8th Washington Hydrogeology Symposium

PROGRAM AND ABSTRACTS

OF THE

8TH WASHINGTON HYDROGEOLOGY SYMPOSIUM

April 26–28, 2011

Hotel Murano

Tacoma, Washington

8th Washington Hydrogeology Symposium

GENERAL SCHEDULE

Date	Activity
Monday *April 25th*	**Field Trip 1:** Late Quaternary Geomorphic Reworking of the Puget Lowlands Downstream of Mount Rainier: Implications for People and Salmon Living with the Rivers *(all day)*
Tuesday *April 26th*	**First Day of Symposium:** Platform Presentations *(all day)* Lunch Provided **Exhibits and Posters** **Evening Poster Session and Reception**
Wednesday *April 27th*	**Second Day of Symposium:** Platform Presentations *(all day)* Lunch Provided **Exhibits and Posters** **Afternoon Panels:** 5A Reclaimed Water 6A Stormwater **Field Trip 2:** Coastal Geology of Tacoma Area Dinner Cruise
Thursday *April 28th*	**Third Day of Symposium:** Platform Presentations *(morning)* **Workshop 1:** Critical Thinking in the Interpretation of Pumping Tests *(all day)* **Workshop 2:** Well Driller and Ecology Well Report Database Workshop *(all day)* **Field Trip 3:** Groundwater-Surface Water Interactions *(afternoon)* **Field Trip 4:** Water Treatment Systems in Tacoma *(afternoon)*
Friday *April 29th*	**Field Trip 5:** Hydrogeology of Beer and Wine Country in the Yakima Valley *(day 1)*
Saturday *April 30th*	**Field Trip 5:** Hydrogeology of Beer and Wine Country in the Yakima Valley *(day 2)*

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CHAIRMAN'S WELCOME

8th Washington Hydrogeology Symposium

Welcome to the 8th Washington Hydrogeology Symposium! We are pleased to relocate this year's Symposium to the newly renovated Hotel Murano. The Hotel Murano offers an upscale meeting place with beautiful mountain and water views, and is surrounded by a wide variety of dining, shopping, and museums. The meeting rooms and facilities within the Hotel Murano are the perfect size to provide the intimate setting needed to facilitate interaction among our attendees.

This year's technical program consists of 59 platform and 22 poster presentations covering all aspects of hydrogeology, water resources management, and water quality. Specific topics include *Water Rights and Policy, Environmental Contamination and Characterization, Innovative Remediation Technologies,* and *Groundwater and Surface Water Interactions.* These will be supplemented with two panels on *Reclaimed Water* and *Stormwater Impacts on Groundwater Quality.* New to the Symposium this year is a technical session covering geological carbon sequestration activities within Washington State. The 2011 Steering Committee has pulled together five exciting field trips, ranging from *Coastal Geology of the Tacoma Area* to *Hydrogeology of Beer and Wine Country in the Yakima Valley*. Three workshops will be presented, including *Critical Thinking in the Interpretation of Pumping Tests,* a tutorial on Ecology's *EIM Database,* and a *Well Driller and Ecology Well Report Database Session,* which can be used to earn continuing education credits in Washington and Oregon.

We are delighted to have three distinguished keynote speakers: Dr. Timothy Scheibe, Dr. Estella Atekwana, and Dr. Eric Steig. Dr. Scheibe, Pacific Northwest National Laboratory, is the 2010 Henry Darcy Distinguished Lecturer and a leader in the characterization and numerical simulation of natural subsurface heterogeneity. Dr. Atekwana, the Clyde Wheeler Sun Chair Professor at the Boone Pickens School of Geology at Oklahoma State University, is an expert in geophysical studies of geomicrobiology processes, and helped pioneer the new sub-discipline of biogeophysics. Dr. Steig is the Director of the Quaternary Research Center at the University of Washington and is a nationally recognized leader in stable isotope geochemistry.

Please take time to visit our Exhibitors, who offer a wide variety of state-of-the-art data collection, analysis, and reporting solutions. 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 and supporting our Sponsors listed on the back cover of the Program.

On behalf of the 8th Washington Hydrogeology Symposium Steering Committee and myself, Welcome! We hope you will have a productive and enjoyable few days at the Symposium, and that you will make plans to join us again in 2013.

