with water quantity water quality problems, urban growth, endangered species, habitat restoration, and economic and global market pressures that are changing local economies and land uses. The presence of listed salmon under the ESA in all of these watersheds is a dominant driver and focus.

Stakeholders

Salmon are an iconic species and a great integrator across the landscape. Since they provide significant economic benefits to the region they are an unusual catalyst to think about the whole natural system and its socioeconomic relationships. Watershed councils, therefore, take a holistic look at a natural system -- ridge top to ridge top -- and the communities that live within them. Stakeholders include a broad array of community members, elected officials, landowners, non-governmental organizations, and local, state and federal government agencies. Many of the landowners represent farming, ranching, and forest interests. Urban interests as landowners are sometimes involved, but less commonly. Because of salmon listings, there are several federal agencies and non-governmental organizations involved.

The stakeholders' interests include what might generally be expected based on agency missions and economic activities that landowners are involved in. They also include a collective interest in the health of the community and watershed -- “the sweet-spot at the nexus of economics and the environment“ as one landowner/watershed council coordinator put it. Watershed council members are articulate about the connection between the health of the watershed and resources to run their schools, and hospitals. They make sophisticated global economic connections to their interests and mission. For many, their interest is our common future.

Plans and Leadership

There were no formal plans developed in Oregon for conflict management. The process, however has been described as “participatory democracy” and “adaptive governance.” When opportunities present themselves for changing land management practices, water right uses, or doing a watershed restoration project to improve watershed health, there may be a watershed council vote or call for consensus. Projects tend to be pursued for the benefits they provide, the learning experience offered, and the example to other landowners and water right holders of what the process and results look like and how they work. Further prioritization occurs at the state level through funding decisions on competitive statewide grants administered by Oregon Watershed Enhancement Board (OWEB) (and to some extent by Bonneville Power Administration (BPA)). Most projects have a monitoring component so that lessons can be learned.

Several types of leaders and leadership were referenced on the tours and in listening sessions. Council members referred to two Governors who built the statewide capacity for watershed councils -- Governor Roberts and Governor Kitzhaber. Some referenced leaders in the Legislature that were pivotal during the early days as well. Several gave credit to federal and state agency staff with a tenacious commitment to some part of the collective vision and who have supported councils with efforts to get permanent funding, technical assistance, and on-the-ground work done.

Council members sang praises of large casts of characters -- both in positions of power as well as those with only the power to show up and try to help. It was very hard to identify any central individual or organization that was making it all happen. People emphasized that it was much more driven by relationships, trust, and a common commitment to a vision.

[Terms in the literature to describe the range of leadership include "servant leadership," "catalytic leadership," "leadership with authority," and "leadership without authority."]

Institutional Arrangements

The listening sessions and visits to date have been with watershed councils with long track records and many successes. Their approach has been opportunistic, incremental, adaptive, and sociologically and psychologically strategic throughout their histories. There is still plenty of work to be done and many skeptics about whether the watershed council approach can do enough to restore salmon and watershed health. There are also watershed councils in the state that do not have the cohesiveness and results of the four that were visited.

One participant in a listening session responded to this concern with several of his favorite quotes by Wendall Berry. One quote in particular speaks to this point:

> "I have no large solution to offer. There is, as maybe we all have noticed, a conspicuous shortage of large-scale corrections for problems that have large-scale causes. Our damages to watersheds and ecosystems will have to be corrected one farm, one forest, one acre at a time."

In addition to the institutional structures and funding in place to support watershed councils' work (e.g. OWEB, Soil and Water Conservation Districts, Natural Resources Conservation Service, Bonneville Power Authority, Department of Environmental Quality, Oregon Department of Transportation and several other state and federal agencies), many cited certain behaviors by institutional representatives as productive. They emphasized the importance of participants in general being able to:

- apply policy and science on a site-specific basis,
- work within a watershed scale,
- work as a community member, not as a "specialist,"
- have good communication skills,
- partner well,
- be respectful of local culture and the issues that natural resource workers face,
- integrate local knowledge,
- understand how to work with complete systems -- not just individual pieces,
- be sensitive to values of the community,
- volunteer, and
- network.

One said, “Condescendence is lethal.”

Tools, Techniques, and Training

Desirable tools, techniques and training can be summarized to include: listening skills, understanding organizational and institutional change; leadership training; collaborative learning; cultural proficiency; self-awareness; participatory and Jeffersonian democracy; and supporting skills for “conflict transformation.”

