State of Washington Water Research Center
Annual Technical Report
FY 2006

Introduction

The mission of the State of Washington Water Research Center (SWWRC) is to facilitate, coordinate, conduct, and administer water related research important to the State of Washington and the region; educate and train engineers, scientists, and other professionals through participation in research and outreach projects; and disseminate information on water related issues through technical publications, newsletters, reports, sponsorship of seminars, workshops, conferences as well as other outreach and educational activities.

The SWWRC has developed a multi-pronged approach to accomplish these goals. To promote research and outreach, the SWWRC has been organized into five program areas: Watershed Management, Groundwater Systems, Environmental Limnology, Vadose Zone Processes, and Outreach and Education. These programs have helped prepare several multidisciplinary research proposals and provide better links between faculty and the SWWRC. These are in addition to the Director's primary research interests in surface-groundwater interaction, remote sensing, and stormwater. The SWWRC is also involved in international research and education activities.

Lessons learned from the research and outreach components are disseminated to faculty and used by the Director to enhance the education goal. Research projects are also used as a mechanism to fund graduate and undergraduate students.

The SWWRC is continuing its intensive efforts to reach out to agencies, organizations, and faculty throughout Washington State. Activities include presentations to watershed groups, participation in regional water quality meetings, and personal contacts. A dynamic web page has been created and is continually updated to share information with stakeholders.

It is within this overall context that the USGS-funded project activities reported in this document must be inserted. These include the internally funded projects as well as the national awards to the Center. These projects provide a solid core to the diverse efforts of the SWWRC. Water quantity and quality issues continue to be a major concern in the State of Washington due to the endangered species act, population growth, industrial requirements, and agricultural activities. Emerging issues such as water resources management in the face of global warming, water reuse, energy-related water quantity and quality considerations, ecological water demands, and storm water runoff regulations are also beginning to raise concerns. All of these issues will be important drivers of the activities of the SWWRC in the foreseeable future.

Research Program

In accordance with its mission, the SWWRC facilitates, coordinates, conducts, and administers water-related research important to the State of Washington and the region. Research priorities for the State of Washington are established by a Joint Scientific Committee which includes representatives from water resource professionals at state agencies, universities, and the local USGS office. The SWWRC supports competitively awarded internal grants involving water projects evaluated by the Joint Scientific Committee. The SWWRC also actively seeks multidisciplinary research at local, state, and national levels. Meetings between stakeholder groups, potential funding agencies, and research faculty are arranged as opportunities arise. Faculty are apprized of any opportunities. The SWWRC also submits proposals on its own behalf.

During FY 2006, three local research projects were selected for funding by the SWWRC: (1) Transport of Colloids in Soils Studied by Geocentrifuge Techniques, (2) Effects of Sediment Oxygenation on Methylmercury Bioaccumulation in Benthic Biota, and (3) Developing a Sediment Model for Use in the TMDL Process in the Inland Northwest. As described below, these projects address state issues but are also relevant to national interests.

One national project was run through the SWWRC during this period: West Wide Drought Forecasting System: A Scientific Foundation for National Integrated Drought Information System (NIDIS). An update of this project is also presented in this report.

One other project was funded through the USGS/Water Institute partnership. The project involves a USGS project in Jordan where the SWWRC assists by hiring Jordanian nationals to conduct research to Improve Groundwater Management in Jordan. An update on this project is provided.

Transport of Colloids in Soils Studied by Geocentrifuge Techniques

Basic Information

Title:	Transport of Colloids in Soils Studied by Geocentrifuge Techniques
Project Number:	2006WA147B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	Washington, 5th District
Research Category:	Water Quality
Focus Category:	Hydrology, Methods, Groundwater
Descriptors:	Colloids, Particles, Transport, Pathogens
Principal Investigators:	Markus Flury, Prabhakar Sharma

Publication

1. Sharma, Prabhakar; Markus Flury; and E.D. Mattson, Studying Colloid Transport in Porous Media using Geocentrifuge. Submitted to Environment Science Technology (in review).
2. Sharma, Prabhakar. 2007. Studying Colloid Transport in Porous Media at Different Acceleration. Oral presentation to the Department of Crop and Soil Science, Washington State University, Pullman, Washington.
3. Sharma, Prabhakar, Markus Flury, and E. Mattson. 2006. Fate and Transport of Colloid in the Subsurface. Poster Presentation at the Annual meeting of Agricultural and Biological Engineers, Portland, Oregon.
4. Sharma, Prabhakar, Markus Flury, and E. D. Mattson, 2006, On the use of Geocentrifuges to Study Colloid Transport in Porous Media, Oral Presentation at the Inland Northwest Research Alliance 2006 Environmental and Subsurface Science Symposium, Moscow, Idaho, September 25-27, 2006.
5. Flury, Markus and Prabhakar Sharma, 2007, Transport of Colloids in Soils Studied by Geocentrifuge Techniques, State of Washington Water Research Center, Washington State University, Pullman, Washington. State of Washington Water Research Center Report WRR-28, 26 pages.

PROBLEM AND RESEARCH OBJECTIVES

Pharmaceuticals, pathogens, pesticides, and heavy metals often move through soils by the process of colloid or colloid-facilitated transport. Colloids are commonly defined as particles less than 10 μm in diameter that can remain suspended in aqueous solution for considerable amounts of time. Pharmaceuticals, pesticides, and heavy metals are prone to attach to colloids in soils, and pathogenic microorganisms are considered colloids themselves. It is therefore important to understand the mechanisms of colloid transport in soils. The length of time to conduct flow and transport experiments in porous media had led researchers to use centrifuges as tools to evaluate subsurface transport processes. Geocentrifuges are particularly useful to study transport processes in soils, because the flow rates, which are inherently slow in soils, can be sped up considerably. However, there is a need to assure the applicability of geocentrifuges for studying colloid transport. The overall goal of this study was to test the suitability of geocentrifuges to study colloid transport in soils. Specifically, we addressed the following objectives:

- Determine critical centrifugal accelerations as a function of colloid specific density and diameter.
- Evaluate the correction factor in the theoretical relationship for critical acceleration by using geocentrifuges.

This study combines colloid transport theory with laboratory experimentation. First, we developed a theoretical framework to describe colloid transport in geocentrifuges. We rigorously tested the theory by a series of geocentrifuge experiments. Colloid filtration experiments were carried out with representative soil colloids under different centrifugal accelerations.

METHODOLOGY

Objective 1: *Determine critical centrifugal accelerations as a function of colloid specific density and diameter*

Colloid removal from the fluid phase during transport in porous media under favorable attachment conditions can be described by filtration theory (Rajagopalan and Tien, 1976). However, under conditions unfavorable for colloid attachment, filtration theory does not apply. It was observed that colloid concentration profiles in porous media did not follow the exponential decrease expected from filtration theory (Tufenkji and Elimelech, 2004). Another deviation from filtration theory is that under unfavorable conditions, deposition rates of colloids decrease with increasing flow rate (Tong and Johnson, 2006).

In many environmental situations, colloid attachment occurs under unfavorable conditions (Johnson et al., 2005). No theory is currently available to predict colloid deposition under unfavorable conditions. However, it is expected that sedimentation and diffusion play an important role in the deposition process. To assess the effect of acceleration on colloid transport in porous media, we therefore use a theory based on sedimentation and diffusion. We consider the relative importance of sedimentation and diffusion as affected by acceleration.