Sincerely,

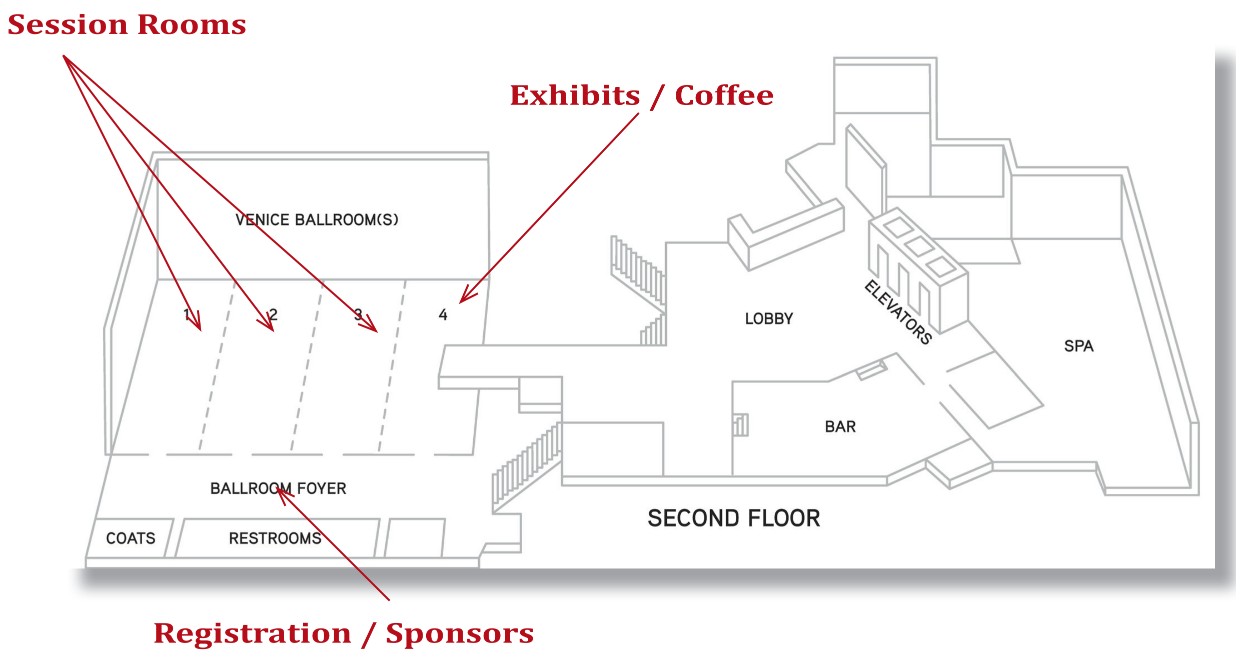
Chris F. Brown

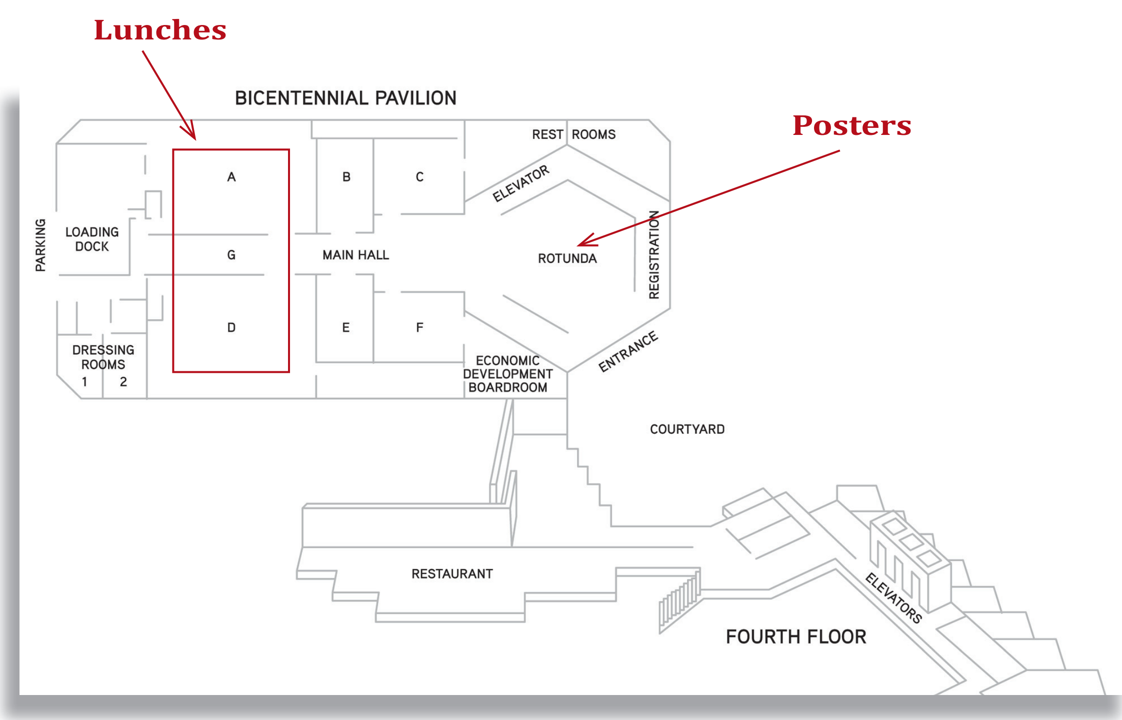
2011 Symposium Chair

Pacific Northwest National Laboratory

8th Washington Hydrogeology Symposium

KEY LOCATIONS





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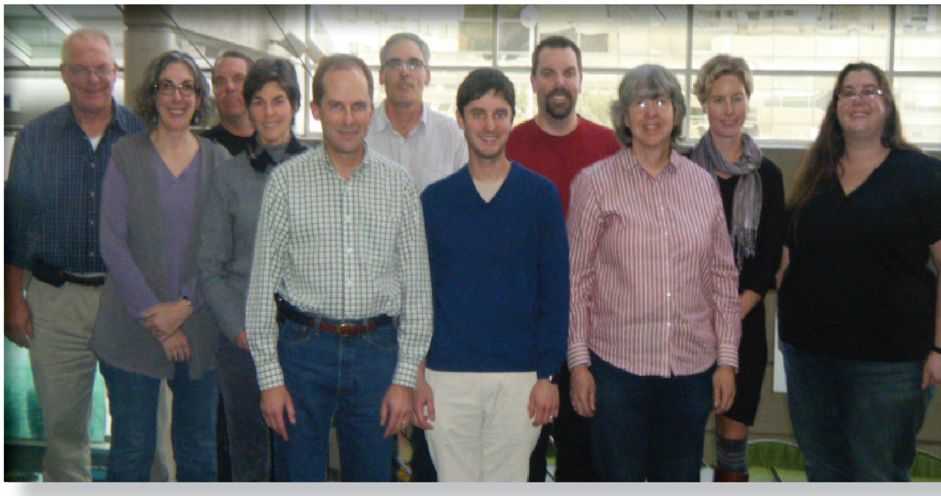

(left to right) Sandy Williamson, Sue Kahle, Joel Purdy, Donna Buxton, Mark Freshley, Bob Mitchell, Andy Gendaszek, Chris Brown, Laurie Morgan, Heidi Bullock, Michelle Valenta.

STEERING COMMITEE

8th Washington Hydrogeology Symposium Steering Committee

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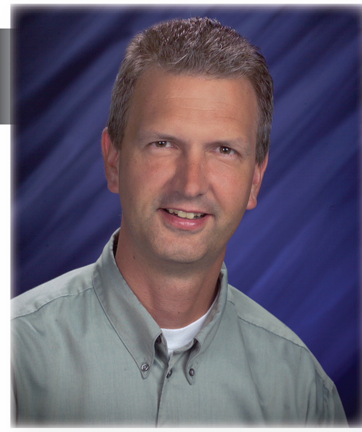
Tuesday, April 26, 2011			
7:30 AM	**Check-in and Registration** (Venice Foyer)		
9:00 AM	**Opening Session:** Welcome, Opening Remarks (**Venice 2 & 3**) **Keynote 1** - *Timothy D. Scheibe, Ph.D., Pacific Northwest National Laborabory* - **Quantifying Flow and Reactive Transport in the Heterogeneous Subsurface Environment: From Pores to Porous Media and Facies to Aquifers**		
10:15 AM	**Refreshment Break | Exhibits** (Venice 4)		
10:45 AM	**1A - Flow and Transport Modeling** (Venice 2)	**1B - Water Inventory Modeling** (Venice 3)	
SESSION 1	**A Reactive Transport Model of Mercury Fate in Sediment** *Brad Bessinger, S.S. Papadopulos & Associates* **The Pitfalls of "Plug and Chug" Modeling** *Joseph Caggiano, Washington State Department of Ecology* **Modeling Groundwater Behavior Using FRACMAN and FeFLOW at the Buckhorn Mountain Gold Mine** *B Todd Hoffman, Golder Associates* **Incorporation of Baseflow Component in the Water Erosion Prediction Project (WEPP) Model** *Anurag Srivastava, Washington State University*	**River-Aquifer Exchanges in the Yakima River Basin, Washington** *John Vaccaro, U.S. Geological Survey* **Evidence for Hydrogeologic Compartmentalization in the Columbia River Basalt Group (CRBG)** *Kevin Lindsey, GSI Water Solutions, Inc.* **Interpretation of Aquifer System Responses to a Long-Term Basin-Wide Aquifer Test in the Palouse Basin of Eastern Washington and Northern Idaho** *Katie Moran, University of Idaho* **Constructing and Calibrating Large Models: Lessons from the Yakima River Basin Groundwater Flow Model:** *Matt Bachmann, U.S. Geological Survey*	
12:15 PM	**Hosted Luncheon (Bicentennial Pavilion)**		
1:45 PM	**2A - Modeling/Data Management** (Venice 1)	**2B - Predicting Climate Change** (Venice 2)	**2C- Water Rights and Policy** (Venice 3)
SESSION 2	**Water Demand Forecast Model Development in Spokane County, WA:** *Mike Hermanson, Spokane County* **Vashon-Maury Island Volunteer Data Collection Effort** *Eric Ferguson, King County DNRP* **Stream View Photo Website, a Proposal** *Alex [Sandy] Williamson, U.S. Geological Survey Retired*	**Potential Impacts of Climate Change on Groundwater Resources of the Columbia River Basin** *John Vaccaro, U.S. Geological Survey* **Modeling the Effects of Climate Change on Snowpack and Streamflow in the Nooksack River Basin** *Robert Mitchell, Western Washington University*	**Information Management System for Water Right Mitigation Compliance – City of North Bend** *Alyssa Neir, Golder Associates Inc.* **Well Construction Regulations in Washington** *William Lum, II, Washington Department of Ecology* **Washington State Certified Water Right Examiner Program** *Douglas Wood, Washington Department of Ecology*
2:55 PM	**Refreshment Break | Exhibits** (Venice 4)		
3:15 PM	**3A - Environmental Contamination & Characterization** (Venice 1)	**3B - CO2 Sequestration** (Venice 2)	**3C - Innovative Remediation Technologies, Part I** (Venice 3)
SESSION 3	**Accelerated Weathering of LAW Glasses Using the Pressurized Unsaturated Flow Test Method** *Michelle Valenta, Pacific Northwest National Laboratory* **Geophysics and Site Characterization at the Hanford Site** *Brian Cubbage, Hydrogeophysics Inc.* **Evaluation of Copper and Nickel in Groundwater at a Shoreline MTCA Site** *Troy Bussey, PIONEER Technologies Corporation* **Single-well Thermal Tracer Tests using Distributed Temperature Sensing** *Andrew Leaf, Sound Earth Strategies, Inc. & University of Wisconsin-Madison, Department of Geosciences* **Assessment and Management of PCE in Redmond's Shallow Alluvial Aquifer** *Elaine Dilley, City of Redmond*	**Geologic Carbon Sequestration Regulations in Washington State** *John Stormon, Washington State Department of Ecology* **The Wallula Basalt CO2 Sequestration Pilot Project** *Pete McGrail, Pacific Northwest National Laboratory* **Integration of Basalt Aquifer Geomodels for Evaluation of CO2 Sequestration Potential in the Columbia River Basalt Group** *Charlotte Sullivan, Pacific Northwest National Laboratory* **Hydrologic Test Characterization Results from the DOE Regional CO2 Partnership, Wallula Basalt Pilot Study** *Frank Spane, Pacific Northwest National Laboratory* **INSAR and Gravity Surveys of a Large Aquifer Storage and Recovery Site in Pendleton, OR: Application to Large CO2 Storage** *Alain Bonneville, Pacific Northwest National Laboratory*	**Monitoring Functional Genes to Evaluate the Effectiveness of EOx at Gasoline-Impacted Sites** *Sheri Knox, EOS Remediation* **Using Groundwater Recirculation To Obtain Rapid, Site-wide Biodegradation of Petroleum Hydrocarbons or Chlorinated Solvents** *Brian Timmins, ETEC, LLC* **Accelerated Site Cleanup Using a Sulfate-Enhanced In Situ Remediation Strategy** *Sheri Knox, EOS Remediation* **Optical DO Technology Provides Real-Time Measurement Solution for Groundwater Remediation** *Bill Mann, In-Situ Inc*
4:45 PM	**Poster Session and Symposium Reception (Bicentennial Pavilion Rotunda)**		
7:00 PM	*Tuesday Sessions Adjourn*		