Appendix 3

OWEB Conference themes and recommendations

- think broadly to include connecting restoration with communities and the economy -- more options and more opportunity for finding common ground/vision
- working at the landscape scale seems necessary to meet restoration needs, yet this is still not done much and is more of an art than a science
- “act locally” -- know something about the local community; learn who they are and why they are the way they are before you try to change them
- conflict “resolution”/conflict “tolerance” - discuss different applications -- are you trying to adopt a new set of rules or are you trying to live together?
- importance of trust-building and how that happens
- what does it take to effectively partner?
- species by species/issue by issue vs. landscape vs. ecosystem recovery and productivity
- tipping points
- where does change come from?
- What are the big engines and how do we think about and prepare for these? (demographic changes, global warming, drought, trends in food systems, development, tourism, etc.)
- Be alert to trigger words.
- Mosaic thinking rather than scale -- there'll be niche marketing and commodity groups need to think about how to enter at all levels.
- what level of risk-taking is supported given circumstances
- how do we move away from our conflict over differences and support opportunities and collective hopes and aspirations -- construct institutions tieing into desires and core interest of humans.
- understand value systems
- develop courage
- trust
- gain comfort with difficult discussions
- recognize the deep commitment that precedes you and that you may never have seen/heard about anything like what you experience.
- importance of place-based efforts that have local commitment following scientific assessment.

Drawn from presentations and conversations with Jeff Oveson, Coby Minton, Diane Snyder, Tom Byler, Ken Bierly, Tom Shafer, Lori Warner, Jackie Dingfelder, John Runyon, Besty Parry, Donna Silverberg, Nan Evans, Jane O'Keefe, Roger Wood, James Honey, Joe Witworth, Extension folks.

Appendix 4

WPM 599: Water Governance and Conflict Management
Spring 2007: Course Description and Schedule

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Office Hours: By appointment

"No problem can be solved form the same level of consciousness that created it."
– Albert Einstein

"[S]hift to a higher realm of perception to find solutions to our problems and resolve conflicts. By doing this, we find opportunities in problems."
– Alberto Villoldo

Course Description
Experience suggests that in order to meet 21st Century water resource demands we must seek and share new methods, tools, and structures that help us move beyond entrenched positions to a common vision of the future. This includes creating tools, methods, and capacity to facilitate diverse interests and cultures coming together to craft strategies and policies that achieve mutual gains at all levels both before crisis strikes and even within times of crisis. The structures need to speak across multiple scales of decision-making in order to harmonize activities. Collaborative and less confrontational approaches are needed to build community rather than disrupt it. Overall, this era challenges us to seek new strategies that foster sustained, long-term environmental stewardship connecting people with the resource and their communities, and connecting communities and more centralized institutions to support stewardship efforts.

This capstone course for the graduate certificate in water conflict management and transformation offers an opportunity for students to learn about current and leading edge ways to make progress in complex watershed health restoration and contentious water situations. It explores conflict tolerance, prevention, management, and transformation through collaborative watershed restoration structures as well as through models of negotiation.

Readings, lectures and class discussions will explore the literature, practices and applications of negotiation and conflict resolution; organizational learning and change; new institutional networks and relationships; and leadership. It will explore it from the individual level to the societal level.

There will be an emphasis on experiential learning. Classes offer a place to learn and practice skills as well as hear from experts in the field that are using different approaches to negotiation and problemsolving. Students will also chose a field experience (watershed council meeting, city council forum, shadowing, conference, seminar, etc.) and report on it at the end of the term. Finally, the course will help students understand how creative, messy and inelegant these processes and solutions can be.

Learning Objectives

By the end of the term you will:

- Have increased your listening skills through practice and critique;
- Have increased your understanding of the culture and environment you "swim in" to include power of "frames," and multiple perspectives and scales (both geographic and temporal) on water conflict;
- Be able to reframe water conflicts from intractable to transformable through application of different negotiation tools, and different guiding philosophies and perspectives;
- Enhance joy in life and openness in your heart;
- Demonstrate creativity in the face of intransigence and negativity regarding water conflicts through in-class role plays; and,
- Have practiced and demonstrated your skills with a wide range of conflict transformation tools through in-class and extra-mural exercises.

Rules of the Road

- Be respectful and maintain a professional tone
- Be responsible
- Be inclusive
- Class starts and ends on time
- Turn off cell phones, beepers, pagers, computers, etc.
- Check your e-mail and BlackBoard regularly for information and announcements.
- Follow University policies regarding plagerism and other ethical conduct.

Readings and Texts

Articles for class are available on the class BlackBoard site.

