7th Washington Hydrogeology Symposium

Program

April 28 - 30, 2009

The Greater Tacoma Convention & Trade Center

Organized by: Washington State Department of Ecology; USGS science for a changing world

http://www.ecy.wa.gov/events/hg

7th Washington
Hydrogeology Symposium

GENERAL SCHEDULE

DATE	ACTIVITY
Sunday, April 26	**Field Trip 1 (Day 1):** Hydrogeology of Beer and Wine in the Yakima Valley
Monday, April 27	**Field Trip 1 (Day 2):** ~~Hydrogeology of Beer and Wine in the Yakima Valley~~ (Canceled) **Field Trip 2:** Hydrogeologic Implications of Removing Elwha River Dams
Tuesday, April 28	**1st Day of Symposium:** All Day Talks, Lunch Provided **Afternoon Poster & Exhibitor Session** **Evening Reception**
Wednesday, April 29	**2nd Day of Symposium:** All Day Talks, Lunch Provided **Morning Workshop:** (1) Ecology's Environmental Information Management (EIM) Database **Afternoon Panels:** (1) Are Critical Areas Ordinances Protecting Water Supplies? (2) Professional Licensure **Field Trip 3:** Coastal Cliff Geology Dinner Cruise
Thursday, April 30	**3rd Day of Symposium:** Half Day Talks **All Day Workshop:** (5) Well Driller Session **Afternoon Workshops:** (2) HOC Sorption; (3) Subsurface Heterogeneity; (4) Ground-Water Recharge **Field Trip 4:** ~~Fiber Optic Distributed Temperature Sensing~~ (Canceled) **Field Trip 5** (Day 1): Hydrogeology of the San Juan Islands
Friday, May 1	**Field Trip 5** (Day 2): Hydrogeology of the San Juan Islands

7th Washington
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Welcome!

Welcome to the 7th Washington Hydrogeology Symposium! Our venue at the Greater Tacoma Convention and Trade Center in Tacoma, Washington, offers an upscale meeting place surrounded by beautiful mountain and water views and a wide variety of dining, shopping, and museum-going opportunities.

We have assembled a program of 60 talks and 22 poster presentations this year, including such topics as *Geochemistry and Contaminant Mobility, Water Rights Mitigation,* and *Ground and Surface Water Interactions.* We have exciting field trips, ranging from the *Hydrogeologic Implications of Removing the Elwha River Dams* to *Hydrogeology of the San Juan Islands*. Five workshops will be presented, including *Subsurface Heterogeneity* and a *Well Driller Session* good for continuing education credits. We also have two panels this year that will discuss *Critical Areas Ordinances* and *Professional Licensure*.

At this year's Symposium, opening remarks will be provided by Jay Manning, Director of the Washington State Department of Ecology. Keynote speakers will include Dr. Richelle Allen-King, State University of New York at Buffalo, a leader in the study of geochemical processes on the fate and transport of contaminants in ground and surface waters; Dr. Ingrid Verstraeten, U.S. Geological Survey, International Water Resources Branch, Reston, Virginia, and Dr. Gary S. Weissmann, University of New Mexico, whose expertise includes detailed geological characterization of subsurface heterogeneity in aquifers and petroleum reservoirs.

Our Exhibitors offer a wide variety of state-of-the-art data collection, analysis, and reporting solutions and highlights of important programs and services. Our Sponsors deserve a special *Thank You* during these especially difficult economic times. Through their generosity, our sponsorship goals were exceeded and the Symposium continues to be able to offer this meeting at a very affordable price. Please join us in thanking our Sponsors listed on the back cover of the Program.

The Symposium provides a unique opportunity to connect with other professional hydrogeologists, geologists, and hydrologists from throughout the Pacific Northwest. On behalf of the 7th Washington Hydrogeology Symposium Steering Committee and myself, *Welcome!* We hope that you will have a productive and enjoyable few days at the Symposium and that you will make plans to join us again in 2011.

Best Regards,

Sue Kahle, LHG

2009 Symposium Chair
U.S. Geological Survey, Tacoma, WA

Left to right: (Top row) Laura Klasner, Sandra Caldwell, Bryony Stasney, Ken Johnson, Christopher Gellasch, Laurie Morgan, Alex K. (Sandy) Williamson; (Bottom row) Christopher Brown, Donna Freier, Sue Kahle, Mark Freshley, Marcia Knadle, John Pearch.

7th Washington Hydrogeology Symposium Steering Committee

Sue Kahle	– U.S. Geological Survey, Chair
Mark Freshley	– Pacific Northwest National Laboratory, Vice Chair
Brian Drost	– U.S. Geological Survey (retired), Treasurer
Donna Freier	– City of Olympia, Secretary
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Bryony Stasney	– Golder Associates Inc., Officer at Large
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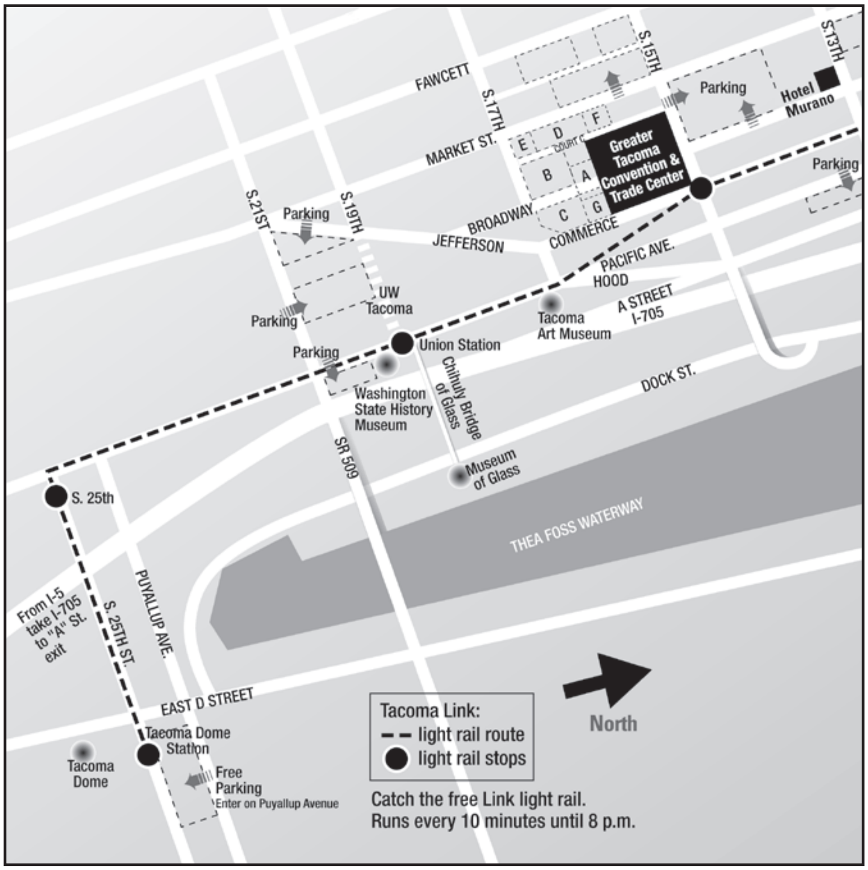
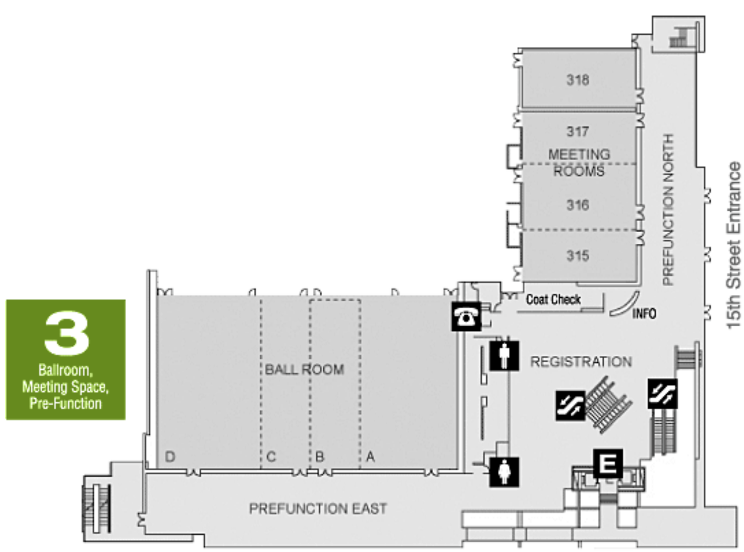
Christopher Brown	– Pacific Northwest National Laboratory, Poster Session, Student Coordinator
Heidi Bullock	– Landau Associates Inc., Committee at Large
Sandra Caldwell	– Washington Department of Ecology, Panel Coordinator
Christopher Curran	– U.S. Geological Survey, Field Trip Coordinator
Christopher Gellasch	– U.S. Army, Workshop Coordinator
Ken Johnson	– U.S. Geological Survey, Committee at Large
Laura Klasner	– Washington Department of Ecology, Panel Coordinator
Marcia Knadle	– U.S. Environmental Protection Agency
Bob Miller	– Robert D. Miller Consulting, Inc., Well Driller Session Coordinator
Robert Mitchell	– Western Washington University, Committee at Large
Christine Neumiller	– Washington Department of Ecology, Webmaster
John Pearch	– Washington Department of Ecology, Field Trip Coordinator
Charles San Juan	– Washington Department of Ecology, Committee at Large, 2007 Chair
Jason Shira	– Washington Department of Ecology, Committee at Large
Joy Thompson	– Washington State University, Event Coordinator
Gary Walvatne	– Hahn and Associates Inc., Committee at Large
Sandy Williamson	– U.S. Geological Survey, Committee at Large, 2003 Chair

The Greater Tacoma Convention & Trade Center

The Greater Tacoma Convention & Trade Center is at 1500 Broadway, Tacoma, WA 98402. Directions are available online at *http://www.tacomaconventioncenter.com/plan_directions.html* or by phone at *(253) 830-6601*.





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PROGRAM SCHEDULE

	TUESDAY APRIL 28, 2009 - REGISTRATION 7:30 AM		
8:30 AM	Welcome: Sue Kahle, Chair, 2009 Hydrogeology Symposium, U.S. Geological Survey (Ballroom A & B)		
8:45 AM	Opening Remarks: Jay Manning, Director, Washington State Dept. of Ecology (Ballroom A & B)		
9:00 AM	Keynote 1: Dr. Richelle M. Allen-King – From Grains to Aquifers – Building a Geologic Framework for Organic Contaminant Transport in Sediments (Ballroom A & B)		
10:00 AM	**Break**		
10:30 AM	1A: GENERAL HYDROGEOLOGY (RM 316)	1B: GEOCHEMISTRY AND CONTAMINANT MOBILITY (RM 317)	
SESSION 1	**The Conceptual Site Model: Simple in Concept, Complex in Application:** *Joe Caggiano, WA Dept. of Ecology* **Testing at the Hanford Site 300 Area Integrated Field Challenge, Washington:** *Mark Freshley, Pacific NW Nat'l Lab-PNNL* **Hydrology, Scientists, and Water Infrastructure in Pakistan and Afghanistan:** *Alex (Sandy) Williamson, U.S. Geological Survey* **Evaluation of Groundwater Quality at U.S. and Coalition Forces Bases in Afghanistan:** *Chris Gellasch, U.S. Army*	**Environmental Isotopes and Age Tracers in the Columbia Basin Groundwater Management Area (GWMA), Washington:** *Dimitri Vlassopoulos, Papadopulos and Assoc.* **Stable Isotope Hydrogeology in the Palouse Basin, Southeastern Washington: Utility of an Environmental Tracer in Studies of Recharge, Contamination, and Global Change:** *Kent Keller, Washington State University* **Different Uranium Phases on Contaminated Sediments:** *Wooyong Um, Pacific NW Nat'l Lab-PNNL* **Uranium Contamination in the 300 Area: Emergent Data and Their Impact on the Source Term Conceptual Model:** *Chris Brown, Pacific NW Nat'l Lab-PNNL*	
12:00 PM	LUNCH and Keynote 2: Dr. Ingrid Verstraeten – USGS Capacity Building Efforts in Water Resources in the Developing World – Issues and Challenges (Ballroom A & B)		
1:30 PM	2A: WATER QUALITY I (RM 316)	2B: WATER RIGHTS MITIGATION I (RM 317)	
SESSION 2	**Distribution and Seasonal Trends of Nitrate in Unconfined Aquifers of the Pasco and Quincy Basins, Washington:** *Jessica Goin, Papadopulos and Assoc.* **Arsenic in the Chamokane Valley Aquifers:** *Bryony Stasney, Golder Associates Inc.* **Predicting Pesticide Concentrations in Shallow Ground Water Across the United States Using a Process-Based Model Linked to a Geographic Information System:** *Frank Voss, U.S. Geological Survey*	**Water Rights and Mitigation in Washington:** *Tom Culhane, WA Dept. of Ecology* **The Changing Face of Practical Mitigation: How Case Law and New Technical Approaches Continue to Move the Bar:** *Jill Van Hulle, Pacific Groundwater Group* **Model Prediction of Diffuse Impacts to Multiple Streams on the Dungeness Peninsula: A Basin-Scale Perspective in Mitigation Strategy:** *Peter Schwartzman, Pacific Groundwater Group*	
2:30 PM	**Break**		
3:00 PM	3A: WATER QUALITY II (RM 316)	3B: WATER RIGHTS MITIGATION II (RM 317)	
SESSION 3	**Out of Site, But on Our Minds….How to Protect Water Quality with Drywell Best Management Practices that Work:** *Daniel Scarpine, Aquarius Environmental* **Wastewater Land Treatment Systems in the Columbia Basin Irrigation Project – Regulatory Requirements to Protect the Ground Water:** *Don Nichols, WA Dept. of Ecology* **Meeting Water Demands and Controlling Saltwater Intrusion in Southern California:** *Bill Mann, In-Situ Inc.*	**Habitat-Based Mitigations to Baseflow Impacts: Two Case Studies:** *Linton Wildrick, Pacific Groundwater Group* **Model Prediction of Streamflow Capture and a Habitat Based Mitigation Approach for Baseflow Impacts: City of Camas:** *Dan Matlock, Pacific Groundwater Group* **Streamflow Augmentation for Water Rights Mitigation at the Buckhorn Mountain Gold Mine in Northeast Washington:** *Jay Pietraszek, Golder Associates Inc.*	
4:00 – 7:00 PM	Exhibitors Reception & Poster Session –Authors Present (Prefunction North & Registration) Evening Function –Reception/Hearty Appetizers (Prefunction East)		

PROGRAM SCHEDULE—CONTINUED

WEDNESDAY APRIL 29, 2009 - REGISTRATION 7:30 AM			
8:30 AM	**Keynote 3: Dr. Gary Weissmann – The Influence of Heterogeneity at Multiple Scales on Groundwater Flow and Dispersion Character (Ballroom A & B)**		
9:30 AM	**Break**		
10:00 AM	**4A: HYDROGEOLOGY – ENGINEERING GEOLOGY (RM 316)**	**4B: VADOSE ZONE AND GROUNDWATER CHARACTERIZATION (RM 317)**	**4C: WORKSHOP 1 - ECOLOGY'S ENVIRONMENTAL INFORMATION MANAGEMENT (EIM) DATABASE (RM 318)**
SESSION 4	**Hydrogeology of the Brightwater Conveyance Project, King and Snohomish Counties, Washington:** *David McCormack, Aspect Consulting* **Groundwater Monitoring Program for the Brightwater Conveyance System Project:** *Howard Young, Camp Dresser & McKee Inc.* **Hydrogeology of the Cascadia Sewer Bore Alignment, Pierce County, Washington:** *Curtis Koger, Associated Earth Sciences, Inc.* **Hydrogeologic Controls and Impacts of Quaternary Landslides Along the White Bluffs of the Columbia River, South-Central Washington:** *Bruce Bjornstad, Pacific NW Nat'l Lab-PNNL*	**200 East Area Increases in Groundwater Contamination at the Hanford Site, Washington, since 1992:** *Stan Sobczyk, Nez Perce Tribe* **Surface Geophysical Exploration at Selected Tank Farm Areas at the U.S. Department of Energy Hanford Site, near Richland, Washington:** *Dale Rucker, hydroGEOPHYSICS, Inc.* **Application of a Wet/Wet Differential Pressure Sensor for Vertical Hydraulic Gradient Measurement:** *Brad Fritz, Pacific NW Nat'l Lab-PNNL* **Southeastern Idaho Water Delivery Calls: Real-Time Water Administration in a Large Interconnected Arid River Basin:** *John Koreny, HDR, Inc., Substitute Paper*	This session will include a demonstration and Q&A session on how to get data from Ecology's Environmental Information Management (EIM) database. EIM is Ecology's main database for environmental monitoring data, containing over 6 million records on physical, chemical, and biological analyses and measurements. We will cover the standard Database Search as well as the newer custom search and analytical tool, MyEIM. *Christine Neumiller, WA Dept. of Ecology*
11:30 AM	**Lunch (provided): No Speakers**		
1:00 PM	**5A: GROUND- AND SURFACE-WATER INTERACTIONS - MARINE (RM 316)**	**5B: VADOSE ZONE AND GROUNDWATER REMEDIATION (RM 317)**	**5C: PANEL 1 - ARE CRITICAL AREAS ORDINANCES PROTECTING WATER SUPPLIES? (RM 318)**
SESSION 5	**Ground Water Sources and Impacts in Lynch Cove, Hood Canal, Washington:** *Ed Josberger, U.S. Geological Survey* **Submarine Ground-Water Discharge of Mercury to Sinclair Inlet, Puget Sound from the Bremerton Naval Complex, Washington, USA:** *Tony Paulson, U.S. Geological Survey* **Analysis of Pumping Test Data from a Tidally Influenced Aquifer:** *Roy Jensen, Hart Crowser, Inc.* **Recent Temperature Surveys for Locating Ground-Water Discharge in River, Estuary and Nearshore Environments of Western Washington Using Fiber-Optic Cable:** *Chris Curran, U.S. Geological Survey*	**Combined Effect of Anthropogenic Hydrological Alterations and Complex Hydrogeology on a TCE Plume:** *Ken Reid, Landau Assoc.* **Vadose Zone Monitoring of the T-Tank Farm Interim Surface Barrier:** *Fred Zhang, Pacific NW Nat'l Lab-PNNL* **Dissolution and Precipitation of Hanford Soil and Fe-Rich Micas During Contact with Tank Waste Leachates and their Bearing on Aqueous Tc(VII) Attenuation:** *Jonathan Icenhower, Pacific NW Nat'l Lab-PNNL* **Use of Large-Scale Aquifer Dye Tracer Test for Design of In-Situ Bioremediation through Vegetable Oil Injection:** *Clint Jacob, Landau Assoc.*	This panel will discuss lessons learned since the Growth Management Act was put in place and local jurisdictions started applying ordinances to regulate new development. The discussion will also look forward to how we could improve groundwater pollution prevention efforts to protect drinking water sources. The panel is being designed to include local planners and regulators, land developers, hydrogeologists, a citizen group representative and representatives of the Washington State Departments of Ecology, Health and Community Trade and Economic Development.
2:30 PM	**Break**		
3:00 PM	**6A: GROUND- AND SURFACE-WATER INTERACTIONS - RIVERINE (RM 316)**	**6B: ENVIRONMENTAL REMEDIATION (RM 317)**	**6C: PANEL 2 - PROFESSIONAL LICENSURE (RM 318)**
SESSION 6	**A Historical Perspective on Riverbank Spring Discharges from the Hanford Site to the Columbia River:** *Gregory Patton, Pacific NW Nat'l Lab-PNNL* **Contaminant Concentration Variability in a Dynamic Hydrologic Setting: Implications for Monitoring:** *Bob Peterson, Pacific NW Nat'l Lab-PNNL* **Evaluation of Lateral and Vertical Temperature Trends in a Shallow Unconfined Aquifer Adjacent to the Columbia River, Chelan County, Washington:** *Jim Hay, Robinson, Noble and Saltbush* **Influence of the Hyporheic Zone on Supersaturated Gas Exposure to Incubating Chum Salmon:** *Evan Arntzen, Pacific NW Nat'l Lab-PNNL*	**Blending Remediation Technologies Accelerates Defensible Site Closure:** *Craig Dockter, Hart Crowser, Inc.* **What Can Bio Do for You?:** *Benni Jonsson, Landau Assoc.* **Combined Emulsified Oil-pH Buffer for ERD in Acidic Aquifers:** *Gary Birk, EOS Environmental, Inc.* **Remediation of Rapidly Moving LNAPL in Bedrock under Emergency Conditions near Crystal Mountain, Washington:** *Rob Leet, GeoEngineers, Inc.*	The Department of Licensing will provide a half-hour talk on how to obtain professional licensure as a geologist-in-training, geologist, hydrogeologist or engineering geologist. Following this talk a panel discussion will provide perspective on licensing questions and issues. Panelists from the academic, consulting and regulatory fields have been invited.

Program Schedule—Continued

WEDNESDAY APRIL 29, 2009 - CONTINUED			
4:30 PM	**Break**		
5:30 PM	**Field Trip 3 - Coastal Cliff Geology Dinner Cruise**		
THURSDAY APRIL 30, 2009 - REGISTRATION 8:00 AM			
8:30 AM	**7A: DATA MANAGEMENT (RM 316)**	**7B: CLIMATE CHANGE (RM317)**	**WORKSHOP 5 - WELL DRILLER SESSION (8:00 AM - 4:00 PM) (RM 318)**
SESSION 7	**Integrating Water Right, Well Log and Water System Databases through GIS for Island County and the Department of Ecology:** *Robert Smith, GeoEngineers, Inc.* **Using "High-Definition" Geographical Information System Datasets in Development of Ground-Water Flow Models:** *Ken Johnson, U.S. Geological Survey* **Data and Information Management to Support Remedial Decisions:** *George Last, Pacific NW Nat'l Lab-PNNL* **Workflow Automation in Environmental Data Management:** *Sarah Wright, Earthsoft, Inc.*	**Approaches for Assessing Ground-Water Availability under Competing Demands and Climate Change:** *Matt Bachmann, U.S. Geological Survey* **Simulated Hydrologic Response of a Large Mesoscale Basin to Climatic and Physiographic Variability, and Relation to Atmospheric Indices:** *John Vaccaro, U.S. Geological Survey* **Sequim Hydrologic System Overview: Observed Trends and a Glimpse into the Future:** *Glen Wallace, Pacific Groundwater Group* **Where Is the Rain-on-Snow Zone in the West–Central Washington Cascades? Monte Carlo Simulation of Large Storms in the Northwest:** *Matt Brunengo, Portland State University*	For the first time offered anywhere, this session will provide 2.0 hours of continuing education units (CEUs) for Washington rules and 2.0 hours of continuing education credits (CECs) for Oregon rules. Each of these presentations will briefly discuss the state-specific laws governing the drilling of geotechnical holes, water wells and monitor wells, including notices and reporting requirements for drillers, geologists and engineers. The session will also offer general continuing education related to the design and installation of low-cost groundwater sparging and soil vapor extraction systems, an off-site sonic drilling demonstration, and other presentations to be determined. **($35.00 with Symposium Registration, $100.00 Workshop Only Registration)**
10:00 AM	**Break**		
10:15 AM	**8A: GROUNDWATER MODELING (RM316)**	**8B: GROUNDWATER SUPPLY (RM317)**	**WORKSHOP 5 - WELL DRILLER SESSION - CONTINUED**
SESSION 8	**An Updated Hydrogeological Conceptual Model of the Hawks Prairie Area of Thurston County:** *Eric Weber, Landau Assoc.* **Design Constraints on an Open Loop Ground Source Heat Pump System in Southeastern Washington:** *Vicky Freedman, Pacific NW Nat'l Lab-PNNL* **A Geochemical Reactive Transport Model of Arsenic and Trihalomethanes in Aquifer Storage Recovery Systems:** *Brad Bessinger, Papadopulos and Assoc.* **Numerical Analysis of Groundwater Using Advanced Real-Time Imaging:** *John Lambie, Aquifer Resources Management*	**Groundwater Information Management and Data Visualization for Enhanced Aquifer Utilization in Water Supply:** *John Dustman, Aquifer Resources Management* **Watershed Studies: Managing Water Resources for Sustainability on Vashon-Maury Island:** *Eric Ferguson, King Co.* **Protecting and Managing the Wildcat Creek Aquifer:** *Laurie Morgan, WA Dept. of Ecology* **Ground-Water Availability for the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho:** *Rick Dinicola, U.S. Geological Survey*	**Off-Site** **Afternnon Drilling Demonstration**
11:45 AM	**Door Prize Drawing and Closing Remarks (Registration)**		
END OF SYMPOSIUM			
THURSDAY AFTERNOON - FRIDAY, APRIL 30 - MAY 1, 2009			
Workshops 2, 3, & 4 and Field Trip 5 (Departs at Noon)			
1:30 PM - 4:30 PM	**WORKSHOP 2 (RM 316)**	**WORKSHOP 3 (RM 317)**	**WORKSHOP 4 (RM 318)**
WORK-SHOPS	**Nonlinear HOC Sorption: Why It Is Important, Why We Usually Ignore It, and What to Do About It:** *Dr. Richelle M. Allen-King, , University at Buffalo (SUNY)*	**Subsurface Heterogeneity: Why It Is Important, Why We Usually Ignore It, and What to Do About It:** *Dr. Gary Weissmann, University of New Mexico*	**Methods for Estimating Ground-Water Recharge:** *Richard W. Healy, U.S. Geological Survey*

Dr. Richelle M. Allen-King[1]

Department of Geology, University at Buffalo (SUNY)

From Grains to Aquifers – Building a Geologic Framework for Organic Contaminant Transport in Sediments

It has been known for nearly three decades that organic contaminant retardation is caused by interaction with organic carbon or carbonaceous matter (CM), quantified as the fraction organic carbon (f_{oc}) content. What is not as well recognized or applied in practice is the impact that the type of CM can have on transport - especially important in low f_{oc} aquifers. Common in sediments deposited since the late Devonian, condensed forms of CM can exhibit K_{oc}s (=K_d/f_{oc} where K_d is the sorption distribution coefficient at a particular contaminant concentration) that are 10 to 100 times greater than the 'literature' or 'reference' values. These 'excess' K_{oc}s result from adsorption interactions between the contaminants and condensed CM that also cause nonlinear (e.g concentration dependent) and competitive sorption among similarly structured organic contaminant co-solutes.

This presentation will discuss how a geologic framework can inform models of the transport properties of sedimentary aquifers (from the grain to the aquifer scale) and provide the basis for contaminant transport simulation. The source rocks, environment, and post depositional processes all play important roles in controlling the types of CM deposited and retained within sedimentary aquifers. At the 'within aquifer' scale – we demonstrate a lithofacies approach to describe and model the spatial distribution of reactive transport properties. Contrasts between field sites in different regions exemplify differing behaviors towards organic contaminants that are related to source materials and post depositional processes through understanding the type of CM and geology. Practical examples of the effects of 'excess' sorption on contaminant mass storage, transport, and remediation, will be presented.

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[1] Dr. Richelle Allen-King is Professor and Chair of the Department of Geology at University at Buffalo (SUNY). She received her Ph.D. from the Department of Earth Sciences, University of Waterloo and B.A. from the Department of Chemistry at the University of California, San Diego. Her research focuses on the geochemical processes that control the fate and transport of contaminants in ground and surface waters. She was selected as the National Ground Water Associations Henry Darcy Distinguished Lecturer for 2003 and in that role presented her research at more than 60 national and international venues. She has served on groundwater remediation and aquifer storage committees for the National Research Council as well as serving two terms as a member of their Water Science and Technology Board. She has also served as Associate Editor for the Water Resources Research and is currently serving in this role for Ground Water. Recent funding for her research has been received from the National Science Foundation, the National Institutes for Water Research, and the Department of Energy.

Dr. Ingrid Verstraeten[1]

U.S. Geological Survey International Water Resources Branch, Reston, Virginia

USGS Capacity Building Efforts in Water Resources in the Developing World- Issues and Challenges

Access to adequate and safe supplies of water of poor people is a major problem in developing countries, affecting health, food supply, and security. A growing world population has increased the demand for water, while water resources remain limited. Currently, millions of people in developing countries are lacking a potable water supply and the scientific information needed to assess and manage their water resources. To remediate these conditions, a sound monitoring infrastructure and management strategy are needed to assess, understand, and manage water resources. The development of famine early warning systems have inspired the innovative use of remote sensing, numerical modeling, geographic information systems, and decision support systems for enhancing water-resources assessments and management. Generally, in order for these remedial measures to be successful the capacity of the local citizens, managers, and government entities needs to be significantly increased. These efforts mostly focus on higher education, including institutional capacity-building and networking, education for research at the postgraduate level, continuing professional education, and to activities targeting the training of trainers.

As part of its international mission, the U.S. Geological Survey (USGS) engages in numerous partnership efforts to improve the understanding and wise management of water resources throughout the world. Recently, the USGS has cooperated with local, regional, and national agencies and non-governmental organizations (NGO's) using variable approaches depending on country and agency or NGO needs/mission. Most recently, the USGS has been active in Afghanistan, Pakistan, Jordan, United Arab Emirates, Sudan, Ethiopia, Madagascar, Cape Verde, Mozambique, and Ecuador.