Wednesday, April 27, 2011		
8:00 AM	**Registration Desk Opens** (Venice Foyer)	
8:30 AM	**General Session with Keynote 2 -** *Estella Atekwana, Ph.D., Oklahoma State University* **- Biogeophysics: A Novel Approach for Imaging Subsurface Biogeochemical Processes (Venice 2 & 3)**	
9:30 AM	**Refreshment Break | Exhibits** (Venice 4)	
10:00 AM	**4A - Water Resources Groundwater Availability** (Venice 1)	**4B - Vadose Zone Contamination & Transport** (Venice 3)
SESSION 4	**Development of a 3,500-gpm Groundwater Supply for the Lower Elwha Klallam Tribe's New Salmon Hatchery** *Joel Purdy, GeoEngineers, Inc.* **The Potential to Augment Stream Flow using Ground Water, Bertrand Creek, Northwest Whatcom County, Washington** *Bridget August, Associated Earth Sciences, Inc* **Numerical Simulation of the Groundwater-Flow System in the Chambers-Clover Creek Watershed and Vicinity** *Ken Johnson, U.S. Geological Survey* **Riddle Me This! OR The Case of the Bastard Beach** *Mike Krautkramer, Robinson Noble, Inc.*	**Conceptual Models for Predictive Simulations of Soil Desiccation at the Field Scale** *Vicky Freedman, Pacific Northwest National Laboratory* **Radionuclide Immobilization and Flow Path Modifications by Dissolution and Secondary Precipitates** *Guohui Wang, Pacific Northwest National Laboratory* **Technetium-99 and Uranium-238 Contamination on Sediments in the BC Cribs and Trenches Area** *Wooyong Um, Pacific Northwest National Laboratory*
11:30 AM	**Hosted Luncheon and Keynote 3 -** *Eric Steig, Ph.D., University of Washington* **- New Frontiers in the use of Isotopes of Water: Climate, Atmospheric Circulation, and Oxygen 17 (Bicentennial Pavilion)**	
1:00 PM	**5A - Panel - Reclaimed Water** (Venice 1)	**5B - Innovative Remediation Technologies, Part II** (Venice 3)
SESSION 5	**Reclaimed Water -- What's Next?** **Moderator:** *Laurie Morgan* **Panel Members:** *Jim McCauley, Karla Fowler, Heather Trim, Ken Alexander* As water availability becomes more and more of a concern, and water needs grow, reclaimed water is more and more a vital sustainable resource. This panel brings together panelists who have been actively engaged in Washington's Reclaimed Water Advisory Committee.	**Multiple Remediation Approaches Demonstrate Cumulative Effectiveness in Treating Tetrachloroethene** *Troy Fowler, Hart Crowser, Inc.* **Donor Borings: Novel Use of Electron Donor Backfill for Bioremediation of a TCE Source Zone** *Christophe Venot, Landau Associates* **Enhanced Anaerobic Bioremediation of Petroleum by Nitrate Injection: Pilot- and Full-Scale Results** *Clinton Jacob, Landau Associates* **Multiple-Tiered Remediation Approach to Prevent Concentration Rebound at an Active Fueling Station** *Craig Dockter, Hart Crowser, Inc.*
2:50 PM	**Refreshment Break | Exhibits** (Venice 4)	
3:10 PM	**6A - Panel – Stormwater Impacts on Groundwater Quality** (Venice 2)	**6B - Innovative Remediation Technologies, Part III** (Venice 3)
SESSION 6	**Stormwater Impacts on Groundwater Quality** **Moderator:** *J. Scott KIndred* **Panel Members***: J. Scott Kindred, Robert Lindsay, Barbara Adkins,* This series of presentations will present monitoring data and/or studies that address the potential for groundwater contamination associated with stormwater infiltration, with case studies from Portland, Spokane, and the Idaho Panhandle.	**Issues Related to the Attenuation Processes to Remediate Metals and Radionuclides in Groundwater** *Dibakar (Dib) Goswami, Washington State Department of Ecology* **Foam: Reactant Transport Media for In-Situ Immobilization of Radionuclide and Metallic Contaminants** *Martin Foote, MSETA* **Removal of Heavy Metals in Acid Mine Drainage using Carbonate Cancrinite and Sodalite** *Jung-Seok Yang, Pacific Northwest National Laboratory* **Resin Testing to Recover Technetium-99 and Uranium from 200 West Area Groundwater, Hanford Site, Richland, Washington** *Mark Byrnes, CH2M Hill Plateau Remediation Company (CHPRC)* **Use of Reclaimed Water for Watershed Enhancement** *Sally Brown, University of Washington*
5:50 PM	**Field Trip 2 – Dinner Cruise: Coastal Geology of Tacoma Area**	

Thursday, April 28, 2011		
8:00 AM	**Registration Desk Opens** (Venice Foyer)	
8:00 AM	**Workshop 1: Critical Thinking in the Interpretation of Pumping Tests:** (USGS)	**Workshop 2: Well Driller and Ecology Well Report Database Workshop** (Venice 1)
8:30 AM	**7A - Engineering Geology: Landslides** (Venice 1)	**7B - GW/SW Interactions, Groundwater Dependent Ecosystems** (Venice 3)
SESSION 7	**The Role of Groundwater in the Nile Valley Landslide, Yakima County, Washington** *Thomas C. Badger, WSDOT* **Preliminary Lahar Hazard and Loss Estimations for Mount Rainier, Washington** *Recep Cakir, Department of Natural Resources - Geology and Earth Resources* **When Push Comes to Shove: Stream Channel Relocation by Lahars as Documented Using Sub-fossil Trees** *Kenneth Cameron, Oregon Department of Environmental Quality* **Large Seafloor Mounds in Hood Canal: Possible Earthquake-Induced Landslides** *Timothy Walsh, Department of Natural Resources*	**Predicting Groundwater Gradients Adjacent to a Dam-Controlled River** *Roy Jensen, Hart Crowser, Inc.* **Estimating Groundwater Discharge and Nutrient Loading to Lynch Cove, Hood Canal, WA** *Rich Sheibley, U.S. Geological Survey* **Hydrogeologic Controls on Aquifer - Columbia River Interactions, 300 Area IFRC Project, Hanford Site, Washington** *Bruce N. Bjornstad, Pacific Northwest National Laboratory* **Aquifer-River Interactions: Implications for the 300 Area Uranium Plume, Hanford Site, Washington** *Robert E. Peterson, Pacific Northwest National Laboratory*
10:00 AM	**Refreshment Break | Exhibits** (Venice 4)	
10:20 AM	**8A - Engineering Geology: Liquefaction** (Venice 1)	**8B - GW/SW Interactions, Hyporheic Zones** (Venice 3)
SESSION 8	**Soil Shaking Levels and Liquefaction Susceptibilities at Walla Walla and Aberdeen School Sites** *Recep Cakir, Washington State Department of Natural Resources, Geology and Earth Resources* **State Agencies Collaborate in Evaluating Seismic Stability of an Unpermitted Dam** *Jerald LaVassar, Washington State Department of Ecology Dam Safety Office* **Mapping the Extent of a Near-Surface, Low-Velocity, Saturated Zone using Microtremor Noise Recording** *Marc Fish, Washington Department of Transportation*	**Chinook Salmon Redd Distribution on the Cowlitz River, WA and Associated Habitat Features** *Katherine Murray, Pacific Northwest National Laboratory* **Development of a Conceptual Chum Salmon Emergence Model for Ives Island** *Evan Arntzen, Pacific Northwest National Laboratory*
11:30 AM	**Wrap-up / Door Prizes** (Venice 3)	
12:00 PM	**2011 Symposium Adjourns**	
1:00 PM	~~**Workshop 3: EIM Database Workshop** (Venice 3)~~ CANCELLED	**Field Trip 4: Water Treatment Systems in Tacoma: Tour of Both Sewage & Drinking Water Treatment Plants**
1:30 PM	**Field Trip 3: Groundwater-Surface Water Interactions-Demonstration of Fiber Optic Distributed Sensing**	
Friday–Saturday, April 29–30, 2011		
All day	**Field Trip 5: Hydrogeology of Beer and Wine Country in the Yakima Valley**	

Tuesday, 9:00 AM

‖ Keynote Speaker 1



TIMOTHY D. SCHEIBE, PH.D.