Texts for the class are:
Wallace Stegner, <u>Beyond the Hundredth Meridian</u>, 1954.
William Ury, <u>Getting Past No: Negotiating with Difficult People</u>, 1991
John Paul Lederach, <u>Conflict Transformation</u>, 2003.

Course Structure

Most classes will begin with a "warm up" – something to help us move into a more creative place to work from in class. We will then have a lecture and discussion concerning the week's topic, and reflecting on assigned readings. This will be followed by experiential exercises, and a class debrief of the exercises.

Between classes, you will be asked to complete the reading assignments and experiment with ideas from class in your daily lives and class project. You will then be asked to self-debrief through journaling about these experiences.

Course Requirements and Evaluation

In addition to the in-class exercises, there will be a term project that provides you an opportunity to apply and synthesize your coursework within a real-world circumstance. Each course element is described briefly below.

1. Class Participation/Class Debriefing: 30 points.

Students will be expected to participate in class discussion, exercises and the class debrief. Since much of the class material will be discussed, developed, and practiced in class, your attendance and participation in all classes is required. It is expected that you come to each class prepared – having read the assigned material ahead of time and be ready to refer to it in our discussions. We will also spend part of every class debriefing. This will be an opportunity to learn and practice reflecting on class exercises and your experience in a critical, positive, constructive way and responding to other's reflections.

2. Self-Debriefing/Journal: 40 points

We will ask you to keep a journal during the duration of the class. Some weeks you will be asked to reflect on a specific question or questions. Other weeks we may give you an article or case study to apply class material to, analyze, and reflect upon. You will also be asked to do self-debriefing of your experiences both in and outside of the classroom.

3. Class Project/Applied Experience: 30 points

Our understanding of theories, concepts and tools we discuss and practice in class will deepen when we apply them to real-world efforts. Your class project/field experience is an opportunity to put these into practice. During the term, you will be asked to attend a public forum, such as a city council meeting or local watershed council meeting, or "shadow" a leader to observe the public discussion, input and decisionmaking process. We suggest you choose something that you can attend at least 2 times during the term. This will offer an opportunity to reflect on and/or use skills and understanding gained in class to current challenges in our community.

You will develop a term project on these field experiences. These can be creative and come in a usual or unusual form: a paper, movie, role play, song, poster, etc. It should reflect a well-organized, applied exploration of the term's class material, as well as a demonstration and critique of your mastery of concepts, tools, and theories explored throughout the term. The modality you chose should convey your experience, analysis, and synthesis clearly, reflecting original and critical thought.

WPM 599: Water Governance and Conflict Management: Spring 2007

This class meets Wednesdays from 12:00 noon to 2:50 pm in the Women's Building Room 205.

Dates	Major Topics	Reading Assignments (to be read by class on day listed). Check Blackboard weekly for additional postings.
April 4	Conflict and Context: Self-Awareness and Involvement	Wolf, Aaron, et al, "Managing Water Conflict and Cooperation," 2005 State of the World: Redfining Global Security, pp. 80-95. Isaacs, William, 1999, Dialogue and the Art of Thinking Together, "A Conversation with a Center, Not Sides."
April 11	Conflict and Context: Institutional History, Challenges and Opportunities	Wilkinson, Charles, "West's Grand Old Water Doctrine Dies." Wilkinson, Charles, "Water in the West," Open Spaces: Views from the Northwest, Vol.1, No.3 (Summer 1998), pp. 13-19. Arun Agrawal and Clark C. Gibson (1999), "Enchantment and Disenchantment: The Role of Community in Natural Resource Conservation," World Development, 27 (4), April, 629-49 John W. Meyer, Brian Rowan, "Institutionalized Organizations: Formal Structure as Myth and Ceremony**,"** The American Journal of Sociology, Vol. 83, No. 2 (Sep., 1977), pp. 340-363
April 18	Conflict Resolution	Ury, Getting Past No, 1991. (Entire book) Utton Center, "Crossing Cultural Boundaries," 2005. Pyramic Lake case study
April 25	Changing Perceptions -- Expanding Choices	Glennon, Robert, "Water Scarcity, Marketing, and Privatization." Neuman, Janet C., "The Good, the Bad, and the Ugly: The first Ten Years of the Oregon Water Trust." 2004.
May 2	Changing Perceptions -- Basins without Boundaries	Behavioral Assumptions of Policy Tools (Schneider and Ingram) South African Constitution EnLibra Sadoff and Grey
May 9	Enhancing and Sharing Benefits	Lederach, Conflict Transformation, 2003.
May 16	Building Skills and New Ways to Relate to Systems and Each Other	Clumsy solutions (Lach, Ingram, and Rayner) Arun Agrawal and Clark C. Gibson (1999), "Enchantment and Disenchantment: The Role of Community in Natural Resource Conservation," World Development, 27 (4), April, 629-49