[1]Dr. Verstraeten is a Senior Physical Scientist/Hydrologist with the USGS International Water Resources Branch working on issues pertaining to the UN and UNESCO, providing technical assistance to Department of State on policy regarding water resources, serving as advisor and liaison with the Millennium Challenge Corporation, and managing and coordinating water resources projects in the Middle East, Africa, and Asia funded by USGS or the World Bank. In this capacity, she develops, and manages international water/natural resources programs. Activities include (1) project management, (2) technical assistance, (3) scientific and technical exchange, and (4) participation in committees, programs, and symposia of international commissions, treaty organizations, and United Nations (U.N.) specialized agencies. Assistance is bilateral or multilateral designed to assist recipient countries in achieving an independent capability for water resources investigations and management through growth and development of counterpart institutions. It also consists of short-term assistance such as workshops, study tours and exchanges of scientists.

Dr. Gary Weissmann[1]

Black Family Professor of Hydrology,
Department of Earth & Planetary Sciences,
University of New Mexico.

The Influence of Heterogeneity at Multiple Scales on Groundwater Flow and Dispersion Character

In sedimentary aquifers, groundwater flow velocities are strongly influenced by the heterogeneity of lithofacies present in the system. The variable velocity field results in a non-Fickian (or non-Gaussian) dispersion character, contrary to dispersion distributions commonly used in current groundwater models. This dispersion character appears to occur at all scales – from pore-scale to regional-scale – and may be reasonably captured by a power law distribution. Models that reasonably reflect the geologic heterogeneity have the potential to help resolve statistical distributions and possible dispersion parameters that may capture this velocity variability. At the small-scale (meter-scale), we use terrestrial lidar to develop lithofacies maps of outcrop analogs, producing models that show significant groundwater focusing into high-conductivity zones. At larger scales (plume to regional scales), we applied transition probability geostatistics to represent the heterogeneity. Transport simulations through all of these models show the non-Fickian character. These results show the importance of capturing aquifer heterogeneity in order to reasonably represent groundwater flow systems for both contaminant transport and water supply models, and they also indicate directions of focus for future studies.

[1]Dr. Gary Weissmann is an Associate Professor and the Black Family Professor of Hydrology in the Department of Earth and Planetary Sciences at the University of New Mexico. He received his PhD in Hydrologic Sciences from the University of California at Davis, and both his MS and BA in Geology from the University of Colorado at Boulder. He has about two decades of professional experience in petroleum geology and hydrogeology in addition to his academic experience. Dr. Weissmann's research focuses on sedimentologic and stratigraphic characterization of aquifer systems and on interpreting fluvial deposits in the rock record. He is currently an associate editor for the journals Ground Water and Environmental Geology. Recent funding for his research has been received from the Department of Energy and the National Science Foundation.

Oral Abstracts

The Conceptual Site Model; Simple in Concept, Complex in Application

Joseph A. Caggiano[1]

A conceptual model can be envisioned as picture of a waste site that includes sources, pathways, contaminants and receptors. When uncertainty exists in input parameters, numerous conceptual models may be needed to capture the variability and uncertainty in model inputs that need investigation. With new input data, conceptual models may be refined or discarded to converge on a waste site representation needed to develop an improved numerical model to simulate flow, transport, compare remedial alternatives and possibly predict risk. Any simulation is only as good as the conceptual model, the input data, and the values chosen for input parameters.

In a perfect world, all input parameters are known. Because of uncertainty, assumptions, estimates and approximations of waste type and volume, media and flow paths are used in a conceptual model. The ensuing numerical model establishes simplifying assumptions, conventions and boundaries to enable the simulation. When input parameter values differ from reality, any numerical model and predictions of flow, transport and risk are oversimplified, not representative and of limited use. Project needs affect the scale of both conceptual and numerical models.

Conceptual models of waste sites in the Central Plateau at the U.S. Department of Energy's Hanford Site illustrate the complexity of both the conceptual and numerical modeling process. Waste stream compositions and concentrations changed with time, site stratigraphy is physically and chemically heterogeneous and highly variable at several scales, and groundwater flow in the unconfined aquifer changed with time because of liquid waste discharges. Waste infiltrating through a heterogeneous stratigraphy changed composition as constituents were removed by reaction with sediment. Waste volumes and compositions were altered by spills and leaks from infrastructure. Numerical models used to predict future flow and transport should replicate past waste releases and transport through the vadose zone to groundwater and should change to incorporate revised input data.

[1] *Washington State Department of Ecology, Nuclear Waste Program, 3100 Port of Benton Boulevard, Richland, WA 99354; Telephone: (509) 372-7915; E-mail jcag461@ecy.wa.gov*

Testing at the Hanford Site 300 Area Integrated Field Challenge, Washington

*John M. Zachara[1], **Mark D. Freshley[2]**, Vincent R. Vermeul[3], Brad G. Fritz[4], Rob D. Mackley[5], James P. McKinley[6], Mark L. Rockhold[7], and Anderson L. Ward[8]*

The U.S. Department of Energy Office of Science, Environmental Remediation Sciences Division is supporting an Integrated Field Challenge Research Site at Hanford's 300 Area. The site is located within the footprint of a waste-disposal pond that received past discharges of uranium-containing liquid effluent and has since been decommissioned by excavating contaminated sediments. Despite these actions, a uranium plume has persisted in the groundwater adjacent to the Columbia River. The persistence of the plume is postulated to result from a complex relationship between hydrological, geochemical, and microbial processes as well as rate-limited mass transfer in highly heterogeneous sediments. The research site has now been established, consisting of 35 wells at 10-m spacing. Detailed field characterization studies are underway, including hydraulic and tracer testing. The hydraulic gradient at the site is relatively flat, and measured hydraulic permeability is high. The flow field in the well network was characterized with an injection test consisting of water and sodium bromide tracer. The tracer test was monitored with 1) water sampling and an array of conductivity, pH, bromide, pressure, and temperature electrodes installed within the well screens and 2) an array of electrical resistivity sensors. The results of the initial tracer test and other planned field tests in combination with detailed laboratory characterization will be used to develop parameters for modeling the processes controlling the persistence of the uranium plume.

Pacific Northwest National Laboratory, MSIN K9-33, P.O. Box 999, Richland, WA 99352; Fax: (509) 372-6089
[1] *Telephone: (509) 371-6355; E-mail : john.zachara@pnl.gov*
[2] *Telephone: (509) 372-6094; E-mail: mark.freshley@pnl.gov (presentor)*
[3] *Telephone: (509) 371-7170; E-mail: vince.vermeul@pnl.gov*
[4] *Telephone: (509) 371-7119; E-mail: Bradley.Fritz@pnl.gov*
[5] *Telephone: (509) 371-7178; E-mail: rob.mackley@pnl.gov*
[6] *Telephone: (509) 371-6386; E-mail: james.mckinley@pnl.gov*
[7] *Telephone: (509) 375-2516; E-mail: Mark.Rockhold@pnl.gov*
[8] *Telephone: (509) 372-4417; E-mail: andy.ward@pnl.gov*

Hydrology, Scientists, and Water Infrastructure in Pakistan, and Afghanistan

Alex K. (Sandy) Williamson[1]

In October 2007, I went to Pakistan and in June 2008, I went to Afghanistan for the USGS. I am working on a U.S. State Department funded project to help develop water databases, a data warehouse, and a national data standards committee in Pakistan. I went to Afghanistan to teach part of a water-resources course to about 30 professionals, focusing on data storage, GPS usage, and Google Maps & Earth.

The Hydrology, Science, and Water Resources infrastructure, both physical and organizational in these two countries are quite different from what we are familiar with in the United States. The physiography, land use, and hydrology of Pakistan and Afghanistan are similar to California and Nevada, respectively. Pakistan is the *sixth most populous country* in the world. Pakistan's largest city is Karachi, with 16 million people living in around the city, making it the world's second largest city proper behind Mumbai, India. The Indus River system has several reservoirs larger than Lake Roosevelt behind Grand Coulee Dam. The Indus River valley is largely irrigated and has several canals on the same scale as large canals in California. The most severe known water-quality problems are high concentrations of bacteria, nutrients, and arsenic. The Pakistan Ministry of Health estimates that 600 children younger than 5 years old die every day due to bacterial contamination and that most of these deaths likely are water-quality related. Many city water systems are not pressurized 24 hours a day and water is not chlorinated; therefore, the public water supply is susceptible to contamination. Pakistan's Water and Power agency employs 150,000 people and delivers power to most citizens in the country. Other government water-related agencies are relatively small.

Afghanistan's capital city, Kabul, is a city of 4 million people. During our visit, we met with officials in well-guarded government buildings during the day, but for safety, stayed on U.S. Embassy grounds at night. No local bus service is available in Kabul. Drinking water comes from hand pumped wells on many main city streets. Each well is about 4-6 blocks apart. The water quality problems in Kabul are similar to those in Pakistan, but maybe less severe. Electric Hydropower is not available 24 hours a day (nor year round). The government does not charge individuals for electricity usage. Most nights the city is quite dark with lights seen only from properties with generators. The many small generators contribute to very poor air quality.

Scientists in both countries were eager for our help and eager to learn. I am looking forward to future trips there and helping the Pakistanis develop a national water data base for many of their government agencies.

[1] *U.S. Geological Survey, NAWQA National Data Base Team Leader, 934 Broadway, Suite 300, Tacoma, WA 98402; Telephone: (253) 552-1683; E-mail:akwill@usgs.gov Fax: (253) 552-1581*

Evaluation of Groundwater Quality at U.S. and Coalition Forces Bases in Afghanistan

Major Christopher A. Gellasch, P.G.[1]

Groundwater is the primary source of non-drinking water at numerous military bases utilized by both U.S. and Coalition Forces in Afghanistan. Most of these bases are located in mountainous terrain with limited access to surface water sources. Typically, the wells penetrate unconsolidated alluvium and provide adequate quantities of water.

During a deployment to Afghanistan from April 2005 to April 2006 the author conducted a study to evaluate the groundwater wells in use at several bases. Site surveys were the primary means of investigation supplemented by well sampling data dating back to 2002. Results of water sampling were utilized to determine any potential health risks from exposure to untreated well water. Naturally occurring minerals were the most likely cause of wells exceeding military water quality standards, but a lack of well head protection and/or poor well placement were the most common deficiencies observed in base camp wells.

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[1] *U.S. Army Center for Health Promotion and Preventive Medicine – West, Box 339500, MS 115, Fort Lewis, WA 98433, Telephone: (253) 966-0069/0008, Fax: (253) 966-0163, E-mail: Christopher.gellasch@us.army.mil*

Environmental Isotopes and Age Tracers in the Columbia Basin Groundwater Management Area (GWMA), Washington

Dimitri Vlassopoulos[1], Jessica C. Goin[2], Carey Gazis[3] and Vern Johnson[4]

The aquifer system within the 21,000 square kilometer Columbia Basin GWMA ranges from shallow, unconfined sedimentary aquifers to a series of stacked, semi-confined to confined zones within the underlying Columbia River Basalt Group (CRBG). Increased groundwater use for irrigation, urban and domestic supply over the past decades has resulted in static water level declines in the basalt aquifers of more than 50 meters in some parts of GWMA.

Selected irrigation, municipal and private supply wells, and surface water bodies representing potential recharge sources, were sampled and analyzed for a suite of geochemical and isotopic parameters including major and trace element concentrations, stable isotopes (O, H, C), and age tracers (radiocarbon, tritium, CFCs and sulfur hexafluoride) in order to elucidate the origins of the groundwater resource and, in particular, to evaluate recharge relationships in the deeper basalt aquifer system. CFC, SF6, and tritium data indicate relatively young recharge ages (a few years to a few decades) for water samples from shallow sedimentary aquifers. Calculated recharge ages for multiple tracers are discordant in samples from some deeper municipal supply wells which are open over large vertical intervals in basalt, indicating intra-borehole mixing of groundwater from different flow paths ranging in age from recent to several thousand years. Radiocarbon and stable isotope data indicate much of the water sampled by irrigation wells completed in the deeper basalt aquifers is more than 10,000 years old and has not seen significant recharge during the Holocene. However, traces of CFCs and SF6 are also detected in many of these wells and indicate admixture of small amounts (less than 1-2 percent) of a relatively young water component which may be due to cross-formational flow or borehole leakage.

The results of this study show that natural recharge to some of the deeper aquifer zones is presently very limited but was higher in the past. This finding has implications for groundwater availability and renewability and suggests a need for careful management of withdrawals to ensure sustainable use of the groundwater resource.

[1] *S.S.Papadopulos & Associates, 510 SW Third Avenue, Suite 200, Portland, OR 97204; Telephone: (503) 222-6639; E-mail: dimitri@sspa.com*
[2] *S.S.Papadopulos & Associates, 510 SW Third Avenue, Suite 200, Portland, OR 97204; Telephone: (503) 222-6639; E-mail: jgoin@sspa.com*
[3] *Department of Geological Sciences, Central Washington University, 400 E. University Way, Ellensburg, WA 98926-7418; Telephone: (509) 963-2820; Email: cgazis@geology.cwu.edu*
[4] *PO Box 1368, Richland, WA 99352; Telephone: (509) 374-7664; Email: geezer2@msn.com*

Stable Isotope Hydrogeology in the Palouse Basin, Southeastern Washington: Utility of an Environmental Tracer in Studies of Recharge, Contamination, and Global Change

C. Kent Keller[1], Bryan G. Moravec[1,2] and Jeffrey L. Smith[3]

The stable isotopic composition of water carries physical-hydrologic information which can be used to test ideas about how a watershed works. Distributions of the oxygen-18 content of water ($\delta^{18}O$) were monitored in groundwater and in nested agricultural catchments draining 6 – 5700 ha near Pullman, WA. Nearly ten years of $\delta^{18}O$ data revealed very different seasonal dynamics from the strong variations exhibited by nitrate (at levels exceeding the MCL by up to four times) and electrical conductivity. Large seasonal and event-scale variations in precipitation $\delta^{18}O$ could be traced into soil water, but these fluctuations were largely absent from tile drainage and streamflow, which exhibited flow-weighted $\delta^{18}O$ values in a narrow range nearly identical with the isotopic mean of winter precipitation. These patterns showed that conceptual models of streamflow generation developed in other settings are not necessarily applicable to the dynamics observed in this rainfed, winter-precipitation region. Comparisons with the stratified distributions of $\delta^{18}O$ observed in loess- and basalt-hosted groundwaters have implications for understanding recharge mechanisms and long-term climate change. The catchment data may reveal a decadal signal of climate change in the Pacific Northwest.

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[1] *School of Earth and Environmental Sciences, Washington State University, Pullman, WA; E-mail: ckkeller@wsu.edu*
[2] *School of Natural Resources, University of Arizona, Tucson, AZ; E-mail: bgmoravec@yahoo.com*
[3] *Department of Crop and Soil Sciences and USDA/ARS, Washington State University, Pullman, WA, E-mail: jlsmith@wsu.edu*

Different Uranium Phases on Contaminated Sediments

Wooyong Um[1], Christopher F. Brown[2], R. Jeffrey Serne[3],

Zheming Wang[4], and Benjamin D. Williams[5]

Macroscopic and spectroscopic investigations conducted on sediments collected from Hanford's 241-U single-shell tank farm showed that U(VI) existed as different surface phases on sediments as a function of depth. Dominant U(VI) silicate minerals (boltwoodite/uranophane) were found in shallow sediments with high U(VI) concentrations. In intermediate depth sediments, adsorbed phases of U(VI) dominated, but a small amount of precipitated U(VI) was also present. Deep-depth sediments showed the presence of natural uranium and no contact with leaking waste. This natural uranium was relatively resistant to water leaching due to entrapment within the mineral structure.

Most of the U(VI) was preferentially associated with the silt/clay size fraction, especially for the precipitated U(VI) phase(s) on the shallow sediments. In the shallow depth sediments, leaching with (bi)carbonate solution resulted in continuously increasing U(VI) concentrations, which was consistent with increasing dissolved Si concentration. Due to the presence of U(VI) silicate minerals in the shallow sediments, (bi)carbonate leaching resulted in two different U(VI) release rates from both desorption and dissolution. The molecular level studies including micro-XRF, XAFS, and TRLIF showed similar results to those found in macroscopic leaching experiments. U(VI) silicate minerals were evident in shallow depth sediments, however it was not easy to differentiate uranophane from boltwoodite because of their similarity in mineral structure.

Different surface phases of U(VI) on the contaminated sediments in the Hanford tank farm vadose zone indicate that the U(VI) release mechanism is complicated and should be considered to occur through both dissolution and desorption of U(VI) into vadose zone pore water. A more detailed characterization of the sediments should be conducted to provide further information on U(VI) surface phases in order to develop a more accurate U(VI) transport model through the Hanford tank farm vadose zone sediments.

Pacific Northwest National Laboratory, Energy and Environment Directorate, P.O. Box 999, MSIN P7-22, Richland, WA 99352

[1] *Telephone: (509) 376-4627; Fax: 509-376-4890; E-mail: Wooyong.Um@pnl.gov*

[2] *Telephone: (509) 376-8389; Fax: 509-376-4890; E-mail: Christopher.Brown@pnl.gov*

[3] *Telephone: (509) 376-8429; Fax: 509-376-4890; E-mail: jeff.serne@pnl.gov*

[4] *Telephone: (509) 376-6349; Fax: 509-376-6354; E-mail: zheming.wang@pnl.gov*

[5] *Telephone: (509) 376-1655; Fax: 509-376-4890; E-mail: benjamin.williams@pnl.gov*

Uranium Contamination in the 300 Area: Emergent Data and Their Impact on the Source Term Conceptual Model

Christopher F. Brown[1], Wooyong Um[2], and R. Jeffrey Serne[3]

Opportunistic sediment samples collected during a drilling campaign at the Hanford Site in 2007 became available for uranium characterization in 2008. The primary objectives of this characterization activity were to determine the extent of uranium contamination in the sediments and quantify the leachable (labile) concentration of uranium in the sediments. Concentrations of water-extractable uranium were quite dilute in all of the sediments analyzed. It was unexpected that the sediments collected farthest from known 300 Area waste sites contained the greatest concentrations of water-extractable uranium. A similar profile of contaminant uranium was evident in all three of the boreholes studied. At all locations, the peak concentrations of water-extractable uranium were found in the deep vadose zone and capillary fringe.

Batch leach tests focused on determining the concentration of labile uranium in the sediments revealed two primary trends. The first trend involved a rather rapid release of approximately 85% of the uranium from the sediment. The second trend can be characterized as a slow, continual release of uranium from the sediments. The two trends evident in these experiments likely result from two types of uranium being present in the sediments. The readily leachable uranium is likely present as a sorbed species while the more recalcitrant uranium is likely present as discrete uranium-bearing minerals or micro precipitates.

Within the 300 Area, river water influx and mixing with groundwater or pore water in the capillary fringe results in highly dynamic changes in pore water chemistry and is a main mechanism controlling the continuous resupply of dissolved uranium to the existing groundwater plume. Uranium from the contaminated sediments both above and just below the fluctuating water table is slowly entering the 300 Area groundwater system through desorption and/or dissolution processes. In addition, the dissolved uranium can be re-adsorbed to sediments due to decreased carbonate concentrations when the more saline groundwater becomes diluted by Columbia River water during high river stage. This fluctuating water table elevation and varying pore water chemical composition caused by seasonal and diurnal variations in the river stage can result in alternating adsorption-desorption processes that retard the migration of uranium to the Columbia River.

Pacific Northwest National Laboratory, Energy and Environment Directorate, P.O. Box 999, MSIN P7-22, Richland, WA 99352
[1] Telephone: (509) 376-8389; Fax: 509-376-4890; E-mail: Christopher.Brown@pnl.gov
[2] Telephone: (509) 376-4627; Fax: 509-376-4890; E-mail: Wooyong.Um@pnl.gov
[3] Telephone: (509) 376-8429; Fax: 509-376-4890; E-mail: jeff.serne@pnl.gov

Distribution and Seasonal Trends of Nitrate in Unconfined Aquifers of the Pasco and Quincy Basins, Washington

Jessica C. Goin[1] and Dimitri Vlassopoulos[2]

During 2006-2007, the Columbia Basin Ground Water Management Area (GWMA) conducted a year-long monthly groundwater quality and water level monitoring program of domestic wells drawing from the suprabasalt sediment aquifer system in the Pasco Basin (70 wells) in southwestern Franklin County and the Quincy Basin (70 wells) in central Grant County, two areas within GWMA characterized by relatively high rural population densities and abundant irrigated agriculture. The purpose of the sampling program was to expand the existing GWMA database of nitrate concentrations in shallow groundwater and identify major factors influencing nitrate distribution and seasonal variability within these areas.

In the Pasco Basin, nitrate concentrations ranged from <0.01 to 70.4 mg/L as nitrogen with a median value of 9.95 mg/L (49% of samples and 69% of wells exceeded the MCL of 10 mg/L). Concentrations are generally higher in areas with relatively flat hydraulic gradients, suggesting slower groundwater throughflow rates resulting in less dilution of annual nitrate loads to the aquifer. Nitrate concentrations tend to decrease with depth below the water table, with most of the MCL exceedances occurring within the upper 40 feet of saturated thickness. Lower concentrations are also observed in wells screened below less permeable silt and clay units which can in places serve as a protective barrier to downward movement of nitrate impacted groundwater.

In the Quincy Basin, nitrate concentrations ranged from <0.01 to 31.6 mg/L as nitrogen with a median value of 4.42 mg/L (9% of samples and 14% of wells exceeded the MCL). MCL exceedances are limited to the upper 130 feet of saturated thickness, and concentrations are generally lower in wells screened in coarser grained sand and gravel units, indicating more efficient flushing and dilution. Although area-wide median monthly concentrations do not show a seasonal trend, peak monthly concentrations are lower between June and September indicating seasonal effects are important on a local scale.

The spatial distributions and correlations of monthly nitrate concentrations with water levels also indicate that seepage from unlined canals and streams locally enhances recharge to the shallow aquifer systems during the irrigation season, and can offset part of the impact on groundwater quality by dilution processes.

S.S. Papadopulos and Associates, Inc., Suite 200, 510 SW Third Avenue, Portland OR 97204; (503) 222-6639; Fax: (503) 548-4401
[1] *Email: JGoin@sspa.com*
[2] *Email: Dimitri@sspa.com*

Arsenic in the Chamokane Valley Aquifers

Bryony Stasney, L.HG.[1], Alex Dailey, P.E.[2], Robert Anderson, L.HG.[3]

The U.S. Indian Health Service's Spokane District Office is working with the Spokane Tribe of Indians to characterize hydrogeology and identify options to address elevated arsenic levels above the new Environmental Protection Agency (EPA) Maximum Contaminant Level (MCL)[1] for arsenic of 0.01 mg/L for two water systems that are owned and operated by the Spokane Tribe and are located on the Spokane Indian Reservation. The Spokane Indian Reservation is located in northeastern Washington and is bordered by Chamokane Creek to the east, the Spokane River to the south and the Columbia River to the west. The two water systems both withdraw water from wells located in the Chamokane Valley, just west of Chamokane Creek.

The Indian Health Service and the Spokane Tribe selected a phased approach for the project: Phase 1 – identify arsenic source(s), characterize the local hydrogeology to support new well siting and conduct a preliminary assessment of options to meet arsenic standards; Phase 2 – if new sources appear feasible, confirm potential new well sites through the installation and development of test wells and/or testing existing wells, and develop plans and cost estimates for installation of production wells and delivery of an adequate supply of good quality water to the two systems; and, Phase 3 - if new sources do not appear feasible, assess arsenic treatment alternatives and provide recommendations for the appropriate technology or technologies to implement.

At the time of writing this abstract (October 2008), Phase 1 of the study is complete. It is anticipated that Phase 2 will be complete by April 2009. The Phase 1 study results indicate that: elevated arsenic is associated with the lower Chamokane Valley aquifer and also with the sand and gravel lenses within the fine-grained sediments that occur between the upper and lower Chamokane Valley aquifers; arsenic occurs naturally within these sediments; redox and pH conditions are favorable for arsenic release into solution; and, the most likely release mechanism for arsenic is oxidation of sulfides containing arsenic and dissolution of arsenic. Ongoing work has identified sites that have the potential for installation of wells to produce water with low arsenic levels. These sites have been selected for further investigation by balancing the potential for better quality water with the cost to develop a new source.

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[1] *Golder Associates Inc., 1200 West Ironwood Drive, Suite 201, Coeur d'Alene, ID 83814; Telephone: (208) 676-9933; Fax (208) 676-8602; E-mail bstasney@golder.com*

[2] *U.S. Indian Health Service, Spokane District Office, 1919 E. Francis Ave., Spokane, WA 99208; Telephone: (509) 484-9341 x222; E-mail Alexander.Dailey@ihs.gov*

[3] *Golder Associates Inc., 18300 NE Union Hill Road, Suite 200, Redmond, WA 98052-3333; Telephone: (425) 883-0777; Fax (425) 882-5498; E-mail: banderson@golder.com*

Predicting Pesticide Concentrations in Shallow Ground Water Across the United States Using a Process-Based Model Linked to a Geographic Information System

Frank D. Voss[1], Jack E. Barbash[2], and Michael E. Wieczorek[3]

Evaluating the vulnerability of ground water to pesticide contamination is an important step in developing a protection plan for drinking water. Current methods for evaluating vulnerability are based on subjective rating systems or statistical methods that can be applied only if the pesticide of interest has been frequently detected in water samples. In an effort to take advantage of process-based models that incorporate the current understanding of pesticide fate and transport within the unsaturated zone and newly available national soils data sets, a system was developed to predict pesticide concentrations in shallow ground water at locations throughout the conterminous United States.

The system consists of a process-based model for simulating pesticide transport and fate within the unsaturated zone, a database for storing model input data, and a geographic information system for processing and displaying spatial data. Methods were developed to retrieve and process soils data from county soil surveys that recently have become available on the Internet from the U.S. Department of Agriculture and to calculate soil hydraulic properties. Additional software programs were written to transfer data from the system database to model input files, run the model on a series of networked computers, and adjust pesticide transformation rates for temperature.

The system was tested at 1,247 sites located in 10 Corn Belt states by comparing simulated concentrations of the pesticide atrazine with atrazine concentrations measured at the sites by the U.S. Geological Survey's National Water Quality Assessment program. This represents the first time a modeling system of this type has been used to characterize the vulnerability of ground water to pesticides.

U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402; Fax (253) 552-1582
[1] Telephone (253) 552-1689; E-mail: fdvoss@usgs.gov
[2] Telephone (253) 552-1610; E-mail: jbarbash@usgs.gov
U.S. Geological Survey, Maryland Water Science Center, 8987 Yellow Brick Road, Baltimore, MD 21237; Fax (410) 238-4210;
[3]Telephone: (410) 238-4250; E-mail: mewieczor@usgs.gov

Water Rights and Mitigation in Washington

Tom Culhane[1]

Washington water law requires the Department of Ecology (Ecology) to apply a four-part test when evaluating water right applications. That test requires Ecology to determine that: water is available for appropriation; water will be applied to a beneficial use; the proposed use will not impair existing rights; and the proposed use will not be detrimental to the public interest. (RCW 90.03.290; RCW 90.44.060) Near closed water bodies, proposed withdrawals often fail the water availability and the no detriment to the public interest tests. In the case of instream flows not being met, proposed withdrawals often fail the no impairment to existing rights test. The Legislature has authorized Ecology to consider “resource management techniques” (i.e., mitigation) when making water availability determinations or considering whether the impacts of diversions or withdrawals can be offset. (RCW 90.44.055; RCW 90.03.255) In addition, the PCHB has helped shape Ecology’s perspective on mitigation. Given the many constraints on issuing water rights, Ecology’s approach typically has been to accept only in-kind and place mitigation in association with water rights.

Under the mitigation statutes, mitigation must address environmental benefits and costs, and must make water available or otherwise offset adverse impacts. Some of the in-kind mitigation strategies that have been proposed involve: relinquishing or putting existing water rights into trust, conservation, surface or ground water storage and recovery, transferring water into basins, and streamflow augmentation (pump and dump schemes). Some proposed out-of-kind strategies involve: out of place mitigation, non-water mitigation (protection/enhancement of riparian areas), monetary contributions to water banks, natural vegetation removal, and reclaimed water return flows as mitigation.

In some instances, rule changes and potentially even statute changes would be required before out-of-kind mitigation can be accepted. In other cases, out-of-kind mitigation is unacceptable due to damage of other environmental assets and/or questionable benefits.

There are many technical challenges associated with understanding mitigation strategies including evaluating the magnitude, location, timing, and water quality of impacts of a particular project. Often these parameters can be estimated with simple calculations, analytical or numeric models. However, the uncertainty associated with such methods can be high and the data needed to increase certainty often is not available. PCHB decisions have indicated that acceptable mitigation plans should have a high level of certainty, in large part because most water rights are intended to be used forever.

[1] *Department of Ecology, Water Resources Program, P.O. Box 47600, Olympia, WA 98504-77600; Telephone: (360) 407-7407, Fax: (360) 407-6574, E-mail: tcul461@ecy.wa.gov*

The Changing Face of Practical Mitigation: How Case Law and New Technical Approaches Continue to Move the Bar

Jill Van Hulle[1]

Mitigation is a concept that the Department of Ecology and would-be water users have been wrestling with for decades. While Washington water law allows applicants for water right permits to include mitigation plans as part of their proposals in order to offset potential adverse effects of their proposed water use, many mitigation plans are the result of settlement discussions around permit applications that are denied.

In today's world both the technical and legal issues surrounding water allocation are carefully negotiated between those who need water and the Department of Ecology. What constitutes acceptable mitigation remains a moving target, shaped by case law and by constantly improving technical approaches. Additionally we see new roles for other parties as Ecology's process expands to include other stakeholders such as Tribes, Environmental Groups and development interest.