Energy and Environment Directorate
Pacific Northwest National Laboratory

Quantifying Flow and Reactive Transport in the Heterogeneous Subsurface Environment: from Pores to Porous Media and Facies to Aquifers

Hydrogeologists working on problems related to groundwater contamination, remediation, or water quality protection face an extraordinary challenge: The fundamental transport and reaction processes that control contaminant fate occur at length scales that are many orders of magnitude smaller than the scales at which predictions of observable phenomena are needed. Spatial variability (heterogeneity) of physical and biogeochemical properties exists across the entire range of relevant scales. In this presentation, we will take a numerical journey through this range of length scales. Along the way, we will examine a number of case studies that illustrate both the challenges posed and some exciting ways that advanced computational methods are being brought to bear on these problems. We will start by examining pore-scale simulations of flow, transport, and reactions in porous media, in which the complex geometry of solid grains and pore spaces is explicitly quantified. Pore-scale models are being used to develop new understanding of fundamental processes that can be incorporated into larger-scale models that treat porous media as effective continua. We will consider the applicability of two approaches: 1) direct upscaling of pore-scale simulation results using various methods, and 2) multiscale hybrid modeling, in which pore- and continuum-scale models are combined within a single simulation. At the continuum scale, complex geological heterogeneity is expressed at a multitude of scales. For example, in sedimentary aquifers, one may observe sediment architectural elements such as lamination (typ. mm), cross-bedding (typ. cm), and larger units such as beds, bed sets, facies, formations, aquifers and aquitards. We will examine the representation of geologic heterogeneity in reactive transport models, with a focus on the effects of correlated physical and biogeochemical heterogeneity. These issues will be presented in the context of a number of field sites relevant to US Department of Energy contamination problems including a bacterial transport site, a uranium bioremediation site, and a site with persistent uranium contamination associated with diffusion-controlled mass transfer processes.

Bio

Tim Scheibe, Ph.D., joined Pacific Northwest National Laboratory in September 1992 and is currently a staff scientist in the Hydrology Technical Group. He received his bachelors degree in geological engineering from Washington State University, a master's in civil engineering from the University of Washington, and a Ph.D. in civil engineering from Stanford University. At PNNL, he has been responsible for proposal development, project management, and technical contributions in a number of different areas of environmental research and technology development broadly related to the hydrologic sciences. His primary research focus is on characterization and numerical simulation of natural subsurface heterogeneity, and its impacts on biogeochemically reactive transport in groundwater systems. His research projects include both computational and field experimental elements. Recently, he has worked on problems in the area of subsurface biogeochemistry, including microbial transport in groundwater, and bioremediation of metals and radionuclides. He is currently collaborating with computational scientists and applied mathematicians to simulate coupled flow, transport, and biogeochemical processes at cellular, pore, and continuum scales. His research is supported primarily by the Department of Energy's Office of Science through the Environmental Remediation Science Program and the Scientific Discovery through Advanced Computing Program. In 2010, Dr. Scheibe served as the NGWA Henry Darcy Distinguished Lecturer.

ESTELLA ATEKWANA, PH.D.

*Boone Pickens School of Geology,
Oklahoma State University*

Biogeophysics: A Novel Approach for Imaging Subsurface Biogeochemical Processes

Microbial induced changes in water-rock-sediment environments over variable time scales cause changes in the physical properties of these environments that may potentially be detected, and measured using geophysical methodologies. Recognition of this potential has resulted in the development of a new sub-discipline in geophysics called 'Biogeophysics', which combines the fields of environmental microbiology, biogeochemistry, geomicrobiology, and geophysics. Both field and laboratory studies over the last decade have demonstrated the potential of geophysical technologies to (1) probe the presence of microbial cells and biofilms in subsurface geologic media, (2) investigate the interactions between microorganisms and subsurface geologic media, (3) assess biogeochemical transformations and biogeochemical reaction rates, and (4) investigate the alteration of physical properties of subsurface geologic media resulting from microbial activity. Hence, using biogeophysical technologies we can measure not simply the subsurface physical and chemical properties of the subsurface, as geophysical methods are conventionally used, but also the detection of microbes, microbial growth, and microbe-mineral interactions. The unique properties of geophysical datasets (e.g. non-invasive data acquisition, spatially continuous properties retrieved) provide an opportunity to explore biogeochemical processes at the field-scale. This presentation will highlight some of the important advancements in biogeophysics by examining both laboratory and field-scale studies at contaminated sites as well as some important challenges that provide an opportunity for further research in this new field.

Bio

Estella A. Atekwana received a B.S. in Geology (magna cum laude) and MS from Howard University, Washington DC and a PhD in geophysics from Dalhousie University, Halifax, Nova Scotia, Canada. She is currently the Clyde Wheeler Sun Chair Professor at the Boone Pickens School of Geology at Oklahoma State University. She was previously a Professor at the University of Missouri-Rolla now Missouri University of Science and Technology, and spent ten years at Western Michigan University as a faculty member in the department of Geosciences. She has served as a panelist for several federal funding agencies including NSF, DOE, NIH and on the National Academy of Sciences – National Research Council Committee to Assess the Performance of Engineered Barriers. Her research on geophysical studies of geomicrobiology processes has helped to pioneer the new sub-discipline of biogeophysics. Her biogeophysical research has included studies on biofilm growth and development, microbial attachment and transport in porous media, electrical and seismic imaging of microbial processes, and biogeophysical signatures of hydrocarbon contaminated sites. She currently has an ongoing project to investigate the biogeophysical signatures associated with microbial transformation of the BP Deep Horizon oil spill. Atekwana also has research interest in tectonophysics with particular attention to incipient continental rifting along the East African Rift System and extensional terranes in southwest Turkey. She has served on the executive committee of the American Geophysical Union (Budget & Finance Committee and Meetings Committee), Board of Directors for the ; Vice President Committees for Environmental and Engineering Geophysical Society, Committee of Special Merits (Society of Exploration Geophysicists Foundation). She is a member of the American Geophysical Union, Geological Society of America, Society of Exploration Geophysicists, National Association of Black Geologists and Geophysicists, Environmental and Engineering Geophysical Society, and Geochemical Society.

ERIC STEIG, PH.D.

Director of the Quaternary Research Center at the University of Washington

New Frontiers in the use of Isotopes of Water: Climate, Atmospheric Circulation, and Oxygen 17

Advances in both the modeling and measurement of stable isotope ratios in water are revolutionizing our understanding of the hydrological cycle, particularly in the atmosphere. This talk will describe some of those new advances, including laser spectroscopy measurements, analysis of the rarely-measured H-2-17-O isotopologue, and incorporation of isotope in climate models, and report on the latest measurements of isotope ratios in deep ice cores obtained from the Antarctic ice sheet.

Bio

Eric Steig is the Director of the Quaternary Research Center at the University of Washington. He completed his Ph.D. in Geological Sciences at UW in 1995, was Research Assistant Professor at the University of Colorado from 1996-1998 and Assistant Professor at the University of Pennsylvania before returning to UW in 2001. Dr. Steig is the founding co-director of ISOLAB, a state-of-the art isotope geochemistry facility involving research ranging from climate and atmospheric chemistry to geobiology.

Panel 5A: Reclaimed Water - What's Next?

Moderator: Laurie Morgan

As water availability becomes more of a concern and water needs grow, reclaimed water is becoming a more vital sustainable resource. This panel brings together panelists who have been actively engaged in Washington's Reclaimed Water Advisory Committee.

The Washington Dept. of Ecology is the lead state agency for reclaimed water. Jim McCauley will report on the current status of the Reclaimed Water Act, rulemaking, and guidance.

The LOTT Clean Water Alliance is the utility that treats wastewater and produces reclaimed water for the Lacey-Olympia-Tumwater, Washington urban area. LOTT operates two state-of-the-art reclaimed water plants. Reclaimed water from the LOTT facilities is used for non-potable uses, including park irrigation, water features, toilet flushing, and for recharging groundwater. Karla Fowler will discuss opportunities and challenges for reclaimed water from the utility's point of view.

People for Puget Sound is actively engaged in environmental issues. Heather Trim will represent the environmental issues and opportunities associated with reclaimed water.

Gray & Osborne is managing the development of the Department of Ecology's Reclaimed Water Facilities Manual that will provide guidance on permitting, planning and design of reclaimed water facilities in Washington State once the State's new reclaimed water rule goes into effect. Ken Alexander will focus on using reclaimed water for groundwater recharge.