		Naturalistic Decision Making (Klein)
May 23	Opportunities through Emerging Issues, New Governance Structures, and Sharing Hopes and Aspirations	Senge, et al, Presence (selection) Isaacs, William, 1999, Dialogue and the Art of Thinking Together, "Setting the Container." (Meeting management readings)
May 30	Leadership in Complex Times	Isaacs, William, 1999, Dialogue and the Art of Thinking Together, "Convening Dialogue." Ury, Getting to Peace: Transforming Conflict at Home, at Work, and in the World, Ch 3. Senge, Presence, ch. 15. Article on civil society from *Yes! A Journal of Positive Futures*
June 6	Acknowlegding Passages, Reflection and Integration	Kaufmann

April 4

Conflict and Context: Self-Awareness and Involvement

- Introduction to hydropolitics and general frameworks for addressing water conflict (Aaron Wolf, Denise Lach, Julia Doermann)
- Self-awareness and listening skills in conflict and its resolution (Aaron Wolf)

April 11

Conflict and Context: Institutional History, Challenges and Opportunities

- Guest Lecture: Geoff Huntington – The role of U.S. and western environmental and water laws in conflict
- The social and institutional context (Denise Lach)

April 18

Conflict Resolution and Perceptual States

- Perceptual states – transforming conflict within and through ourselves (Julia Doermann)
- Understanding the stories that give our lives meaning
- Using perceptual states with groups and in the natural resources/water policy arena for reframing conflict and finding solutions (Julia Doermann)

April 25

Changing Perceptions -- Expanding Choices

- Guest lecture: Bruce Aylward, Deschutes River Conservancy – Using market tools, water management tools, exchanging goods or funds for water, water banks, etc. to increase opportunities for conflict resolution

<u>May 2</u>

Changing Perceptions -- Basins without Boundaries

- Looking at scale (Aaron Wolf)
- Other frameworks for understanding and addressing conflict (Denise Lach and Julia Doermann)

<u>May 9</u>

Enhancing and Sharing Benefits

- Guest lecture: James Honey, Sustainable Northwest – Reframing water conflicts to sustainability (i.e. considering ecology, economy and community concerns simultaneously) in the Klamath Basin
- Seeing from the Whole (in constrast to reductionist thinking)

<u>May 16</u>

Building Skills and New Ways to Relate to Systems and Each Other

- Place-based networked organizations (e.g. watershed councils); social trust; and decisionmaking. (Denise Lach)
- Hearing positions, interests, and collective myths (the stories that give us meaning) in conflict and finding new opportunities

<u>May 23</u>

Opportunities through Emerging Issues, New Governance Structures, and Sharing Hopes and Aspirations

- Guest lecture: Ken Bierly – How communities share hopes and aspirations; how the "heart" enters public policy and its implementation (The Oregon Plan for Salmon and Watershed Restoration); and the use of a guiding philosophy
- Meeting skills, meaningful measurements of success/kairos time; the importance of relationships (Denise Lach)

<u>May 30</u>

Leadership in Complex Times

- Guest lecture: Kathleen Dean Moore – water and awe: the ethical and spiritual aspects of water
- New types of leadership and assessing what is needed; advice for leaders; and collaboration across broad scales. (Julia Doermann)

<u>June 6</u>

Acknowledging Passages, Reflection and Integration

- Taking it forward, reentry, class debrief (Doermann, Lach, and Wolf)

Appendix 5

WRP 509: Water Governance Practicum
Summer 2007: Course Description and Schedule
June 18-22, 2007

Instructors

Aaron Wolf, Geosciences	wolfa@geo.oregonstate.edu
Denise Lach, Sociology	denise.lach@oregonstate.edu
Julia Doermann, Institute for Water and Watersheds	juliadoermann@hotmail.com

Hosts

Grande Ronde Model Watershed Program	La Grande & Enterprise, OR
Wallowa Resources	Enterprise, OR

Course Description

Though watershed councils are still relatively new and growing in their capacity, these place-based, networked structures offer an example of 21st Century governance structures that can operate and be a place to integrate many of the 20th Century laws and institutions. They are increasingly able to simultaneously hold multiple, often-competing elements of a community – its environment, economic interests, and social needs, and offer a community structure for making resource decisions that benefit the entire watershed and its inhabitants.