Strategies for mitigation are as varied as the conditions they are designed to protect and improve. Looking back over the numerous decisions that Ecology has made we see an evolution from early, simplistic "pump-and-dump" schemes such as those proposed for numerous small residential developments (e.g. Miller Land and Timber) to today's highly sophisticated management regimes (e.g. City of North Bend) –some of which that tax the math skills of even the most competent water system operators. Habitat enhancement mitigations have progressed from the historic Clark County PUD Salmon Creek MOU to the recent multi-stakeholder Lake Tapps Water Supply Project.

This presentation will examine the range of mitigation approaches used; the nature of water-for-water and habitat-based mitigation schemes, and the ongoing role of legal decisions in shaping mitigation policy.

[1] *Pacific Groundwater Group, 2377 Eastlake Avenue East, Seattle WA 98102; Telephone: (206) 329-0141; Fax: (206) 329-6968; E-mail: Jill@pgwg.com*

Model Prediction of Diffuse Impacts to Multiple Streams on the Dungeness Peninsula: A Basin-Scale Perspective in Mitigation Strategy

Peter Schwartzman[1]

The increased use of groundwater flow models to estimate impacts from new water-rights has dramatically changed the nature of predicted impacts, thus changing the nature of accompanying mitigation requirements. Ecology typically requires mitigations to be same in kind (drop-for-drop replacement of water), same in place (upstream impacts are not permitted), and same in time (changing the timing of baseflows is not permitted). Without a groundwater flow model, a water-rights applicant would typically identify the stream(s) closest to the point of withdrawal and employ analytical methods to estimate pumping impacts on stream baseflows. Most of these analytical approaches likely resulted in identifying only the dominant components of streamflow capture (i.e. greatest impact on nearby streams), and did not identify minor impacts on more distant streams. Groundwater flow models significantly change that situation because they force estimation of streamflow capture on all streams included in the model.

A properly designed groundwater flow model will include surface-water features that are hydraulically connected to the groundwater system. Basin-scale models that include multiple streams can predict diffuse capture from these streams, especially if the pumping occurs in a deep confined aquifer that causes widespread drawdown. Although associated baseflow impacts may be small, they can be distributed over a large geographic area – thus presenting the water-right applicant with the unattainable task of delivering small amounts of mitigation water to multiple streams across an entire watershed, basin or WRIA. An example is provided in the recently developed groundwater flow model of the Dungeness Peninsula, which includes 10 small streams and the Dungeness River. Prior to the application of groundwater flow models, such diffuse impacts would not have been estimated or identified.

Groundwater flow models clearly represent an advance in tools for basin-wide management of hydrologic resources, especially in areas with complex hydrogeologic frameworks. While models force us to “open our eyes” to the holistic functioning of the hydrologic system, their use in predicting pumping impacts present new challenges that force us to “open our minds” to new approaches in mitigation. Such approaches could include an integrated (basin-wide) approach to mitigation planning and habitat-based mitigation. Ideas for the integrated basin-wide approach are discussed in further detail.

[1] *Pacific Groundwater Group, 2377 Eastlake Avenue East, Seattle WA 98102; Telephone: (206) 329-0141l Fax: (206) 329-6968; E-mail: Peter@pgwg.com*

Out of Site, But on Our Minds….How to Protect Water Quality With Drywell Best Management Practices That Work

Daniel A Scarpine, P.E.[1]

This presentation will focus on the challenge of selecting appropriate solution to protect water quality in urban sites with drywells. Through a narrative of site considerations and regulation review, we delve into industrial and commercial stormwater projects and bring to light the conflicting guidance that affects your next project. First, we'll review the importance of selecting, sizing and integration of treatment BMPs relative to stated performance expectations and federal water quality standards. We will finish with a look at case studies of several industrial sites where field monitoring will show us what we can truly expect for performance.

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[1] Daniel Scarpine's career has been dedicated to the implementation of innovative and practical water treatment systems. Mr. Scarpine is the founder of Aquarius Environmental specialty engineering and consulting firm based in Portland, OR. Prior to founding Aquarius Environmental, Mr. Scarpine was a founding partner of StormwateRx where he served as Vice-President leading the design and development of the highly effective Aquip™ filtration system and the Clara solids and oil separator. Mr. Scarpine's prior experience includes Contech (formerly Stormwater Management, Inc) where he led application engineering for the industrial division. Mr Scarpine also worked for a number of years as a Chemical Facilities Engineer at Intel Corporation leading the design and construction of ultra-high purity water and numerous wastewater treatment systems. Early in his career Mr. Scarpine served the power and refining industries with GE Water and Process Technologies (formerly Ecolochem). Mr. Scarpine has a BS in Environmental Engineering from Virginia Tech and is a registered professional environmental engineer in Oregon and Washington.

Aquarius Environmental, 3204 Northeast 40th Ave., Portland, OR 97212; Telephone (503) 317-5114; (www.aquariusenv.com); E-mail: daniels@aquariusenv.com

Wastewater Land Treatment Systems in the Columbia Basin Irrigation Project – Regulatory Requirements to Protect the Ground Water

Don Nichols[1]

The Columbia Basin Irrigation Project in central Washington diverts water from the Columbia River to irrigate approximately 600,000 acres and create a multi-billion dollar production agriculture economy. Many of the crops are processed within the basin and shipped out in bulk containers or commercial packages. Due to the general absence of surface waters wastewater from the different crop processors is land applied via spray irrigation for final treatment. Processing can be seasonal (corn; peas) or year around (potatoes), and the volume of process wastewater can range from 500,000 gallons per day to 2.5 million gallons per day. Nitrogen loading can be as high as 700,000 lbs of nitrogen per year and the organic load can be eight million pounds of biochemical oxygen demand. Dissolved salt loading can be problematic given the low requirement and uptake by most crops. Load values can exceed five million pounds per year.

Engineering design approval and discharge permits issued by the Washington Department of Ecology for these processors require each land treatment system to provide AKART (all know, available, and reasonable methods of treatment) ,and use irrigation and crop management practices to protect the ground water. AKART includes storing the wastewater in lined impoundments during the winter non-growing season that can hold as much as 600 million gallons, and spread the nutrient and water loads over an expanded sprayfield system that can exceed 5000 acres.

To help insure the protection of the ground water, ground water monitoring systems have been installed to monitor up- and downgradient conditions, and can include over 20 wells with monthly monitoring requirements. Other monitoring tools include vadose zone monitoring as well as soil and crop monitoring.

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[1] *Washington State Department of Ecology, Eastern Regional Office, N. 4601 Monroe Street, Spokane, WA 99205; Fax: (509) 329-3529; Telephone: (509) 329-3524; E-mail: dnic461@ecy.wa.gov*

Meeting Water Demands and Controlling Saltwater Intrusion in Southern California

Bill Mann[1]

Due to increasing water demands, decreasing supplies of imported water, and recurring drought conditions, state and local governments are expanding or developing groundwater replenishment or recharge systems. These systems divert highly treated wastewater, currently discharged into the ocean or local surface waters, into natural storage areas. Reclaimed waters, once purified, are injected into seawater intrusion barriers, piped to recharge areas, or discharged to surface waters and eventually diverted to groundwater basins. Water management agencies aim to meet future water demands, protect against droughts, and preserve high-quality groundwater through innovative, cost-effective, and environmentally sensitive basin management practices.

The existing and future limitations of water resources in Southern California have prompted more efficient management of water supplies. The Water Replenishment District (WRD) is the regional groundwater management agency for overall water resource management in southern Los Angeles County. As the population continues to increase, it becomes even more important to maximize the use of both imported and recycled or local water sources available to the WRD. The WRD manages groundwater for nearly four million residents in 43 cities of southern Los Angeles County.

To meet requirements of the California Water Code Section 60300, WRD hydrogeologists and engineers track groundwater levels from a network of specialized monitoring wells and from groundwater producer's production wells. Currently, the network consists of about 220 WRD and USGS-installed monitoring wells at 48 locations throughout the District and is supplemented by existing groundwater production wells. Currently, 100 wells are outfit with In-Situ® Level TROLL® 500 instruments that accurately measure and log water level and temperature data every six hours. The primary purpose of water level monitoring is to meet statutory responsibility to maintain groundwater availability. The Level TROLL 500s reduce trips to the field and enhance the WRD's monitoring program by allowing for more measurements, which increases data resolution.

[1] *In-Situ Inc., 221 E. Lincoln Avenue, Fort Collins, CO 80524; Fax (970) 498-1598; Telephone (360) 809-3554; E-mail: bmann@in-situ.com*

Habitat-Based Mitigations to Baseflow Impacts: Two Case Studies

Linton Wildrick[1]

In many areas of the state, the transfer of existing water rights to new locations is the only viable way of securing water to meet new needs. Furthermore, the majority of water rights available for acquisition and transfer were issued for irrigation, and thus have a seasonal period of use. In many situations, due to seasonal timing issues, the predicted reduction in baseflow from water-right transfers cannot be completely mitigated drop-for-drop. The Washington Department of Ecology's recent policy shift to require full mitigation during winter months, when a seasonal water right (usually irrigation) is transferred to a year-round right, has increased the difficulty of arranging full water-for-water mitigation. To the extent that this is not practical or affordable, a project proponent has few alternative means to mitigate a project's effects. Habitat-based mitigation programs appear to be rational alternatives, because streamflow reduction tends to reduce aquatic habitat, to some extent.

Department of Fish and Wildlife (WDFW) has identified situations where project proponents can provide habitat preservation or net improvement in lieu of perfect water-for-water replacements. In two projects in western Washington, one in the Lewis River Basin and one in the Chehalis River Basin, WDFW has (1) accepted permanent easements to protect streamside habitat in the first case, and (2) accepted a commitment to greatly improve instream habitat for one small tributary in exchange for minor reduction of instream habitat in another. Both case studies involve small streams that are not closed by rule or by WDFW recommendation, but which are tributary to streams closed to further appropriation or streams with mandated minimum instream flow standards that are not being met.

These and other creative means for habitat mitigation must be recognized by both State agencies as valid tools to achieve overall improvements in water management and conservation, while allowing projects requiring water-right transfers to move forward to serve social needs.

[1] *Pacific Groundwater Group, 2377 Eastlake Avenue East, Seattle WA 98102; Telephone: (206) 329-0141; Fax: (206) 329-6968; E-mail: Linton@pgwg.com*

Model Prediction of Streamflow Capture and a Habitat Based Mitigation Approach for Baseflow Impacts: City of Camas

Dan Matlock[1]

The City of Camas historically obtained its water from two surface water sources and nine groundwater wells. Surface water has been diverted from Jones and Boulder Creeks, tributaries to the Little Washougal River. Groundwater has been withdrawn from the floodplain of the lower Washougal River. Other significant local groundwater users include the City of Washougal and Georgia Pacific. In 2003, the City of Camas applied for 4,790 acre-feet/year of new water rights from the principal aquifer beneath the Washougal River floodplain to meet their projected 20 year growth targets.

In support of the water-right application, Pacific Groundwater Group (PGG) characterized the hydrogeologic framework beneath the lower Washougal floodplain, historic pumping and groundwater level responses, hydraulic connections between the Washougal River and the principal aquifer. PGG's consultant team also performed seepage surveys along the Washougal River and habitat evaluations of the forementioned streams. PGG's evaluation indicated a high transmissivity aquifer in hydraulic continuity with both the Washougal and Columbia rivers, where seasonal pumping causes a local hydraulic disconnect between Washougal River and the water table centered on the pumping cone of depression. Habitat evaluation showed low-flow conditions in the Washougal and Little Washougal rivers as a limiting factor for salmonid habitat during the summer and early fall months. PGG incorporated this hydrogeologic information into a groundwater flow model and used the model to estimate pumping impacts to Washougal River baseflows.

Mitigation sources that offset the exact temporal distribution streamflow capture were unavailable. PGG and City staff developed a mitigation approach that actually increased usable habitat upstream of the City's wellfield. The approach required the City to forego use of its water rights on Jones and Boulder creeks during the critical habitat period (summer and early fall), thus resulting in 2 cfs increased flow in the Little Washougal River and portions of the mainstem. This mitigation represents a significant improvement to habitat on the Little Washougal River, fully mitigates pumping impacts on the main-stem Washougal River during the critical low-flow months, but does not address residual impacts during high-flow months. The habitat improvements during the low-flow months far outweigh minor impacts on the main stem during the high-flow months, and provide about 13 miles of improved stream habitat. Water-rights processing included participation by Ecology, PGG, the City of Camas, WDFW and the Lower Columbia Fish Recovery Board and resulted in a win-win outcome in which all parties (including habitat in the basin) derived benefit from the mitigation approach.

[1] *Pacific Groundwater Group, 2377 Eastlake Avenue East, Seattle WA 98102; Telephone: (206) 329-0141; Fax: (206) 329-6968; E-mail: Dan@pgwg.com*

Streamflow Augmentation for Water Rights Mitigation at the Buckhorn Mountain Gold Mine in Northeast Washington

Jay Pietraszek[1] and David Banton[2]

Groundwater is being used to augment streamflows in Myers Creek, a tributary to the Kettle River in Northeast Washington. The purpose of the augmentation is to mitigate for the reduction in streamflows associated with mine dewatering at the Buckhorn Mountain Mine. The objective is to increase streamflows in Myers Creek by about 10 gpm, which is the approximate impact of mining activities on streamflows in Myers Creek. Mitigation is required under the mine's water rights when the streamflow in Myers Creek drops below 1 cfs during the irrigation season (from July through September), because there is a senior water right that requires a streamflow of 1 cfs downstream of the mining area.

Augmentation testing and monitoring was conducted during summer baseflow conditions in 2007 and 2008. During the augmentation period, groundwater is pumped from an irrigation well that is situated approximately 600 feet from Myers Creek. The well taps a permeable, unconfined alluvial aquifer. Groundwater is pumped at a rate of approximately 125 gallons per minute (gpm) and discharged directly into Myers Creek via irrigation lines. The changes in groundwater levels during pumping are measured in the irrigation well and at three observation wells situated between 200 and 500 feet from the irrigation well. Streamflows in Myers Creek are measured with two streamflow gaging stations. One gaging station is approximately 1,400 feet upstream of the pumping well and the other gage is approximately 300 feet downstream of the augmentation point.

The data indicate that discharging approximately 125 gpm into Myers Creek for over 30 days results in increased streamflows downstream of the augmentation point. At the start of pumping, the net benefit is similar to the full augmentation rate. The streamflow benefit gradually declines as pumping continues, but the net benefit after approximately 30 to 35 days of pumping is between 55 to 95 gpm. The observed increase in streamflow from augmentation is similar to that predicted using analytical models which predict a net streamflow improvement of 60 to 70 gpm after 30 days of pumping at 125 gpm. These findings indicate that under the appropriate hydrogeological conditions groundwater augmentation can be a successful management tool for mitigating seasonally-reduced streamflows in alluvial stream and aquifer systems.

Golder Associates Inc., 18300 NE Union Hill Rd Suite 200, Redmond, WA, 98052; Fax: (425) 882-5498
[1] *Telephone: (425) 883-0777, ext. 2204; E-mail: jpietraszek@golder.com*
[2] *Telephone: (425) 883-0777, ext. 2123; E-mail: dbanton@golder.com*

Hydrogeology of the Brightwater Conveyance Project, King and Snohomish Counties, Washington

David H. McCormack[1], Doug L. Hillman[2], and John E. Newby[3]

A new regional wastewater treatment plant (Brightwater) is under construction near Woodinville, Washington. A conveyance system composed of 13 miles of 14- to 24-foot diameter tunnels up to 480 feet deep and a mile of micro tunnels will convey untreated wastewater to the treatment plant and treated effluent to a deepwater outfall in Puget Sound. Five portals and shafts up to 205 feet deep and an underground pump station are required to construct and operate the system. Three water districts utilize regional aquifers for municipal supply along the conveyance route.

The tunnel alignment extends east to west, across the orientation of the glaciated hills. Subsurface conditions were explored with over 200 borings to an average depth of 265 feet. Groundwater monitoring instrumentation included about 250 monitoring wells and grouted-in vibrating wire piezometers. Hydraulic characterization included groundwater level monitoring, slug testing, and pumping tests in environmentally sensitive areas, adding considerable knowledge on the Vashon Advance Outwash Aquifer and other regional aquifers.

Explorations encountered deposits from at least 8 different glacial and non-glacial climate cycles. This alternation of glacial and non-glacial sequences combined with erosion between cycles resulted in complex hydrostratigraphy. Recharge occurs in upland areas, with downward groundwater gradients. Low-lying areas generally exhibited upward groundwater gradients, with heads at tunnel level measured at up to 30 feet above ground surface. Strong tidal influences were measured up to 4 miles inland from Puget Sound.

The hydrogeologic investigation and analyses focused on predictive analyses to select construction methods that would limit groundwater impacts with heads at the tunnel face up to 7.3 bars or 245 feet and deep portals and shafts in alluvial valleys with shallow water tables and settlement sensitive soils. Aquifer testing programs were completed to provide design data for selection of shoring methods, minimize settlement and impacts to wetlands and streams, and develop specification for monitoring groundwater during construction.

Aspect Consulting, LLC, 401 Second Avenue S., Suite 201, Seattle, WA 98104; Fax: (206) 838-5853
[1] Telephone: (206) 838-5834; E-mail: dmccormack@aspectconsulting.com
[2] Telephone: (206) 838-5833; E-mail: dhillman@aspectconsulting.com
Camp Dresser & McKee, Inc., 11811 NE 1st St., Suite 201, Bellevue, WA, 98005 Fax: (425) 646-9523
[3] Telephone: (425) 453-8383; E-mail: newbyje@cdm.com

Groundwater Monitoring Program for the Brightwater Conveyance System Project

Howard S. Young[1] and John E. Newby[2]

King County developed and implemented a groundwater monitoring program to document anticipated limited impacts on groundwater levels during the Brightwater Conveyance System tunnel mining and portal and shaft construction. The alignment spans from Woodinville to Point Wells, including 13 miles of bored tunnel and 5 portal and shaft excavations. Tunnel mining and excavation are being conducted through the shallow alluvial aquifers, the Vashon Advance Outwash Aquifer, the deeper pre-Vashon aquifers, and associated aquitards. Protection of groundwater resources and limiting impact to groundwater users is a fundamental project requirement and construction methods were selected accordingly.

The groundwater monitoring program includes: 1) determining baseline conditions through long-term groundwater level monitoring prior to and during construction; 2) groundwater level monitoring during construction within 1,000 feet of active tunneling or construction; and 3) continued long-term monitoring after tunnel completion. Short and long-term impacts are evaluated through comparison of construction and post-construction groundwater level trends with the pre-construction baseline. Monitoring points include observation wells and grouted-in vibrating wire piezometers equipped with dataloggers. Monitoring points target aquifers and the water bearing strata between aquifers and the tunnel invert. Data is downloaded weekly and posted to an online Project Instrumentation Database (PID). The PID provides easy access to the data for the contractor and construction management, providing a powerful tool for groundwater impact evaluation and decision making.

As of April 2009, approximately 9 miles of tunneling and all of the portal and shafts have been completed and the groundwater monitoring program is effectively documenting subtle groundwater level changes. During tunnel mining through confined aquifers, transient decreases and increases groundwater levels are observed at distances over 1,000 feet from the active tunnel face. Groundwater monitoring instrumentation provided a continuous record of aquifer drawdown and recovery during deeper aquifer depressurizing at the North Kenmore Portal. Impacts due to groundwater leakage and variation in tunnel boring machine face pressure were identified through review of the groundwater level data and proved useful in troubleshooting construction problems.

Camp Dresser & McKee, Inc. 11811 NE 1st St., Suite 201, Bellevue, WA 98003; Fax: (425) 646-9523
[1] Telephone: (425) 453-8383; E-mail: younghs@cdm.com
[2] Telephone: (425) 453-8383; E-mail: newbyje@cdm.com

Hydrogeology of the Cascadia Sewer Bore Alignment, Pierce County, Washington

Curtis J. Koger[1] *and Lara B. Koger*[2]

The Cascadia Corporation is developing an employment based planned community on a glaciated upland plateau northeast of the City of Orting in Pierce County, Washington. A 42-inch-diameter, directional sewer bore over 3,000 feet long was proposed to connect the upland development to the existing City of Orting wastewater treatment plant adjacent to the Carbon River. The bore alignment required horizontal directional drilling (HDD) through Recent alluvium and mudflow deposits in the valley, boring beneath the Carbon River, and through a complex sequence of consolidated glacial and non-glacial deposits beneath the upland.

Extensive subsurface exploration delineated multiple aquifer intervals along the trajectory of the proposed alignment including: (1) a Valley Aquifer formed in Recent alluvium; (2) a Shallow Upland Aquifer contained in both glacial and non-glacial deposits; (3) a highly productive Upper Orting Aquifer; and (4) a deep aquifer within the lower portion of the Orting Drift (Lower Orting Aquifer). The Upper Orting Aquifer and Lower Orting Aquifer are separated by a highly heterogeneous interval termed the Discontinuous Flow Zone.

A connection was created between the highly productive Upper Orting Aquifer and the Discontinuous Flow Zone by the borehole during pilot hole drilling and preliminary reaming operations. Due to the cross-connection, ground water levels in the underlying water bearing zones of the Discontinuous Flow Zone increased. When water levels in the Discontinuous Flow Zone were high, spring flow rates on the bluff increased indicating the spring zones are hydraulically connected to ground water in the Discontinuous Flow Zone. When the borehole was pressurized, all water levels increased and spring flows increased. When ground water was allowed to flow through the lower end of the borehole, all water levels and spring flows decreased.

Aquifer parameters in the Upper Orting Aquifer were calculated using the Hantush Jacob leaky aquifer solution following a 26-hour aquifer test. The Upper Orting Aquifer is interpreted to behave as a leaky aquifer system. Diagnostic plots of the drawdown data combined with parameter results indicate the actual drawdown response in the wells deviates from the theoretical solution predicted by Hantush Jacob, indicating the system is more complex than simulated by the available aquifer solutions.

[1] *AESI, 911 5th Ave Ste 100, Kirkland, WA 98033; Telephone: (425) 827-7701; Fax: (425) 827-5424; E-mail: ckoger@aesgeo.com*
[2] *AESI, 805 MLK Jr. Way, Tacoma, WA 98405; Telephone (253)722-2992; Fax: (253) 722-2993; E-mail: lkoger@aesgeo.com*

Hydrogeologic Controls and Impacts of Quaternary Landslides Along the White Bluffs of the Columbia River, South-Central Washington

Bruce N. Bjornstad[1] *and Robert E. Peterson*[2]

The White Bluffs comprise a tall erosional escarpment composed of semi-consolidated, fine-grained sediments of the Pliocene Ringold Formation. Ringold sediments slowly accumulated in the Pasco Basin up to 3 million years ago in a fluvial-lacustrine environment. Since then, the Columbia River and Ice Age floods have removed up to 200 m of the Ringold from the basin interior. A record of slumping exists along the White Bluffs, beginning with periodic high-recharge, Ice Age flood events. One slide event is preserved as a broad debris fan that rerouted the channel of the Columbia River during an earlier flood event. This slide lacks the characteristic hummocky topography of landslides smoothed over by the last Ice Age flood(s), which also generated White Bluffs slides.

Since the Pleistocene, landsliding on the bluffs was dormant until the 1970s, when increased infiltration of moisture from agricultural activities caused a resurgence of slumping. Excess irrigation water percolates downward before moving laterally upon lower-permeability Ringold strata. Springwater sapping along the bluff face greatly reduces internal soil strength, leading to slope failure. Heads of landslides characteristically consist of back-rotated slump blocks that transition to debris flows downslope. Toes of the fluidized debris flows often fan out into the Columbia River.

An example of adverse effects resulting from landsliding occurs near Locke Island, 55 km north of Richland. To enhance wildlife habitat, irrigation water was diverted to a man-made pond 3 km north of Locke Island. The percolating pond water followed an Ice Age flood paleochannel to the bluff face, where slumping ensued. These slides diverted and pushed the Columbia away from the bluffs toward Locke Island, a culturally sensitive area. The deflection of the river toward the island promoted bank erosion opposite the landslide. Since monitoring of bank erosion began in 1994, as much as 42 m of Locke Island have been lost to erosion by the river. Accelerated rates of erosion occur following periods of especially high river stage every few years. Impacts from increased erosion threaten archaeological sites as well as some of the most prolific salmon-spawning habitat in the vicinity of Locke Island due to increased siltation. Landsliding and its damaging effects likely will continue until vadose zone recharge via unlined irrigation canals, ponds, and over-irrigation is significantly reduced or eliminated.

Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352
[1] *Telephone: (509) 371-7223; Fax: (509) 371-7249; E-mail: Bruce.Bjornstad@pnl.gov*
[2] *Telephone: (509) 371-7226; Fax: (509) 371-7083; E-mail: Robert.Peterson@pnl.gov*

200 East Area Increases in Groundwater Contamination at the Hanford Site, Washington, Since 1992

Stanley M. Sobczyk[1]

Large plumes of contaminated groundwater resulted from plutonium production at the Hanford Site, Washington. Ongoing degradation of groundwater quality underneath the 200 East Area has been occurring since the early 1990s This extensive groundwater contamination is attributed primarily to the persistent migration of tank waste through the vadose zone to groundwater. The development of new groundwater plumes underneath 200 East Area is particularly problematic as the travel time to the Columbia River has been estimated as short as six years once the B Pond groundwater mound completely dissipates.

Post-1990 groundwater maps for gross beta, nitrate, technetium-99, tritium, and uranium have been developed for 200 East Area using the electronic listings of radiological and chemical monitoring data in Hanford site Groundwater Monitoring reports. Due to the limited amount of monitoring data prior to the early 1990s, the groundwater conditions were plotted at one-year increments for the time periods between 1992 and 2007 using RockWorks™v14 software. The study area encompasses approximately 24.9 km^2. The number of groundwater monitoring wells sampled varies from year to year. Typically, about 200 samples were available for each year that was mapped. The monitoring data for each year were gridded using an inverse-distance algorithm. The study area was gridded into 50 m cells. When multiple monitoring results occurred within a cell, the results were averaged using the RockWorks™v14 declustering option prior to applying the inverse-distance algorithm.

Since 1992, uranium, gross beta, technetium-99, and nitrate groundwater plumes in 200 East Area have grown in size and concentration while the tritium plumes appear to be shrinking primarily due to radioactive decay. In the northwest portion of the area, new uranium groundwater plume has developed, while the existing comingled gross beta, technetium-99, and nitrate groundwater plume continues to enlarge. The 1951 241-BX-102 tank leak is the source of uranium and a source of nitrate, gross beta and technetium-99. Other potential sources of nitrate, gross beta and technetium-99 are tank leaks in BY and B tank farms with a lesser current contribution from the BY Cribs. New gross beta and technetium-99 plumes have resulted from tank leaks in Waste Management Areas A-AX and C In the northeast corner of the area, a new nitrate plume has developed with potential vadose zone source(s) from either the Low-Level Waste Management Area 2, the Liquid Effluent Retention Facility, or both. The Purex cribs are the source of the highest activity observed in the tritium plume.

[1]*Nez Perce Tribe, Environmental Restoration and Waste Management Program, P.O. Box 365, Lapwai, ID 83832; Fax: (208) 843-7378; Telephone: (208) 843-7375 ext 3751; E-mail: stans@nezperce.org*

Surface Geophysical Exploration at Selected Tank Farm Areas at the U.S. Department of Energy Hanford Site, Near Richland, Washington

Dale Rucker[1], *Marc Levitt*[2], *Jason Greenwood*[3], *Gill Noonan*[4], *Brian* Cubbage[5],

Michael McNeil[6], *Marcel P. Bergeron*[7], *Colin Henderson*[8], *and David Myers*[9]

Analyses of surface geophysical characterization data were completed during fiscal year 2008 for the S-SX and the TX-TY tank farms and the surrounding areas within the 200 West Area at the U.S. Department of Energy Hanford Site in Washington State. The study objectives were to collect and analyze electrical resistivity data in order to identify and locate discrete low resistivity regions in the subsurface to guide future drilling, soil sampling and geochemical analysis efforts.

The TX-TY farms study involved the installation and subsequent data collection from surface-to-surface (STS) electrodes spaced 6-m apart along 26,712 total linear meters of cable arranged 30 meters apart in an orthogonal grid. The STS data were acquired along 47 individual lines of which 23 were oriented in a south-north direction and 24 lines were oriented in an east-west direction. The total data area covering approximately 82 acres included the two tank farms and seven other waste focus areas outside of the farms.

Both the S-SX and TX-TY farm investigations also utilized a Well-to-Well (WTW) long electrode resistivity measurement method. The TX-TY farm characterization study made use of 105 steel-cased vadose zone wells, 30 groundwater wells, and 27 point source electrodes. The S-SX farm investigation included data acquisition for a WTW survey that collected resistivity data using 21 groundwater wells and 132 vadose zone wells, totaling 153 wells.