Panel Members:

Jim McCauley is a Senior Engineer with the Washington State Department of Ecology**.** He has almost 30 years of experience working as an environmental engineer for government and the private sector. Jim received his BA from Marshall University and MSE from West Virginia University. He has spent most of his career designing, reviewing and managing drinking water projects. He spent 2 years as an assistant professor and operator trainer with the University of Alaska. He continues to teach online classes. Currently, his primary responsibilities include technical assistance to reclaimed water applicants and development of Washington's proposed reclaimed water rule and guidance manual.

Karla Fowler is the Director of Community Relations and Environmental Policy for the LOTT Clean Water Alliance. Karla is responsible for reclaimed water and water conservation programs; public information, education and involvement; environmental evaluations; and regulatory permitting. She chairs a local inter-agency Reclaimed Water Policies Task Force and serves on the Washington State Reclaimed Water Use Rule Advisory Committee. She has worked for LOTT for more than 15 years. Current memberships include the Water Environment Federation, WaterReuse Association, and Water Reuse Committee of the Pacific Northwest Clean Water Association.

Heather Trim, Urban Bays and Toxics Program Manager for People For Puget Sound**,** has more than 20 years of experience in environmental work. In Los Angeles, she worked for the Regional Water Quality Control Board on water quality standards, regulatory permits, and pollution assessments of both surface and ground water for Los Angeles and Ventura Counties. She then was staff scientist for the Los Angeles and San Gabriel Rivers Watershed Council focusing on various projects leading to the greening of the rivers, including water quality, stormwater issues, pollution assessments and habitat renewal. She joined People For Puget Sound in 2002. She works on reducing toxic pollution and protecting shoreline health in Puget Sound and also focuses on a range of Seattle issues – waterfront, habitat, stormwater, and landuse.

Ken Alexander is a Principal/Project Manager with Gray & Osborne**.** In addition to managing the firm's Vancouver, Washington, office he is the company's lead reclaimed water planning engineer. Gray & Osborne has participated in the planning of six operating water reclamation and reuse projects in the State of Washington, including the design of five Class A water reclamation facilities, more than 17 miles of reclaimed water distribution piping and reuse facilities comprising of irrigation systems, truck filling stations, a fish pond, a constructed wetlands/streamflow augmentation system, as well as several groundwater recharge systems using surface percolation basins. Ken was the lead engineer for planning five of the firm's six reclaimed water facilities and was the lead design engineer for three of the reclaimed water treatment plants designed by Gray & Osborne. All told, the facilities he has planned or designed have the potential to reuse more than 1.75 billion gallons of reclaimed water per year. He was a pioneer in the design and development of groundwater recharge systems for reclaimed water that including more than 29 acres of recharge basins with the capacity to recharge groundwater in arid regions of Eastern Washington. Currently he is managing the development of the Department of Ecology's Reclaimed Water Facilities Manual that will provide guidance on permitting, planning and design of reclaimed water facilities in Washington State once the State's new reclaimed water rule goes into effect. He is a registered engineer in Washington, Oregon, Virginia and Hawaii, a Certified Emergency Manager and recently retired from the Navy Reserve with 30 years of service that included more than 15 years on active duty.

Panel 6A: Stormwater Impacts on Groundwater Quality

Moderator: J. Scott Kindred

This series of presentations will present monitoring data and/or studies that address the potential for groundwater contamination associated with stormwater infiltration, with case studies from Portland, Spokane, and the Idaho Panhandle.

Stormwater infiltration has been a common practice for many decades across Washington State and Oregon. Typically, infiltration ponds have been used in Western Washington and dry wells have been used in Eastern Washington and many areas in Oregon. The benefits associated with stormwater discharge to groundwater include the following: 1) On-site flow control provides a cost effective means to manage stormwater, 2) stormwater infiltration can increase groundwater elevations and summer baseflows in streams, and 3) reduced toxic loading to surface waters such as Puget Sound. Although there is no clear evidence that stormwater infiltration presents a significant threat to groundwater quality, both Washington and Oregon have identified the potential for impacts to groundwater and have developed stormwater underground injection control (UIC) programs. This series of presentations will present monitoring data and/or studies that address the potential for groundwater contamination associated with stormwater infiltration, with case studies from Portland, Spokane, and the Idaho Panhandle.

Panel Members:

J. Scott Kindred, PE (Moderator) is an Associate Water Resources Engineer with Aspect Consulting. He is a P.E. in the state of Washington and has 20 plus years of consulting experience, primarily in the areas of hydrogeology and environmental remediation. Mr. Kindred specializes in the design and implementation of stormwater infiltration systems. With expertise in hydrogeology, contaminant fate and transport, and civil design, he is uniquely qualified to address the range of issues associated with stormwater infiltration. He was responsible for the site characterization, design, and testing of a series of deep (>70 ft) underground injection control (UIC) wells in Kittitas County, a large infiltration system that included over 150 deep dug drains, a large infiltration system at Fort Lewis, and numerous additional infiltration projects. In addition, Mr. Kindred has been the project manager and technical contributor for numerous environmental remediation projects, with experience on CERCLA and MTCA sites, site assessment and remediation design, Phase I and Phase II Environmental Site Assessments, and landfill closure. Scott has a Bachelors degree in geology from Brown University and a Masters degree in civil engineering from Massachusetts Institute of Technology.

Robert C. Lindsay is the Water Resources Manager of the Spokane County Division of Utilities. He is a licensed hydrogeologist in the state of Washington and a registered geologist in the state of Idaho. Mr. Lindsay has served Spokane County since 2004; his primary responsibilities include oversight of a comprehensive groundwater quality monitoring program of the Spokane Valley/Rathdrum Prairie Aquifer, implementation of a regional aquifer education and outreach program, and coordination of watershed planning efforts in the Spokane River and Little Spokane River basins. Mr. Lindsay also has over 20 years of professional consulting experience in the private sector; his focus was primarily in the areas of hydrogeologic investigation, environmental assessment and remediation of commercial/industrial sites, stormwater and wastewater facilities, and landfills. Rob has a Bachelors degree in environmental geology from Western Washington University and completed post-graduate training in engineering geology and hydrogeology at California State University Los Angeles.

Barbara Adkins is the Underground Injection Control (UIC) Program Manager for the City of Portland, Oregon. She manages the City's UIC Program and city-wide UIC Water Pollution Control Facilities (WPCF) permit – the first issued in the state of Oregon and nation for stormwater discharges to UICs. She has 16 years of experience working for municipal government in stormwater quality for surface and ground water protection. Her expertise is developing, implementing, and managing Underground Injection Control (UIC) and Municipal Separate Storm Sewer Systems (MS4) sampling and erosion control programs. She serves as an Oregon Association of Clean Water Agencies (ACWA) board member and co-chairs the ACWA Groundwater Committee.

Oral Abstracts

A Reactive Transport Model of Mercury Fate in Sediment

Brad Bessinger, *S.S. Papadopulos & Associates*
Dimitri Vlassopoulos, Anchor QEA
Susana Serrano, School of Natural Sciences, University of California, Merced
Peggy O'Day, School of Natural Sciences, University of California, Merced

In order to evaluate remedial alternatives for mercury-contaminated sites, it is necessary to understand the mobility and bioavailability of the various chemical forms present in the system. For mercury, knowledge of site redox equilibria, dissolved sulfide and organic ligand concentrations, pH, and microbially-mediated methylation/demethylation reactions is additionally required. Geochemical reactive transport modeling is a potentially-useful tool for site evaluations because models can be formulated to include each of these parameters.

In the present study, a biogeochemical reactive transport model was developed to predict mercury mobility and bioavailability in sediment affected by upwelling contaminated groundwater. The objective of modeling was to identify the range of conditions where natural attenuation is a viable remedial option. Included in the model were heterogeneous and homogeneous equilibrium speciation reactions (including surface complexation and organo-metal reactions), and kinetic-based reactions describing biodegradation of organic carbon, redox transformations, mercury methylation, and demethylation. Simulations were performed for freshwater and marine sediment, and a range of groundwater compositions (important groundwater variables included pH, sulfide concentration, and the abundance and degradation rates of labile organic carbon).

Model predictions show that the primary attenuation mechanism for mercury in subaqueous sediment is precipitation of meta-cinnabar (HgS). This precludes a simple distribution coefficient approach to modeling. In addition, mercury-DOM sorption onto iron oxides and mercury-SOM complexation are also important under certain environmental conditions. Finally, the model predicts that the distribution of mercury in sediment changes over time, leading to variations in the concentration of methylmercury available for bioaccumulation. Natural attenuation may be a viable, depending on porewater chemistry and groundwater advection rates.