The root mean square displacement of a colloid by diffusion is (Hiemenz and Ragagopalan, 1997):

$$\bar{x} = \sqrt{2Dt} \tag{1}$$

where D is the diffusion coefficient, k is the Boltzmann constant, T is absolute temperature, η is the dynamic viscosity, d_c is the colloid diameter, and t is time.

The apparent velocity of diffusion is:

$$v_{diff} = \frac{x}{t} = \sqrt{\frac{2D}{t}} = \frac{2D}{x} \tag{2}$$

where x is distance. The apparent velocity of diffusion is time- or scale-dependent. With increasing time or distance, the diffusive velocity decreases. The sedimentation velocity of a colloid is given by Stokes law as:

$$v_{sed} = \frac{d_c^2 a(\Delta\rho)}{18\eta} \tag{3}$$

where a is the acceleration, and $\Delta\rho$ is the density difference between the colloid and the fluid. The random motion of colloids due to diffusion counteracts the linear motion due to sedimentation. In a centrifugation experiment, diffusion is not affected, but sedimentation increases with acceleration, thereby the balance between the two processes changes. We assume that applying a centrifugal acceleration to a colloid transport experiment will not affect the transport results (i.e., colloid deposition) as long as the sedimentation velocity is less or equal to the diffusion velocity multiplied by an empirical factor:

$$v_{sed} \le \xi v_{diff} \tag{4}$$

The parameter includes processes other than sedimentation and diffusion that lead to colloid deposition in a porous medium. When the centrifugal acceleration exceeds a certain threshold, sedimentation dominates diffusion. We can derive the relationship between this threshold acceleration a_T as a function of colloid density and colloid diameter from the equality ($v_{sed} = \xi v_{diff}$) in eq 4 as:

$$a_T = \frac{12\xi kT}{\pi d_c^3 (\Delta\rho) L_c} \tag{5}$$

where L_c is a characteristic length scale of the diffusion process. In a porous medium, we can take this length scale as the average pore size, which we approximate here by the average grain size. Eq 5 allows us to predict the threshold centrifugal acceleration at which the transport behavior of colloids will be altered compared to normal gravity conditions. If the acceleration exceeds the one predicted by eq 5, we expect colloid transport to be affected by centrifugation.

Objective 2: *Evaluate the correction factor in the theoretical relationship for critical acceleration by using geocentrifuges*

The theoretical predictions were tested with colloid transport experiments conducted in water saturated columns. A geocentrifuge was used to vary the centrifugal acceleration and to determine the threshold acceleration beyond which colloid deposition was altered. We conducted a series of colloid filtration experiments using an acrylic column of 1.5-cm ID and 6.4-cm length. The entire column set up was placed on the platform of a 2-m geocentrifuge (Model C61-3 Civil Engineering Centrifuge, Actidyn Systemes, France) at the geocentrifuge laboratory of the Idaho National Laboratory, Idaho Falls, ID. We first conducted the experiments at 1 *g* (normal gravity) without spinning the centrifuge. In subsequent experiment conducted on the 2-m geocentrifuge, once the centrifuge reached its target centrifugal acceleration, the column influent was switched from a background solution containing no colloids to a solution that contained the colloids. The outflow solutions were collected using fraction collector and their concentrations were measured at different wavelengths for different colloids using a spectrophotometer (USB4000 spectrometer, Ocean Optics Inc.). The colloid breakthroughs were analyzed with the advection-dispersion model (ADE) including a first-order colloid deposition term. The statistical differences between estimated model parameters were evaluated with a one-way ANOVA and Tukey pairwise comparison using SAS.

PRINCIPAL FINDINGS AND SIGNIFICANCE

The experimental results and theoretical calculations indicate that colloid transport will be affected by altered force fields during centrifuge experiments. We expect colloid deposition to increase as acceleration exceeds a threshhold acceleration (because of increased sedimentation). This threshold acceleration is determined by the density difference between colloid and the fluid, the colloid size, and the pore size of the porous medium. Theoretical calculations illustrated that centrifuge colloid transport experiments in porous media are the most appropriate for small colloid specific density, colloid diameter, and pore diameters.

The colloids used in our experiments are representative for many subsurface colloids (bacteria, silicates and aluminosilicates, and (hydro)oxides). For inorganic subsurface colloids, such as silicates and iron oxides, colloid transport will be different in centrifuge experiments as compared to normal gravity conditions at already fairly low accelerations. In our experiments accelerations as low as 5 *g* changed the filtration behavior of colloidal hematite and silica. Because of their high particle density, (hydro)oxides will be most affected by centrifugal acceleration. Organic colloids, which have densities close to that of water, i.e., ≈ 1 to 1.4 g/cm^3, are less susceptible to sedimentation. However, natural organic colloids vary a lot in size. For instance, for viruses (particle density: 1.3 to 1.5 g/cm^3, diameter: 24 to 81 nm) threshold accelerations would be in the range of 200 to 10^6 *g*, for coarse and fine textures soils, respectively, so that most geocentrifuge experiments will not affect the transport behavior. Bacteria (particle density: 1.02 g/cm^3, diameter: 1 to 4 μm), however, because of their large size, have threshold accelerations between 1 and 250 *g*, for coarse and fine textures soils, respectively. Overall, the most sensitive parameter determining critical accelerations is the colloid diameter.

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Tufenkji, N., M. Elimelech, 2004, Deviation from the classical colloid filtration theory in the presence of repulsive DLVO interactions. Langmuir, 20, 10818–10828.

Tong, M., W.P. Johnson, 2006, Excess colloid retension in porous media as a function of colloid size, fluid velocity, and grain angularity. Environ. Sci. Technol., 40, 7725–7731.

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Hiemenz, P. C., R. Rajagopalan, 1997, Principles of Colloid and Surface Chemistry, 3rd ed.; Marcel Dekker: New York.

Effects of Sediment Oxygenation on Methylmercury Bioaccumulation in Benthic Biota

Basic Information

Title:	Effects of Sediment Oxygenation on Methylmercury Bioaccumulation in Benthic Biota
Project Number:	2006WA149B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	Washington, Fifth
Research Category:	Water Quality
Focus Category:	Toxic Substances, Sediments, Ecology
Descriptors:	Natural Treatment Systems, Constructed Wetlands, Ammonia, Nitrate, Nitrification, Denitrification
Principal Investigators:	Marc Beutel

Publication

1. Dent, Stephen and Marc Beutel. 2007, Effects of Sediment Oxygenation on Methylmercury Bioaccumulation in Benthic Biota, State of Washington Water Research Center, Washington State University, Pullman, Washington. State of Washington Water Research Center Report WRR-28, 11 pages.
2. Dent, Stephen and Marc Beutel, 2006, Effects of Hypolimnetic Oxygenation on the Bioaccumulation of Hg in Benthic Organisms, Platform Presentation at the Eighth International Conference on Hg as a Global Pollutant, August 2006, Madison, Wisconsin.