Separate two-dimensional and three-dimensional inversion models evaluated the STS and WTW data to estimate distributions of resistivity and identify regions of low resistivity in the subsurface beneath the tank farms and waste site areas. Two-dimensional processing of resistivity STS survey lines collected within the TX-TY Complex area were conducted with the Res2DINV inversion modeling software. Three-dimensional analyses of the STS and WTW data collected in both farm areas were performed with a resistivity inversion software package, called EarthImager3DCL.

hydroGEOPHYSICS, Inc.,Phone (520) 647-3315
[1] *E-mail: drucker@hgiworld.com*
[2] *E-mail: mlevitt@hgiworld.com*
[3] *E-mail: jgreenwood@hgiworld.com*
[4] *E-mail: gnoonan@hgiworld.com*
[5] *E-mail: bcuubbage@hgiworld.com*
[6] *E-mail: mmcneil@hgiworld.com*
[7] *E-mail: mbergeron@hgiworld.com*
[8] *E-mail: chenderson@columbia-energy.com*
[9] *Washington River Protection Solutions; Telephone: (509) 373-3972 E-mail: David_A_Dave_Myers@RL.gov*

Application of a Wet/Wet Differential Pressure Sensor for Vertical Hydraulic Gradient Measurement

Brad G Fritz[1] *and Rob D. Mackley*[2]

Vertical hydraulic gradient is commonly measured in rivers, lakes and streams for studies of ground water-surface water interaction. A number of methods have been applied which can generally be categorized into two methods; separate measurements of surface water elevation and pressure in the subsurface or direct measurements of the head difference with a manometer. Making separate head measurements allows for the use of electronic pressure sensors that provide large data sets which are particularly useful when the vertical hydraulic gradient fluctuates over time. On the other hand, using a manometer based method provides a more rapid measurement with less potential for error and involves a simpler computation to calculate the vertical hydraulic gradient. In this study, we evaluated a wet/wet differential pressure sensor for use in measuring vertical hydraulic gradient. This approach combines the advantages of the two types of methods generally used in previous studies to measure vertical hydraulic gradient. Our results showed that the wet/wet differential pressure sensor provided results comparable to a more traditional method, making it an acceptable method for future use.

Pacific Northwest National Laboratory, 902 Battelle Blvd., Richland, Washington 99352
[1] *Telephone: (509) 371-7119; E-mail: Bradley.fritz@pnl.gov*
[2] *Telephone: (509) 371-7178; E-mail: rob.mackley@pnl.gov*

Southeastern Idaho Water Delivery Calls: Real-Time Water Administration in a Large Interconnected Arid River Basin

John S. Koreny [1]

Water development to irrigate the arid Western U.S. went through three phases of development. Phase I involved the diversion of river flow by pioneers in the late 1800s. Phase II involved the over-allocation of river flow, conflict between water users, litigation and court decrees setting priority for natural flow diversions and Federal support for the construction of large storage reservoirs through the 1950s. Phase III involved large-scale ground water development, increased irrigation efficiency and an increased demand for instream flow. Much of the ground water rights allocated since the 1950s in the larger interconnected river basins with both surface water and ground water users did not involve a full accounting of the effects of junior-priority ground water use on senior-priority river and spring flow water rights. Consequently, water users and administrators are attempting to sort out how depletions by junior-priority ground water pumping over a long time period will be administered in river basins that have been traditionally managed by surface water accounting practices and administrative rules. This is a major issue for basins with major natural river flow and reservoir storage use, since ground water depletions can impact multi-year reservoir storage fill and reliability as well as deplete natural flow. Determining the level of injury and the method of administration during a time of shortage in this type of environment is challenging from both a technical and administrative perspective. The reduction in water supply that may occur from climate change, and the interest in maintenance of instream flow increases the pressure for effective administration policies. Effective administration requires information and predictive tools developed before a shortage occurs, enforcement of water right priority in the delivery of water during times of shortage, and developing effective mitigation strategies that protect the senior-priority user's supply while at the same time providing the junior-priority user with the means to remedy impacts to seniors.

This situation is emerging as a pressing issue and a major driver water policy and management in many arid river basins in the Western U.S. One example is the Upper Snake River Basin and the Eastern Snake Plain Aquifer (ESPA) in Southeastern Idaho, where multiple water right delivery calls have been made by senior-priority surface water users dependent on reservoir storage, river flow diversions and spring flow against junior-priority ground water users. The ESPA extends over about 20,000 square miles in Southeastern Idaho and forms the upper part of the Snake River Basin, one of the largest tributaries to the Columbia River Basin. About 50,000 ground water rights were allocated for wells pumping ground water over 1.6 million acres which are junior in priority to surface water rights. The senior-priority water users include seven large irrigation districts irrigating about 500,000 acres, the Bureau of Reclamation managing about 4.5 million acre-feet of reservoir storage and various fish aquaculture companies dependent on large spring flows in the Thousand Springs reach of the Snake River. The senior-priority surface water users seek mitigation from or curtailment of hydrologically-connected junior-priority ground water users pumping from the Eastern Snake Plain Aquifer (ESPA). Total irrigation from ground water and surface water sources is about 2.4 million acres. In addition, the largest senior-priority ground water user has initiated a delivery call on junior-priority ground water rights. This presentation will summarize the methods used to evaluate injury, the process being used to address the water delivery calls and the issues surrounding real-time administration of water in an interconnected river basin with on-going water shortages.

[1] *John S. Koreny, Senior Project Manager, HDR, Inc., 500-108th Avenue NE, Bellevue, Washington; Telephone (425) 450-6321; Fax: (425) 453-7107; E-mail: jkoreny@hdrinc.com*

Ground Water Sources and Impacts in Lynch Cove, Hood Canal, Washington

Edward G. Josberger[1], C. Chris Chickadel[2], Stephen E. Cox[3], F. William Simonds[4] and Richard W. Sheibley[5]

Ground water flowing into Lynch Cove, Hood Canal, WA, may play an important role in the nitrogen loading of Lynch Cove and on its circulation. Electrical resistivity profiles in Lynch Cove, made by the USGS in 2007 and 2008, show that ground-water discharge is spatially variable and it occurs mainly within the intertidal zone. Seepage measurements made by a variety of techniques indicate that unit discharges range from 2.5 to 40 centimeters per day and yield estimates of ground water nitrogen loading into Lynch cove that ranges from 14 to 750 metric tons per year. When ground water discharge is integrated along the entire shoreline of Lynch Cove, the result is comparable to the climatological flow from the two small rivers that flow into Lynch Cove. To determine the spatial distribution of ground water seeps we imaged the shoreline of Lynch Cove with an airborne thermal infrared camera at the beginning of a flood tide in September of 2008. In the images, cool ground water appears dark and warmer surface water and the exposed intertidal beach appears bright, which clearly shows both the sporadic location and relative strengths of cool ground water seeps at the shoreline. Also visible are small un-gauged streams flowing across the exposed beach and the ground water discharge from the alluvial fans associated with them. To evaluate the importance of these sources on the circulation in Lynch Cove we used a numerical hydrodynamic model of Hood Canal that simulated ground water inputs by a series of small point sources distributed along the shoreline. The model includes the climatolgical averaged flow from the Tahuya and Union Rivers. The results show that reasonable estimates of ground water flow into Lynch Cove can increase the stratification in the surface layers and restrict the vertical mixing.

[1] *USGS Washington Water Science Center, 934 Broadway, Tacoma, WA 98402; Telephone: (253) 552-1643; E-mail: ejosberg@usgs.gov*
[2] *Applied Physics Laboratory, University of Washington, Seattle WA 98105-6699; Telephone (206) 221-7673; E-mail: chikadel@apl.washignton.edu*
[3] *USGS Washington Water Science Center, 934 Broadway, Tacoma, WA 98402; Telephone (235) 552-1623; E-mail: secox@usgs.gov*
[4] *USGS Oregon Water Science Center, Portland, OR 97201, Telephone (503) 251-3262; E-mail: wsimonds@usgs.gov*
[5] *USGS Washington Water Science Center, 934 Broadway, Tacoma, WA 98402; Telephone (253) 552-1611; E-mail: sheibley@usgs.gov*

Submarine Ground-Water Discharge of Mercury to Sinclair Inlet, Puget Sound from the Bremerton Naval Complex, Washington, USA

Anthony J. Paulson[1], Richard Dinicola[2], and Richard J. Wagner[3]

The marine sediments of Sinclair Inlet, adjacent to the Bremerton Naval Complex (BNC), contain the highest overall concentrations of mercury of any Puget Sound embayment. The 2007 Five-Year Review of the BNC Record of Decision indicated that there is insufficient information to determine whether the remedial action is protective of ingestion of mercury in rockfish by subsistence finfishers, and that a monitoring well adjacent to the shoreline contained concentrations of total mercury as high as 5,240 ng/L. In 2008, USGS began an investigation of possible migration of dissolved and particulate from the vicinity of this well to the adjacent marine water. During sampling in January, April and May, dissolved mercury concentrations in this well ranged between 450 and 830 ng/L. During intensive day-long monitoring on May 6 over a tidal range of 5 m, the highest concentrations of mercury were measured at the top of the screened interval and decreased with depth down the 4-m screen. The highest mercury concentrations in the well were measured in saline water several hours after higher high tide when the ground-water flow direction switched from landward to seaward. It is postulated that the salts in seawater intruding into the area upland of the well during the rising tide interacted with contaminated fill material to release mercury into the saline water. This hypothesis will be tested in a tidal study of mercury in the well and in six lower intertidal piezometers during two days in June 2008 when tidal ranges are again 5 m.

U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402; Fax: (253) 552-1581

[1] *Telephone (253) 552-1681; E-mail: apaulson@usgs.gov*

[2] *Telephone (253) 552-1603; E-mail: dinicola@usgs.gov*

[3] *Telephone (253) 552-1685; E-mail: rjwagner@usgs.gov*

Analysis of Pumping Test Data from a Tidally Influenced Aquifer

Roy E. Jensen[1] and Angie Goodwin[2]

A series of aquifer pumping tests were conducted in an tidally influenced aquifer at an industrial site located adjacent to Puget Sound. The purpose of the tests was to determine aquifer parameters and evaluate well hydraulics to support the design of groundwater remediation system. Water levels collected during the test were affected by both drawdown due to pumping and tidal fluctuations. The presence of tidal fluctuations complicate interpretation of the test data.

The aquifer tests were conducted in an unconfined highly permeable aquifer consisting of sand and gravels deposited in a beach environment. Step drawdown, constant rate, and recovery tests were completed in four pumping wells. During the tests, water levels were monitored in both observation and pumping wells during pumping and non- pumping periods. The observed tidal cycle in Puget Sound is characterized by a tidal range of more 12 feet and classified as mixed tides with two high tides and two low tides with a marked diurnal inequality. The tidal response in the aquifer as measured by the tidal efficiency ranged from 2 to 42 percent. The presence of a sloping shoreline and a sheet pile seawall alter the tidal response.

The aquifer test data were evaluated using a combination of traditional aquifer test analytical methods and aquifer test modeling using MODFLOW. In applying the analytical methods, two approaches were used to extract the drawdown signal from the tidally influenced water level data. The first approach relies on visually estimating the drawdown curve. The visual approach requires a strong drawdown signal relative to the tidal signal to construct the drawdown curve and only provides a rough estimate of the drawdown signal. The second approach attempts to filters out the tidal signal using a linear least squares fit method or a spectral decomposition method. Because the tidal signal is composed of a combination of various sine waves with different amplitudes and periods; long periods (14 to 30 days) of water level data are usually required to replicate the tidal signal. We had limited success in applying the filtering approaches primarily because of the challenge of collecting sufficient long periods of water level data. A numerical groundwater flow model was also used to evaluate the aquifer test data. Developing a groundwater flow model was complicated by defining the appropriate boundary conditions and calibrating to the observed transient heads. The results of this study show the value of using a combination of methods for determining hydraulic properties of a tidal influenced aquifer.

Hart Crowser, Inc. 1700 Westlake Avenue North, Suite 200, Seattle, Washington; Fax (206) 328-5581
[1] Senior Hydrogeologist; Telephone (206) 324-9530; E-mail: roy.jensen@hartcrowser.com
[2] Senior Staff Hydrogeologist; Telephone (206) 324-9530; E-mail: angie.goodwin@hartcrowser.com

Recent Temperature Surveys for Locating Ground-Water Discharge in River, Estuary and Nearshore Environments of Western Washington using Fiber-Optic Cable

Chris Curran[1], Rick Dinicola[2], and Jeff Duda[3]

Fiber-optic distributed temperature sensing (DTS) is a new tool that measures environmental temperatures over a large range of spatial and temporal scales with reported accuracies of 0.01 ^{o}C. Recently, the U.S. Geological Survey, as part of the Coastal Habitats in Puget Sound (CHIPS) program, conducted temperature surveys using fiber-optic DTS for the purpose of locating ground-water discharge in three different environments in Western Washington: a cobble-bed channel in the Elwha River, a pocket estuary at the mouth of the Elwha River, and nearshore intertidal zones in the Strait of Juan de Fuca and at the southeast tip of Whidbey Island.

In all deployments, a 3-mm-diameter fiber-optic cable that varied in length between 1.2 and 1.5 km was laid at or near the sediment-water interface. A Sensortran™ DTS unit was used to send a laser pulse through the glass core of the cable and compute fiber temperatures based on the Raman spectra of backscattered light. Temperature profiles were sampled every 5 minutes during deployments that lasted from 19–24 hours.

In both the river and estuary deployments, areas of ground-water discharge were located based on measured temperature contrasts. Ground-water temperatures remained constant, while surface-water temperatures changed over the course of the diurnal cycle due to solar heating. In the river, areas of ground-water discharge were identified in riffle-pool sequences and adjacent to side-channels. In the estuary, changing surface-water temperatures also resulted from the flux of tidal marine water and revealed the circulation pattern of estuary mixing. In the nearshore environment, subtle temperature differences were measured along the intertidal zone and over time as a result of changing tides. In this environment and season (early September), the temperature contrast between submarine ground-water discharge and the marine receiving waters was more difficult to discern. One nearshore deployment compared the sensor response between a buried and unburied cable to help discern subtle temperature differences between ground-water discharge and receiving waters. Fiber-optic DTS has the advantage over traditional temperature loggers of providing continuous spatial and temporal temperature profiles over long distances and will likely emerge as a preferred tool for temperature surveys in hydrologic applications.

U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402; Fax: (253) 552-1581
[1] Telephone: (253) 552-1614; E-mail: ccurran@usgs.gov
[2] Telephone: (253) 552-1603; E-mail: dinicola@usgs.gov
U.S. Geological Survey, Western Fisheries Research Center, 6505 NE 65th St., Seattle, WA 98115; Fax: (206) 526-6654
[3] Telephone: (206) 526-6282 ext. 233; E-mail: jduda@usgs.gov

Combined Effect of Anthropogenic Hydrological Alterations and Complex Hydrogeology on a TCE Plume

Kenneth J. Reid[1], Jerry R. Ninteman[2], Y. Nicholas Garson[3], and Alan Sugino[4]

This presentation will discuss the interactions between the complex hydrogeology and various anthropogenic alterations within the Powder Mill Gulch drainage north of the Boeing plant in Everett, Washington as well as their combined effect on a dissolved TCE plume. A hydrogeologic investigation has been underway since March 2003 as part of a MTCA agreed order to assess the source of TCE contamination in Powder Mill Gulch and to determine the extent of the dissolved phase plume.

Numerous influences exist on groundwater flow and discharge to Powder Mill Creek between the headwaters immediately north of the Boeing Everett Plant and the mouth of the creek approximately 1.7 miles north in Port Gardner Bay. The natural hydrogeologic influences include a regional north-northwesterly groundwater flow direction locally influenced by the gaining portions of Powder Mill Creek, an Esperance Sand aquifer that is divided into two distinct vertical zones via an approximately 4 ft thick silt interbed that underlies most of the study area, the Lawton Clay regional aquitard, and alluvial deposits. The anthropogenic influences include a 20 million gallon stormwater detention basin and a constructed wetland/peat filter stormwater treatment system that both discharge directly to the creek, culverts within the creek, creek realignments, and underground utilities.

Following the initial detections of TCE in the perennial portion of Powder Mill Creek, subsequent investigations identified a more wide-spread dissolved-phase plume with the source area located beneath the stormwater detention basin. From this source area the dissolved-phase TCE plume proved challenging to delineate as Powder Mill Creek incised into the two zones of the Esperance Sand aquifer and the numerous influences on groundwater flow mentioned above came into play.

Landau Associates, 130 2nd Ave South, Edmonds, WA 98020; Telephone (425) 778-0907; Fax: (425) 778-6409
[1] *E-mail: kreid@landauinc.com*
[2] *E-mail: jninteman@landauinc.com*
[3] *The Boeing Company, Boeing EHS Group, P.O. Box 3707, MC 6R4-26, Seattle, WA 98124; Telephone (425) 269-7866; E-mail: nick.garson@boeing.com*
[4] *The Boeing Company, BCA-Everett Environmental Affairs, P.O. Box 3707, MC OP-88, Seattle, WA 98124-220; Telephone (425) 266-8173; E-mail: alan.k.sugino@boeing.com*

Vadose Zone Monitoring of the T-Tank Farm Interim Surface Barrier

Z. Fred Zhang[1], Chris E. Strickland[2], Jim G. Field[3], and Dan L. Parker[4]

A temporary surface barrier has been constructed over a portion of the Hanford's T Tank Farm as part of the T Farm Interim Surface Barrier Demonstration Project. The surface barrier is designed to minimize the infiltration of precipitation into the contaminated soil zone created by the Tank T-106 leak and reduce the rate of movement of the contamination. As part of the demonstration effort, vadose zone moisture is being monitored to assess the effectiveness of the barrier at reducing soil moisture. A solar-powered and remotely controlled system was installed to continuously monitor soil water conditions at four locations (i.e., instrument Nests A, B, C, and D) beneath the barrier and outside the barrier footprint as well as site meteorological conditions. Each instrument nest is composed of a capacitance probe with multiple sensors, multiple heat-dissipation units, and a neutron probe access tube. The principal variables monitored for this purpose are soil-water content and soil-water pressure. Soil temperature, precipitation, and air temperature are also measured. Nest A is placed in the area outside the barrier footprint and serves as a control, providing subsurface conditions outside the influence of the surface-barrier. Nest B is placed at the western edge of the surface barrier, but beneath the barrier. Nest B provides subsurface measurements to assess surface-barrier edge effects. Nests C and D are placed in the area covered by the barrier and are used to assess changes in soil-moisture conditions beneath the interim surface barrier. Monitoring began on September 2006 and continues to the present. Monitoring is planned to continue for two years after the barrier was emplaced. Data collected and stored in the dataloggers can be retrieved remotely any time. To date, the monitoring system has provided continuous high-quality data. The monitoring data in FY 2007 and early FY2008 reflect the baseline of the soil water condition. The data in late FY 2008 and after show the impacts of the surface barrier on soil water conditions.

Pacific Northwest National Laboratory, Richland, WA.
[1] *Telephone: (509) 372-4866; Email: Fred.Zhang@pnl.gov*
[2] *Telephone: (509) 372-6431; Email: Christopher.Strickland@pnl.gov*
Washington River Protection Solutions, Richland, WA
[3] *Telephone: (509) 376-3753; Email: Jim G_Field@rl.gov*
[4] *Telephone: (509) 372-0766; Email: Danny_L_Parker@rl.gov*

Dissolution and Precipitation of Hanford Soil and Fe-Rich Micas During Contact with Tank Waste Leachates and Their Bearing on Aqueous Tc(VII) Attenuation

Jonathan P. Icenhower[1], Nikolla P. Qafoku[2], Christopher F. Brown[3], R. Jeffery Serne[4], C. Thomas Resch[5] and Yuanxian Xia[6]

Production of atomic weapons or nuclear power produces a large amount of ^{99}Tc (~6% yield). The long half-life of ^{99}Tc (2.13×10^5 years) coupled with its high mobility in near surface oxidizing conditions renders this isotope a major contaminant of concern at Hanford, Washington. The bulk of ^{99}Tc resides in 177 underground single- and double-shell tanks along with caustic high ionic strength solutions and sludge awaiting final disposition. Loss of ^{99}Tc-bearing solution from the single-shell tanks to the subsurface has resulted in concentrated contaminant plumes beneath the tanks. The fate of radionuclide elements, such as ^{99}Tc, in this dynamic system of neo-phase formation has not been rigorously determined. We carried out experiments in which a Simulated Tank Waste Leachate (STWL), doped with low concentrations of ^{99}Tc (10^{-6} to 10^{-7} M), was contacted with either Hanford soil or a variety of Fe-rich micas (biotite, clinochlore, or saponite). Ferrous (Fe^{2+})-rich micas may be key components in determining the fate of Tc(VII), if the reductant Fe^{2+} is released and then sorbed onto other soil mineral surfaces.

Preliminary experimental results, conducted at 22° and 50°C, showed that the STWL (1 M NaOH, 1 M $NaNO_3$) caused rapid dissolution and re-precipitation in Hanford soil. Concentrations of Si, Al, Fe and K all rise in the solutions over the course of the experiments (up to 60 days) conducted at 22°C, but Al rises, then drops rapidly, in experiments at 50°C. Concentrations of ^{99}Tc drop and computed partition coefficients, or K_d's, range from 0.54 to 0.70 L/Kg. Another set of experiments were carried out with a STWL that also contained 0.11 M Al, but partitioning of ^{99}Tc was less strong (K_d = 0.10 to 0.24 L/Kg) compared to the Al-absent STWL. Imaging of the post-run products by SEM showed that abundant cancrinite-zeolite phases formed, and these may harbor ^{99}Tc. In sum, the experiments indicate that moderate attenuation of ^{99}Tc is possible in soils affected by migrating caustic, high salinity tank waste plumes.

Pacific Northwest National Laboratory, Applied Geology and Geochemistry Group, 902 Battelle Blvd., K6-81, Richland, WA 99352; Fax: (509) 371-7249
[1] *Telephone: (509) 371-7184; E-mail: jonathan.icenhower@pnl.gov*
[2] *Telephone: (509) 371-6089; E-mail: nik.qafoku@pnl.gov*
[3] *Telephone: (509) 376-8389; E-mail: christopher.brown@pnl.gov*
[4] *Telephone: (509) 376-8429; E-mail: jeff.serne@pnl.gov*
[5] *Telephone: (509) 375-6860; E-mail: tom.resch@pnl.gov*
[6] *Telephone: (509) 373-5767; E-mail: xuanxian.xia@pnl.gov*

Use of Large-Scale Aquifer Dye Tracer Test for Design of *In-situ* Bioremediation Through Vegetable Oil Injection

Clinton L. Jacob[1], Benni Jonsson[2], Christine B. Kimmel[3], Kenneth G. Chaput[4], Jennifer A. Parsons[5], and Mavis D. Kent[6]

A large-scale aquifer tracer test was implemented to support design of electron donor substrate injection for stimulation of bioremediation at an aerospace manufacturing facility in Portland, Oregon. TCE is present in an upper unconfined aquifer and lower confined aquifer where a groundwater pump and treat system has operated since 1997 to provide hydraulic containment and for mass removal. Dye tracer testing was performed to obtain design parameters for donor injection and to determine the influence of extraction wells that will continue to operate for hydraulic containment. The target treatment zone is 30 to 70 ft of saturated clean to silty, sandy gravel in the unconfined aquifer, over an area of approximately 150,000 ft^2 (i.e., 280,000 yd^3 aquifer).

Tracer injection was performed in March 2008 using 95,000 gallons of rhodamine WT dye solution and 26,000 gallons of fluorescein dye solution injected into two wells planned for donor injection. Results discussed will include estimates of maximum dye extent, groundwater seepage velocity, radius of injection, and effective porosity for flow.

The bioremediation design utilizes six existing wells (to be decommissioned due to facility expansion) and two new temporary wells for a one-time electron donor injection. The total design injection volume is 240,000 gal, consisting of a 20 percent oil-in-water emulsion utilizing 10 tanker truck loads (400,000 lb / 53,290 gal) of vegetable oil/surfactant mixture. Extraction wells will be operated selectively during injection to distribute emulsion in the target treatment zone and to minimize transport toward extraction wells that will operate following injection. Contingency measures will address groundwater treatment system fouling and unacceptable concentrations of biological oxygen demand (BOD) and dissolved metals in the system discharge, conditions that could occur due to extraction of reduced groundwater from some extraction wells operated for containment following donor injection. Electron donor injection is planned for October 2008.

Landau Associates, 130 2nd Ave South, Edmonds, WA 98020; Telephone (425) 778-0907; Fax: (425) 778-6409
[1] E-mail: cjacob@landauinc.com
[2] E-mail: bjonsson@landauinc.com
[3] E-mail: ckimmel@landauinc.com
The Boeing Company, PO Box 3707, MC 7A-XP, Seattle, WA 98124
[4] Telephone: (416) 420-7178; Fax: (425) 965-4180; E-mail: Kenneth.G.Chaput@Boeing.com
[5] Telephone (206) 715-7981; Fax (425) 965-4180; E-mail: Jennifer.A.Parsons@Boeing.com
[6] Oregon Department of Environmental Quality, 2020 SW 4th Ave, Suite 400, Portland, OR 97201; Telephone: (503) 667-8414; Fax: (503) 674-5418; E-mail: Kent.Mavis.D@deq.state.or.us

A Historical Perspective on Riverbank Spring Discharges From the Hanford Site to the Columbia River

Gregory W. Patton[1], Robert E. Peterson[2], and Roger L. Dirkes[3]

Past operations at the Hanford Site have resulted in the release of radiological and chemical contaminants to the soil column, groundwater, and ultimately to the nearshore environment along the Columbia River shoreline. Riverbank springs along the Hanford Site bank of the river have been a concern since plutonium production reactors began operating in the late 1940s. Comprehensive sampling of selected riverbank springs at the Hanford Site to monitor legacy contaminants in groundwater that discharges to the river began in 1988 and continues today under the DOE's Public Safety and Resource Protection Program. Riverbank spring water samples have been analyzed for a broad range of radiological and chemical contaminants. The results are evaluated in the context of potential contamination exposures to humans, who use the Hanford Reach for recreational activities, and to other biological receptors that use the shoreline habitat. Information from the program also provides technical information that is used to support environmental restoration decisions.

A recent study presents a comprehensive review of long-term monitoring results for selected locations along the shoreline adjacent to the Hanford Site facilities. Long-term monitoring provides valuable insight because riverbank spring discharges along this shore are heavily influenced by river stage. Significant river stage changes occur over daily, weekly, and seasonal cycles, with variations up to 2 m within a few hours. Bank storage of river water affects the contaminant concentrations of nearshore groundwater and riverbank spring water. The contrast in specific conductivity of river water (<135 µS/cm) with groundwater (>400 µS/cm) provides an indicator of the relative proportions of river water and groundwater in a sample. This information is used to provide insight on contaminant concentrations in groundwater that approaches the river.

Pacific Northwest National Laboratory, Richland, Washington 99352; Fax: (509) 371-7083
[1] *Telephone (509) 371-7071; E-mail: gw.patton@pnl.gov*
[2] *Telephone (509) 371-7226; E-mail: robert.peterson@pnl.gov*
[3] *Telephone (509) 371-7085; E-mail: rl.dirkes@pnl.gov*

Contaminant Concentration Variability in a Dynamic Hydrologic Setting: Implications for Monitoring

Robert E. Peterson,[1] Steven B. Yabusaki,[2] and Mark D. Williams[3]

Contaminant concentrations and mobility characteristics in groundwater at a contaminated site near the Columbia River are influenced by rapidly changing hydrologic conditions. The principal driver for these changes is cyclic variability in river discharge, along with the corresponding variability in river stage near the site. The cyclic variations in the presence of highly transmissive aquifer sediment result in the intrusion of river water into the near-river aquifer and changes in water table elevation throughout the area of groundwater contamination. Contaminant concentrations in this dynamic environment change rapidly because of a) mixing between groundwater and uncontaminated river water, and b) the resupply of contaminants to groundwater via downward movement through the lower portion of the vadose zone, including the zone through which the water table rises and falls. Concentration variability for some contaminants may be introduced also by rapid changes in the geochemical environment where groundwater and river water mix.

The implications of these dynamics for monitoring involve the rapidly changing hydraulic gradients and geochemical conditions. Groundwater movement patterns are complex and need to be considered in the design of monitoring wells and when developing a strategy for collecting samples. An appropriate sampling frequency may need to be tied more closely to seasonal cycles than to sampling at equal time intervals. The rapid change in river conditions even may warrant sampling as frequently as hourly. Likewise, rapid changes in the geochemical environment, which may influence the exchange of contaminants between dissolved forms and aquifer solids, should be considered when developing a monitoring strategy. The variability in contaminant conditions and the periods during which ecological receptors are vulnerable also can be factored into the monitoring strategy.

This analysis of groundwater monitoring results emphasizes the importance of understanding the features and processes associated with contaminant behavior in subsurface environmental pathways when developing a conceptual model to support remediation decisions. Such understanding is relevant to developing an effective and efficient monitoring strategy, in evaluating remediation technologies, and in developing remedial action compliance monitoring criteria. Lessons learned at the representative sites are applicable to other sites located near the interface of hydrologic systems, such as tidal areas.

Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352
[1] *Telephone (509) 371-7226; Fax (509) 371-7083; mail stop K6-75; E-mail: robert.peterson@pnl.gov*
[2] *Telephone (509) 372-6095; Fax (509) 372-6089; mail stop K9-36; E-mail: yabusaki@pnl.gov*
[3] *Telephone (509) 371-7146; Fax (509) 372-6089; mail stop K6-96; E-mail: mark.d.williams@pnl.gov*

Evaluation of Lateral and Vertical Temperature Trends in a Shallow Unconfined Aquifer Adjacent to the Columbia River, Chelan County, Washington

James E. Hay[1]

Access to substantial volumes of cool, pathogen-free ground water is essential to the success of most salmonid hatchery operations. Chelan County PUD operates numerous hatchery programs in concert with its hydroelectric power generation facilities and is currently evaluating the expansion of hatchery operations near Chelan Falls, Washington. The PUD’s existing wellfield extracts water from a very productive, shallow, unconfined aquifer in close communication with the Columbia River. The temperature of the extracted ground water is dominated by the seasonal temperature swings of the adjacent Columbia River, which ranges from 2C (36˚F) to 20˚C (68˚F) and exceeds 13˚C (55˚F) from mid -June through mid-November. Although previous investigations have determined the Columbia River is not thermally stratified due to the rapid exchange of water through the system, portions of the aquifer are thermally stratified. To evaluate both lateral and vertical temperature trends within the aquifer, our investigation deployed temperature probes at multiple depths within available, inactive (unpumped) wells.