John Paul Lederach's Conflict Transformation helps us understand how unusual and visionary this is. He says that conflict transformation requires real change in our current ways of relating that includes and goes beyond the resolution of a specific problem towards a clear and important vision; and in the process, builds healthy relationships and communities, locally to globally. This transformation transforms us as well.

The practicum will take us on a journey to northeastern Oregon. Here, we will take what we've learned during Spring term out to the field and deepen it, check it, and grow it further as we visit projects, players, and the landscape.

Expectations for the class

1. Apply concepts of conflict and governance transformation in a local experience.
2. "Sense the whole" of an ongoing transformative governance structure.
3. Gain skills in understanding the interests/needs of a wide array of stakeholders.
4. Synthesize information into a report for local participants.

Our hosts and who we'll be meeting with

Our two hosts are the Grande Ronde Model Watershed and Wallowa Resources. The Grande Ronde Model Watershed (http://www.grmw.org/) was one of the first watershed councils in the state. They were chosen for funding by the state in the early 1990s (along with some watershed councils in southwestern Oregon), and have had one of the longest track record of doing collaborative restoration work through local governance structures. They work well with the state, the tribes, the federal government and neighboring states in coordinating efforts at different scales and meeting multiple social and environmental goals simultaneously.

Wallowa Resources (http://www.wallowaresources.org/) is another well-functioning group that intentionally deals with some of the economic and social benefits that can be simultaneously pursued with environmental restoration.

This is a great opportunity to get a sense of what it takes individually, institutionally, through relationships, and on-the-ground to work towards the goal of restoring watersheds, salmon and community health. We will also experience some beautiful examples of how people are working from their hearts and souls, and have an opportunity to find out more about what gives them the courage, comfort (or not) and motivation to work in this life-giving way.

Schedule

Sunday, June 17
Depart for Eastern Oregon from in front of Wilkinson Hall on campus

Monday, June 18th
Discussion and visits with Board members and key partners in the GRMW

Tuesday, June 19th
Visit Confederated Tribe of the Umatilla Indian Reservation's Adult Fish Weir to witness the return of adult spring chinook salmon completing their almost-700 mile trip back from the Pacific to Catherine Creek, the site of much collaborative restoration effort.

Visit and discuss common habitat problems and solutions in Catherine Creek to create and/or restore offstream rearing habitat, critical habitat, and fish passage.

Wednesday, June 20

Visit additional sites where partners have created and enhanced wetlands, in part to create habitat and in part to "treat" tail flows from upstream irrigation prior to that water reentering the Wallowa River.

Discuss tools to achieve this, such as a conservation easement, and an inter-basin transfer of water, as well as the effects on the irrigation management of Lostine River water.

Discussion with partners about how we all move into the future with the concerns of water quality, fish habitat, and irrigation all needing to be addressed (including partners from NOAA Fisheries, Nez Perce Tribe Fisheries, Oregon Dept. of Fish & Wildlife, Oregon Dept. of Water Resources, Natural Resources Conservation Service, and Oregon Water Trust.)

Visit example of private landowner cooperation, innovative channel construction, and the potential for small scale eco-tourism in Wallowa County.

Thursday, June 21
Visit the largest re-channel project GRMW has participated in to improve fish spawning and rearing habitat; discuss collaboration in Wallowa County and development of Wallowa County Nez Perce Tribe Salmon Habitat Recovery Plan; and discuss their Community Planning Process - Collaborative Watershed Assessment and Restoration work.

Meet with local rancher to discuss implications of Clean Water Act and related legislation on private ranching and range management in the county.

Practice skills for collaborative work.

Friday, June 22

Students offer presentation on overall impressions from the week.

Technology Transfer of Water Resources Research and Resource Planning in Oregon

Basic Information

Title:	Technology Transfer of Water Resources Research and Resource Planning in Oregon
Project Number:	2006OR77B
Start Date:	3/1/2006
End Date:	2/14/2007
Funding Source:	104B
Congressional District:	Oregon 5th and Oregon 4th
Research Category:	Social Sciences
Focus Category:	Law, Institutions, and Policy, Management and Planning, Education
Descriptors:	
Principal Investigators:	Todd Jarvis

Publication

For 2006, the Institute for Water and Watersheds (IWW) participated and sponsored many events. IWW expanded their website and a monthly newsletter which can be viewed at **http://water.oregonstate.edu**.