PROBLEM AND RESEARCH OBJECTIVES

Mercury (Hg) contamination of fish in lakes and reservoirs is a serious, widespread threat to wildlife and humans that eat lake fish. Hg is a widespread contaminant due in part to its long residence time in the atmosphere. Hg discharged to the atmosphere - power plants are a common source - travels long distances before entering aquatic systems via atmospheric deposition, thereby contaminating relatively pristine ecosystems far from the discharge source. Another key to Hg's potency as a contaminant is its potential to bioaccumulate in biota. Inorganic Hg from atmospheric deposition can be microbiologically transformed to methylmercury (MeHg) by sulfate reducing bacteria (SRB). MeHg accumulates in organisms at the base of the food chain (eg. worms, algae) at concentrations many times higher than in the water. MeHg biomagnifies in tissue of biota at higher trophic levels (eg. insects, fish, water fowl) as they consume contaminated prey.

Anaerobic bottom sediments occur in many productive, moderately deep lakes during the summer and fall, and provide an ideal environment for SRB activity and the concurrent formation of MeHg. MeHg accumulates in sediment pore water and then diffuses into overlaying lake water. Once mixed into the lake, the MeHg bioaccumulates in plankton, then biomagnifies through upper trophic level biota that consume contaminated prey. This phenomenon has been observed in a number of lake ecosystems, where studies have correlated anaerobic conditions with MeHg accumulation in bottom water, and lake mixing with bioaccumulation in lower trophic level biota. Thus, bottom water anoxia coupled with lake mixing is a key entry mechanism for getting Hg into aquatic food webs.

The preliminary goal for this research effort is to evaluate a key concern regarding lake oxygenation; essentially, will the recolonization of previously "dead" anoxic sediments exacerbate the accumulation of Hg up the food web by exposing a lower trophic organism to contaminated sediments. To fulfill this goal several objectives need to be met. First, the selected test organism, the benthic oligochaete *Tubifex tubifex*, needs to be successfully grown in large enough colonies to obtain a broad sample population. Second, an analytical method capable of discerning between total Hg and MeHg is required considering only the MeHg fraction will be transferred up the food web. Third, undisturbed sediment water interfaces from the designated study site must be obtained. Ideally, the oligochaetes would be placed in undisturbed sediment/water interface incubations with known sediment Hg concentrations at varying degrees of oxygenation. The degree of MeHg accumulation in organism would then either validate or disqualify the concern described above.

Early on in our efforts it was realized that colonization of our selected benthic oligochaetes to significant numbers would not be possible within the time frame of this project. This was due to three factors: 1) the unexpected die off of our original starter colony; 2) the slow turnaround from stock *Tubifex tubifex* provider; and 3) the time needed to grow a new starter colony to ample numbers. In order to proceed, our focus shifted to evaluating a synthetic biomimetic device to imitate the oligochaetes interaction with Hg. The methodology section below describes in detail our process for developing a biomimetic device utilizing solid-phase micro extraction (SPME) fibers. Although SPME fibers have been used successfully as biomimetic devices for compounds such as TNT and PCBs, this is the first case of using these devices as a biomimetic device for Hg.

METHODOLOGY

Benthic Oligochaetes: Benthic oligochaetes can be harvested by sieving sediment and isolating the organisms. Once isolated outside their protective sediment the worms come together and form a protective ball. These balls are typically used for starter colonies. Our lab received a ball of *Tubifex tubifex* from Dr. Billie Kerans of Montana State University's Department of Ecology in August of 2006. The organism strain had been cultured in MSU's lab since 1997, originating from a hatchery in California. It was important to get a strain that was acclimated to laboratory conditions and far removed from background Hg contamination present in most aquatic systems. Worms were cultured using the "Efficient method for culturing sludgeworms (*Tubifex tubifex*) for use in sediment toxicity tests" (Browen, Conder and La Point; 2002). Worms were placed in an aquarium with quartz sand and DI water. The prescribed food for the organisms was a combination of distilled water, cleaned iceberg lettuce, and flake fish food blended into a paste. Food was dispensed out in 50 mL aliquots every two weeks.

Biomimetic Devices: Solid-phase microextration fibers were selected as potential surrogates for the interaction of *Tubifex tubifex* with Hg in contaminated sediments. Our approach was based on a modified method from Dr. Jason Conder of the University of North Texas who successfully used SPME fibers as a biomimetic device for benthic oligochaete interactions with TNT. There are many different types of SPME fibers, each one of them very specific to the constituents that are being sampled. We chose a polydimethylsiloxane (PDMS) coating for its affinity for organic Hg species and its use in some Hg analytical techniques. Fibers were obtained through Supelco in 50 cm raw fiber lengths and then cut into a more manageable 2 cm pieces. PDMS is a hydrophobic material which requires a holder that could physically hold the fibers in the solution. Fiber holders were constructed out of pure Teflon disks. The disks were folded in half and slits were cut along the seam. Fibers were successfully held within the slits in the disk by friction and the density of the Teflon disk kept the fibers submerged. All fibers were pretreated by soaking in reagent grade methanol, rinsed in DI water, and let dry in a clean hood for 12 hours.

Chemical Extraction Method: In order to begin calibrating the fibers for a new in situ monitoring technique, a non-solvent based liquid extraction method was developed. This new method was compatible with our current Hg analytical device, a Tekran 2600. The methods included: (1) a "hard" complete digestion in aqua reaga followed by the addition of Bromine Monochloride (BrCl); and (2) a "soft" digestion using BrCl alone, which is typically used for water sample digestion. Fibers were placed three to a holder and soaked in DI, 0.5 ug MeHg/L, and 1.0 ug MeHg/L spiked water for 24 hours to ensure equilibrium was reached. The MeHg stock used was prepared by Frontier Geoscience at a concentration of 1 ug/L unpreserved. Literature values for Hg equilibrium with fibers are on the range of 1 to 2 hours; equilibrium time was not further explored in this experiment. Using a technique we coined as "clean tweezers/dirty tweezers", the individual assigned the dirty tweezers removed the soaking holder with fibers from the incubation vessel and dipped it in a DI bath. The individual assigned the clean tweezers then removed the fiber from the holder and placed them in a digestion vessel containing one of the two digestion solutions. Fibers were digested over night for a period of 12 hours each. Digestion was ceased by removing the fibers from solution with acid washed tweezers and adding BrCl to the aqua reaga vials.

Species Extraction: Using the same procedure listed in the Chemical Extraction Method above with only the soft digestion, the effect of Hg species sorption to the fiber was evaluated. Fibers in their holders were soaked in DI, 0.5 ug/L, and 1.0 ug/L inorganic Hg (Hg^{2+}) and MeHg solutions. The

Hg^{2+} solution was made from a 1,000 mg/L preserved stock used for calibrating the Tekran 2600. Fibers were extracted three to a digestion vial to increase detection sensitivity.

Extraction Time Series: Hg extraction from the fibers over time was evaluated using the same methods described above with varying times of fiber exposure to the digesting solution. Fibers were all soaked in a 1.0 ug/L unpreserved MeHg solution and digested in increments of 12, 24, 36, 48 hours. This procedure was then repeated with the addition of a 4 and 8 hour extraction and a parallel run of fibers soaked in an unpreserved 1 ug/L Hg^{2+} solution. The unpreserved Hg^{2+} solution was made by dissolving 1 g of Mercuric Chloride in 1 L of DI and then brought to the desired concentrations by further dilution with DI.

Natural Water Extractions: Incubations were again repeated using the above procedure, this time substituting natural filtered water from a local wetland for DI water. Natural water was spiked to 0.5 ug/L, half with preserved Hg^{2+} and half with unpreserved MeHg. Extraction time was adjusted to 10 hours based on results from the Extraction Time Series (See Principal Findings and Significance).