Water level and temperature data has been collected at the site for over a year. Water levels in the wells respond to changes in Columbia River stage within minutes to hours, depending on proximity of the well to the river. Much in the same way, the temperature of the river dominates ground water temperatures, particularly in response to pumping. Cool water is preferentially drawn through the upper part of the unconfined aquifer from the river during the winter months, and aquifer temperatures generally increase with depth. Conversely, warm water from the river is drawn into the shallow groundwater system during the summer months and aquifer temperatures will decrease with depth. More unusual findings include: thermal transfers within well borings with discontinuous screened intervals; documentation of the heat contributed by a submersible pump; and a previously unrecognized heat source on the southern end of the property.

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[1] *Robinson, Noble & Saltbush, Inc., 3011 S. Huson St., Suite A, Tacoma, WA 98409; Telephone: (253) 475-7711; Fax: (253) 472-5846; E-mail: jhay@robinson-noble.com*

Influence of the Hyporheic Zone on Supersaturated Gas Exposure to Incubating Chum Salmon

Evan V. Arntzen[1], David R. Geist[2], Katherine J. Murray[3], John Vavrinec[4], Earl M. Dawley[5], and Dennis E. Schwartz[6]

Supersaturated total dissolved gas (TDG) is elevated seasonally in the lower Columbia River, with surface water concentrations approaching 120% saturation of TDG. Chum salmon (*Oncorhynchus keta*) embryos incubating in nearby spawning areas could be affected if depth-compensated TDG concentrations within the hyporheic zone exceed 103% TDG. The objective of this study was to determine if TDG of the hyporheic zone in two chum salmon spawning areas—one in a side channel near Ives Island, Washington, and another on the mainstem Columbia River near Multnomah Falls, Oregon—was affected by the elevated TDG of the surface water. Depth-compensated hyporheic TDG did not exceed 103% at the Multnomah Falls site. However, in the Ives Island area, chum salmon redds were exposed to TDG greater than 103% for more than 600 hours. In response to river depth fluctuations, TDG varied significantly in the Ives Island area, suggesting increased interaction between the hyporheic zone and surface water at that site. We conclude from this study that the interaction between surface water and the hyporheic zone affects the concentration of TDG within the hyporheic zone directly via physical mixing as well as indirectly by altering water chemistry and thus dissolved gas solubility. These interactions are important considerations when estimating TDG exposure within egg pocket environments, facilitating improved exposure estimates, and enabling managers to optimize recovery strategies.

Pacific Northwest National Laboratory, Post Office Box 999, Richland, WA 99352
[1] Telephone: (509) 371-7201; Fax: (509) 371-7160; E-mail: evan.arntzen@pnl.gov
[2] Telephone: (509) 371-7165; Fax: (509) 371-7160; E-mail: david.geist@pnl.gov
University of Washington College of Forest Resources, Post Office Box 352100, Seattle, WA 98195
[3] Telephone: (509) 528-3678; Fax: (206) 685-0790; E-mail: kjm22@gmail.com
Pacific Northwest National Laboratory, 1286 Washington Harbor Road, Sequim, WA 98382
[4] Telephone: (360) 681-3665; Fax: (360) 681-3681; E-mail: john.vavrinec@pnl.gov
National Oceanic and Atmospheric Administration (retired), 561 Grand Avenue, Astoria, OR 97103;
[5] Telephone: (503) 616-3906; E-mail: dawleys@charter.net
U.S. Army Corps of Engineers, Portland District, 333 SW First Avenue, Portland, OR 97204
[6] Telephone: (503) 808-4779; E-mail dennis.e.schwartz@nwp01.usace.army.mil

Blending Remediation Technologies Accelerates Defensible Site Closure

Craig Dockter[1] and Troy Fowler[2]

Chlorinated solvent contamination of soil and groundwater is a growing concern for regulators and property owners. Traditional remediation approaches, including groundwater and vapor extraction, mitigate immediate risk but are rarely able to achieve site closure within acceptable timeframes. Reductive *in situ* bioremediation has accelerated site closure for numerous sites around the world. However, long-term groundwater concentration rebound is frequently observed following completion of an inadequately designed bioremediation project. As a result, cleanup levels may be exceeded, delaying site closure, increasing remediation costs, and extending mitigation efforts.

This phenomenon is often the result of both *in situ* and remediation heterogeneity. Small differences in geology, aqueous geochemistry, and contaminant distribution impact the long-term effectiveness of reductive bioremediation. Additionally, differences in amendment distribution and biological activity may leave some areas over-treated and others under-treated.

By selecting proven combinations of bioremediation approaches, a faster and more defensible path to site closure can be obtained. This includes utilizing a variety of injection techniques and configurations, as well as amendments displaying a variety of biological and chemical characteristics. Based on site conditions, the most effective combination of amendment distribution options may include recirculation, push probe injections, slug injections, or trenching. By utilizing a blend of short-term and long-term electron donors, hydrophobic and hydrophilic amendments, and various essential nutrients, specific treatment zones can be established to accelerate defensible site closure.

Hart Crowser, Inc; 8910 SW Gemini Drive, Beaverton, OR, 97008-7123; Fax: (503) 620-6918
[1] *Senior Associate Engineering Geologist; Telephone: (971) 327-9102; E-mail: craig.dockter@hartcrowser.com*
[2] *Project Biochemist; Telephone: (971) 327-9113; E-mail: troy.fowler@hartcrowser.com*

What Can Bio Do For You?

Clinton L. Jacob[1] *and* ***Benni Jonsson***[2]

Enhanced in-situ bioremediation (EISB) has application to many different contaminants, hydrogeologic settings, contaminant plumes, and contaminant source zones, and can be applied through a number of strategies tailored to site-specific conditions. EISB is increasingly selected because it results in contaminant destruction or immobilization (not ex-situ transfer to a different media), with lower cost, less disruption/exposure, and often less time than more traditional engineered remedies. EISB is an evolving field with ongoing new discoveries and refinements.

EISB can be successfully applied to a large number of contaminants, including:

- Petroleum hydrocarbons
- Chlorinated solvents (chloroethenes, chloromethanes, chloroethanes)
- Other VOCs (e.g., acetone, MEK, chlorobenzene)
- Metals (As, Co, Cd, Cr, Cu, Hg, Ni, Zn) (Ur and Tc-99-partial immobilization)
- Energetics- TNT, RDX, HMX, perchlorate
- Nitrate, sulfate, cyanide
- PAHs, PCBs, pesticides (limited success).

The success of EISB is intrinsically tied to aquifer oxidation/reduction (redox) conditions before, during, and after active treatment. The bacteria responsible for contaminant degradation/immobilization function under specific redox conditions, both aerobic and anaerobic. Different target contaminants require specific aquifer redox conditions and corresponding bacteria for successful treatment.

EISB is stimulated through aquifer or vadose zone delivery of various electron donor/acceptor substrates. Substrates are delivered through injection/infiltration of liquids or slurries, or construction of solid substrate reactive barriers. The preferred treatment approach depends on aquifer characteristics including, depth, saturated thickness, permeability, heterogeneity, natural redox, and groundwater velocity.

Required treatment time may be months to years dependant on contaminant type and concentration, aquifer heterogeneity, groundwater velocity, and treatment approach.

Landau Associates, 130 2nd Ave South, Edmonds, WA 98020; Telephone: (425) 778-0907; Fax: (425) 778-6409;
[1] *E-mail: cjacob@landauinc.com*
[2] *E-mail bjonsson@landauinc.com*

Combined Emulsified Oil-pH Buffer for ERD in Acidic Aquifers

Gary M. Birk[1], *P.E.*; *M. Tony Liebereman*[2], *RSM*; and *Rose Riedel*[3]

Enhanced reductive dechlorination (ERD) can be a very effective approach for groundwater remediation. However, dechlorinators are pH sensitive and dechlorination rates decline below a pH of 6. Reductive dechlorination can significantly reduce the pH in poorly buffered aquifers where a neutral pH is required for biodegradation to proceed. A neutral pH can be maintained using aqueous buffers (commonly $NaHCO_3$). However, this procedure is maintenance intensive and can significantly increase the salt concentration of the aquifer.

An alternative and more effective approach is to simultaneously inject combined soybean oil solid pH buffer emulsion. As the oil-buffer emulsion migrates through the aquifer, chlorinated solvents will partition into the oil. Within a short period of time, the oil-buffer droplets attach to the aquifer solids, providing an ideal environment for reductive dechlorination since the oil droplet contains electron donor (oil), electron acceptor (chlorinated solvent) and a pH buffer to maintain a neutral pH. This presentation will provide information/strategies regarding:

- Anaerobic Biodegradation and pH
- Aquifer Geochemistry and pH
- Aquifer pH Adjustment

[1] *EOS Remediation, LLC, 1101 Nowell Road, Raleigh, North Carolina 27607; Telephone (919) 873-2204; E-mail: gbirk@eosremediation.com*
[2] *Solutions-IES, Inc., 1101 Nowell Road, Raleigh, North Carolina 27607; Telephone (919) 873-1060; E-mail: tlieberman@solutions-ies.com*
[3] *Olympic Environmental Equipment, LLC, 9400 NE Harris Avenue, Indianola, WA 98342; Telephone: (360) 297-5409; E-mail: rose@olympicenv.com; rose@olympicenv.com*

Remediation of Rapidly Moving LNAPL in Bedrock Under Emergency Conditions near Crystal Mountain, Washington

*Jim Miller[1], Steve Woodward[2], Jay Lucas[3], **Rob Leet[4]**, and John Rork[5]*

On November 3, 2006, 18,000 gallons of diesel was released to the ground surface at the site of Puget Sound Energy's backup electrical generator near the Crystal Mountain Ski Resort, just outside Mt. Rainier National Park. The spill site is located on the flank of a north-facing alpine valley at an altitude of approximately 4,100 feet. The site is underlain varying thicknesses of glacial sediment, colluvium, and alluvium deposits that rest above fractured volcaniclastic bedrock.

Emergency response teams were mobilized immediately. Two days after the fuel spill, a diesel seep emerged from a natural groundwater spring located 750 feet downslope of the original spill location. Some of the diesel entered nearby Silver Creek, a perennial alpine stream with small public water supply intakes located about 4 miles downstream. Other springs in close proximity to the original fuel seep began discharging diesel over the next two weeks. A relatively narrow, directionally-biased bedrock fracture system controlled the subsurface migration pathway of the diesel. The diesel plume flowed under confined conditions beneath the unconsolidated surficial deposits for much of the distance between the diesel spill and the fuel seeps.

The sloping, forested fuel seep area was initially inaccessible to construction equipment. Weather conditions during the emergency response also were extremely difficult, including a period of intense rainfall and flooding followed by heavy snowfall. After initial containment of the fuel seep, an interceptor trench extending into fractured bedrock was designed and constructed in the fuel seep areas. The interceptor trench and its associated water treatment equipment were installed and operational by early December. The interceptor trench successfully captured the leading edge of the diesel plume and prevented further migration of free product and dissolved-phase contaminants.

GeoEngineers, 8410 154th Ave NE, Redmond, WA, 98052; Telephone: (425) 861-6000; Fax: (426) 861-6050;
[1]E-mail: jmiller@geoengineers.com
GeoEngineers, 600 Stewart St, Ste 1700, Seattle, WA, 98101; Telephone: (206) 728-2674; Fax: (206) 728-2732
[2] E-mail: swoodward@geoengineers.com
[3] E-mail: jlucas@geoengineers.com
[4] E-mail: rleet@geoengineers.com
[5] Puget Sound Energy, 10885 NE 4th St, PSE-11N, Bellevue, WA, 98004; Telephone: (425) 456-2228; Fax: (425) 462-3587; E-mail: john.rork@pse.com

Integrating Water Right, Well Log and Water System Databases Through GIS for Island County and the Department of Ecology

Robert A. Smith[1], Joel W. Purdy[2] and Michael A. P. Kenrick[3]

Island County, Washington, is generally rural and obtains virtually all drinking water supplies from groundwater. There are more than 300 Group A water systems regulated by the County and State health departments. The adopted Island County Water Resources Management Plan (WRIA 6) contains water management recommendations to improve data collection, monitoring and coordination between regulatory agencies. A key component to fulfilling these recommendations is better electronic data collection. Local and state regulatory agencies each had their own electronic databases and geographical information system (GIS) structures. The different systems were not integrated and retrieving information on public water systems required separate searches of Department of Ecology (Ecology), Department of Health (Health) and Island County Health Department (County Health) files and planning databases. Integrating the data collection through a GIS data system was a critical step.

Ecology contracted GeoEngineers to help the County develop GIS data for the service area boundaries and water right places-of-use for all Group A water systems. In addition, GeoEngineers used well information available from County Health's Microsoft Access database to map points of withdrawal. A major challenge was how to match up water system service areas in Ecology's water right files with the service area boundaries maps in files at Health and County Health. The solution involved digitizing Ecology's county water right certificates and permit documentation from its Water Rights Tracking System database (WRTS). Service area boundaries were digitized and snapped to parcel boundaries made available from Island County's GIS database. Then, GeoEngineers developed GIS topology to check the completeness and accuracy of the data overlays. In addition to integrating all the data from various sources, this project helped County Health to identify and fill gaps in its database. The County is refining the data and moving toward the ultimate goal of using the database as a resource for its permitting process. This presentation discusses some of the major challenges, solutions and lessons learned for others interested in following similar pursuits.

[1]*GeoEngineers, Inc. 1101 S Fawcett Ave, Suite 200, Tacoma, WA 98402; Telephone (253) 383-4940; E-mail: rsmith@geoengineers.com*
[2]*GeoEngineers, Inc. 1550 Woodridge Drive SE, Port Orchard, WA 98366; Telephone (360) 769-8400 E-mail: jpurdy@geoengineers.com*
[3]*GeoEngineers, Inc. 8410 154th Avenue NE, Redmond, WA 98052; Telephone (425) 861-6000 E-mail: mkenrick@geoengineers.com*

Using "High-Definition" Geographical Information System Datasets in Development of Ground-Water Flow Models

Ken Johnson[1]

Computer capacity has been increasing exponentially over several decades, in computational and communications speed, memory size, and software capabilities. Agencies that perform environmental research and protection are now able to develop large data sets to describe processes across large areal extents and periods of time yet are highly precise for fine details of the phenomena. Such large data sets may be considered to be "high definition" (HD), in an analogy to the capabilities of consumer electronic devices. HD data sets are becoming available publicly from various sources and can be obtained, combined, and analyzed synergistically to delineate features in the environment that could not be discerned before highly capable computer systems were available. Most of these datasets are best combined and analyzed through Geographical Information Systems (GIS) software, although other readily accessible software packages also can assist analysis of large data sets.

A common tool for environmental interpretation is ground-water modeling, and many features of the environment must be determined and input to a model. Proprietary Graphical User Interfaces (GUIs) are available to make the process of inputting features easier, but the physical data must be established before it can be input, and HD datasets provide much of these data. Physical features of the environment include: elevations of ground surface and subsurface hydrogeologic layers; extents of geologic deposits; precipitation and recharge inflows through various surface geologic and anthropogenic constraints; surface water stream channel locations and widths, elevation profiles, and flow rates (hydrography); well locations and pumpage rates; lake extents, surface elevations, and depths; return flows to aquifers from septic systems; and ground-water discharges to, and locations of, springs.

The U.S. Geological Survey Washington Water Science Center has been developing ground-water models for aquifer systems in Washington State for many years. Two models currently under development are for aquifers in the lower Skagit Valley area of Skagit and Snohomish Counties, and in the Chambers–Clover Creek basin in Pierce County. These two projects provide examples of HD datasets that were obtained, analyzed, and used to enhance the modeling environment.

[1] *U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402; Telephone: (253) 552-1629; Fax: (253) 552-1581, E-mail: johnson@usgs.gov*

Data and Information Management To Support Remedial Decisions

G.V. Last[1], P.D. Thorne[2], C.J. Murray[3], B.A. Williams[4], R. Khaleel[5], and W.D. Webber[6]

The selection of a preferred remedial action is strongly dependent on thorough analysis of site-specific data and information regarding the nature and extent of contamination, its baseline risks, and projected future risks under various scenarios/remedial alternatives. Numerical analysis and prediction of subsurface contaminant transport are critical tools in these analyses. The complexity of these analyses is dependent on how close the projected results (and associated errors) are to decision thresholds. Where bounding errors from simple analyses overlap with the decision thresholds, the decisions are not obvious and there is more need (and more scrutiny) placed on additional analyses, to narrow the bounding errors and improve resolution of the remedial decision. The conceptual model and basic assumptions, as well as the input parameters included in these numerical analyses are often key points of contention. Traceability and defensibility of these assumptions and parameters back to the raw site-specific field data and observations are crucial to final acceptance of the remedial decisions.

Today, the Hanford Site is engaged in arguably the world's largest remediation effort involving hundreds of waste sites. The US Department of Energy (DOE) recognized the need for a systematic approach to developing conceptual models and parameter assumptions based on, and traceable to, a consistent set of data. To this end, the Soil and Groundwater Remediation Project (currently managed by CH2M Hill Plateau Remediation Company), with participation from various DOE offices and coordination boards, has been charged with development and maintenance of common databases, parameterization, and parameter estimates that form the basis for the various environmental assessments.

Over the last 60 years, the Hanford Site has generated a vast amount of highly variable subsurface data from over 7500 boreholes. These data provide the primary technical basis for interpreting the subsurface framework and the spatial distribution of physical, hydrologic, and geochemical properties. Efforts are currently underway to assemble, integrate and manage (under configuration control) historic interpretations of the major geologic contacts and to select and verify best estimate contact values traceable to the raw borehole data. From this a three-dimensional geologic model has been developed for a portion of the Hanford Site to provide the basis for assignment of assessment-specific parameters that are traceable, reproducible, defensible, and internally consistent.

Pacific Northwest National Laboratory, P. O. Box 999, K6-81, Richland, WA 99352
[1] Fax: (509) 371-7249; Telephone: (509) 371-7080; E-mail: george.last@pnl.gov
[2] Fax (509) 371-7174; Telephone: (509) 371-7220; E-mail: paul.thorne@pnl.gov
[3] Fax (509) 371-7249; Telephone: (509) 376-5848; E-mail: Chris.Murray@pnl.gov
[4] CH2M Hill Plateau Remediation Company, 1200 Jadwin Ave., E6-44, Richland, WA 99352; Fax: (509) 376-2344; Telephone: (509) 376-3060; E-mail: Bruce_A_Williams@rl.gov
[5] Fluor Government Group, 1933 Jadwin Ave., B6-06, Richland, WA 99352; Fax: (509) 376-2265; Telephone: (509) 376-6903; E-mail: Raziuddin_Khaleel@rl.gov
[6] CH2M Hill Plateau Remediation Company, 1933 Jadwin Ave., B6-06, Richland, WA 99352; Fax: (509) 376-2265; Telephone: (509) 376-4744; E-mail: William_D_Webber@rl.gov

Workflow Automation in Environmental Data Management

Sarah Wright[1]

As the volume of soil and groundwater contamination data increases for known and suspected contaminated sites, many environmental agencies, industrial firms, and environmental consulting groups seek to automate large parts of the environmental data management process. While it is necessary to build *ad hoc* queries and look at data in different ways, it is also possible to build automated systems and sub-systems that operate on the data in a fixed manner. Automated systems for data loading and data reporting in response to specific "triggers" in the data have been developed and are being implemented widely across the United States.

With standardized formats for incoming Electronic Data Deliverables (EDDs) in place, incoming EDDs can be screened for correctness and completeness and loaded into EQuIS. Upon a 'pass', the submitter receives an email acknowledging the completed data submission and the data are loaded into EQuIS. Upon a failed EDD, an email is returned with the error log and the data are not loaded.

EQuIS Environmental Information Agents (EIAs) take workflow automation one step further. Agents are software modules that monitor data elements, such as the date or a particular data item, and then perform action(s) when the date or data trigger conditions are met. Reports are then emailed to a list of designated recipients ("no-keystroke reporting") or made available on the Internet/intranet/private network "dashboard" or portal.

[1] *EarthSoft Training Manager; E-mail: Swright@earthsoft.com*

Approaches for Assessing Ground-Water Availability Under Competing Demands and Climate Change

Matthew P. Bachmann[1], D. Matthew Ely[2], and John Vaccaro[3]

The Yakima River Basin in eastern Washington, like many areas of the arid American West, struggles with issues of water allocation. The 1 billion dollar agricultural economy in the basin lowlands is one of the largest in the United States and is principally based on the diversion of about 6,000 ft^3/s of surface water. The mountainous uplands generate the snowmelt runoff for irrigation and fish habitat, making riverine transport of surface water of paramount importance. Surface water in the basin is fully appropriated in average years and over-appropriated in dry years, but there are increasing demands for water for municipal, fisheries, agricultural, industrial, and recreational uses. These demands must be met through the use of groundwater, increased storage, greater conservation, and or purchasing water rights. In some areas, groundwater pumping has caused water level declines of more than 300 ft, potentially reducing streamflow in reaches with senior surface-water rights or instream flow requirements for endangered species. A variety of analytic tools have been developed to address the issues of water management under existing conditions, future growth scenarios, and potential regional climate change, including a comprehensive assessment of groundwater. The hydrologic and hydrogeologic framework that has been developed is integrated into an overlapping series of groundwater models. The models have been designed to evaluate 1) surface water impacts from existing pumpage and potential new pumpage, 2) effects of projected changes in climate on groundwater use, 3) potential improvements in irrigation efficiencies on water availability, 4) artificial recharge and aquifer storage systems, and 5) the relative utility of various aquifer management strategies. In combination, these approaches may lead to a way to accommodate municipal, agricultural, and ecological needs of the basin within the physical limitations of the hydrologic system.

U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA
[1] Telephone: (253) 552-1672; Email: mbachmann@usgs.gov
[2] Telephone: (253) 552-1622; Email: mely@usgs.gov
[3] Telephone: (253) 552-1620; Email: jvaccaro@usgs.gov

Simulated Hydrologic Response of a large Mesoscale Basin to Climatic and Physiographic Variability, and Relation to Atmospheric Indices

J.J. Vaccaro[1]

The potentially large variations in the hydrologic response within large mesoscale basins (on the order of 10^2-10^3 square kilometers) to climatic and physiographic variability have not received much attention. Therefore, the hydrologic response of the Asotin Creek Basin, a large mesoscale basin in southeastern Washington, was analyzed by first simulating water-budget components using a daily water-budget model, which captured much of the hydrologic variability. The water-budget components were then used as measures of the response.
The interaction of the responses of the semiarid lowland part of the basin and those of the more humid uplands results in a complex, nonlinear basin-wide response. A primary finding was that, by way of the hydrology of the root zone, intrabasin climatic and physiographic variability control the temporal and spatial distribution of the diverse and complex response.
The temporal and spatial variations in precipitation and the subsequently partitioned water-budget components are large, and are significantly linked to atmospheric circulation patterns as measured by correlations to two large-scale atmospheric circulation indices, the Southern Oscillation Index and the Pacific/North America Index. The indices are consistently related to seasonal totals of evapotranspiration and recharge. The relations of the indices to monthly totals were more complex. The analysis of the relations strongly indicated that global/ regional climatic variability significantly affect the hydrologic response in mesoscale basins at most time scales.

For at least the climatic regimes present in the Pacific Northwest, the hydrologic response of large mesoscale basins appears to be more a function of climatic variability than of hydrologic heterogeneity. The hydrology of large mesoscale basins should be considered in scaling up from field-plot studies or scaling down from general circulation model studies--this is especially true with respect to the spatial and temporal variability of soil moisture, snowpack, recharge, and evapotranspiration.

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[1] *U.S. Geological Survey, 934 Broadway, Suite 300, Tacoma, WA 98402; Telephone (253) 552-1620; E-mail: jvaccaro@usgs.gov*

Sequim Hydrologic System Overview: Observed Trends and a Glimpse Into The Future

Glen Wallace[1] and Peter Schwartzman[2]

Pacific Groundwater Group recently updated a study of hydrologic trends on the Dungeness Peninsula for the City of Sequim. Major sources of input to the hydrologic system include seasonal snowpack in the Olympic Mountain headwaters of the Dungeness River, precipitation recharge on the land surface, and recharge from leaky irrigation ditches. The study incorporates analysis of trends in snowpack, Dungeness River streamflow, recharge, groundwater levels, irrigation, and water use along with water quality. Groundwater use on the Dungeness Peninsula has increased steadily since 1970 in response to increased population and development – resulting in modest declines in groundwater levels. Lining of ditches has likely also contributed to the water-level declines. Meanwhile, global climate change has resulted in an approximately 60% decline in seasonal snowpack since 1940, and shifts in the timing and magnitude of Dungeness River instream flows. Published climate models of the Pacific Northwest suggest that the observed declining snowpack trends and changes in instream flows will continue for the foreseeable future. The resource demand and climate change trends seen in the Sequim area are mirrored in hydrologic systems throughout the Pacific Northwest. PGG discusses the implications on observed and expected hydrologic trends on water budgets and water resource management strategies for the Dungeness Peninsula.

Pacific Groundwater Group, 2377 Eastlake Avenue East, Seattle, Washington 98102
[1] *E-mail: glen@pgwg.com*
[2] *E-mail: peter@pgwg.com*

Where Is the Rain-on-Snow Zone in the West–Central Washington Cascades? Monte Carlo Simulation of Large Storms in the Northwest

Matthew J. Brunengo[1]

Western North America is susceptible to warm winter storms, when heavy rain plus melting snow can cause high streamflows and erosion. In the Pacific Northwest, most major episodes of regional flooding and landsliding occur during such events. Public recognition of these processes has grown since the mid-1800s, particularly during big events such as those in 1948, 1964-65, 1989-91, and 1996. Scientific research based on theory, instrumental records, and field studies have elucidated many aspects of the phenomena that became known as *rain-on-snow*. Notably, ROS seems more likely and hydrologically important in middle elevations; large-scale changes in land use can affect important processes; and climatic changes could be altering the geography and magnitude of ROS. Yet many questions remain, and many remain to be quantified, such as: how much does ROS affect the long-term frequency of water input? how can we determine the peak rain-on-snow zone, in at least one area within the Northwest?

Sporadic occurrence and spatial variability complicate the study of ROS using observations, but some issues can be addressed by modeling. A simple computer program combining probabilistic and deterministic elements performs Monte Carlo simulation of large “storms” over 1000 “years”, generating realizations of seasonal timing, pre-storm snowpack, and storm-weather conditions. In each model event, precipitation falls, snow accumulates and/or melts, percolation through snow is tracked, and water moves to the ground. The controlling frequency distributions are based on data from the western Washington Cascades (King and Pierce counties), some combined into functions of elevation and date, so the model can be applied to specific sites or generalized elevations. One version calculates snow and percolation for actual weather conditions, to test algorithms and calibrate parameters. Model validation focuses on Stampede Pass, site of a weather station, snow course and SNOTEL on the Cascade crest. The model is evaluated by comparing statistics and frequency-magnitude relations of the instrumental record against model realizations, for precipitation and water available for runoff.

The model is first used to estimate the significance of ROS as varying with elevation. Over a hypothetical millennium, the presence of snowpacks in some events usually reduces the amount of liquid water reaching the ground during model storms: more often where winter snow is common and deeper, but sometimes also at moderate elevations. Considering the results of several metrics, the model suggests that the greatest long-term ROS effect in this region occurs at ~800 m, where melt combines with rain to enhance water delivery to the ground during almost 20% of the major storms, and alters the frequency distribution to increase the magnitude of the rarer events.

[1] *Geology Department, Portland State Univ., P.O. Box 751, Portland, OR 97207-0751;*
E-mail: mbruneng@pdx.edu

An Updated Hydrogeological Conceptual Model of the Hawks Prairie Area of Thurston County

Eric Weber[1]**,** *Anthony Farinacci*[2]

The hydrogeology of the Hawks Prairie area of north Thurston County has been, until recently, relatively uncharacterized. The United States Geologic Survey (USGS) built a conceptual model based primarily on well driller logs and published sections of bluff outcrops along the Nisqually delta. This conceptual model was incorporated into a county-wide numerical groundwater flow model published by the USGS in 1999. Since about 2003, there have been a number of geologic and hydrogeologic studies completed by professional geologists. These studies include a number of carefully logged deep holes and pumping tests. Data from these studies provide information to significantly refine the hydrogeologic conceptual model.

The geologic setting in the Hawks Prairie area reflects Vashon age geologic deposits underlain by older interglacial, glacial and undifferentiated deposits. Vashon age deposits represent the standard sequence of recessional outwash (Qvr), glacial till (Qvt) and advance outwash (Qva). Underlying interglacial deposits or non-glacial deposits are referred to as the Kitsap formation or Olympia transitional beds (Qf). Older glacial deposits underlying the Kitsap formation (Qc) were associated with the Salmon Springs drift or the Penultimate drift. Deeper deposits were described as Teritary/Quaternary undifferentiated deposits (TQu).

The Washington Department of Natural Resources (DNR) published a surficial geologic map in 2003 that included the Hawks Prairie area. This map defined a large area south of Henderson Inlet occupied by fine-grained glacial lacustrine and ice-contact deposits. These deposits were confirmed to be over 110 ft thick in a subsequent boring along Woodland Creek. It is important to recognize the presence and thickness of this unit when making stratigraphic correlations in this area.

The hydrogeologic sequence of Qva aquifer, Qf aquitard and Qc aquifer were traditionally characterized as being relatively thin in the Hawks Prairie area. This sequence was largely considered to be present above sea-level while deeper deposits were assigned to the TQu. A number of recent deep borings indicate that the Qva, Qf and Qc sequence extends to at least 450 ft below sea level. The Qf aquitard is up to 315 ft thick and has a predominant clay texture based on geotechnical testing. The Qc aquifer is very transmissive based on pumping tests and soil texture. The deeper TQu deposits were not encountered.