Institute for Water and Watersheds

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Featured News and Events

- Wednesdays, Oct 3-Nov 26 - **OSU Fall Water Resources Seminar Series:** Revisiting Restoration, Reconstruction, and Renaturalization of Engineered Landscapes: Technical, Political, Legal and Natural Resistance.

- Oct 5 - Poster abstract deadline for **Water in the Pacific Northwest: Moving Science into Policy and Action**, a conference in Stevenson, Wa., Nov 7-9.

Oregonians are beginning to witness the difficulties caused by water limitations. Water quantity and quality issues in the Willamette and Klamath Basins are the Governor's top environmental priorities. This situation is paralleled around the world, and points toward a strong emerging area for growth in research, education, and outreach. OSU is ideally positioned to assume a leadership role in addressing water problems, with about 80 faculty in six colleges who teach and conduct research in areas related to water and watersheds.

In 2005, Oregon State University established the Institute for Water and Watersheds as the hub for water-related teaching and research activities at the University. The goals of the IWW are to:

- provide coordination of water and watershed activities at OSU,
- connect a diverse student body with relevant issues across the state,
- enable capture of new, high-value opportunities for research, education, and outreach,
- engage OSU faculty and students with external stakeholders throughout the state, and
- establish a set of shared water and watershed collaboratories supporting research, teaching and outreach.

Other News and Events...

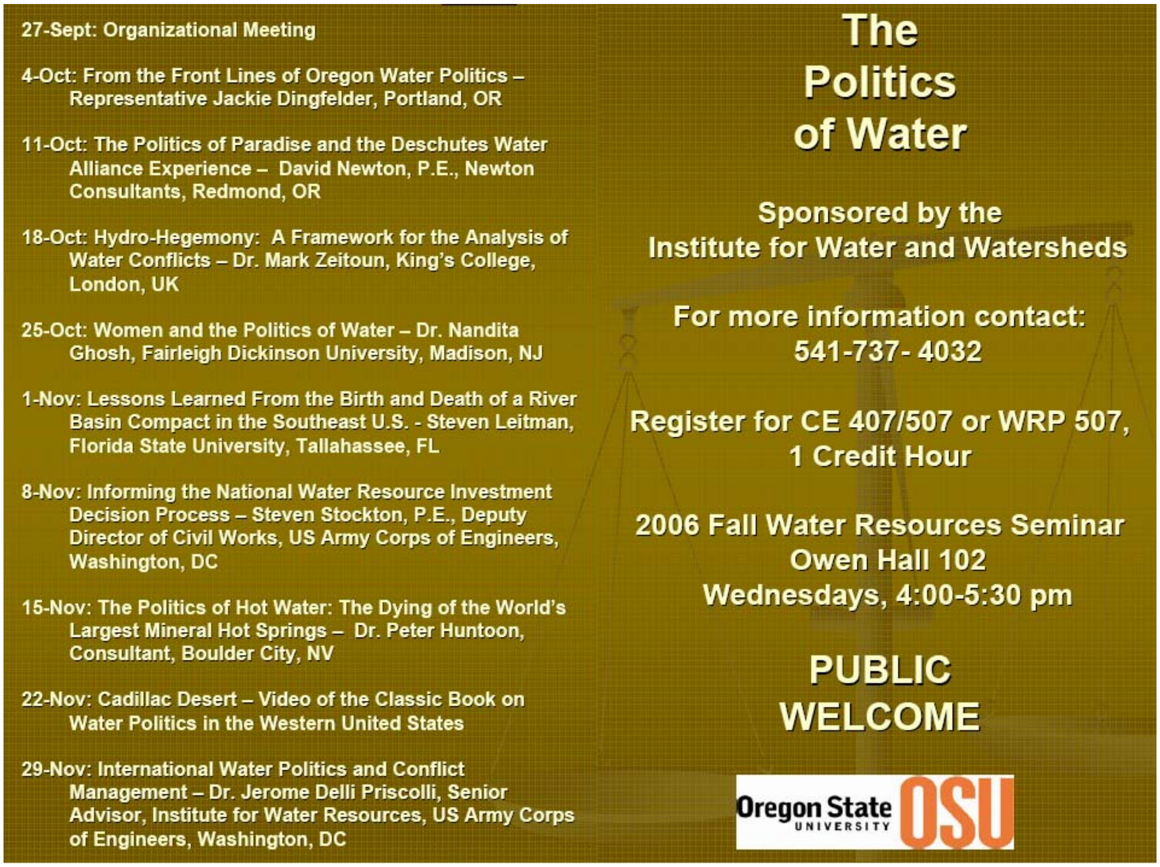
5/15/07 - New Download Available: **Summary Report from the Willamette Environmental Flows Workshop** (PDF; 791k)

6/8/07 - **The June issue of H_2OSU - The IWW Newsletter** is available. Read news from the IWW and the OSU hydro community.