The Pitfalls of "Plug and Chug" Modeling

Joseph Caggiano, *Washington State Department of Ecology*

Computer models to simulate fate and transport of fluids and contaminants through site media are useful tools that provide insight, and can compare expected future performance of remedial/closure options. Public domain or commercially available modeling software allows any user to simplify a site, select parameter values from the literature or limited field characterization, and to run a model based on chosen assumptions and boundary conditions. Models are tools that provide insights and results, but should only support decision making.

Simplifying assumptions are often made to facilitate the running of a particular code. However, the danger is that by using these simplifying assumptions, boundary conditions and unrepresentative parameter values, a model can provide results that do not simulate reality. Basing any closure or remediation decisions on such modeling that does not realistically simulate site conditions is unwise and can lead to erroneous predictions about the choice and/or performance of selected remedial/closure options. As Eileen Poeter (2006) stated, "All Models are Wrong; Some are More Useful than Others." Multiple models using multiple codes may converge on reality. Some examples from the Hanford Site illustrate modeling abuses.

Modeling Groundwater Behavior Using FRACMAN and FeFLOW at the Buckhorn Mountain Gold Mine

B. Todd Hoffman *and David Banton*

Golder Associates

The Buckhorn Mountain Gold Mine is located in Okanogan County in north-central Washington, approximately ten miles from the Canadian border. It is an underground cut and fill mine that started production operations in 2008 and has an expected mine life of about seven years. The mine is situated very close to the top of the mountain peak. The geologic structure of the area is quite complex, and this in turn complicates the flow of the local groundwater.

During the environmental studies for the mine, a numerical flow model was constructed using FeFLOW based on the geologic information, hydraulic properties, and the recharge in the area. This model was used to evaluate the inflow of groundwater into the mine and effectiveness of mine dewatering wells to contain mine seepage. The model consisted of over 400,000 elements and 20 layers. Run times for the model during transient simulations was in the range of tens of hours.

As part of an update to the understanding of the hydrogeology on Buckhorn Mountain, FRACMAN has been used to construct an updated FeFLOW groundwater flow model. FRACMAN is a discrete fracture network modeling software with capabilities to simulate flow through these discrete fracture and fault elements. FRACMAN was used to construct the updated hydrostructural model and adjust the fracture elements in FeFLOW. During the updated calibration, the discrete features are easily modified in FRACMAN and the newly exported properties are directly imported into FeFLOW, which saves significant time over modifying the properties in FeFLOW.

The models utilized measured data collected during the permitting and operation of the Buckhorn Mountain Mine. This includes information on dewatering well pumping rates, groundwater levels, streamflow and discharge from a nearby abandoned underground mine (Roosevelt Adit). Updated geological information was also available from on-going exploration and characterization work at the mine site.

In addition, groundwater flow simulations were made using a simplified FRACMAN model for comparison with the FeFLOW model results. The modeling showed that FRACMAN can be used to provide an overall understanding of the hydrogeological conditions on Buckhorn Mountain with much less computational effort than the FeFLOW model. FRACMAN results were obtained with run times of tens of minutes instead of tens of hours, and the results of the FRACMAN flow models compared well with the more complex simulator.

Incorporation of Baseflow Component in the Water Erosion Prediction Project (WEPP) Model

Anurag Srivastava, *Washington State University*

Li Wang, Washington State University

Joan Wu, Washington State University

Linda Hardesty, Washington State University

William Elliot, USDA Forest Service

Assessment of water discharges into streams is critical to supporting aquatic life and meeting water demands for domestic and commercial purposes. Streams are usually formed from three individual components of runoff, namely surface runoff, subsurface flow, and baseflow. It has been found that surface runoff is more important on small watersheds, subsurface flow on middle-sized watersheds, and baseflow on large watersheds. Baseflow plays a major role in the contribution of runoff as the size of watershed increases.

The Water Erosion Prediction Project (WEPP) model is a physically-based, continuous- simulation model originally developed for small, agricultural watersheds. To improve the applicability of the WEPP model, we have incorporated into it the baseflow component (written in Fortran). WEPP internally-computed daily seepage is used to estimate baseflow from each individual hillslope using a linear reservoir model. The daily baseflow values calculated for all hillslopes in the watershed were weighted by hillslope area to obtain an overall baseflow for the watershed. The developed code was verified and tested by applying it to the Asotin Creek Watershed, a salmon-bearing stream and a tributary to the Snake River. With the baseflow subroutine, users will be able to use WEPP to simulate and predict streamflow from large watersheds with perennial streams.

River-Aquifer Exchanges in the Yakima River Basin, Washington

John Vaccaro, *U.S. Geological Survey*

Information for five datasets is presented and analyzed in order to improve the understanding of river-aquifer exchanges in the Yakima River basin. The information includes data collected during a groundwater investigation of the Yakima River basin aquifer system and data collected and (or) described by others for work conducted during many years. The five datasets are:

1) stable isotope ratios of hydrogen (2H/1H) and oxygen (18O/16O) for groundwater and surface water and tritium (3H) for groundwater;
2) seepage investigations using discharge measurements;
3) vertical hydraulic gradients based on hydraulic heads in the streambed and streams measured using mini-piezometers;
4) groundwater levels and temperature in shallow wells in the floodplain; and
5) thermal profiles (continuous streamflow temperature along river reaches). River-aquifer exchanges are described in terms of streamflow, vertical hydraulic gradients, groundwater temperature and levels, and streamflow temperature. Where appropriate, these exchanges are discussed in terms of salmonid habitat.

Evidence for Hydrogeologic Compartmentalization in the Columbia River Basalt Group (CRBG)

Kevin Lindsey, *GSI Water Solutions, Inc.*

John Porcello, GSI Water Solutions, Inc.

Dimitri Vlassopolus, Anchor, QEA

Patrick Royer, Columbia Basin Ground Water Management Area

Terry Tolan, GSI Water Solutions, Inc.

Walt Burt, GSI Water Solutions, Inc.

Marinko Karanovic, S.S. Papadopulos & Assoc.

Chris Muffels, S.S. Papadopulos & Assoc.

Groundwater recharge, movement, and discharge in the CCRBG aquifer system has been characterized as: (1) strongly influenced by primary framework geologic controls (intraflow structure, stratigraphy, and structural geology) and strataform in nature resulting in discontinuities in the groundwater system to (2) weakly controlled by these features resulting in significant lateral and vertical hydrologic continuity. Ongoing hydrogeologic investigations in the CRBG underlying the GWMA reveal evidence for both regional and local compartmentalization in the aquifer system. This evidence includes: (a) water level data and water level decline data and (b) geochemical analysis of groundwater from the major geologic units and from wells across regional geologic structures and CRBG feeder dike systems.

Water level data for major CRBG units was evaluated using contour maps of the raw data and analyzed using statistical methods that evaluated the data against predicted groundwater pumping, ground surface and open interval elevation, and departures from regional water level trends. These analyses point to varying stratigraphic, feeder dike, and structural influences on CRBG groundwater systems across the GWMA. Historical water level data shows water levels in the shallower portions of the CRBG aquifer system are decoupled from those in the deeper system. Discontinuities in mapped water level data also suggest stratigraphic controls on the groundwater system are present, forming significant hydrologic discontinuities separating the shallower from deeper portions of the system, including those just within the Wanapum Basalt. Analysis of the water level data set also points to the presence of lateral groundwater flow discontinuities, including: (1) the western to central portions of the Frenchman Hills and Saddle Mountains fault/ fold systems, (2) a fold/ fault system extending northeast from Sun Lakes towards Almira, WA, (3) portions of the Ice Harbor and Ginkgo feeder dike systems in the south-central GWMA and (4) the Roza feeder dike system in the north-central GWMA. In each case multiple analyses show changes in water levels and groundwater decline rates that suggest these features separate groundwater flow regimes with varying degrees of hydrologic continuity.

GWMA has collected groundwater geochemical data from over 400 wells, primarily evaluating deeper, large production municipal and irrigation wells. These data show that wells open to the Grande Ronde Basalt predominantly are extracting water that is solely or largely Pleistocene in age. Where evidence of mixing between older groundwater and younger groundwater is found, wells are commonly found in areas where large numbers of shallowly cased and sealed wells are present. Leakage through these wells likely is a primary driver for this groundwater mixing. This data is being used to constrain and calibrate the regional CRBG aquifer system groundwater flow model GWMA is releasing in the spring of 2011. Based on these data several of the primary components of the model will be the importance of stratigraphic controls separating deeper and shallower portions of the aquifer system, the impact of folds and faults on portions of the system, and the apparent roles feeder dikes play in separating different flow regimes in the system.