Landau Associates, 950 Pacific Avenue, Suite 515, Tacoma, WA 98402; Telephone (253) 926-2493; Fax (253) 926-2493
[1] *E-mail: eweber@landauinc.com*
[2] *E-mail: afarinacci@landauinc.com*

Design Constraints on an Open Loop Ground Source Heat Pump System in Southeastern WA

V.L. Freedman[1], Z.F. Zhang[2], S.R. Waichler[3], R.D. Mackley[4], and J.A. Horner[5]

Ground source heat pumps (GSHPs) use the earth's constant temperature to provide heating, cooling, and hot water for buildings. During the winter, the system uses the groundwater as a heat source to heat a building, and in the summer, it uses the groundwater as a heat sink, depositing extra heat from a building. For a new facility being constructed at the Pacific Northwest National Laboratory in Richland, WA, the viability of an open-loop GSHP is being investigated. In this system, a design capacity of 1500 – 2700 gpm is required, but well design must also consider impacts to existing contaminant plume trajectories adjacent to the facility. Moreover, any potential thermal impacts to the nearby Columbia River are to be mitigated. Wells must also be constructed within property boundaries, which further constrains optimizing system design. Results demonstrating the system design, as well as simulations of thermal and contaminant plumes will be presented.

Pacific Northwest National Laboratory
[1] *Telephone (509) 372-4067; E-mail: vicky.freedman@pnl.gov*
[2] *Telephone (509) 372-4866; E-mail: fred.zhang@pnl.gov*
[3] *Telephone (509) 372-4423; E-mail: scott.waichler@pnl.gov*
[4] *Telephone (509) 371-7178; E-mail: rob.mackley@pnl.gov*
[5] *Telephone (509) 371-7237; E-mail: jake.horner@pnl.gov*

A Geochemical Reactive Transport Model of Arsenic and Trihalomethanes in Aquifer Storage Recovery Systems

Brad Bessinger[1] and Dimitri Vlassopoulos[1]

Numerous aquifer storage recovery (ASR) systems are currently being planned and/or operated in the Pacific Northwest. Pursuant to both Washington and Oregon regulations, permitting for these systems must include consideration of the chemical compatibility of surface and ground waters, as there is a potential for groundwater quality to be degraded by chemical transformations that may occur during aquifer storage.

Arsenic and trihalomethanes (THMs) are two drinking water contaminants that have occasionally been detected in groundwater as a result of the operation of ASR systems in the United States. The former is a naturally-occurring element and may potentially be mobilized by geochemical changes within the aquifer induced by injection-extraction cycles. The latter consists of several compounds that can form when reclaimed or treated water is chlorinated prior to injection.

The objective of the current study was to investigate the aquifer and groundwater geochemical characteristics that affect the concentrations of arsenic and THMs in ASR systems. This analysis required the development of a kinetic-based reactive transport model capable of simulating time-dependent dissolution of aquifer minerals, biodegradation of organic carbon, and formation and destruction of THMs.

It was found that the major factors affecting the transport and fate of arsenic and THMs in ASR systems include the following: 1) the extent of chemical and redox disequilibrium between native and injected waters and aquifer minerals; 2) labile organic carbon concentrations; 3) residual chlorine levels in injected water; and 4) residence (storage) time in the aquifer. For arsenic, chemical disequilibrium may initially result in elevated concentrations during recovery due to dissolution of As-bearing sulfides; however, these impacts generally decrease with aquifer conditioning. By contrast, the formation of THMs is affected by labile organic carbon, residual chlorine content, and rates of THM degradation. The potential for THMs to form in an ASR system can be expected to decline over multiple injection-extraction cycles if labile organic carbon primarily originates in the aquifer. THM formation potential can be reduced by altering disinfectant practices and/or storage and recovery times.

The model developed for this study represents a tool to evaluate the effects of site-specific geochemistry and management options on the transport and fate of contaminants in ASR systems.

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[1] *S.S. Papadopulos and Associates, 510 SW 3rd Ave., Suite 200, Portland, OR 97204; Telephone: (503) 222-6639; E-mail: BBessinger@sspa.com*

Numerical Analysis of Groundwater Using Advanced Real-Time Imaging

John E. Dustman[1] *and* ***John M. Lambie, P.E.***[2]

A small watershed at the edge of a large desert valley was analyzed for the quantity and quality of groundwater available to sustain wetlands and to allow for water supply development. Ten groundwater wells were instrumented across the lower portion of the verdant watershed for real time collection of water level information around a wetland near a fault zone. Correlative barometric and temperature data were also collected at the project site. Continuous 5-minute interval data were collected for two months during the summer 2008.

Modeling and analysis of the data was done using a variety of methods to establish the natural yield of the groundwater system to the wetlands. Rainfall events were captured in the data along with aquifer testing to analyze the interaction of the fault system with groundwater baseflow. Diurnal changes in groundwater elevation across the verdant wetland on the edge of the desert were found to be correlative with daily temperature highs. Analysis of groundwater base flow in the watershed using aquifer parameters derived for the watershed from on-site testing was compared to projected consumptive use.

A multi-well program of groundwater extraction testing was conducted and analyzed to evaluate the fault controls on the groundwater basin. Subsequently, a strategy for groundwater utilization for water supply was developed to meet growing population needs along with strategies to sustain wetland habitat.

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[1] *Aquifer Resources Management, Inc., 1217 Bandana Boulevard North, St. Paul, Minnesota 55108; Telephone: (612) 750-4024, Fax: (651)647-0888; E-mail: jdustman@aqresmgt.com*

[2] *Aquifer Resources Management, Inc., 4061 SW Chesapeake Avenue, Portland, Oregon, 97239; Telephone: (503) 381-6043, Fax: (503) 206-7092; E-mail: jlambie@aqresmgt.com*

Groundwater Information Management and Data Visualization for Enhanced Aquifer Utilization in Water Supply

John M. Lambie, P.E[1] *and* ***John E. Dustman***[2]

Climatic variability is promoting increased utilization of groundwater aquifers as water resources both for withdrawal and storage of drinking water. Advancements in disparate technologies are presenting new opportunities for water-utility operators to increase the efficiency and reliability of their groundwater supply systems to meet these challenges. Computer software for real-time visualization of groundwater elevation data incorporating climatic data such as barometric pressure has been developed to utilize the advancements in these technologies. This enables a greatly enhanced understanding and provides improved predictive capability for the groundwater aquifer as a storage and recovery vehicle for drinking water.

Technology developments in three broad areas are enabling improved groundwater management. First, the remote sensing industry is providing new probes that can measure and record important water parameters, and sensor data recorders or transmitters have new telemetric capabilities that enable cellular and web-based access to such data flows. Second, the advancement of geographic information systems(GIS), global-positioning systems(GPS), database, and internet technologies are automating the acquisition, storage, and real-time access to billions of historic data records. Third, data analysis and visualization software are becoming more interactive and now can utilize the complex mathematics of transient groundwater flow to spatially interpret scattered data very precisely and produce views of ground water conditions in real time. Field applications of these technologies have been demonstrated at two municipal water supply wellfields. This paper will present a synopsis of these technologies by demonstrating the processing and visualization of pressure-transducer and GIS data for a typical groundwater-supply wellfield.

The concepts of neural networks to predict ground water conditions under myriad weather and extraction scenarios and "smart" pumps and conveyance systems will be discussed. In addition, this presentation will present a vision of the future ramifications for water resource management of the ongoing advances of these disparate technologies.

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[1] *Aquifer Resources Management, Inc., 4061 SW Chesapeake Avenue, Portland, Oregon, 97239, Telephone: (503) 381-6043; Fax: (503) 206-7092; E-mail: jlambie@aqresmgt.com*
[2] *Aquifer Resources Management, Inc., 1217 Bandana Boulevard North, St. Paul, Minnesota 55108; Telephone: (612) 750-4024, Fax: (651) 647-0888; E-mail: jdustman@aqresmgt.com*

Watershed Studies: Managing Water Resources for Sustainability on Vashon-Maury Island

Eric Ferguson[1], and Laurence Stockton[2]

The Vashon-Maury Island (VMI) watershed is a sole source island aquifer located in the Puget Sound. All drinking water sources on the island (springs, surface water, and groundwater) are supplied by precipitation. Understanding the water budget for VMI and changes that are occurring in response to human activities and climate is critical to determining the amount of drinking water that can be used on a sustained basis.

In 2005, King County and the Vashon-Maury Island Ground Water Protection Committee (GWPC) wrote a Watershed Plan for the islands as a stand-alone sub-area within the WRIA 15 planning area. The principal reasons for preparing a watershed plan were (1) the uncertainty in the amount and sustainability of groundwater, (2) a need to assess the health of Island streams and (3) the potential for contamination of the Island sole source aquifers. The goal of the watershed plan is to protect and assure the water supply, by implementing specific recommendations concerning water quantity and quality issues affecting the Island. The VMI GWPC is now working to define hydrologic sustainability indicators and goals for sustainable long term management of the island's water resources.

King County has designed a scientific evaluation of the water supply issues (both water quantity and quality) on VMI called the Water Resources Evaluation. This project monitors the surface and groundwater for both water quantity and quality to record and identify changes over time. Precipitation is also monitored island wide to better assess local variation. An island-wide comprehensive groundwater flow model has been prepared and recently converted into an integrated surface-groundwater model. The integrated model is now being used to evaluate groundwater and surface water quantity under various projected future land-use and climate change scenarios.

Watershed plan implementation activities to date including the Water Resource Evaluation modeling results, an assessment of the implications for VMI water resources and strategies to ensure future sustainability of the VMI water resource will be presented.

King County Department of Natural Resources and Parks, Water & Land Division, 201 S. Jackson Street, Suite 600, Seattle, WA 98104
[1] Telephone: (206) 263-6512; Fax: (206) 296-0192; E-mail: eric.ferguson@kingcounty.gov
[2] Telephone: (206) 296-1910; Fax: (206) 296-0192; E-mail: laurence.stockton@kingcounty.gov

Protecting and Managing the Wildcat Creek Aquifer

Laurie Morgan[1]

The Growth Management Act requires the designation and protection of Critical Aquifer Recharge Areas for the protection of public drinking water supplies. Aquifers cross city and county boundaries, so cooperation in planning and execution of ordinances is essential to achieve protection of these public drinking water supplies.

The Wildcat Creek Aquifer is in Grays Harbor County east of Elma. The City of McCleary and Grays Harbor County residents in this area rely on the Wildcat Creek Aquifer for their water supply. Along with the City of McCleary municipal wells, there are some smaller community water systems and individual wells. The aquifer is bounded on the south by sedimentary rock hills and to the north by the Olympic Peninsula basalts. These formations also form the basement beneath the glacial material that makes up the aquifer. The depth to the basement is on the order of 100 or so feet. The valley where the aquifer is located is just roughly a couple of miles across and roughly five to six miles long.

Faced with development pressures and the knowledge that the Wildcat Aquifer is essentially the only source of water for this area, Grays Harbor County enacted a development moratorium and a planning consultant was hired to make recommendations. Jim Arthur, the planning consultant, and Linton Wildrick, Pacific Groundwater Group, wrote the report Wildcat Creek Aquifer – Hydrology, Regulatory Alternative and Recommendations – Final Report, June 2008. This report details the hydrogeologic characteristics of the aquifer and recommends management measures for McCleary and Grays Harbor. The development moratorium has been lifted, and Grays Harbor County has drafted their Critical Aquifer Recharge Area ordinance.

Management measures recommended in the report include, among other things, maximizing recharge; preventing contamination; monitoring well water and measuring stream flows; regulating land use; and managing the aquifer comprehensively through compatible city and county policies, actions and ordinances.

Tracking water occurrence with monitoring enables evaluations such as whether wells may go dry in especially dry years and the status of ground water baseflow to streams. Monitoring existing wells periodically for water quality would allow contamination to be detected so that measures could be taken to remove or mitigate pollution sources.

Especially because of the limited extent of this aquifer and local recharge source, evaluation and management of the Wildcat Aquifer is a convenient microcosm that illustrates the issues facing jurisdictions across the state as they grapple with water supply, water quality protection and development.

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[1] *Washington State Dept. of Ecology; P.O. Box 47600, Olympia, WA 98504-7600; Telephone: (360) 407-6483; Fax: (360) 407-6426; E-mail: lmor461@ecy.wa.gov*

Ground-Water Availability for the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho

Richard S. Dinicola[1], Dave Morgan[2], Gabriel Senay[3], Sue Kahle[4], Erick Burns[5], Dan Snyder[6], Matt Ely[7], Theresa Olsen[8], Tiffany Jacklin[9], Jon Haynes[10]

The Columbia Plateau Regional Aquifer System covers more than 60,000 square miles of eastern Washington and Oregon and western Idaho. The primary aquifers are basalts of the Columbia River Basalt Group and overlying basin-fill sediments. Ground-water availability issues in the basin include widespread water-level declines caused by pumping, corresponding reductions in base flow to rivers and associated effects on water temperature and quality, and effects of climate change on ground-water recharge, base flow, and ground-water availability.

The U.S. Geological Survey (USGS) is assessing the availability and use of the Nation's ground-water resources and developing tools to help evaluate future system response to various human and environmental demands and climate change. As part of the National assessment program, USGS Water Science Centers in Washington, Oregon, and Idaho initiated a study of ground-water availability of the Columbia Plateau Regional Aquifer System in 2008. The major study elements include documenting changes in the status of the system, quantifying the hydrologic budget, updating the regional hydrogeologic framework, and simulating the system with a numerical ground-water flow model.

Region-wide synoptic water-level measurements scheduled for spring 2009 will help assess changes in the status of the system. MODIS (Moderate Resolution Imaging Spectroradiometer) and other satellite imagery are being used to help estimate irrigation water use on a regional scale from 1989-2007. These estimates are being validated using recent detailed water-use estimates for the Yakima River Basin. The regional hydrogeologic framework has been updated by incorporating new information from large-scale hydrogeologic studies and using novel geostatistical techniques. The focus for 2009 is to complete development of the conceptual model, including a first-order hydrologic budget, and to begin construction o E-mail f the ground-water flow model.

U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402; Fax (253) 552-1581
[1] Telephone: (253) 552-1603; E-mail: dinicola@usgs.gov
[4] Telephone: (253) 552-1616; E-mail: sckahle@usgs.gov
[7] Telephone: (253) 552-1622; E-mail: mely@usgs.gov
[8] Telephone: (253) 552-1652; E-mail tdolsen@usgs.gov
U.S. Geological Survey, Oregon Water Science Center, 2130 SW 5th Ave., Portland, OR 97201; Fax: (503) 251-3470
[2] Telephone: (503) 251-3263; E-mail: dsmorgan@usgs.gov
[5] Telephone: (503) 251-3250; E-mail: burns@usgs.gov
[6] Telephone: (503) 251-3287; E-mail: dtsnyder@usgs.gov,
[9] Telephone: (503) 251-3284; E-mail: tiffany@usgs.gov
[10] Telephone: (503) 251-3468; E-mail: jvhaynes@usgs.gov
U.S. Geological Survey, EROS, 47914 252nd Street, Sioux Falls, SD 57198
[3] Telephone: (605) 594-2758; E-mail: senay@usgs.gov

7th Washington Hydrogeology Symposium

POSTERS

April 28, 4:00 – 5:30 PM

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2.	**Modifications to DPM—A Deep Percolation Model for Estimating Ground-Water Recharge:** *John Vaccaro, U.S. Geological Survey*	13.	**The Contaminated Groundwater to Surface Water (GW-SW) Pathway: Some Case Studies at Contaminated Sites and Regulatory Implications in Washington State:** *Jerome Cruz, WA Dept. of Ecology*
3.	**Hydrologic and Thermal Conditions of the Eastbank Aquifer System near Rocky Reach Dam, Douglas County, Washington:** *Marijke van Heeswijk, U.S. Geological Survey*	14.	**Geochemical Analysis of Surface and Groundwaters around Cle Elum, Washington; Implications for the Proposed Exempt Well Moratorium:** *David Hickey, Central Washington University*
4.	**The Effects of Timber Harvest on Watershed Hydrology near Kalaloch, Olympic Peninsula, WA:** *Casey Hanell, Western Washington University*	15.	**Estimating the Probability of Elevated Nitrate Concentrations in Ground Water in Washington State:** *Lonna Frans, U.S. Geological Survey*
5.	**Modeling the Effects of Land Use Practices on the Hydrology of Ebey's Prairie, Whidbey Island, Washington:** *Michael Larrabee, Western Washington University*	16.	**Nitrate in Manure, Groundwater, Soil, and Grass Crop at a Dairy Field Overlying the Sumas-Blaine Aquifer:** *Barbara Carey, WA Dept. of Ecology*
6.	**Ground Water Controls on Surface Water in Horseshoe Lake, King County, Washington:** *Jennifer Saltonstall, Associated Earth Sciences, Inc.*	17.	**Naturally Occurring Aqueous Arsenic and Seawater Intrusion on Lummi Island, Washington:** *Erica Martell, Western Washington University*
7.	**Determining Changes in Land Use and Land Cover in the Chamokane Creek Basin, Washington, Using Remote Sensing:** *Sonja Lin, U.S. Geological Survey*	18.	**An Evaluation of Extraction Techniques for Quantifying Tc-99 in Contaminated Sediments:** *Michelle Valenta, Pacific NW Nat'l Lab-PNNL*
8.	**Estimated Crop Irrigation Water Use in the Pacific Northwest, 2005:** *Ron Lane, U.S. Geological Survey*	19.	**Use of Narrow-Diameter, Direct-Push Wells to Characterize and Remediate Carbon Tetrachloride in the 200 West Area, Hanford Site, Washington:** *Ken Moser, Vista Engineering*
9.	**Hydrogeologic Framework in Tributary Subbasins of the Lower Skagit River, Skagit and Snohomish Counties, Washington:** *Mark Savoca, U.S. Geological Survey*	20.	**Final Remedy for Treating 200 West Area Groundwater, Hanford Site, Washington:** *Mark E. Byrnes, CH2M Hill Plateau Remediation Company*
10.	**Unique Geochemistry of Gravelly Lake, Tacoma, WA: Evidence for a Deep Groundwater Component:** *Ben Shapiro, University of Puget Sound*	21.	**Soil Water Influence on the Oxygen Isotope Ratio of Soil CO2 Flux to the Atmosphere:** *Clayton Larkins, Central Washington University*
11.	**Hydrogeologic Framework for the Chambers-Clover Creek Watershed, Pierce County, Washington:** *Wendy Welch, U.S. Geological Survey*	22.	**A Stable Isotope Study of Soil Water Budgets Along a Climate Transect in a Snowmelt Dominated System:** *Travis Hammond, Central Washington University*

Data Access via Web Services; The New Alphabet Soup of Data Sharing

John E. Tooley[1]

The National Environmental Information Exchange Network, a joint venture of the Environmental Council of States and the U.S. Environmental Protection Agency, has provided a set of data-sharing standards and services which allow data exchange across boundaries, both geographic and institutional. The 'Exchange Network' is a standards-based collection of internet protocols such as eXtensible Markup Language (XML), Hypertext Transport Protocol (HTTP), web services, and Simple Object Access Protocol (SOAP). This alphabet soup of technologies provides a vendor-agnostic approach to share data and allows these data to be mixed in a number of imaginative ways.

The USGS has recently joined the Exchange Network party by adding Web Services to publish data from the National Water Information System (NWIS). Water-Quality data are now available using the same data standards and parameter vocabulary as EPA. At last we can access data from USGS, EPA, and several state and tribal governments using the same protocols, vocabulary, and access technology.

Consumers of these data are free to construct interfaces, analytical tools, and models based on these services, and are encouraged to be innovative. This poster illustrates how the services connect together, and shows how data users will be able to take advantage of these innovations.

[1] *Washington State Department of Ecology, Applications and Data Services, P.O. Box 47600, Olympia, WA 98504-7600; Telephone: (360) 407-6418; Fax: (360) 407-6493; E-mail: jtoo461@ecy.wa.gov*

Modifications to DPM—A Deep Percolation Model for Estimating Ground-Water Recharge

John J. Vaccaro[1] and Marijke van Heeswijk[2]

The Deep Percolation Model (DPM) is a daily water-budget model developed by the U.S. Geological Survey for estimating ground-water recharge from precipitation and irrigation. Recharge is defined as the amount of water leaving either the active root zone (deep percolation) or, in the case of bare soils such as sand dunes, the mapped depth of the soil column. DPM is designed to create independent estimates of ground-water recharge for ground-water flow models and can be used at scales ranging from field plots to large regions with variations in climatic, soil, land-use, and land-cover conditions.

DPM Version 1 was released in 1987 and Version 2 was released in 1997. Version 2 eliminated the requirement for a quadrilateral model-grid system and allowed for soils in the root or soil zone to saturate. In addition, the method used to calculate surface runoff was changed to a combination of an approximation of Darcy flow for saturated soils and saturation excess, and the Priestly-Taylor potential evapotranspiration method was added for non-agricultural land-use/land-cover options. Agricultural land-use/land-cover options continued to use the original Jensen-Haise method of DPM Version 1. A revision to DPM Version 2 incorporated after 1997 included the option of specifying time-varying saturated vertical hydraulic conductivities—the limiting infiltration rate below the root zone.

DPM Version 3.0 was released in 2008 and enhances Version 2 by making it consistent with a modularized version of DPM released in 2007 that is included in the U.S. Geological Survey's Modular Modeling System (MMS). Revisions include the addition of new land-use/land-cover options, the simulation of snowmelt during rain-on-snow conditions as a function of wind speed, the estimation of incoming solar radiation if no solar radiation data are available, the option of applying irrigation above or below the vegetation canopy, the option of distributing precipitation areally using monthly instead of annual weighting factors, reading input and output file names externally to the program, and sizing arrays so it is less likely that users will need to recompile the program. DPM Version 3.0 is backward compatible with datasets created for Version 2. DPM Version 3.0 may be downloaded from *http://wa.water.usgs.gov/dpm* and the equivalent MMS version of DPM may be downloaded from links provided in *http://pubs.usgs.gov/sir/2006/5318/pdf/sir20065318.pdf.*

U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402; Fax: (253) 552-1581

[1] E-mail: jvaccaro@usgs.gov; Telephone: (253) 552-1620

[2] E-mail: heeswijk@usgs.gov; Telephone: (253) 552-1625

Hydrologic and Thermal Conditions of the Eastbank Aquifer System near Rocky Reach Dam, Douglas County, Washington

Marijke van Heeswijk[1] *and Stephen E. Cox*[2]

The Lower and Combined Aquifers of the Eastbank Aquifer system, located in a river-terrace deposit along the Columbia River near Rocky Reach Dam, Washington are primarily recharged by the Columbia River and provide water to a salmonids hatchery and a regional water system servicing the cities of Wenatchee, East Wenatchee, and parts of unincorporated Chelan and Douglas Counties. In 2006, mean annual pumpage by the hatchery and regional water system was about 43 and 16 cubic feet per second, respectively. Successful hatchery fish production needs cool water and concerns over possibly increasing ground-water temperatures prompted an analysis of hourly ground-water and river temperatures measured by the Chelan County PUD from January 1991 through August 2007. The results indicate increasing interannual trends in temperatures in most of the Lower and Combined Aquifers from 1999 through 2006 that correspond to increasing trends in the annual mean and annual maximum river temperatures during the same period of 0.07 and 0.17°C per year, respectively, which are within the natural variability of the river temperatures. There were no trends in the annual minimum river temperatures during the same period, and there were no trends in the annual minimum, mean, and maximum river temperatures from 1991 through 1998 and from 1991 through 2007. Because most of the Lower and Combined Aquifers reached thermal equilibrium—defined by constant time lags between changes in river temperatures and subsequent changes in ground-water temperatures—prior to 1999 and seasonal pumpage patterns were relatively stable from 1999 through 2006, increasing interannual trends in ground-water temperatures are most likely explained by increasing trends in river temperatures.

Analyses of water-level data collected on July 18, 2007 and dissolved-constituent and bacterial concentrations in samples collected August 20–22, 2007 showed that most of the water pumped by the hatchery recharges along the river at the generally shortest distance between the hatchery well field and the river. In addition, analyses of the historical ground-water temperature data showed that at historical pumping rates, water pumped by the hatchery recharged about two months prior to the time it was pumped from the aquifer.

U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402; Fax (253) 552-1581
[1] *E-mail:* heeswijk@usgs.gov*; Telephone (253) 552-1625*
[2] *E-mail:* secox@usgs.gov*; Telephone (253) 552-1623*

The Effects of Timber Harvest on Watershed Hydrology Near Kalaloch, Olympic Peninsula, WA

Casey Hanell[1] and Robert Mitchell[2]

The effects of timber harvesting on canopy interception and evapotranspiration and hence soil and groundwater levels continue to be the subject of research throughout the Pacific Northwest because of their influence on slope stability. We used a combination of field measurements and numerical modeling to explore the affect of timber harvesting on runoff and groundwater levels in a moderately steep watershed (2 sq-km) located 6 km southeast of Kalaloch, WA on the coast of the Olympic peninsula.

Hourly water-levels were monitored with data loggers in 10 shallow piezometers for two years. Water-levels were correlated to precipitation data collected at three on-site rain gauges positioned under the tree canopy and open air precipitation measurements recorded at the Black Knob weather station 25 km south of the research site. In all 10 bores, rapid water level rise is observed and the strongest correlation between peak water levels and precipitation occurs within several hours after the onset of the event. The rapid water level rise may be the result of the capillary fringe extending to the ground surface. During a precipitation event, water held in tension becomes groundwater, rapidly saturating the soil column.

The Distributed Hydrology Soils Vegetation Model (DHSVM) predicts clear-cut timber harvest will result in a 10 percent reduction in evapotranspiration over the two year period from February 2005 through February 2007. The DHSVM predicts this 10 percent reduction in evapotranspiration will result in a 6 percent increase in streamflow and a 4 percent increase in soil moisture and groundwater recharge. These field and modeling results suggest that timber harvesting at this site will influence shallow soils to a higher degree than deeper aquifer systems that control the stability of deep-seated landslides.

Timber harvest at the research site began in the summer of 2008 and is still occurring at the time of this abstract submission. Following timber harvest, data collection will continue and will be compared to pre-harvest data and model predicted responses.

[1] *Washington State Department of Natural Resources, Land Management Division, 1111 Washington St. SE, Olympia, WA 98504; Telephone: (360) 457-2570 ext. 221; Fax: (360) 452-4922; E-mail: casey.hanell@dnr.wa.gov*

[2] *Western Washington University, Geology Department, 516 High St., Bellingham, WA 98225; Telephone: (360) 650-3591; Fax: (360) 650-7302; E-mail: robert.mitchell@geol.wwu.edu*

Modeling the Effects of Land Use Practices on the Hydrology of Ebey's Prairie, Whidbey Island, Washington

Michael Larrabee[1] and Robert Mitchell[2]

Ebey's Prairie is a broad low terrace, approximately 6 km^2 in size, located within the Ebey's Landing National Historical Reserve on Whidbey Island, WA. The prairie, which is underlain by a complex sequence of glacial marine deposits, is primarily used for agricultural. In the mid-1900s, agricultural drainage tiles, drainage ditches and fill were installed by local landowners to increase tillable acreage. It is believed that these activities may have altered the runoff on the prairie, and subsequently aquifer recharge.

Little is known of the original surface and shallow groundwater movement within Ebey's Prairie. It is thought that the prairie was once bisected by a broad riparian corridor consisting of waterlogged soils, swampy areas, seasonal ponds, and intermittent flows, which likely contributed to aquifer recharge. However, modern surface water on the prairie is limited to a small marsh and seasonal creek. Although the local aquifer recharge is dependent on precipitation, the region receives less than 530 mm (21 in) of rain annually. Over-pumping of groundwater has resulted in salt water intrusion into coastal wells. As a result, there has been an increased interest in the historic hydrology of the prairie and its relationship to aquifer recharge.

Our research is using the Distributed Hydrology-Soil-Vegetation Model (DHSVM) to simulate the modern and historic surface hydrology of Ebey's Prairie and to quantify the effect of land-use practices on surface hydrologic conditions and aquifer recharge. A hydrologic model for the modern conditions is being created and calibrated to discharge measurements taken from a seasonal creek located in the prairie. We are using a combination of remote sensing imagery, soils data, oral interviews, historic photos, and geophysical techniques to develop a conceptual picture of the historic water features. These features will then be simulated in the calibrated DHSVM model and comparatively analyzed with simulations of the modern hydrology.

This project was initiated by the National Park Service in order to improve the understanding of the local water resources and subsequently assist with the management of the resource. Additionally, information learned from this project may be useful to the City of Coupeville, which is considering several storm-water management actions, including water impoundments in Ebey's Prairie.

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[1] Western Washington University, Geology Department, 516 High Street, Bellingham, WA, 98225-9080; Telephone: (360) 734-1657; Fax: (360) 650-7302; E-mail: larrabm@cc.wwu.edu

[2] Western Washington University, Geology Department, 516 High Street, Bellingham, WA, 98225-9080; Telephone: (360) 650-3591; Fax: (360) 650-7302; E-mail: robert.mitchell@geol.wwu.edu

Ground Water Controls on Surface Water in Horseshoe Lake, King County, Washington

Jennifer Hilden Saltonstall[1], Curtis J. Koger[2], and Bridget August[3]

Horseshoe Lake is a small lake formed in a closed depression located in southeast King County with a history of dramatic surface water level fluctuation. Surface water flooding of surrounding residential property has occurred in 1991 and 1996, and most recently threatened in early 2007. Recent geologic and hydrogeologic subsurface exploration information, Horseshoe Lake surface water elevation data, and ground water elevation data from shallow and deeper aquifer intervals have been integrated to develop a conceptual hydrogeologic model of ground water – surface water interactions in the Horseshoe Lake subbasin. The Horseshoe Lake topographic depression was formed by meltwater erosion through low-permeability Vashon lodgement till deposits that separate overlying shallow Vashon recessional outwash ground water from deeper pre-Olympia ground water. The Horseshoe Lake depression is essentially a window into the underlying pre-Olympia aquifer. This conceptual hydrogeologic model is fundamentally different than previous ground water studies of the lake system, which modeled the lake system as perched above low-permeability Vashon lodgement till.