Mercury Analysis: Hg analysis was performed following EPA's method 1631 for total Hg using our in house Tekran 2600 Cold Vapor Atomic Fluorescence Spectroscopy (CVAFS) Autoanalyzer. All glassware and devices used were cleaned and soaked in a 50% HNO_3 acid bath for two days. Clean hands/dirty hands techniques were used when ever handling fibers, samples, and standards.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Culturing benthic oligochaetes takes time and experience. After the initial die off of our original culture it became apparent that growing a large enough population in the time window of this project would not be possible. Instead, the process of developing an in situ biomimetic sampling device to take the place of the benthic oligochaetes is presented here.

Chemical Extraction Method: Although PDMS fibers have been used in Hg analytical techniques, they are typically not used as in situ sampling devices and based on our analytical capabilities it was not possible to use the standard thermal or solvent extraction methods that the fibers were designed for. As described above, a hard and soft digestion method were developed and evaluated. The assumption was made that the hard, soil type digestion would release all of the Hg from the PDMS matrix. Both the hard and the soft digests performed identically and in a linear fashion between the DI, 0.5 ug/L, and 1.0 ug/L MeHg solution soak. Based on the performance of this extraction series the soft digest was selected for all subsequent extraction series due to its compatibility with Method 1631.

Species Extraction: SPME fibers are hydrophobic and designed to sorb organic compounds. Historically SPME has been used for MeHg analysis. To verify the selectivity of the PDMS fiber, parallel incubations of both MeHg and Hg^{2+} were conducted using the soft digestion method in soaks of 0, 0.5, and 1.0 ug/L of each species. The fibers per digestion vial were increased from 1 to 3 in order to increase detection sensitivity. Both MeHg and Hg^{2+} had linear extraction slopes; however, the Hg^{2+} had nearly double the sorption capacity. This demonstrated that the fibers were not specifically selective for MeHg and that a speciation analytical technique would be required when using the fibers in heterogeneous environmental Hg solutions.

Extraction Time Series: A time series extraction test was used to determine the efficiency of the extraction. Ideally, a mass balance would have been preferred but as the fibers extract such a minute amount out of solution, our analytical techniques are not sensitive enough to "close the loop". Fibers soaked in 1 ug/L MeHg solution were extracted in 12, 24, 36, and 48 hour time intervals. The 12 hour digestion resulted in the most Hg extracted; the amount extracted dropped by half at 36 hours. This may be due to the creation of sorption sites in the siloxane matrix as it is oxidized by BrCl. The subsequent increase in the Hg release at hour 48 may indicate that the oxidizing power of BrCl was spent. The time series was repeated again with the added time points 4 and 8 hours, and with a parallel series with unpreserved Hg^{2+}. Unpreserved Hg^{2+} was used this time to see if the acidic preservative had any type of influence on the sorption. MeHg extractions at 4 hours had higher yield in one vial but less in another; however, the 8 hour extraction was fairly consistent with the 12 hour extraction from the previous run. The rest of the time series was on par with the previous run. The extraction of Hg^{2+} however, was consistently lower than the MeHg extractions, indicating that the preservative may have enhanced the sorption of the inorganic species. The trend over time with the Hg^{2+} was similar to that of MeHg, however Hg^{2+} sorption reached its lowest point one time step earlier at hour 24.

Natural Water Extractions: To determine the effect of competing ions and complexes on the sorption of Hg to the fibers, filtered wetland water was used in place of DI water. Fibers were soaked in 0.5 ug/L Hg^{2+} and MeHg spiked natural water followed by extraction. Results showed a greater than four fold decrease in the fibers ability to sorb both forms of Hg. This implies that either other cations are out competing Hg for negative sites on the fiber or anions are complexing with the Hg species and creating neutral or negative complexes. Either way it would appear that the sensitivity of the fiber decreases with the presence of other ions and complexes in solution.

Concluding Thoughts: It was unexpected to have as much inorganic Hg sorb to the fiber as observed, even considering the unpreserved Hg^{2+} extraction. It is apparent that for this technology to be a successful Hg biomimetic device, analytical speciation capabilities must be utilized. Our research group has solicited the help of Dr. Gary Gill and the Battelle Marine Sciences Laboratory in Sequim, Washington. The analytical laboratory has full Hg analysis capabilities. The natural water portion of this project will be carried out in the summer of 2007 at the Battelle facility. Another issue that will be addressed, based on these preliminary results, is that SPME fibers have a very small volume of coating, which is proportional to how much Hg will be sorbed. In order to be applicable in a natural setting our research group will use PDMS coated disks, with an order of magnitude greater volume, that can be inserted directly in the sediment. By collaborating with Battelle's Hg laboratory and increasing the volume of PDMS per sampling unit, we intend to produce a fully functional Hg biomimetic device within the near future.

Developing a Sediment Model for Use in the TMDL Processes in the Inland Northwest

Basic Information

Title:	Developing a Sediment Model for Use in the TMDL Processes in the Inland Northwest
Project Number:	2006WA157B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	Washington 5
Research Category:	Water Quality
Focus Category:	Models, Sediments, Management and Planning
Descriptors:	TMDL, Modeling, Sediments, Nutrients, Winter Runoff, Erosion
Principal Investigators:	Shulin Chen

Publication

PROBLEM AND RESEARCH OBJECTIVES

Washington State is still facing water quality issues as nearly 650 water bodies in the state are failing to meet water quality standards due primarily to end of pipe discharges from point sources within cities and industries and diffuse runoff from non-point sources. The Total Maximum Daily Load (TMDL) program was established by the Clean Water Act as a process to regulate both point sources and non-point sources so that the integrity of the water quality could be protected. A TMDL is a calculation of both the maximum amount of a pollutant that a water body can receive and still meet water quality standards and an allocation of that amount to the pollutant's sources. The Washington Department of Ecology has until 2013 to develop and implement TMDLs for the state's nearly 650 polluted water bodies.

Most impaired water bodies are affected by more than one pollutant, among which sediment has been identified as a primary pollutant. Besides direct environmental impact, sediment is often the carrier for other pollutants such as nutrients and bacteria. Sediment allocation is thus an important component in many efforts of TMDL development, including that in Washington State. Because of difficulties in direct measurement of sediment amount, science based technical tools such as mathematical models have become essential in the TMDL process, as well as in the planning, design, and implementation of watershed projects. Unfortunately, mathematical models that are well accepted for sediment prediction required in TMDL development are limited. For example, in the models listed by the Washington Department of Ecology for TMDL studies (http://www.ecy.wa.gov/programs/eap/models/), sediment models that are considered applicable to Washington are lacking. This is mainly due to the fact that the land use and climatic uniqueness of the region cause models developed for other regions to not perform well in this region without modifications.

The limitations in using other regional models such as USLE/RUSEL for the Inland Northwest become clear by noting the needs of the TMDL process as well as the unique conditions under which erosion events occur. First, the application of an annual based model for TMDL development is questionable, as the major erosion events of the Inland Northwest occur primarily in winter time. Second, the use of an event erosivity factor, $EI_{30,}$ is not suitable, as a large portion of the erosion events of this region occur as a result of snow melt or rain on snow and with low rain intensity. Third, although by changing the annual based erosion prediction to event based prediction, and by considering runoff volume, MUSLE represents an improvement to USLE/ RUSLE for application in TMDL development, rain on snow and/or melting under frozen soil conditions in this region will have a significant impact on the sediment produced from a watershed compared with rain on unfrozen soil. Therefore, verification and modification of the above models is necessary for their applications to this region. The primary objective of this project is collecting data from a watershed in the Inland Pacific Northwest to verify the practicality of the existing model in this region and prepare the data set for modifying the model.