Interpretation of Aquifer System Responses to a Long-Term Basin-Wide Aquifer Test in the Palouse Basin of Eastern Washington and Northern Idaho

Katie Moran, *University of Idaho*

James Osiensky, University of Idaho

Accurate aquifer storativity (S) estimates are essential for proper groundwater resource evaluation and management, especially in sole-source systems such as the Palouse Basin of eastern Washington and northwest Idaho. Uncertainties concerning the horizontal extent and boundary conditions of the aquifer system complicate evaluation of annual groundwater declines due to municipal pumping and the potential effects of growth or implementation of water conservation measures. Several lines of evidence such as barometric efficiencies, aquifer compressibilities, and results of short-term aquifer tests, suggest that aquifer system storativity in the Palouse Basin is very low and/or recharge is greater than expected relative the perceived size of the basin. However, prior to this investigation, little was known about the details of annual aquifer system responses to specific variations in daily, monthly or annual pumping.

To evaluate the meaning of aquifer system storativity on an annual time frame, a comprehensive year-long, basin-wide, aquifer test was completed to calibrate long-term aquifer system responses to known and anticipated boundary conditions and calculated hydraulic properties. Drawdown data for selected observation wells were analyzed together with all municipal pumping schedules for the cities of Pullman, WA; Moscow, ID; Palouse, WA; and Colfax, WA using the principle of superposition. Extended analysis of these data over different time scales revealed information about the degree of hydraulic connection within the basin, characteristics of the physical boundary conditions, and the reasonable range of aquifer system storativity on an annual time frame. The ability to select different “windows” of short and long-term pumping/drawdown data from within the continuous, annual data sets enhanced the evaluation of aquifer storativity through averaging of discrete system responses to spatially and temporally variable pumping stresses. These conditions facilitated interpretation of aquifer system responses by traditional analytical methods of aquifer test analysis.

Constructing and Calibrating Large Models: Lessons from the Yakima River Basin Groundwater Flow Model

Matt Bachmann, *U.S. Geological Survey*

Competing demands for water resources in the Yakima River Basin have generated conflicts between municipal, agricultural, and ecological needs. An ongoing multi-year study of the basin's coupled groundwater and surface water supplies has culminated in a large and complex groundwater model that simulates flow between compartmentalized alluvial basins, deep basalt aquifers, and the rivers that meet the majority of water demand.

Tight discretization of a large model domain, many small model time steps, thousands of groundwater wells, complex geologic structure, numerous diversions and returns of surface water, and spatially heterogeneous aquifer property and boundary condition maps can combine to generate MODFLOW input files that far exceed storage capacity of commonly used graphical user interfaces. Recent advances in computational capabilities have made such large models possible, but traditional methods of preparing model input and interpreting model outputs need to be reinterpreted in light of the size of the data files now being utilized.

Models of this complexity, despite their challenges, have also afforded hydrologists the opportunity to simulate environmental processes at scales more relevant to managers and decision makers. The increased utility of these models suggests that future modeling efforts will continue to face the problems inherent in reconciling software limitations with hardware advances.

Water Demand Forecast Model Development in Spokane County, WA

Mike Hermanson, *Spokane County*

Water demand forecasting is an essential element of successful water resources management. The recently released report by the Washington Department of Ecology to the Legislature and Governor put forth four key components to a "bold new approach to managing water resources" which included the preparation of comprehensive localized water inventories that address water supply and current and future demand for all uses. In 2009 Spokane County realized the importance of quantifying water demands and began developing a county wide water demand forecast model which was completed in October 2010.

The forecast model was built to accommodate a wide variety of analyses of current and future demand and will be a valuable resource for water resource planning in the county. The model, built in Microsoft Excel, is disaggregated by water use sector, spatially, and temporally and is comprised of a variety of subsector models that vary in complexity from econometric to unit use. The model has been used for a range of analysis from forecasting future withdrawals from the largest water resource in the county, the Spokane Valley Rathdrum Prairie Aquifer, to evaluating future demand from self supplied residents in subbasins of the Little Spokane River Basin. The model can also be used to analyze the seasonality of demand and the impact of weather changes on water use, an important aspect to management of water resources that seeks to address not only the quantity of water, but the timing.

As Ecology places more emphasis on preparing localized water inventories, including current and future demand, the experience in developing the Spokane County water demand forecast model could be valuable to other jurisdictions in the State.

Vashon-Maury Island Volunteer Data Collection Effort

Eric Ferguson, *King County DNRP*

King County Groundwater Protection Program implemented a volunteer water level data collection effort on Vashon-Maury Island in 2001. Initial interest and response was great with 27 individuals wanting to participate in the 12 month study. After 18 months, the number of volunteers dropped dramatically. In May 2010, five volunteers that continued from this initial effort passed their 10 year mark. These records are some of the longest water level data for Vashon-Maury Island.

Three different aquifer zones of Vashon-Maury Island are being monitored by these volunteers. Three of the sites show seasonal variability of water level data up to 10 feet, while the other two sites have little to no annually change. Plots of data verses time show trends of both decreasing and increasing water levels through time for a few sites.

Starting in May 2007, all five volunteers began reporting water usage data along with the water level data. Three of these volunteers are permit-exempt wells plus two Public Water Systems: one small Group A and one Group B. The usage to date ranges from less than 30 gallons per day (GPD) to over 1000 GPD per connection. Most volunteers show a pattern of usage of more GPD during dry periods and less during wet periods. The data is collected and sent to King County via e-mail approximately monthly.

Stream View Photo Website, a Proposal

Alex (Sandy) Williamson, *U.S. Geological Survey Retired, now Volunteer*

This idea is for a website / data base of photos; still, 3D, and video, oriented entirely to streams, a la Google's Street View, but for streams. Each entry would be stream indexed to NHD and geolocated in space and time. There would be a date selection slider to view a date-range of photos on the mapped area of interest.

Uses for these photos/mosaics-3D views/videos along streams are envisioned to be:

1. The public can visualize streams everywhere as easily as they can visualize streets now - more attention leads to more and better conservation.
2. Anyone working with streams could be able to virtually 'go there' to the stream reach[es] in question without leaving their desk to investigate anomalies, do recon, etc. This would have a wide audience among fishermen and kayaker/rafters.
3. Document riparian habitat conditions and changes from now or in the past to the future. Enable visualization of extent of stream changes from the future back to present or some other time.
4. Allow easy visualization of stream channel and riparian area conditions and effects.
5. Allow the public access to historic USGS stream photos (taken over last 140 years) in a systematic way.
6. Plan where to go on vacation and be more connected to rivers – maybe partnering with Park Service.
7. Document erosion and sedimentation of banks and bars along streams.
8. Document land use changes near streams.
9. Inventory geomorphic features in stream channels.
10. Frame of reference about flooding issues and what a flood depth means visually.
11. Allow mashups with other apps that are geographically tied to streams.

Approach to access the stream photos: Unified map driven user interface to both sets of A.) still singles and videos and B.) 3-D views of stream reaches. Group A photos shown as clickable points on map shown as thumbnails to side like Picasa or Flickr, Group B shown as colored highlighting along stream reaches showing availability of 3D views.

Closest example now is at mapthefallen.org using Google earth with pictures in place of the soldier icons. Just delete the lines around the globe to imagine.

Sources of Photos: A. still photos and video taken at a point contributed by the public or scientists and managers.

1. Mine existing sources, like Google Picasa and Yahoo Flickr using API to subset [and NHD stream index] pics that are currently geotagged to be near streams. (After seeking their help and or permission). Maybe in the future there will be place recognition software for water features and or landform features, like there is face recognition software now.
2. Work with a partner to host a repository of user contributed volunteer stream photos, like openstreetmaps.org does for streets, like Flickr or Picasa/Panoramio: a. USGS photos – historic photos @20k stream gages over the last 130 years, and b. Public volunteer taken photos would add to the collection.

B. 3-D views of streams taken by 3-D camera setups along a stream reach. Facilitate USGS and others with projects of photo documentation using inexpensive ($1500) 360 degree camera setups.