Water level monitoring data demonstrate Horseshoe Lake is not formed in a till-bottomed depression. Since the till is missing there is a direct hydraulic connection between Horseshoe Lake and deeper ground water, with Horseshoe Lake providing a source of recharge to the pre-Olympia aquifer. The surface water level in Horseshoe Lake generally mirrors the ground water levels in the deeper pre-Olympia aquifer; however, the Horseshoe Lake elevations are higher, indicating vertical flow from the lake into the pre-Olympia aquifer.

Based on ground water elevation data from multiple monitoring wells, ground water flow in the pre-Olympia aquifer interval is primarily toward the southwest, and flows to springs within Crisp Creek and along the northern wall of the Green River Valley.

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[1] Associated Earth Sciences, Inc., 911 5th Ave, Suite 100, Kirkland, WA 98033; www.aesgeo.com; Telephone (425) 827-7701; Fax (425) 827-5424; E-mail: jsaltonstall@aesgeo.com

[2] Associated Earth Sciences, Inc., 911 5th Ave, Suite 100, Kirkland, WA 98033; www.aesgeo.com; Telephone (425) 827-7701; Fax (425) 827-5424; E-mail: ckoger@aesgeo.com

[3] Associated Earth Sciences, Inc., 2911 1/2 Hewitt Ave, Suite 2, Everett, WA 98201 E-mail: www.aesgeo.com; Telephone (425) 259-0522; Fax (425) 252-3408 E-mail: baugust@aesgeo.com

Determining Changes in Land Use and Land Cover in the Chamokane Creek Basin, Washington, Using Remote Sensing

Sonja Lin[1] and Sue Kahle[2]

Residential development in the Chamokane Creek basin, Stevens County, Washington, is expected to increase ground-water use and potentially affect streamflow in the basin. The U.S. Geological Survey is conducting a study in cooperation with the Bureau of Indian Affairs, the Spokane Tribe, and the Washington Department of Ecology to describe the ground- and surface-water system of the basin and to examine the potential effects of increased ground-water use on water resources in the basin.

Ground water that is exempt from State water-right permitting requirements is difficult to quantify. Remote sensing techniques can help identify and estimate current and historical exempt uses. Furthermore, changes in land use and land cover need to be incorporated into the conceptual model of the basin's ground- and surface-water system to accurately describe historical and current hydrologic conditions. Land use and land cover can influence components of the hydrologic system, such as recharge and evapotranspiration rates. Remote sensing and spatial statistics can be used to determine and analyze general land use patterns and land cover changes, as well as help estimate changes in exempt water use in the basin.

Water rights in the basin were adjudicated in 1979; therefore, we will use imagery from the late 1970s (exact year will depend on availability) as a benchmark to assess changes in land use and land cover from pre-adjudication to present. The basic components of this analysis include (1) data preparation, (2) data analysis, and (3) accuracy assessment.

U.S. Geological Survey, 934 Broadway, Suite 300, Tacoma, WA 98402; Fax: (253) 552-1581
[1] Telephone: (253) 552-1659; E-mail: slin@usgs.gov
[2] Telephone: (253) 552-1616; E-mail: sckahle@usgs.gov

Estimated Crop Irrigation Water Use in the Pacific Northwest, 2005

Ron Lane[1]

Water use in the Pacific Northwest has evolved in the past century from meager domestic and stock water needs to the current complex requirements for public-water supplies, large irrigation projects, industrial plants and numerous other uses. Since 1950, the U.S. Geological Survey has, at five-year intervals, compiled and published estimates of the amount of water used for various purposes throughout the United States. In addition, water use reports for some individual states have been routinely published. However, because water-use and management decisions made in one state may affect water resources in adjacent states we must begin to examine and analyze water use at the regional level and not just at the state level. This poster presents the Crop Irrigation Water Use in the Pacific Northwest using data compiled and published by the States of Washington, Oregon, and Idaho for 2005. This single-water use category accounted for 80 percent of the total reported fresh water use in the Pacific Northwest during 2005.

[1] *U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402; Telephone: (253) 552-1604; Fax: (253) 552-1581; E-mail: rclane@usgs.gov*

Hydrogeologic Framework in Tributary Subbasins of the Lower Skagit River, Skagit and Snohomish Counties, Washington

Mark Savoca[1] and Theresa Olsen [2]

Recent population growth along the Interstate Highway 5 corridor near Mt. Vernon, Washington has led to increased domestic water use, with many new wells serving residents concentrated in four tributary subbasins of the Skagit River. These subbasins include the East Fork and mainstem of Nookachamps Creek, Carpenter Creek, and Fisher Creek. Planning for future development in these subbasins requires an understanding of their ground-water resources and, in particular, how future ground-water use likely will affect streamflow in the tributaries. In June 2006, the U.S. Geological Survey (USGS) Washington Water Science Center, in cooperation with Skagit County and the Washington Department of Ecology (Ecology), began a project to characterize the ground- and surface-water flow system in the tributary subbasins, and to integrate this and other information into a numerical flow model. A hydrogeologic framework of the area was constructed as part of this study.

Geologic units in the study area record a complex history of accretion along the continental margin, mountain building, deposition of terrestrial and marine sediments, igneous intrusion, and the repeated advance and retreat of continental glaciers. Defining the extents and thicknesses of aquifers and confining beds within these geologic units was essential to understanding ground-water flow and movement of water between aquifers and nearby streams. Construction of the hydrogeologic framework began with the merging of existing 1:100,000 and 1:24,000 digital surficial geologic maps. A dataset of more than 300 well logs was assembled from USGS and Ecology databases. Geologic and hydrogeologic unit assignments were made based on lithologic interpretations of those logs and guided by stratigraphic interpretations from previous investigations by the Washington Department of Natural resources. Maps of hydrogeologic unit extents and the interpolated elevations of unit tops were constructed using a Geographical Information System.

U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402

[1] *Telephone: (253) 552-1660; Fax: (253) 552-1581; E-mail: mesavoca@usgs.gov*

[2] *Telephone: (253) 552-1652; Fax: (253) 552-1581; E-mail: tdolsen@usgs.gov*

Unique Geochemistry of Gravelly Lake, Tacoma, WA: Evidence for a Deep Groundwater Component

***B.M. SHAPIRO*[1]**, *and J.H. TEPPER*[1]

Gravelly Lake (GL) is one of numerous kettle lakes in Pierce County. The substrate in the area is composed of several glacial outwash and till units. This lake covers an area of ~65 hectares and has no surface water inputs; the main water source is groundwater. American Lake (AL) lies up gradient from GL suggesting transport of groundwater in the shallow aquifer from AL to GL. Compared to AL, GL exhibits more stratification, greater clarity (Secchi depths to 9.5m), and higher SiO_2, Ca, Mg, and alkalinity. Another unique feature is a color change from steel-blue to aquamarine during summer months. The primary goals of the project are to characterize the composition of water at different depths and seasons, establish processes responsible for chemical variation, and identify factors responsible for unique chemical characteristics of GL.

Over an eight-month period 80 samples were collected and analyzed. Levels of major cations (Si = 5.6 ppm, Ca = 13.4 ppm, Mg = 5.2 ppm) are notably higher (up to 390% for Si) in GL than AL. GL showed more variation with depth than in AL. Month-to-month variations in GL spring chemistry track variations in AL water chemistry, indicating rapid (< 1 month) groundwater flow from AL to GL springs. However, the compositions of the groundwater springs reflect more than one end-member. Spring compositions vary (from one to another and month to month), consistent with mixing between AL water and an additional groundwater component. The elevated Si levels are the result of deep groundwater. The chemistry of GL is most similar to the deep groundwater component; whereas the springs mostly resemble AL. Seasonal trends in whole lake element loading (Si increased 2.5 fold from June-Jan.) reflect changes in relative contribution of shallow versus deep groundwater. A recent USGS study has identified a localized linear disruption of the confining layer between the shallow aquifer and deeper aquifers that may provide a window for deep groundwater transport. We conclude that deep groundwater is the dominate source of water at GL during summer months when lower rainfall results in diminished flow from AL. Diatoms were also recognized in sediment collected from GL. We attribute the aquamarine color of GL water in summer months to precipitation of calcite driven by diatom photosynthesis when Si is high.

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[1] *University of Puget Sound, Geology Department, 1500 N. Warner Street, Tacoma,WA 98416; E-mail bmshapiro@ups.edu*

Hydrogeologic Framework for the Chambers-Clover Creek Watershed, Pierce County, Washington

Wendy Welch[1] and Burt Clothier[2]

The Chambers-Clover Creek Watershed (CCCW) covers about 180 square miles in the southern Puget Sound Lowland of Pierce County in western Washington. The watershed is underlain by as much as 2,000 feet of unconsolidated sediments that are the result of multiple Pleistocene glacial and interglacial periods. Defining extents and thicknesses of the aquifers and confining units within these unconsolidated sediments is essential to understanding ground-water flow and interactions with surface water features.

In April 2006, the U.S. Geological Survey (USGS) Washington Water Science Center began a project to characterize the water resources and create a numerical ground-water flow model of the CCCW. As part of that project, a more detailed hydrogeologic framework of the area was needed.

Four major elements were completed to construct the hydrogeologic framework. A digital surficial geology map was compiled by merging existing 1:100,000 digital data with scanned and digitized 1:24,000 geologic maps. A dataset of more than 450 wells was assembled from the USGS National Water Information System database and hydrogeologic unit assignments were made incorporating surficial geology, drillers' logs, and previous investigations. Eight cross-sections were created to illustrate the likely correlations between hydrogeologic units across the entire study area. Finally, maps were created to show the extents of the hydrogeologic units and the interpolated elevations of the unit tops.

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[1] U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402; Telephone: (253) 552-1673; Fax: (253) 552-1581; E-mail: wwelch@usgs.gov

[2] Robinson, Noble and Saltbush, Incorporated, 3011 South Huson Street, Suite A, Tacoma, WA 98409; Telephone (253) 475-7711; Fax (253) 472-5846; E-mail: bclothier@robinson-noble.com

Ground-Water Flow Model of Lower Skagit River Valley, Skagit and Snohomish Counties, Washington

Ken Johnson [1] and Lisl Fasser [2]

The U.S. Geological Survey (USGS) Washington Water Science Center, in cooperation with the Washington State Department of Ecology (Ecology) and Skagit County, is developing a numerical model of ground-water flow for parts of the lower Skagit River valley area of Skagit and Snohomish Counties. Local stakeholders had raised concerns that residential development and increased domestic water usage could affect stream baseflows. This project focuses on the potential effects of ground-water withdrawals on several tributaries of the lower Skagit River, including Carpenter Creek (also Hill Ditch) and Fischer Creek, and the mainstem and East Fork of Nookachamps Creek.

Data collection for the project included drilling exploratory borings and wells and establishing a ground-water and surface-water monitoring network. Many environmental conditions were monitored including baseflows for determining gaining and losing reaches, year-round streamflows at gaging stations, monthly or continuous water levels in domestic and dedicated wells, and seasonal ground-water levels and gradients in the Skagit River delta west of the study area. A new digital elevation model of the area was prepared using LiDAR methodology. Drillers' log data from USGS and Ecology databases were interpreted, in conjunction with previous geologic interpretations by the Washington State Department of Natural Resources, to provide a hydrogeologic framework for the numerical model.

The ground-water flow model includes well withdrawals by public water systems and individual residences; a representation of the complex hydrogeologic framework using the Hydrologic-Unit Flow (HUF) package; recharge based on a precipitation distribution augmented by septic system return flows; stream and lake boundary conditions; fluxes across the Skagit River delta; and submarine ground-water discharges to Skagit Bay. The model initially was calibrated using average monthly water levels and baseflow seepages to simulate steady-state conditions, and then was expanded to include seasonal transient conditions. This model currently is being used to estimate potential effects from implementation of several management alternatives.

U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98402
[1] Telephone: (253) 552-1629; Fax: (253) 552-1581; E-mail: johnson@usgs.gov
[2] Telephone: (253) 552-1642; Fax: (253) 552-1581; E-mail: efasser@usgs.gov

The Contaminated Groundwater to Surface Water (GW-SW) Pathway: Some Case Studies at Contaminated Sites and Regulatory Implications in Washington State

Jerome Cruz[1], Charles San Juan[2], Hun Seak Park[3]

Identifying and evaluating contaminated groundwater plumes that discharge to a surface water body have important implications for successful cleanup and compliance in contaminated sites that are near surface water. During site characterization, the elements of the conceptual model would include hydraulic evidence for continuous or periodic discharge into surface water (baseflow, submarine discharge, preferential pathways, seeps, etc.), presence of a product or dissolved plume and plume source, source mass loading, biological/chemical transformations at the groundwater-surface water interface, exposure pathways or impacts to sediments and water, and appropriate cleanup levels at the point of compliance. Especially at many small shoreline contaminated sites in western Washington, it is common to find that little is done to properly characterize this pathway. The following subjects are examined in the context of this pathway under the MTCA cleanup regulation:

- Some examples of submarine discharge and plume discharge of contaminated groundwater or product in Washington state are presented;
- Existing MTCA rule language on the subject of the groundwater–surface water interface are revisited along with some implications in regulatory compliance;
- Discussion of the groundwater-surface water interface and points of compliance at sites near surface water are presented;
- Problematic issues and recommendations are presented in demonstrating compliance at sites with tidal influence, institutionally-controlled sites with persistent contaminant sources, or sites seeking to use natural attenuation as the single preferred remedial alternative.

[1] *Washington State Department of Ecology, Toxics Cleanup Program Northwest Regional Office, 3190 160th Ave SE, Bellevue, WA 98008-5452; Telephone: (425) 649-7094; Fax: (425) 649-7098; E-mail: jcru461@ecy.wa.gov*

[2] *Washington State Department of Ecology, Toxics Cleanup Program Information & Policy, PO Box 47600, Olympia, WA 98504-7600; Telephone: (360) 407-7191; Fax: (360) 407-7154; E-mail: csan461@ecy.wa.gov*

[3] *Washington State Department of Ecology, Toxics Cleanup Program Land & Aquatic Lands Cleanup, PO Box 47600, Olympia, WA 98504-7600; Telephone: (360) 407-7189; Fax: (360) 407-7154; E-mail: hpar461@ecy.wa.gov*

Geochemical Analysis of Surface and Groundwaters Around Cle Elum, WA; Implications for the Proposed Exempt Well Moratorium

David Hickey[1],Ryan Opitz[2], Travis Hammond[3], Clayton Larkins[4], and Carey Gazis[5]

The Yakima River drainage is one of the most heavily irrigated regions in the state and water use has been much contested and litigated. It is important to understand the relationship between groundwater and surface water because all of the surface water in the Yakima drainage is appropriated and many water rights holders depend on this water for their livelihood. Due to this water demand in the drainage and the increase in drilling of domestic wells, a moratorium on exempt well drilling was proposed in 2007. In particular, residents were concerned about groundwater supplies in the uppermost Yakima River watershed, the area around the towns of Cle Elum and Roslyn, and the impact of continued development there on surface water supplies. The hydrogeology of this area is poorly understood due to the complex stratigraphy where the valley floor meets the bedrock of the Cascade Range

In this study geochemical data is used to evaluate the surface-groundwater interaction in the area around Cle Elum, WA. The study was begun as a class project for an Environmental Geochemistry class at Central Washington University. Students collected samples from over 30 domestic wells and nearby surface water sources in the Cle Elum/Roslyn area. Trace element and major ion data will be presented for these samples and will be used along with statistical analysis to draw conclusions regarding the different sub-surface water bearing units as well as the relationship between the surface and ground waters.

Central Washington University, Department of Geological Sciences, 400 E. University Way, Ellensburg, WA 98926-7418, Telephone: (509) 963-2820
[1] *Email: HickeyD@cwu.edu*
[2] *Email: opitzr@cwu.edu*
[3] *Email: hammondt@cwu.edu*
[2] *Email: larkinsc@cwu.edu*
[5] *Email: cgazis@geology.cwu.edu*

Estimating the Probability of Elevated Nitrate Concentrations in Ground Water in Washington State

Lonna M. Frans[1]

Logistic regression was used to relate anthropogenic (manmade) and natural variables to the occurrence of elevated nitrate concentrations in ground water in Washington State. Variables that were analyzed included well depth, ground-water recharge rate, precipitation, population density, fertilizer application amounts, soil characteristics, hydrogeomorphic regions, and land-use types. The variables that best explained the occurrence of elevated nitrate concentrations (defined as concentrations of nitrite plus nitrate as nitrogen greater than 2 milligrams per liter) were the percentage of agricultural land use in a 4-kilometer radius of a well, population density, precipitation, soil drainage class, and well depth. Based on the relations between these variables and measured nitrate concentrations, logistic regression models were developed to estimate the probability of nitrate concentrations in ground water exceeding 2 milligrams per liter. Maps of Washington State were produced that illustrate these estimated probabilities for wells drilled to 145 feet below land surface (median well depth) and the estimated depth to which wells would need to be drilled to have a 90-percent probability of drawing water with a nitrate concentration less than 2 milligrams per liter. Maps showing the estimated probability of elevated nitrate concentrations indicated that the agricultural regions are most at risk followed by urban areas. The estimated depths to which wells would need to be drilled to have a 90-percent probability of obtaining water with nitrate concentrations less than 2 milligrams per liter exceeded 1,000 feet in the agricultural regions; whereas, wells in urban areas generally would need to be drilled to depths in excess of 400 feet.

[1] *U.S. Geological Survey, Washington Water Science Center, 934 Broadway Ave. Suite 300, Tacoma, WA 98402; Telephone: (253) 552-1694; Fax: (253) 552-1581; E-mail: lmfrans@usgs.gov*

Nitrate in Manure, Groundwater, Soil, and Grass Crop at a Dairy Field Overlying the Sumas-Blaine Aquifer

Barbara M. Carey[1], Joe Harrison[2], and Lynn Johnson-VanWieringen[3]

Nitrate concentrations in the Sumas-Blaine Aquifer near the Canadian border have been impacted by agricultural sources including dairy and raspberry farming on both sides of the border. The Sumas-Blaine Aquifer is the main drinking water source for rural residents in north-central Whatcom County. The purpose of the study was to observe nitrogen dynamics in a typical grass field receiving dairy manure. For four years we have intensively monitored nitrate and related parameters in groundwater, soil, manure, and grass crop on a 22-acre field. Seven monitoring wells were installed in the field, six near the top of the aquifer (13 feet) and one at the bottom (38 feet). The field is located near the western edge of the aquifer, where depth to water is shallower (0-11 feet), and the substrate is finer than the eastern half of the aquifer.

The field was re-seeded in spring 2004, just prior to the start of the study. Tillage that occurred during re-seeding resulted in rapid mineralization of accumulated soil organic nitrogen. Mean nitrate+nitrite-N concentrations in groundwater near the top of the water table reached 30 mg/L the winter following re-seeding, while mean 2004 fall soil nitrate concentration was 31 mg/kg (weekly samples September-October). For three years following tillage, manure application ranged from 360-645 lb/acre total N (37-64% as ammonia-N) resulted in decreasing groundwater nitrate+nitrite-N concentratons. Monthly mean nitrate+nitrite-N concentrations in groundwater have been less than 10 mg/L, the maximum contaminant level for drinking water, for 15 months. Mean fall soil nitrate concentrations during 2005 to 2007 were 16 to 21 mg/kg, and crop yields ranged from 5.3 to 7.2 tons/acre dry matter (340-450 lb/acre N).

The combination of low dissolved oxygen and adequate organic carbon in this part of the aquifer provided conditions suitable for denitrification in over half of the shallow monitoring wells.

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[1] *Washington State Department of Ecology, P.O. Box 47710, Olympia, WA 98504-7710; Telephone: (360) 407-6769; Fax: (360) 407-6884; E-mail: bcar461@ecy.wa.gov*

[2] *Washington State University, 7612 Pioneer Way, Puyallup, WA 98371; Telephone: (253) 445-4638; Fax: (253) 445-4569; E-mail: jhharrison@wsu.edu*

[3] *Washington State University, 8418 VanBuren Rd, Everson, WA 98247; Telephone: (360) 966-0216; Fax: (253) 445-4569; E-mail: vanwieringen@wsu.edu*

Naturally Occurring Aqueous Arsenic and Seawater Intrusion on Lummi Island, Washington

Erica Martell[1] *and Robert Mitchell*[2]

Lummi Island is an 8.8 mi^2 elongated island located in the Puget Sound six miles west of Bellingham, Washington. Lummi Island has a relatively small population of approximately 900 permanent and 1,500 seasonal residents. Freshwater on northern Lummi Island is primarily stored in fractured sandstone bedrock (Chuckanut formation) and unconsolidated glacial sediments. Two different types of groundwater contamination are present in these aquifers: naturally occurring arsenic and seawater intrusion. The naturally occurring arsenic varies spatially throughout the island, and the concentrations fluctuate seasonally. Additionally, seawater ions are intruding into the groundwater supply, which is the primary source of drinking water for the residents of the island. The process of mobilization of the naturally occurring arsenic and the extent of the seawater intrusion has not been fully explored. The purpose of this study is to determine the geochemical, physical, and seasonal influences on both arsenic concentrations and seawater ions on Lummi Island.

We have collected water samples and *in situ* measurements from about 40 wells distributed throughout northern Lummi Island for geochemical analysis in April and September, 2006. The relationship between aquifer materials, arsenic, and seasonality are being explored using a combination of statistical analyses, redox chemistry, rock element analysis, and Scanning Electron Microscopy. The extent of the seawater intrusion is being examined using major ion plots on Piper and Stiff diagrams.

Preliminary findings indicate no correlation between iron or manganese and arsenic concentrations. However, a positive correlation was found between major seawater ions and arsenic occurrence. This correlation will be used to predict arsenic concentrations with major ion values. Water samples and rock element analysis both indicate that arsenic occurrence is most prominent within the sandstone bedrock layer.

Western Washington University, Geology Department, 516 High Street, Bellingham, WA 98225-9080
[1] *Telephone: (360) 650-3581; Fax: (360) 650-7302; E-mail: martele2@cc.wwu.edu*
[2] *Telephone: (360) 650-3591; Fax: (360) 650-7302; E-mail: robert.mitchell@geol.wwu.edu*

An Evaluation of Extraction Techniques for QuantifyingTc-99 in Contaminated Sediments

Michelle Valenta[1], Christopher F. Brown[2], R. Jeffrey Serne[3], Anne Hylden[4], and Dennese Smith[5]

Technetium-99 (Tc-99) is a contaminant of interest at the U.S. Department of Energy's Hanford Site, located in southeastern Washington State, due to its long half life (2.2 x 10^5 years) and mobility in subsurface environments. Under oxidizing, neutral conditions, technetium has a valence state of +7 and forms the highly mobile pertechnetate anion (TcO_4^-). Therefore, K_d values of 0 mL/g are generally used to describe the partitioning of Tc-99 under these conditions. With a K_d of 0 ml/g, it has been assumed that the addition of water to a sediment contaminated with Tc-99 will result in total extraction of the Tc-99. However, previous results have shown a quantifiable difference between water-extractable and acid-leachable Tc-99 activities in sediments from several boreholes emplaced on the Hanford Site. A study to test different extraction techniques for their ability to fully extract Tc-99 from contaminated sediments was conducted using 25 Hanford Site sediments containing Tc-99 at activities ranging from 1 to greater than 1000 pCi/g. Water extraction (WE), acid digestion (AD) and microwave-assisted digestion (MD) were performed on each sample. Half of the filtrate from each extraction was immediately analyzed for Tc-99 (using ICP-MS), and the other half was treated using TEVA® resin prior to Tc-99 analysis. A laboratory control sample (LCS) was prepared and taken through the same extractions as the sediments. The LCS consisted of an uncontaminated sediment that was put into a ball mill for several seconds to further homogenize the sample. After grinding, a known activity of Tc-99 was added to the sediment. The non-resin treated samples resulted in 70% recovery of Tc-99 in the LCS from WE, 90% recovery from AD, and 120% recovery from MD. For the resin-treated samples, the MD results became more accurate, resulting in 102% recovery of Tc-99 from the LCS. Recovery for the WE and AD remained approximately the same post-resin treatment. An additional LCS was created that excluded grinding of the sediment prior to the addition of the Tc-99 spike. The WE for this LCS resulted in an average recovery of 104% vs. 82% recovery in the AD and 116% recovery in the MD. While the MD results were comparable to the previous LCS experiment, the WE resulted in a much higher recovery, and the AD resulted in a slightly lower recovery. The lower recovery of Tc-99 in the water extracts of the LCS that was ground in the ball mill suggests that some of the Tc-99 in the spike may have been reduced by fresh ferrous iron surfaces exposed during grinding of the sediment. These results imply than a technique more robust that water extraction may be required to quantify total Tc-99 concentrations in contaminated sediments obtained using split-spoon sampling or drive barrel techniques where disaggregation of Hanford gravel and coarse sand particles may expose fresh iron-bearing minerals that might lead to technetium reduction.

Pacific Northwest National Laboratory, PO Box 999, MS P7-22, Richland, WA 99352
[1] *Telephone: (509) 372-2485; Fax: (509) 376-4890; E-mail: Michelle.Valenta@pnl.gov*
[2] *Telephone: (509) 376-8389; Fax: (509) 376-4890; E-mail: Christopher.Brown@pnl.gov*
[3] *Telephone: (509) 376-8429; Fax: (509) 376-4890; E-mail: Jeff.Serne@pnl.gov*
[4] *PNNL SULI student*
[5] *Telephone: (509) 373-6337; Fax: (509) 376-4890; E-mail: dennese.smith@pnl.gov*

Use of Narrow-Diameter, Direct-Push Wells to Characterize and Remediate Carbon Tetrachloride in the 200 West Area, Hanford Site, Washington

Ken Moser[1], Wes Bratton[2], and Virginia Rohay[3]

Carbon tetrachloride was discharged to three liquid waste disposal sites in the 200 West Area of the Hanford Site from 1955 to 1973. The sites received carbon tetrachloride in mixtures with other organics (e.g., tributyl phosphate) and also entrained/dissolved in aqueous phase liquids. Soil vapor extraction (SVE) through perforated or screened wells was initiated in 1992 to remediate the vadose zone underlying these waste sites. A soil sample collected in 2003 from approximately 19.4 to 20.1 m depth in well 299-W15-46, which was being drilled near the 216-Z-9 Trench waste site, was found to contain a relatively high concentration of carbon tetrachloride (380 mg/kg). This high concentration is believed to be associated with a silt layer that is present from 19.8 to 20.4 m depth and had not been remediated by the existing SVE wells. The high concentration suggests that the carbon tetrachloride is present as a DNAPL. In 2006, a comprehensive field study culminated with direct-push technology to investigate the extent of this silt layer and associated carbon tetrachloride soil concentrations in the vicinity of this waste site. Similar carbon tetrachloride concentrations (390 mg/kg) were detected in a soil sample from 19.5 to 20.1 m depth at P66, the push location ~3.1 m east of well 299-W15-46. Carbon tetrachloride was not detected in samples from this depth at the other nearby push locations: P69 (~6.3 m west of well 299-W15-46), P68 (~12.1 m east of well 299-W15-46) and P67 (~3.9 m south of well 299-W15-46).

Narrow-diameter SVE wells were installed at push locations P66 (well C4937), P68 (well C5340), and P69 (well C4938). The wells are screened from 18 m to 19.7 m and have outside diameters of 3.6 cm. The wells were added on-line to the 14.2 m^3/min (500 ft^3/min) SVE system in June 2007 and produced flows of approximately 0.3 m^3/min (9 ft^3/min). During SVE, the carbon tetrachloride soil vapor concentrations were significantly higher in well C4937, the location with the DNAPL soil sample. During monitoring following SVE, concentrations at C4937 and C4938 have been comparable.

Pressure testing was conducted at these three narrow-diameter wells in October 2008 to evaluate the zone of influence of these wells. If analysis of the data indicates that the wells have adequate zones of influence to support shallow (less than 30 m deep) SVE, a direct-push technology will be considered in the future for SVE well installation as part of the remedial action for carbon tetrachloride in the vadose zone.

Vista Engineering Technologies, LLC, 1355 Columbia Park Trail, Richland, WA 99352; Telephone: (509) 737-1377; Fax: (509) 737-1383
[1] E-mail: moser@vistaengr.com
[2] E-mail: bratton@vistaengr.com
[3] CH2M Hill Plateau Remediation Company, MSIN E6-44, P.O. Box 1600, Richland, WA 99352; Telephone: (509) 373-3803; Fax: (509) 373-3974; E-mail: Virginia_J_Rohay@rl.gov

Final Remedy for Treating 200 West Area Groundwater, Hanford Site, Washington

Mark E. Byrnes[1], *Amadeo J. Rossi Jr.*[2], *and Arlene C. Tortoso*[3]

The 200-ZP-1 Groundwater Operable Unit (OU) is one of two groundwater OUs located within the 200 West Area groundwater aggregate areas of the Hanford Site. An interim pump-and-treat system for this OU was implemented in 1995 to control the 2,000-µg/L contour of a 5-mi^2 carbon tetrachloride plume associated with the Plutonium Finishing Plant. Fourteen extraction wells and five injection wells are currently operating at a combined rate of approximately 320 gal/min. The primary contaminants of concern include carbon tetrachloride, trichloroethylene, technetium-99, iodine-129, hexavalent chromium, tritium, and nitrate.