METHODOLOGY

The study was conducted on Dartford Creek Watershed, a subwatershed of the Little Spokane River Watershed. Data collection focused on runoff hydrography and sediment yield. A sampling station was installed at the outlet of the Dartford Creek Watershed. The station included a continuous flow sensor and an automatic sampler. An ISCO automatic water sampler (6712) was installed for sediment sample collection, flow water level and rainfall recording. Samples were automatically collected after each storm event. Manual (hand grab) samples were also collected as reference and complementary. All the samples were transported back to the Water Quality and Waste Analysis Lab at WSU for analysis of sediment concentration. Two sampling programs, A and B, were

implemented. Program A was for the event period and the interval of sampling was every two hours. Program B was for the background/baseflow period, the interval sampling was every three days. Sampling criterion was adjusted according to the water level change to obtain the sediment samples with different water levels (different flow rate). Additional devices were installed for water level measurements. The continuous flow recorder installed was self-contained pressure transducers and loggers that record the water depth at an interval of every 15 minutes. It consisted of the Water Level Logger (WL15) from Global Water Instrumentation. The data were downloaded to a PC periodically. A correlation between flow rate and water depth called a "rating curve" (a stage-discharge relationship) was established using the data obtained from a series discharge measurements made according to the USGS midsection method.

A weather station was also installed at the watershed, where precipitation, wind speed and direction, air and soil temperatures were the major parameters monitored.

The field data was processed to derive important relationships on sediment yield. The data processing mainly involved the conversion of measured water levels to discharge rate, the delineation of storm events from the discharge rate, and the estimation of total sediment yield from the discharge data and the sediment concentration. After the data was processed, mathematical manipulations were performed to verify the Modified Universal Soil Loss Equation (MUSLE):

$$SY_e = X_e K L S C_e P_e \qquad (1)$$

where SY_e is the event total sediment yield. Additionally,

$$X_e = \alpha(Q_e q_p)^{0.56} \qquad (2)$$

where α is an empirical coefficient which is independent of climate, soil, vegetation, conservation practice, or management; Q_e is runoff amount and q_p is the peak runoff rate obtained during the erosion event; and K, L, and S are as defined for the USLE with Ce and Pe being event C and P values.

Due to the fact Equation (2) is the key of MUSLE, the data analysis was focused on verifying the relationship. With taking natural logarithm to both sides of Equation (2), the following equations were obtained:

$$Ln(SY_e)=0.56Ln(Q_e q_p) +M \qquad (3)$$

$$Ln(SY_e)=aLn(Q_e q_p) +M \qquad (4)$$

For each event, SY_e value was calculated from the flow and sediment data collected at the outlet of the watershed. The values of Q_e and q_p were also measured at the outlet. The slope of the linear regression of Equation (4) will define the coefficient "a" which in turn can be compared with the existing value (0.56) used in the current MUSEL model.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Major findings of the project results can be summarized in three aspects, including (1) sediment yields, (2) discrepancy with the existing MUSEL model, and (3) analysis of relative impact of discharge versus peak flow rate upon sediment yield.

Sediment yields

Total 14 events were measured during the 2006-2007 winter season with discharge rate ranging from 319,510 ft^3 to 3154760 ft^3. The peak discharges ranged from 3.11 ft^3/s to 6.86 ft^3/s. Significant amount of sediments was produced from each of these events, ranging from 0.4 to 16 metric tons.

Comparisons with MUSEL

The relationship between sediment yield and the product of total event discharge and peak flow is illustrated in Figure 1. Regression equation indicates that the value of "a" as in Equation (4) is 0.934. The current value used in MUSEL is 0.56. The results obtained in this study suggest that a modification to the MUSEL model may be necessary for use in TMDL in the Inland Pacific Northwest in terms of the coefficient.

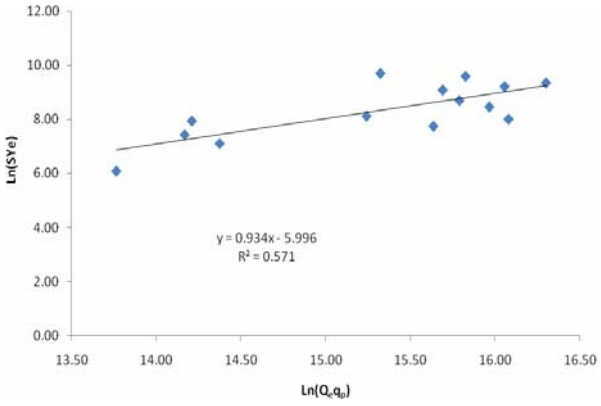

Figure 1. Correlation between sediment yield and product of total event discharge and peak flow

It can be noted that the R^2 value of the above correlation was not high. One contributing factor to the variations might be the fact that these events were different in ways they occurred. According to the weather station data and field records, some of these events were caused by rain, some by snow melt, and some by rain on snow. The soil conditions also varied, as for some events the field was frozen and non-frozen for others.

Impact of discharge versus peak flow rate upon sediment yield

The relative impact of the total event discharge on sediment yield is presented in Figure 2 in comparison with that of peak flow (Figure 3). It can be seen from the coefficients of the correlation equations that peak flow had more significant impact on the total sediment yield than that of total discharge of the event. These results may provide some insight as to the nature of the erosion process of the watershed, whether the process is limited by the detachment or transport of the soil particles in the upland areas.

It needs to be pointed out that multi-year data are required for watershed modeling studies. Due to the limitation of the project scope, data from a single season was collected and used for the above analysis. Therefore, the results presented here are preliminary in nature. Further verifications are recommended before the results are used for this and other similar watersheds.

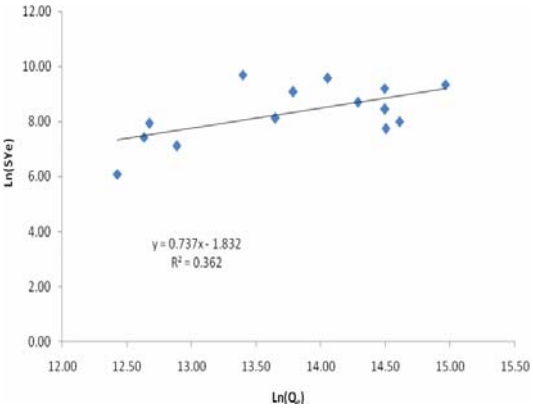

Figure 2. Sediment yield versus total discharge

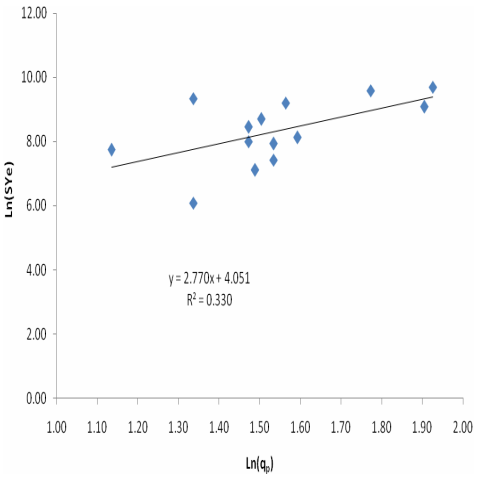

Figure 3. Sediment yield versus peak flow

West-Wide Drought Forecasting System: A Scientific Foundation for NIDIS

Basic Information

Title:	West-Wide Drought Forecasting System: A Scientific Foundation for NIDIS
Project Number:	2006WA180G
Start Date:	9/1/2006
End Date:	8/31/2009
Funding Source:	104G
Congressional District:	7
Research Category:	Climate and Hydrologic Processes
Focus Category:	Drought, Hydrology, Management and Planning
Descriptors:	Drought Forecast, Drought Mitigation
Principal Investigators:	Anne Steinemann, Dennis Lettenmaier, Andrew Wood