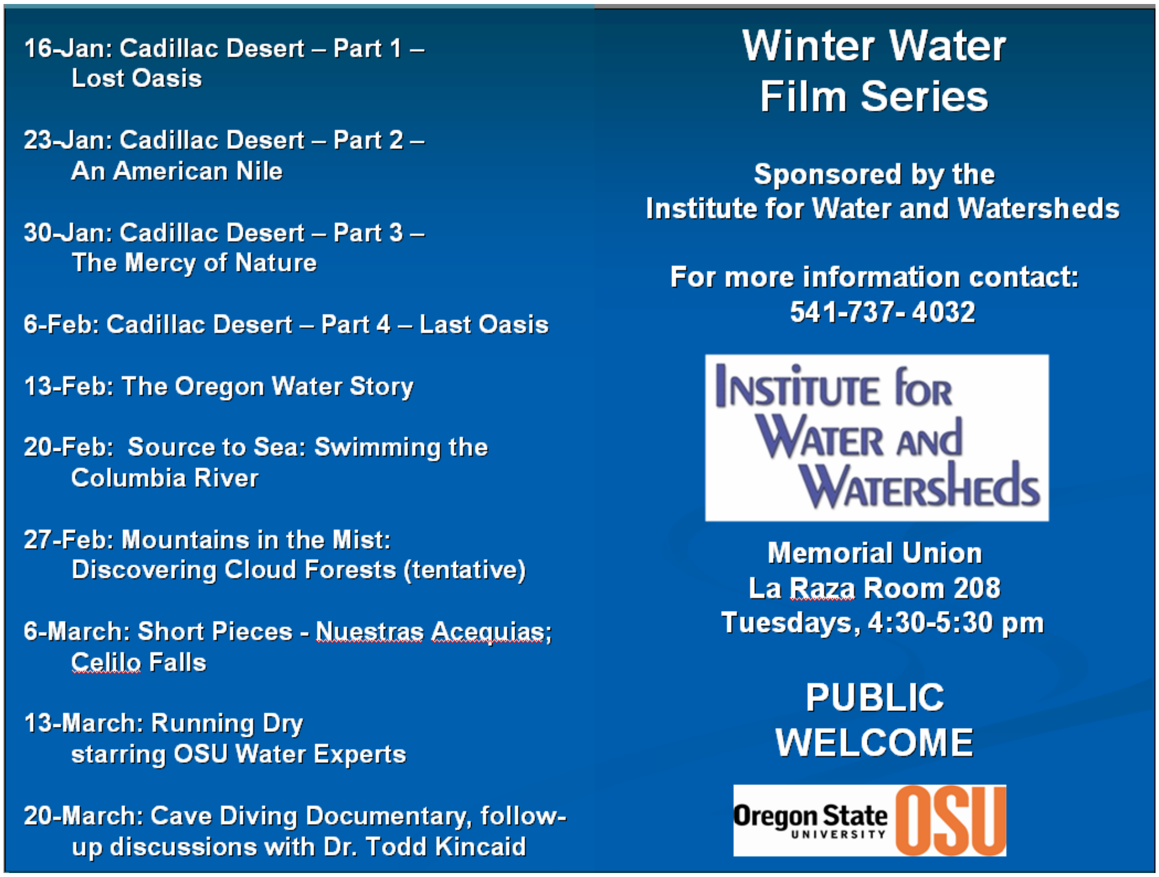
Link to a calendar of upcoming water resources events...

Visitors to this page since 12/7/06:
04526

IWW continues to sponsor a fall seminar series on water policy with invited scholars from across the United States. As outlined in the following figure, topics ranged from local to international. Approximately 40 students in disciplines ranging from engineering, geosciences, and economics attended the weekly sessions.