The *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* remedial investigation/feasibility study process was recently completed for the 200-ZP-1 OU with the signing of the final Record of Decision in September 2008. The selected remedy requires the installation of a full-scale pump-and-treat system, combined with flow-path control, monitored natural attenuation, and institutional controls.

The full-scale groundwater pump-and-treat system will be installed to reduce the mass of the contaminants of concern by a minimum of 95% in 25 years. The estimated pumping rate required to meet this objective is 1,600 gal/min. Recent groundwater modeling results suggest that the treatment system will be comprised of approximately 20 groundwater extraction wells and 16 injection wells. The groundwater treatment facility is currently being designed to accommodate a maximum flow rate of 2,500 gal/min to allow the flexibility of treating potentially higher pumping rates from the 200-ZP-1 OU, as well as water from the 200-UP-1 OU to the south. The contaminant removal methods that are currently proposed include (1) ion exchange (e.g., Purolite® A-530E resin) to remove the technetium-99 and iodine-129; (2) bio-reactors to address nitrate and hexavalent chromium, and to knock down the carbon tetrachloride and trichloroethylene concentrations; and (3) air stripping to remove the remaining carbon tetrachloride and trichloroethylene. While there currently are no treatment methods for tritium, the short half-life (12 years) for this contaminant will naturally reduce concentrations below drinking water standards within the timeframe of the remedy. Phase I operations are scheduled to begin by the end of 2011.

CH2M Hill Plateau Remediation Company, Groundwater Remediation Project, PO Box 1000, Richland, WA 99352
[1] *Telephone: (509) 373-3996; E-mail: mark_e_byrnes@rl.gov (presenter)*
[2] *Telephone: (509) 373-3330; E-mail: Amadeo_J_Rossi@rl.gov*
[3] *U.S. Department of Energy, Richland Operations Office, 825 Jadwin Avenue, Richland, WA 99352; Telephone: (509) 373-9631; E-mail: Arlene_C_Tortoso@rl.gov*

Soil Water Influence on the Oxygen Isotope Ratio of Soil CO_2 Flux to the Atmosphere

Clayton Larkins[1], Carey Gazis[2]

Soil hydrology is strongly linked to the carbon cycle in soils in a number of ways. Soil moisture and soil water movement control rates of organic matter decomposition, movement of inorganic and organic carbon, as well as the distribution and types of plants present. Soil water also acts as a major influence on the oxygen isotope composition of soil CO_2, as evolving CO_2 undergoes the following isotope exchange reaction with soil water:

$$H_2{}^{18}O_{(l)} + CO_{2(g)} \leftrightarrow H^+ + [HCO_2{}^{18}O]^-_{(aq)} \leftrightarrow H_2O_{(l)} + CO^{18}O_{(g)}$$

The rate at which this equilibration reaction occurs with respect to the rate of CO_2 diffusion from the soil dictates the degree to which soil CO_2 flux will reflect isotopic equilibrium with soil water. In this study, the $\delta^{18}O$ of soil CO_2 flux and soil CO_2 at depth is analyzed and compared to the $\delta^{18}O$ of soil water across a precipitation gradient in eastern Washington. Analysis of soil moisture content, soil moisture $\delta^{18}O$, and soil temperature measured at the time of CO_2 sampling will be used to model the influence of these environmental variables on the oxygen isotope composition of soil CO_2 flux.

Respiration from terrestrial soils to the atmosphere is a major flux of CO_2 to the atmospheric reservoir. The impacts of changing global climate on this flux are of interest as increased global temperatures could potentially induce a positive feedback resulting in increased soil CO_2 production and release. Oxygen isotopes combined with mass balance equations are useful for estimating inputs to atmospheric CO_2. For this method, the distinct $\delta^{18}O$ signature of all major CO_2 fluxes to the atmosphere must be known. The $\delta^{18}O$ of soil CO_2, however, is the least well constrained of CO_2 fluxes to the atmosphere, largely due to the difficulty involved with measuring this isotopic flux.

This field investigation is aimed at constraining the relationship between the $\delta^{18}O$ of soil water and the $\delta^{18}O$ of soil CO_2 by monitoring these two parameters with respect to changing environmental factors across a precipitation gradient. Identifying such relationships will enhance our ability to model and potentially monitor global soil carbon flux to the atmosphere.

Central Washington University, Department of Geology, 400 E University Way, Ellensburg, WA 98926;
[1] Telephone: (509) 963-2707; Fax: (509) 963-2821; E-mail: Larkinsc@cwu.edu
[2] Telephone: (509) 963-2820; Fax: (509) 963-2821; E-mail: cgazis@geology.cwu.edu

A Stable Isotope Study of Soil Water Budgets Along a Climate Transect in a Snowmelt Dominated System

Travis Hammond[1], and Carey Gazis[2]

The soil water budget is an integral part of the overall water budget of a particular watershed and/or groundwater basin. Studies characterizing soil water residence times, and style and rates of downward flow can give insight into aquifer recharge rates and estimates of evapotranspirative losses. In this study oxygen and hydrogen stable isotope data in combination with a mass balance approach was used to track inputs, flux between soil water compartments, and outputs in order to understand climatic influence on the soil water budget in a snowmelt-dominated hydrologic system in central Washington.

Precipitation, snowmelt, and two types of soil water (total soil water and lysimeter water) were sampled at four sites along a wet to dry transect form Snoqualmie Pass to Ellensburg, WA. Preliminary isotopic data along with precipitation amounts from the driest site demonstrated that water moves through the soil column by both piston flow and by preferential flow along conduits to the lower soil water compartments. Piston flow appeared to predominate after smaller rainfall events as evidenced by deep total soil water isotope values that retain an isotopic signature from evaporative losses at a shallower level. After significant recharge events, isotope values from both shallow and deep samples of total soil water and mobile soil water (water not hygroscopically bound to soil particles) demonstrated mixing of pre-existing soil water with newly added recharge water. During these periods, rapid isotopic changes in deep soil water in response to recharge are an indication of preferential flow to the lower soil water compartment.

A previous study performed in the present study area demonstrated that non-fractionating losses (downward percolation and transpiration) were nearly zero in the late summer to fall at the driest site while at the wetter site these losses were significant (~0.8 mm/day) (Robertson and Gazis, 2006). The current study allows for a more detailed characterization of the contributions of the individual non-fractionating and fractionating components such as transpiration, downward percolation, and evaporation, to the soil water budget.

Central Washington University Department of Geological Sciences, 400 University Way, Ellensburg, WA 98926; Telephone (509) 963-2820
[1]*E-mail: hammondt@cwu.edu*
[2]*E-mail: cgazis@geology.cwu.edu*

PANELS

PANEL #1

Are Critical Areas Ordinances Protecting Water Supplies?

TIME: Wednesday, April 29, 1:00-2:30 PM.

This panel will discuss lessons learned since the Growth Management Act was put in place and local jurisdictions started applying ordinances to regulate new development. The discussion will also look forward to how we could improve groundwater pollution prevention efforts to protect drinking water sources. The panel is being designed to include local planners and regulators, land developers, hydrogeologists, a citizen group representative, with moderation by the Washington Departments of Ecology, Health, and Community Trade and Economic Development.

COST PER PERSON: No charge.

MAXIMUM SIZE: 50

PANELISTS: Rob Lindsay, Spokane County Water Resources; Doug Peters, Senior Planner, WA Dept. of Community, Trade and Economic Development; Laurie Morgan, WA Dept. of Ecology. Other invited panelists include representatives of the regulating, consulting and development community. **CONTACTS:** Donna Freier, City of Olympia, *dfreier@ci.olympia.wa.us*, *(360) 753-8793*; Laurie Morgan, WA Dept. of Ecology, *lmor461@ecy.wa.gov*, *(360) 407-6483*.

PANEL #2

Professional Licensure

TIME: Wednesday, April 29, 3:00 to 4:30 PM.

Dr. Jeffrey Randall, Washington State DOL Geologist Licensing Board Chair, will provide a half-hour talk on how to obtain professional licensure as a geologist-in-training, geologist, hydrogeologist or engineering geologist. Following this talk a panel discussion will provide perspective on licensing questions and issues. Panelists from the academic, consulting and regulatory fields have been invited.

COST PER PERSON: No charge.

MAXIMUM SIZE: 50

PANELISTS: Kathleen Goodman, AMEC, *kathleen.goodman@amec.com*, *(206) 342-1760*; Dr. Robert Mitchell, Western Washington University, *robert.mitchell@geol.wwu.edu*, *(360) 650-3591*; Nnamdi Madakor, WA Dept. of Ecology, *nmad461@ecy.wa.gov*, *(360) 407-7244*. **CONTACTS:** Sandra Caldwell, WA Dept. of Ecology, *saca461@ecy.wa.gov*, *(360) 407-7209*; Laura Klasner, WA Dept. of Ecology, *lkla461@ecy.wa.gov*, *(360) 407-6265*.

WORKSHOPS

Some Workshops may become space-limited (first come, first served), and some may be cancelled if minimum pre-registration targets are not met. Registrants will be notified by e-mail of Workshop details. Fees will be refunded if cancellations occur. All workshops will be held at the Greater Tacoma Convention and Trade Center.

WORKSHOP #1

Ecology's Environmental Information Management (EIM) Database

TIME: Wednesday, April 29, 10:00 to 11:30 AM.

This session will include a demonstration and Q&A session on how to get data from Ecology's Environmental Information Management (EIM) database. EIM is Ecology's main database for environmental monitoring data, containing over 6 million records on physical, chemical, and biological analyses and measurements. We will cover the standard Database Search as well as the newer custom search and analytical tool, MyEIM.

COST PER PERSON: No charge.

MAXIMUM SIZE: 50

LEADER & CONTACT: Chris Neumiller, WA Dept of Ecology, *cneu461@ecy.wa.gov*, *(360) 407-6258*.

WORKSHOP #2

Nonlinear HOC Sorption: Why It Is Important, Why We Usually Ignore It, and What to Do About It

TIME: Thursday, April 30, 1:30 to 4:30 PM.

Recent work has shown that condensed forms of carbonaceous matter (CM), such as char and kerogen, act as 'super sorbents' of hydrophobic organic contaminants (HOC). Even low concentrations of condensed CMs can have significant effects on the transport and partitioning behavior of HOCs. Standard approaches (such as $K_{oc}f_{oc}$) to contaminant study in groundwater typically do not include nonlinear adsorption that describes this behavior. When nonlinear adsorption is neglected, it can exert the following biases in contaminated site evaluation: Significant underestimation of the total soil concentration needed to be protective of groundwater quality; overestimation of equilibrium groundwater concentrations calculated from total soil analyses; underestimation of total mass in a plume from observed groundwater concentrations. Because the differences between the true values and empirically based linear estimates can differ by as much 10-100 fold in some circumstances, this can lead to significant unnecessary costs for remediation.

This workshop will provide a context and rationale for the standard values used in the empirical approach and discusses the conditions in which adsorption processes are likely to be important. Examples of the impacts of condensed CM on contaminant distribution in groundwater will be presented and multiphase partitioning calculations will be reviewed. Chlorinated solvents in low carbon content aquifers will be emphasized. Example calculations will be based on real data. Practical suggestions for real field sites will be discussed.

COST PER PERSON: $50.

MAXIMUM SIZE: 35 participants; minimum: 18.

LEADER: Dr. Richelle M. Allen-King, Professor and Chair, Department of Geology, University at Buffalo (SUNY) (*richelle@buffalo.edu*). **CONTACT:** Christopher Gellasch, U.S. Army, *christopher.gellasch@us.army.mil, (253) 966-0069*.

WORKSHOP #3

Subsurface Heterogeneity: Why It Is Important, Why We Usually Ignore It, and What to Do About It

TIME: Thursday, April 30, 1:30 to 4:30 PM.

Inadequacies of transport models are most commonly attributed to insufficient representation of heterogeneity and its control of scale-dependent dispersion, early breakthrough due to preferential flow, and long-term (decades to centuries) tailing. This is often seen by the nearly ubiquitous ineffectiveness of pump-and-treat remediation. Moreover, recent studies have shown that interpretation of so-called groundwater age data can be dubious or misleading unless one has a transport model with good representation of subsurface heterogeneity. We have also seen that something as “simple” as a pumping test may be misinterpreted without a good understanding of subsurface complexities. How can we do a better job?

This workshop will show examples of how the lack of geologic characterization of heterogeneity in flow and transport models can diminish the reliability and utility of groundwater models, especially transport models. We will then ask ourselves the question: “If we know heterogeneity is so important, why do we usually ignore it?” The ensuing discussion will help lead us to insights regarding how the philosophy and science of hydrogeology might evolve so as to resolve this problem. The last portion of the workshop will be devoted to presentation of some approaches to modeling and understanding the influence of subsurface heterogeneity, including the transition probability approach and use of outcrop analogs for aquifers. These approaches allow relatively easy infusion of geologic and geophysical information into quantitative models of geologic heterogeneity.

COST PER PERSON: $50.

MAXIMUM SIZE: 35 participants; minimum: 18.

LEADER: Dr. Gary Weissmann, Associate Professor, Black Family Professor of Hydrology, University of New Mexico, *weissman@unm.edu*. **CONTACT:** Christopher Gellasch, U.S. Army, *christopher.gellasch@us.army.mil*, *(253) 966-0069*.

WORKSHOP #4

Methods for Estimating Ground-Water Recharge

TIME: Thursday, April 30, 1:30 to 4:30 PM.

Estimates of groundwater recharge are required to accurately assess water resources and evaluate aquifer vulnerability to contamination. This course will review theory, assumptions, uncertainties, advantages, and limitations of different approaches for estimating recharge rates. Methods to be discussed include water-budget methods, various modeling approaches, the water-table fluctuation method, tracer methods, and methods based on streamflow data. Examples will be presented to demonstrate application of the different methods. The course is aimed at practicing hydrologists and advanced hydrology students.

COST PER PERSON: $50.

MAXIMUM SIZE: 35 participants; minimum: 18.

LEADER: Richard W. Healy, U.S. Geological Survey, *rwhealy@usgs.gov*, *(303) 236-5392*. **CONTACT:** Christopher Gellasch, U.S. Army, *christopher.gellasch@us.army.mil*, *(253) 966-0069*.

WORKSHOP #5

Well Driller Session

TIME: Thursday, April 30, 8:00 AM to 4:00 PM.

For the first time offered anywhere, this session will provide 2.0 hours of continuing education units (CEUs) for Washington rules and 2.0 hours of continuing education credits (CECs) for Oregon rules. Each of these presentations will briefly discuss the state-specific laws governing the drilling of geotechnical holes, water wells and monitor wells, including notices and reporting requirements for drillers, geologists, and engineers. The session will also offer general continuing education related to the design and installation of low-cost groundwater sparging and soil vapor extraction systems, an off-site sonic drilling demonstration, and other presentations to be determined.

COST PER PERSON: One-day fee of $100.00 for Driller Training Workshop only. If attendee is registered for entire symposium, an additional fee of only $35.00 is required to attend this workshop. Fees include lunch on Thursday.

MAXIMUM SIZE: 50

LEADERS: Bill Lum, WA Dept. of Ecology, *blum461@ecy.wa.gov*, *(360) 407-6648*; Tracy Fox, Oregon Water Resources Department. **CONTACT:** Bob Miller, *robertmiller8701@comcast.net*, *(503) 650-7726*.

Workshop #5: Regulation of Well Construction in Washington

William E. Lum, II[1] *and Marian Bruner*[2]

Well construction in Washington is regulated by Chapter 18.104 Revised Code of Washington, the "Water Well Construction Act (1971)." Among other things, this law defines a well, specifies required design and construction standards, and defines who can construct a well. "Minimum Standards for Construction and Maintenance of Wells," Chapter 173-160 WAC (Washington Administrative Code), and "Rules and Regulations Governing the Regulation and Licensing of Well Contractors and Operators," Chapter 173-162 WAC, are the regulations (the implementation of the law) dealing with well design and construction and licensing of persons constructing wells, respectively. These regulations are administered by Ecology (Washington Department of Ecology).

"Operators" (licensed well drillers) are required to obtain continuing education to enhance their professional skills. CEUs (Continuing Education Units) are earned by attending continuing education programs offered by approved providers whose programs are reviewed and approved by Ecology. When renewing an operator's license, regulations require that at least 2 CEU hours must cover Washington State Laws and Regulations, this presentation satisfies that requirement.

The presentation will answer some basic questions such as: What does Ecology regulate? What is a well? Who can construct a well? Is a Licensed Geologist or Hydrogeologist exempt from further licensing? How (and why) do I decommission a well? Who can decommission a well? How can I get a variance from the regulations? Where can I get more information? How do I contact Ecology?

We will also discuss using wells to obtain geothermal energy. What regulations apply when using this "green" energy to heat and cool your home or business?

Washington Department of Ecology;
Water Resources Program; Engineering and Technical Support Unit;
P. O. Box 47600; Olympia, WA 98504-7600; FAX 360-407-7162
[1] *Phone 360-407-6648; Email: blum461@ecy.wa.gov*
[1] *Phone 360-407-6650; Email: mbru461@ecy.wa.gov*

Workshop #5: Regulation of Well Construction in Oregon

Tracy Fox[1], Kris Byrd[2], and Laurie Norton[3]

Well construction in Oregon is regulated by Oregon Revised Statute (ORS) 537.747 through ORS 537.796, and ORS 537.990 through 537.992. These laws are implemented by Oregon Administrative Rules (OAR) Chapter 690, Divisions 200 through 240. Together, these laws regulate well construction in Oregon. OAR Chapters 690, Divisions 200 through 230 are the Water Supply Well Construction Standards and OAR Chapter 690, Division 240 is the Well Construction Standards for Construction, Maintenance, Alteration, Conversion and Abandonment of Monitoring Wells, Geotechnical Holes, and Other Holes in Oregon. Together these laws and rules define a well, specify who can construct a well, set licensing requirements, require continuing education for license renewal, specify well construction standards, set well abandonment standards, define the well identification program, set out the requirements for pump testing nonexempt wells, outline the enforcement process, and define the standards and procedures for low-temperature geothermal wells.

A “Notice of Beginning of Construction” (Start Card) is required prior to beginning work on a water supply or monitoring well. The presentation will review the requirements, which changed as of January 1, 2009, in addition to what information is required on the Start Card and submittal options.

A well report is required for each water supply well, monitoring well, and geotechnical hole constructed, altered, converted, or abandoned in Oregon. The presentation will answer basic questions about reporting requirements for Water Supply Well Reports, Monitoring Well Reports, and Geotechnical Hole Reports, including how best to complete a well report and how to file it with Oregon Water Resources Department.

The presentation will briefly cover Oregon's well construction requirements, specifically the water supply well abandonment standards and the changes to the abandonment standards that took effect January 1, 2009.

Oregon Water Resources Department
Well Construction and Compliance Section
725 Summer Street NE, Suite A; Salem, Oregon 97301-1266
Fax 503-986-0902
[1] *Phone 503-986-0856; Email Tracy.L.Fox@wrd.state.or.us*
[2] *Phone 503-986-0851; Email Kris.R.Byrd@wrd.state.or.us*
[3] *Phone 503-986-0850; Email Laurie.K.Norton@wrd.state.or.us*

FIELD TRIPS

Some Field Trips may become space limited (first come, first served), and some may be cancelled if minimum pre-registration targets are not met or if access to field trip areas is closed due to road, safety, or security conditions. Registrants will be notified by e-mail of Field Trip details. Fees will be refunded if cancellations occur. Unless indicated otherwise, all Field Trips will start and end at the Greater Tacoma Convention and Trade Center.

FIELD TRIP #1

Hydrogeology of Beer and Wine in the Yakima Valley

CANCELED

TIME: Sunday, April 26, 8 AM to Monday, April 27, 6 PM.

Washington State ranks first in the United States in the production of hops and second in the production of wine grapes. Nearly all of Washington's hop and wine-grape production is located in the lower Yakima River Basin, where the climate and geology are ideally suited. The lower Yakima River Basin is one of the most intensively irrigated areas in the United States. Most of this irrigation water has been supplied by surface-water reservoirs and canal systems. However, increasing demands for water for agricultural, municipal, fisheries, industrial, and recreational uses have strained these surface–water resources, and spurred the increased use of groundwater resources.

This field trip will explore the many aspects of the geology and hydrogeology in the lower Yakima River Basin, particularly as they relate to water resources that support the local beer and wine industries. During this 2-day trip, we will make several stops for a hands-on look at the geology of these two sedimentary basins, including ancestral Columbia and Yakima River sediments and Ice Age flood deposits. We will make other stops where we can overlook portions of the basin and discuss proposed projects designed to enhance water resources, and we will stop at a local brewery and winery to taste, first hand, the fruits of this unique hydrogeologic system.

COST PER PERSON: $190 (double occupancy), $240 (single occupancy), includes transportation by van, overnight stay in Richland, WA, box lunches (2), morning and afternoon refreshments, guide book, and a catered dinner featuring local wines on Sunday night.

MAXIMUM SIZE: 20 participants; minimum: 8.

LEADERS: George Last, Pacific NW Nat'l Lab-PNNL, *george.last@pnl.gov, (509) 371-7080*; Matt Bachmann, U.S. Geological Survey, *mbachmann@usgs.gov, (253) 552-1672*; Alan Busacca, VINITAS Vineyard Consultants, LLC, *alan@vinitas.net*; Bruce Bjornstad, Pacific NW Nat'l Lab-PNNL, *bruce.bjornstad@pnl.gov, (509) 371-7223*. **CONTACT:** Chris Curran, U.S. Geological Survey, *ccurran@usgs.gov, (253) 552-1614.*

FIELD TRIP #2

Hydrogeologic Implications of Removing the Elwha River Dams

TIME: Monday, April 27, 7:30 AM to 6 PM.

The Elwha River Ecosystem and Fisheries Restoration Act of 1992 authorized the Secretary of the Interior to acquire and remove the Elwha and Glines Canyon Dams on the Elwha River to fully restore the ecosystem and native anadramous fisheries. Commencing in 2012, the 108-foot-tall Elwha Dam and the 210-foot-tall Glines Canyon Dam are scheduled to be dismantled in stages, reopening 70 miles of prime salmon and steelhead spawning habitat. The Elwha project offers a unique opportunity to fully restore a river since nearly all the river's watershed is preserved within the relatively undeveloped environment of Olympic National Park. Removing the two dams is expected to temporarily increase the amount of silt in the river since some 18 million cubic yards of sediment have been trapped behind the dams over the last 93 years. The resulting flooding and increased silt will impact multiple water users downstream including the City of Port Angeles, the WDFW fish hatchery, the Lower Elwha Klallam Tribe, and many other water users. A new water-treatment plant is currently under construction to treat the highly turbid water diverted from the Elwha River. This field trip will visit the Glines Canyon Dam, the Elwha Dam, the City of Port Angeles Ranney groundwater collector, the WDFW State hatchery and the Lower Elwha Klallam Tribe salmon recovery project site near the Elwha estuary.

COST PER PERSON: $45, includes transportation by van, box lunch, and field trip handouts.

MAXIMUM SIZE: 20 participants; minimum: 8.

LEADERS: John Pearch, WA Dept. of Ecology, *jope461@ecy.wa.gov*, *(360) 407-0297*; Brian Winter, Olympic National Park; Steve Sperr, City of Port Angeles; Jeff Duda, Western Fish Research Center, USGS; Mike McHenry and Matt Bierne, Lower Elwha Klallam Tribe. **CONTACT:** Chris Curran, U.S. Geological Survey, *ccurran@usgs.gov*, *(253) 552-1614*.

FIELD TRIP #3
Coastal Cliff Geology Dinner Cruise

TIME: Wednesday evening, April 29, 5:30 to 9 PM.

This field trip features a unique opportunity to enjoy great geology from a different perspective as well as an opportunity to network with colleagues in the delightful surroundings of an evening buffet dinner cruise. Kathy Troost, Brian Sherrod, and friends will lead an evening boat cruise departing from Thea Foss Waterway and traveling along the bluffs of Point Defiance and the Tacoma Narrows to the site of the new Tacoma Narrows Bridge. Along the way, trip leaders will describe the geology, the Tacoma fault zone, coastlines and shoreline processes, landslides, the foundation for the Tacoma Narrows Bridge, culture and history, the Port of Tacoma fill and Puyallup River delta, habitats and environmental conditions, and Puget Sound. Exposures of well-dated Quaternary sediments will be visible, including at measured sections where Olympia, Whidbey, Possession, and Double Bluff-aged deposits have been identified with absolute age dating techniques. Participants will receive a guidebook with color maps, images, and a fold out geologic strip map with measured sections. This trip will include a buffet dinner and choice of beverage onboard the charter vessel "My Girl", a 69-foot-long Coast Guard certified vessel with a professional, licensed crew. The boat has inside seating for 65, a sun deck, enclosed aft deck, rest rooms, and much more. We will have sunlight until about 8 PM. The boat is docked within walking distance of the Greater Tacoma Convention and Trade Center and will depart from the dock promptly at 6:00 pm (*http://www.mygirltheboat.com/*).

COST PER PERSON: $85

MAXIMUM SIZE: 65 participants; minimum: 50.

LEADER: Kathy Troost, University of Washington, *ktroost@u.washington.edu, (206) 616-9769.* **CONTACT:** Chris Curran, U.S. Geological Survey, *ccurran@usgs.gov*, *(253) 552-1614.*

FIELD TRIP #4
Fiber-Optic Distributed Temperature Sensing

CANCELED

TIME: Thursday afternoon, April 30, 1:30 to 4:30 PM.

Hydrologists from the USGS will demonstrate the use of Fiber-Optic Distributed Temperature Sensing for measuring stream temperatures and evaluating ground-water discharge to a local Pierce County stream. This new technology allows for high-resolution, real-time monitoring of temperature along the entire length of an optical fiber at a spatial resolution of less than 1 meter and thermal resolution of less than 0.1 degree Celsius, at sub-minute measurement intervals. We will demonstrate how a fiber is deployed in a stream and the collection of real-time temperature data. We will describe data interpretation and instrumentation options with a focus on applying the technology to streams and rivers in the Pacific Northwest as well as to the Puget Sound near-shore environment.

COST PER PERSON: $25

MAXIMUM SIZE: 20 participants; minimum: 10.

LEADERS & CONTACTS: Rick Dinicola, U.S. Geological Survey, *dinicola@usgs.gov*, *(253) 552-1603*; Chris Curran, U.S. Geological Survey, *ccurran@usgs*.gov, *(253) 552-1614*.

FIELD TRIP #5

Hydrogeology of the San Juan Islands

TIME: Thursday, April 30, 12:00 Noon to Friday, May 1, 9:00 PM. (Depart at 12:00 Noon)

The geology on the San Juan Islands makes it hard to naturally store water, since the Islands are composed primarily of bedrock and thin soils. Such terrain has little capability to absorb rainfall to replenish groundwater aquifers. Because of the geology, a large percentage of rainwater runs off into the Puget Sound unless it can be captured for beneficial use.

Groundwater and surface water are limited on the San Juan Islands. Groundwater can be difficult to find and extract from bedrock. Existing wells can go dry or become contaminated with salt water. Thus, many Island residents have to find alternative water sources to meet their water needs. Larger water-system operations use primarily surface-water reservoirs for their water supply. Some Island residents also use rooftop rainwater collection systems for their water supply. For some areas, rainwater may be the only water resource available. Other water systems use desalination plants (reverse osmosis), that remove excess salt and minerals from diverted sea water. Other residents resort to having water trucked or shipped in.

The local Watershed Planning Unit (San Juan County Water Resource Management Committee) requested that Washington State Department of Ecology (Ecology) develop a rainwater collection permit under the local Watershed Planning process. In response, Ecology is working with the community to develop a faster and simpler rooftop rainwater collection permitting process for domestic use on an island-by-island basis.

Desalination plants and other salt water diversions or withdrawals do not require a water right permit from Ecology. However, Ecology's Water Resource Program Policy (1015) requires all diversions or withdrawals of salt water be constructed to protect against the induction of salt water into fresh water aquifers. In contrast, larger surface water reservoirs (such as Cascade Lake and Mountain Lake) on Orcas Island supply plentiful water to many communities throughout eastern Orcas Island, which have surface water rights that date back to the early 1900's.

This field trip will visit various water-system facilities on Orcas Island including surface-water reservoirs, wells, a rainwater catchment, and a desalination plant. Local experts on the geology and water system operators have been invited to participate during the field trip. Short lectures also will be presented on the geology of the San Juan Islands and sea water intrusion.

COST PER PERSON: $160, includes transportation by van and ferry, overnight stay on Orcas Island at Camp Orkila cabins, a catered dinner Thursday night, breakfast Friday morning, box lunches for Friday lunch, and a guide book.

MAXMUM SIZE: 20 participants; minimum: 10.

LEADERS: John Pearch, WA Dept. of Ecology, *jope461@ecy.wa.gov*, *(360) 407-0297*; Vicki Heater, San Juan Island Health Dept., *vickih@co.san-juan.wa.us*, *(360) 378-4474*; Paul Kamin, East Sound Water Users Association, *(360) 376-2127*; and Jerry Liszak, WA Dept. of Ecology, *jlis461@ecy.wa.gov*, *(425) 649-7013*. Additional trip leaders have been invited to participate. **CONTACT:** Chris Curran, U.S. Geological Survey, *ccurran@usgs.gov*, *(253) 552-1614*.

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