Publication

1. Wood, A.W. Correcting errors in streamflow forecast ensemble mean and spread. Submitted to Journal of Hydrometeorology (in review).
2. Steinemann, A., 2007, Climate Forecasts for Drought Management, NOAA Climate Prediction Applications Science Workshop, Seattle, March 21, 2007.
3. Rosenberg, E., A. W. Wood, Q. Tang, A. Steinemann, B. Imam, S. Sorooshian, and D. P. Lettenmaier, 2007, Improving Water Resources Management in the Western United States through Use of Remote Sensing Data and Seasonal Climate Forecasts," Poster Presentation at the 5th Annual Climate Prediction Applications Science Workshop,Seattle, Washington, March 20-23, 2007.
4. Shukla, S., D. Alexander, A. Steinemann, and A. W. Wood, 2007, Applications of Medium Range To Seasonal/Interannual Climate Forecasts For Water Resources Management in the Yakima River Basin of Washington State, Poster Presentation at the 5th Annual Climate Prediction Applications Science Workshop, Seattle, Washington, March 20-23, 2007.
5. Lettenmaier, D. P., A. W. Wood and K. Andreadis, 2006, A System for Real-time Prediction of Hydrological and Agricultural Drought over the Continental U.S., EOS Transactions, American Geophysical Union, Fall Meeting Supplement, 87(52): Abstract G31A-07.
6. Fontaine, M., and A. Steinemann, 2007, Assessing and Mitigating Drought in Washington State, Poster Presentation at the 5th Annual NOAA Climate Prediction Applications Science Workshop, Seattle, Washington, March 20-23, 2007.
7. Shukla, S., D. Alexander, A. Steinemann A., and A. W. Wood, 2007, Applications of Medium Range To Seasonal/Interannual Climate Forecasts For Water Resources Management in the Yakima River Basin of Washington State, Water Center Annual Review of Research, University of Washington, Seattle, Washington, February 14, 2007,
8. Wood, A. W., A. Steinemann, D. Alexander,and S. Shukla,2006, Applications of Medium Range To Seasonal/Interannual Climate Forecasts For Water Resources Management in the Yakima River Basin of Washington State, EOS Transactions, American Geophysical Union, Fall Meeting Supplement, 87(52): Abstract HC53-0648.
9. Fontaine, M., and A. Steinemann, A., 2006, Assessing and Mitigating Drought in Washington State, UW/UBC Hydrology Conference.
10. Annual Review of Research: A Symposium of Water Research Hosted by the University of Washington Water Center. 2007. February 14, 2007. http://depts.washington.edu/cwws

PROBLEM AND RESEARCH OBJECTIVES

Drought is the costliest natural hazard in the U.S., averaging $6-8 billion in damages annually (FEMA, 2004). The 1988 central U.S. drought alone cost almost $62 billion (NCDC, 2006). Forecasts and real-time assessments of drought offer the potential to mitigate drought impacts. However, current drought monitoring systems for the western U.S. lack a predictive component for specific hydrologic indicators. Further, given that hydrologic impacts account for most drought losses, USGS data are essential to making drought forecasts useful.

We propose to develop a drought forecast and nowcast system for the western U.S., which will serve as a scientific framework for prediction and assessment of agricultural (soil moisture) and hydrologic (streamflow) drought in the region. This work, in collaboration with USGS personnel, will provide early warning capabilities and science-based indicators that are critical for the National Integrated Drought Information System (NIDIS), an effort of the Western Governors' Association (WGA), the National Drought Mitigation Center (NDMC), NOAA, the USGS, and other agencies. Our work will also contribute to the U.S. Drought Monitor, which currently uses our National Surface Water Monitor, by incorporating USGS data into methods to characterize and forecast drought conditions, persistence, and recovery. Further, the PIs and their students will work directly with water managers in selected states in the region (Washington, California, and others) to apply this forecast system to water resources decisions.

Our proposed drought forecasting system will build upon the University of Washington's operational West-Wide Hydrologic Forecast System and National Surface Water Monitor. In doing so, we will extend the Variable Infiltration Capacity (VIC) macroscale hydrology model to utilize, via data assimilation methods, USGS hydrologic data in ways not currently exploited by prominent drought information services, such as the U.S. Drought Monitor.

Our specific objectives are to (1) implement a version of the VIC model that represents near-surface groundwater directly and thus can incorporate USGS well level data; (2) assimilate observations not presently used in the West-Wide system that are highly relevant to drought, such as USGS streamflow data from HCDN and similar stations, soil moisture information, and USGS well data; (3) produce probabilistic forecasts of drought persistence and recovery using ensemble prediction methods that incorporate climate forecasts out to one year; and (4) work with the WGA, the NDMC, and other users, such as state water agencies, to incorporate the resulting drought forecasts and nowcasts into drought information systems and water management decisions.

In addition to interactions with the WGA and the NDMC, we will work closely with Dr. Randall Hanson and Dr. Michael Dettinger of the USGS California Water Science Center in San Diego. Specifically, we will work with Drs. Hanson and Dettinger in (1) testing VIC predictions of well level anomalies at selected locations in California, (2) development of algorithms for assimilation of USGS well level and streamflow data, as well as other hydrologic data, into the drought forecasting system, (3) obtaining retrospective and real-time hydrologic data, and (4) validation of drought nowcasts and forecasts across the western U.S. study domain.

METHODOLOGY

The overall goal of the proposed project is to develop a drought forecast and nowcast system for the western U.S. (which we will define as the continental U.S. west of the Mississippi River), which can serve as a scientific framework for assessment and prediction of agricultural (soil moisture), and hydrologic (streamflow) drought in the region, and as the scientific core of NIDIS. The system will leverage the existing University of Washington WHFS and SWM. Our specific objectives are:

(1) To implement a version of the VIC model described by Liang et al. (2003) that represents near-surface groundwater (water table) directly, and hence will be capable of incorporating USGS well level observations via data assimilation in areas where there is strong connectivity between groundwater and surface water systems;

(2) To develop procedures for assimilating observations that are not presently incorporated in the WHFS but are highly relevant to drought, such as USGS well data, USGS streamflow data from HCDN and similar stations not greatly affected by water management, and soil moisture from such sources as the NRCS SCAN network and state networks where such data are available;

(3) To develop methods for producing probabilistic forecasts of drought persistence and recovery, using ensemble prediction methods that incorporate official NOAA CPC ensemble climate forecasts for lead times out to one year; and

(4) To work with the NDMC, the WGA, and other users (primarily state agencies in the western U.S.) to incorporate the resulting drought nowcasts and forecasts into water management decisions and into drought information systems such as the Drought Monitor/Outlook and NIDIS.