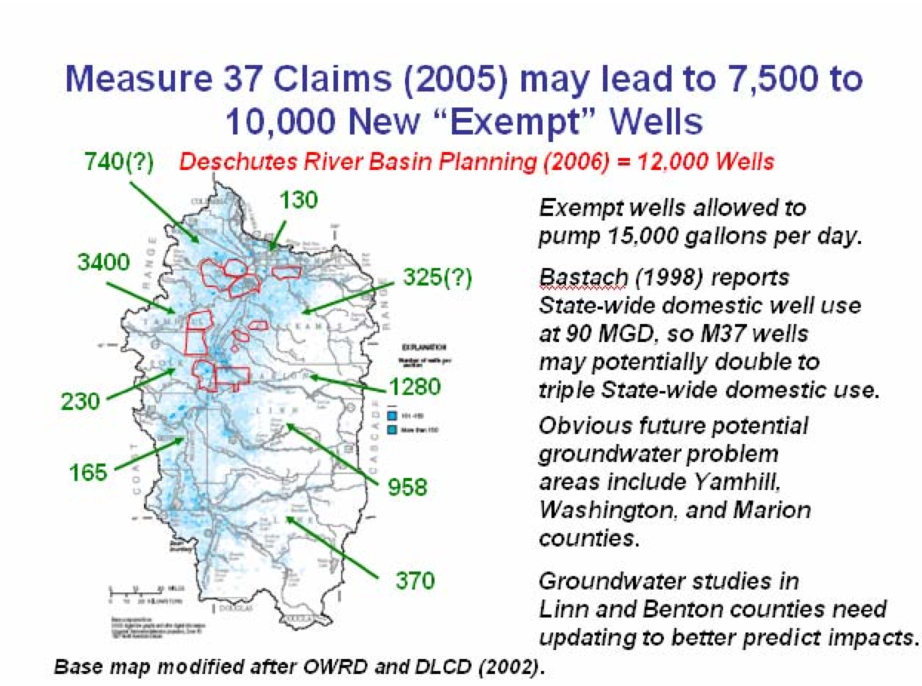


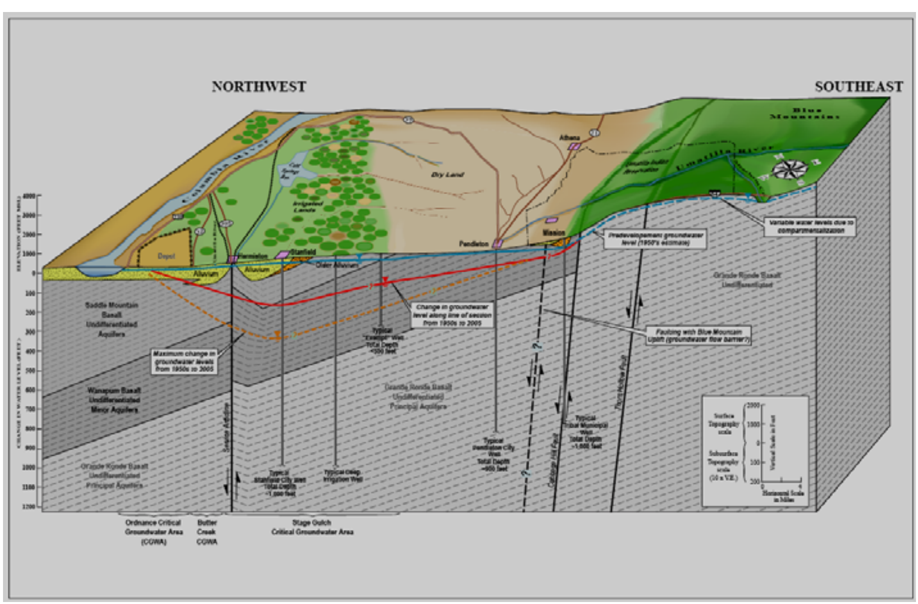
IWW also sponsored a water film series each week during the winter term of 2007. The film series was open to the public, and was regularly attended by 15 to 20 people with the bulk of the attendees being the general public.



At the local level, IWW staff continues to present research on new land use reforms and groundwater use associated with Oregon's Ballot Measure 37. This presentation was given to about 20 different groups, including watershed councils and county planning commissions. In related matters, IWW staff continued their outreach work for the Umatilla County Critical Groundwater Solutions Task Force where groundwater levels have dropped nearly 500 feet in 50 years.

At the national level, IWW staff presented at conferences sponsored by the Association of American Geographers in San Francisco and the National Groundwater Association in Albuquerque, New Mexico. At the international level, IWW staff was invited to present at a NATO Advanced Studies Institute in Varna, Bulgaria.





Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	0	0	0	0	0
Masters	2	0	0	0	2
Ph.D.	0	0	0	0	0
Post-Doc.	1	0	0	0	1
Total	3	0	0	0	3

Notable Awards and Achievements

Publications from Prior Projects