PRINCIPAL FINDINGS AND SIGNIFICANCE

A statewide drought monitoring system has been implemented using the VIC hydrologic model at 1/16 degree (about 6 km grid mesh). This system provides real-time, daily updating analyses (maps, datasets, and timeseries of hydrologic variables) that characterize hydrologic conditions throughout the state, presented via a website. Work has begun to prepare the statewide monitoring system with the embedded focus region as the initializing state for 2 week to 1 year lead hydrologic forecasts, from which it will be possible to obtain drought onset and recovery predictions. These will be based on both ensemble streamflow prediction (ESP) techniques advanced by the National Weather Service, and NCEP Climate Prediction Center seasonal outlooks. To this end, the Climate Prediction Center's new consolidated forecast (not previously available to the public) has been obtained and is being evaluated in the Washington State domain. In addition, preliminary work to develop methods for forecast error reduction has resulted in a submitted paper (listed below).

We have implemented and tested a drought recovery strategy, based on initializing of VIC hydrology model with current (soil moisture) conditions, and running forward in time with ensembles of future climate conditions. We have performed initial testing of this method using the southwestern U.S. drought of winter 2005-6 as a case study, and using Ensemble Streamflow Prediction (ESP) methods, wherein the ensembles are drawn from sequences of past observations, as the ensembles (the method is easily generalized to utilize ensembles from other sources, such as the ensemble version of the CPC "official" forecasts that we use in our western U.S. streamflow forecasting. Figure 1 shows results from the winter 2005-6 case study. Probabilistic outcomes will be compared with nominal conditions (as simulated with the VIC model using the true forcings) for the retrospective period, and maps of the accuracy of climate recovery predictions will be produced as a function of season and lead-time. Figure 2 compares the ensembles of predicted soil moisture, averaged over the Arizona-California portion of the drought, compared with "actual" (real-time) model soil moisture over the 6-month forecast period.

We have also implemented a drought nowcast system in real-time, and are in the process of implementing a drought forecasting system over the western U.S. domain, using methods similar to those illustrated in Figures 1 and 2, at one-quarter degree spatial resolution (our current Surface Water Monitor uses one-half degree resolution). We have recently implemented a drought

identification system at the SW Monitor native ½ degree resolution. We summarize the method below.

The VIC hydrologic model produces near real-time, spatially and temporally continuous fields of drought-related variables such as soil moisture and streamflow (we focus here on soil moisture). Drought is defined locally at each model pixel using a thresholding method, i.e. whenever soil moisture or runoff are below a certain threshold value the pixel is classified as being "in drought". Instead of using the absolute values of soil moisture (or runoff), droughts are identified by expressing each pixel's soil moisture as percentiles of their 1915-2004 respective model climatology. This essentially normalizes the soil moisture and runoff time series to range of 0 to 1 across the domain. The threshold chosen here is 0.2, which corresponds to severe drought, with severity being calculated as the percentage remainder of the subtraction of the soil moisture (or runoff) percentile from unity.

Soil moisture and runoff spatial fields are estimated and used to produce weekly maps, which are then used in the drought identification procedure. In order to keep a certain temporal continuity in the areas identified as drought from one timestep to the next, we have to apply some kind of temporal persistence constraint. This ensures that areas are classified as drought recovered relatively consistently, given that this is a near real-time application. Drought transition probabilities (probability that a pixel will recover if it was in drought the previous 1, 2 or 3 weeks) were calculated from the model climatology. These are then used after the first stage of drought identification (any pixel below the 20^{th} percentile is classified as drought) to retain the temporal persistence in drought areas. The recovery probability threshold is set to 50%, but this can be adjusted accordingly.

The algorithm continues by applying a spatial median filter using a 5x5 window, in order to attain some spatial smoothing by minimally distorting the actual percentile values. The initial partitioning of the image then follows, by grouping adjacent pixels that are in drought into clusters. This fragmented image is then adjusted by merging clusters that are sufficiently close in terms of distance, and eliminating drought clusters that occupy less than the area of 20 model pixels. The final step includes the reclassification of pixels that are within larger drought areas as being in drought, by examining the neighborhood of each pixel not in drought within a radius of 3 model pixels. This procedure results in a map of drought areas, and also allows for their consistent tracking through time. Figure 3 shows results of application of the method over the continental U.S. starting in early May, 2007, as droughts were evolving in both the southeastern and southwestern U.S., and proceeding through the first week in June, 2007 (a few days before this report was written). The spatial limits of drought are updated once per week. We are interacting with CPC personnel who are reviewing the method, but we believe that it has great promise for producing a more objective delineation of drought extent and severity that is currently possible in publications such as the National Drought Monitor.

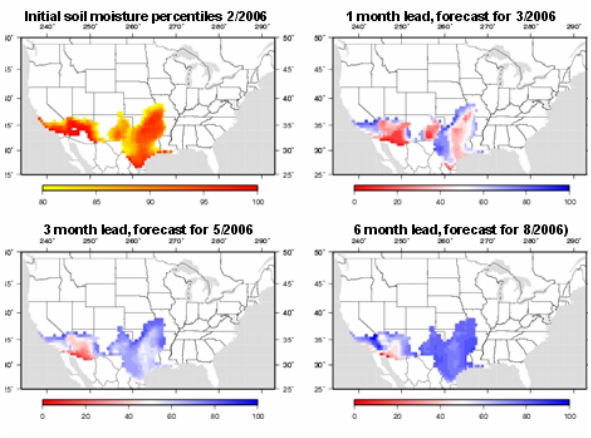

Figure 1: Projected progression of SW U.S. drought prediction beginning with observed soil moisture in February, 2006 (percentiles relative to 1915-2003 historical period). Subsequent plots show estimated probability of soil moisture exceeding 1915-2003 mean for lead times of 1, 3, and 6 months, beginning with February, 2006.

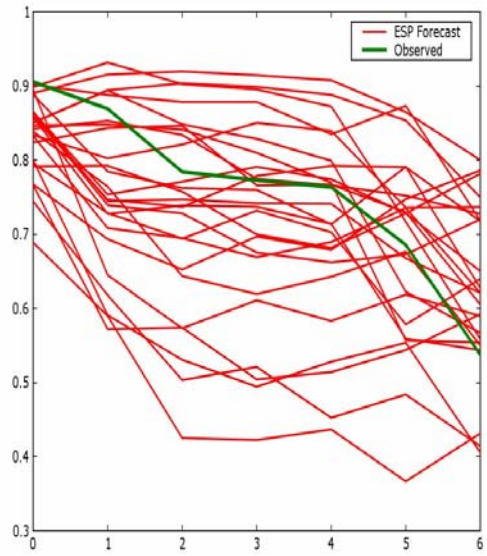

Figure 2: Spatial average soil moisture over AZ-CA portion of drought in Fig. 1 starting on Feb. 1, 2006, and progressing through August, as compared with "actual" soil moisture (real-time model estimates).

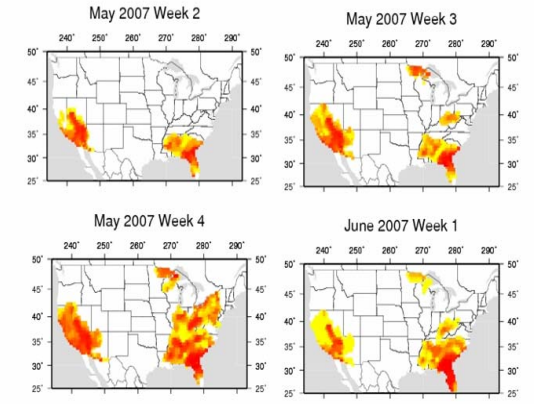

Figure 3: Estimated extend of drought over continental U.S. as of first week of June, 2007, and evolution over previous three weeks. Soil moisture percentiles are relative to 1915-2004 climatology, color bar as in UW Surface Water Monitor

Information Transfer Program

The State of Washington Water Research Center (SWWRC) believes that Outreach and Education are critically important components to its mission. The primary goal is to facilitate information exchange by providing opportunities for combining the academic work of research universities in the state with potential users and water stakeholders. This process occurs through a variety of activities, formal and informal, that raise the visibility of university research results throughout the Pacific Northwest. Federal, state and local agencies, non-governmental organizations, watershed groups, and concerned citizens are in need of interpreted science that can be applied to solving the regions water problems. The SWWRC makes substantial efforts to facilitate this process. The items described in the following Information Transfer Report constitute the core of the technology transfer activities.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2005WA114B
Start Date:	3/1/2005
End Date:	2/29/2008
Funding Source:	104B
Congressional District:	Washington 5th
Research Category:	Not Applicable
Focus Category:	Education, Management and Planning, None
Descriptors:	Outreach, Information Transfer
Principal Investigators:	Michael Ernest Barber

Publication

1. Barber, M. and B. Bower, 2006, Evaluating Diversion Alternatives Affecting Environmental Flows and Temperatures, Presentation at UCOWR/NIWR Annual Conference, Increasing Fresh Water Supplies, Santa Fe, New Mexico.
2. Simmons,R., M. Barber, and J. Dobrowloski, 2006, Washington State University - Providing Solutions to Critical Water Issues, National Association of State Land Grant Universities and Colleges, NASULGC Science Exhibit on the Hill, Washington, D.C.

To achieve the goals outlined in the introduction, the following information transfer activities were conducted.

The SWWRC co-sponsored a Palouse Aquifer Water Summit meeting aimed at educating the local residents and decision makers on issues related to groundwater pumping and subsequent drawdown.

Meetings with the Spokane/Rathdrum Prairie Aquifer Committee continued into 2006 as part of a joint project with the USGS and the Water Institutes in Idaho and Washington aimed at determining water availability across state boundaries. A public forum was held to discuss issues and preliminary findings with the general public.

Attended UCOWR meeting in Santa Fe, New Mexico to network with regional water professionals, attend NIWR Board meeting, and participate in conference. The Director gave an oral presentation at the conference on a project initiated and facilitated through SWWRC.

Continued funding for a USDA-CSREES grant was received. The project helps to coordinate research and extension activities of the Water Research Institutes and Extension Services in Alaska, Idaho, Oregon, and Washington with EPA Region 10. Six meetings are held each year and communication between researchers, extension faculty, and government agencies is expanding rapidly. The SWWRC began organizing a two-day regional water quantity and quality conference titled Moving Science into Policy and Action. This highly successful conference series is generally well received and significantly raises the visibility of the SWWRC and university researchers in the region as well as help disseminate important technical and policy related information. The conference will be proceeded by both ½ day workshop and a day-long bus tour of highlighting the science-policy trade-offs related to salmon restoration and hydropower generation in the area.

We continued to actively participate in a strategic regional surface water initiative funded by the Department of Energy through the Inland Northwest Research Alliance (INRA). The project involves the Water Institutes and the Universities of Alaska, Idaho, Utah, and Washington as well as Boise State University, the University of Montana, Idaho State University and Montana State. The project involves bi-monthly conference calls aimed at establishing a regional needs assessment and a coordinated research and education program aimed at integrating water science, policy, and decision making. A needs assessment related to water resources education and research was begun in FY 2006 and should be completed soon.

Updating our Web site is a continuous process. This is an important avenue for us to present information about the activities of the Center and the research faculty in the state as well as news and events, research reports, and opportunities for research funding. This media requires nearly continuous work to ensure that the material is current ant the look of the page is up to date. We also continued the process of having research reports available for download via PDF format rather than mailing of paper copies.

Our database of interested stakeholders is also constantly being updated. Currently over 3,000 names are included. Information for a second database of water resources expertise at Land

Grant Universities in the Pacific Northwest, initiated in 2004, was also updated with work continuing on this project.

The SWWRC Director traveled to Israel and Jordan to coordinate and participate in a needs assessment report identifying multilateral educating and training opportunities for professional staff in the Israeli, Jordanian and Palestinian water sectors. The Director also began planning for a project involving revitalizing agriculture in Iraq through a multi-university partnership and the WSU International Programs office.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	0	1	0	0	1
Ph.D.	2	1	0	0	3
Post-Doc.	0	0	0	0	0
Total	4	2	0	0	6

Notable Awards and Achievements

A project funded through the USGS/Water Institute partnership reported last year from our local USGS office in Tacoma to assist in developing a Preliminary Numerical Flow Model Development for the Spokane Valley-Rathdrum Prairie Aquifer led to a significant grant to both the USGS and the State of Washington Water Research Center from the USEPA.

Due in large part to the information transfer activities, the SWWRC Director was invited to serve on the State of Washington’s Reclaimed Water Use Rule Advisory Committee.

Publications from Prior Projects

1. 2005WA115B ("Using Stable Isotopes to Trace Nitrate Sources and Surface Water-Groundwater Interactions in the Upper Yakima River Drainage") - Water Resources Research Institute Reports - Gazis, Carey A., 2006, Using Stable Isotopes to Trace Nitrate Sources and Surface Water-Groundwater Interactions in the Upper Yakima River Drainage, State of Washington Water Research Center, Washington State University, Pullman, Washington, Water Research Center Report WRR-25, 13 pages.
2. 2005WA116B ("Removal of the Human Pathogen Giardia intestinales from Ground Water") - Dissertations - Rust, Colleen Frances, 2006, Removal of the Human Pathogen Giardia intestinales from Groundwater, MS Thesis, Geology, Washington State University, Pullman, Washington. 134 p.
3. 2005WA116B ("Removal of the Human Pathogen Giardia intestinales from Ground Water") - Water Resources Research Institute Reports - Rust, Colleen Frances, 2006, Removal of the Human Pathogen Giardia intestinales from Groundwater. State of Washington Water Research Center, Washington State University, Pullman, Washington, Water Research Center Report WRR-26, 134 p.
4. 2002WA19G ("Using environmental tracers to improve prediction of nonpoint pollutant loadings from fields to streams at multiple watershed scales") - Water Resources Research Institute Reports - Keller, C. Kent, Richelle M. Allen-King, and Shulin Chen, 2006, Using Environmental Tracers to Improve Prediction of Nonpoint Pollutant Loadings from Fields to Streams at Multiple Watershed Scales, State of Washington Water Research Center, Washington State University, Pullman,

Washington, Water Research Center Report No. WRR-20, 61 pp.