Potential Impacts of Climate Change on Groundwater Resources of the Columbia River Basin

John Vaccaro, *U.S. Geological Survey*

Potential future groundwater recharge in the Columbia River basin was estimated with the Deep Percolation Model (DPM) using air-temperature and precipitation inputs predicted by the average of five General Circulation Models (GCMs). The estimates indicate a significant reduction in future groundwater recharge, which, when applied to existing groundwater-flow models of the Columbia Plateau aquifer system in Washington and the upper Deschutes River basin in Oregon, results in future groundwater-level declines in excess of 100 feet over current conditions. If future groundwater pumpage were to increase, water-level declines would be even larger. Large declines in groundwater levels will result in significant reductions in groundwater discharge to rivers and streams, thereby impacting aquatic habitat by increasing stream temperatures, altering stream chemistry, and reducing or, in some cases, eliminating thermal refugia that salmonids and other biota rely on for survival. The study of potential impacts of climate change on groundwater recharge and baseflow has received relatively little attention compared to the study of impacts on other components of the water budget, such as snow accumulation, melt, and streamflow. Improving our understanding of groundwater recharge in response to climate change is critical, however, if aquatic-habitat and wildlife-management tools are to be developed that accurately forecast multiple effects of climate change on groundwater discharge to rivers and streams.

Modeling the Effects of Climate Change on Snowpack and Streamflow in the Nooksack River Basin

Robert Mitchell, *Western Washington University, Bellingham, WA*

Susan Dickerson, Landau Associates, Inc., Seatlle, WA

The Nooksack River has its headwaters in the North Cascade Mountains and drains a 2300 km2 area in northwestern Washington State. The timing and magnitude of streamflow in the high relief drainage basin is largely controlled by the snowpack and snowmelt, which is problematic because forecasts of future climate made by general circulation models (GCMs) predict increases in temperature and changes to precipitation in western Washington. Understanding the response of the basin and river to climate change is important for water resources planning because municipalities, tribes, and industry depend on the river for water use and for fish habitat. To assist Whatcom County's Flood Control Zone District, we used GCM climate forecasts and the Distributed-Hydrology-Soil-Vegetation Model (DHSVM) to simulate future changes to timing and magnitude of streamflow in the higher elevations of the Nooksack River. The DHSVM is a physically based, spatially distributed hydrology model that simulates a water and energy balance at the pixel scale of a digital elevation model. We used recent meteorological and landcover data to calibrate and validate the DHSVM. Multiple coarse-resolution GCM forecasts were downscaled to the Nooksack basin using 50 years of local weather, following the methods of previous regional studies, for use as meteorological input to the calibrated DHSVM.

Simulations of future streamflow and snowpack in the Nooksack River basin surrounding the years 2025, 2050 and 2075 varied in magnitude, which reflects both the range of GCM forecasts used and the natural variability in the 50 years of local weather. In general, the DHSVM simulations predict increased winter flows, decreased summer flows, decreased snowpack, and a shift in timing of the spring melt peak and maximum snow water equivalent. These results are consistent with previous regional studies which document that temperature-related effects on precipitation and melting are driving changes to snow-melt dominated basins. Modeling results for future peak flow events indicate an increase in both the frequency and magnitudes of floods, but uncertainties are high for modeling the absolute magnitudes of peak flows.

Information Management System for Water Right Mitigation Compliance – City of North Bend

Alyssa Neir, *Golder Associates Inc.*

Nicole DeNovio, Golder Associates Inc.

Conrad Muller, Golder Associates Inc.

New groundwater appropriations in many parts of Washington state are subject to minimum instream flow restrictions. In areas where there is hydraulic continuity between groundwater and streams, developing new groundwater rights has been subject to intense scrutiny and uncertainty, particularly for municipal providers. Groundwater under the City of North Bend, located in Western Washington is in hydraulic continuity with the Snoqualmie River. The City obtained a new ground water right in 2008 with a requirement to mitigate for the impacts from its withdrawals. The mitigation was based on a contract purchase of water from an adjacent watershed and direct transfer of that water into the Snoqualmie River on days that minimum instream flows are not met.

The City's daily mitigation requirement is determined using a series of analytical stream depletion calculations, performed on a daily basis, that estimate the City's impact from the past 20 days of pumping. A variety of real-time data are necessary to implement the calculations. A web-based data collection system collects the necessary inputs, performs the calculations, and provides daily direction to the City's personnel on mitigation requirements. The system interfaces with the City's telemetry system and also monitors USGS real-time streamflow to determine instream flow status. The system stores the data associated with over 90 variables, including the inputs to the calculations and the results. The system is designed to produce a variety of monitoring reports that are submitted to Ecology and stakeholders to demonstrate compliance with the conditions of the water right. The database system automatically generates event reports, quarterly reports and annual reports.

The mitigation requirements for the City's water right are one of the more complex yet developed in Washington state. The online database enables the City to manage its mitigation requirement on a daily basis with the click of a button.

Well Construction Regulations in Washington

William Lum, II, *Washington Department of Ecology*

Water well and resource protection well construction is regulated by law and rule in Washington. As defined in law, a well has no minimum depth or diameter. Most wells require a seal in the annular space surrounding the casing to prevent migration of contaminants through that space into the ground.

Construction methods and materials (casing, well screens, and sealing materials, for example) used in the construction and decommissioning of wells are regulated. Most sealing materials must be approved by National Sanitation Foundation/American National Standards Institute per their 60 or 61 standard.

Well construction and decommissioning requires prior notice to Ecology, fees apply to most activities. Written or electronic notice is allowed. Electronic payment is not allowed. Water well construction may require that a Water Right be issued by Ecology before well construction commences. Water Right processing may take considerable time and may be expensive.

Persons constructing and decommissioning wells must be licensed to do so by Ecology. In certain circumstances, an exemption allows water wells to be constructed by unlicensed homeowners. Licensed professional engineers, architects, and land surveyors may also be exempt from further licensing requirements for construction and decommissioning of wells if in the performance of duties covered by those licenses.

Definition of a well from the law, regulated materials, and paperwork, fee, and licensing requirements for well construction and decommissioning will be explained.

Washington State Certified Water Right Examiner Program

Douglas Wood, *Department of Ecology - Water Resources Program*

In 2010 the Washington State Legislature enacted RCW 90.03.655, a new section of the Water Code which creates a Certified Water Right Examiners (CWRE) Program.

The Department of Ecology's Water Resources Program is currently drafting Program Guidance and considering an Administrative Rule to implement the CWRE Program. Once the program is implemented, CWREs will be responsible to conducting Proof Exams for permit holders for new water rights and water right holders who have had changes or transfer to their water rights approved by Ecology.

The purpose of this presentation is to provide background on the draft Rule and Guidance expected to be implemented in 2011. The presentation will include details on qualifications, exams, knowledge required for certification, fees, renewals, bonding, and the duties and responsibilities of CWREs.

Accelerated Weathering of LAW Glasses Using the Pressurized Unsaturated Flow Test Method

Michelle Valenta, *Pacific Northwest National Laboratory*

Kenton Rod, Pacific Northwest National Laboratory

Eric Pierce, Oak Ridge National Laboratory

The integrated disposal facility (IDF) performance assessment (PA) must account for the long-term corrosion of low-activity waste glass and subsequent release of radionuclides. The glass corrosion rate is one of the key parameters affecting the overall performance of the disposal system. The computer calculations performed as part of the IDF PA require a list of secondary alteration products that are expected to form as a result of the glass-water reaction. The pressurized unsaturated flow (PUF) test is one of the accelerated test methods used to develop a chemical reaction network of secondary phases. Unlike other accelerated weathering test methods, PUF experiments are conducted under hydraulically unsaturated conditions, thereby mimicking the open-flow and transport conditions expected to occur in the IDF. Results from recent experiments on a subset of LAW glasses suggest these data are consistent with results obtained from earlier LAW glass formulations and suggest these glasses are a durable waste form.

Geophysics and Site Characterization at the Hanford Site

Brian Cubbage, *Hydrogeophysics Inc*

Malcolm Gander, CHPRC

Kevin Leary, Department of Energy

Geophysics and Site Characterization at the Hanford Site: The Successful Use of Electrical Resistivity to Position Boreholes to Define Deep Vadose Zone Contamination.

At the Hanford Nuclear Reservation in eastern Washington, production of uranium and plutonium resulted in the planned release of large quantities of acidic wastewater to unlined excavations (cribs). From 1952 until 1960, the 216-U-8 Crib received approximately 379,000,000 L (100,000,000 gal) of wastewater consisting of 25,500 kg (56,218 lb) uranium, 1,029,000 kg (1,013 tons) of nitrate, 2.7 Ci of technetium-99, and other fission products including strontium-90 and cesium-137. The 216-U-8 Crib reportedly holds the largest inventory of waste uranium of any Crib on the Hanford Site. Historic boreholes confirmed the presence of nitrate and radionuclide contaminants, which indicated a suitable target to be mapped using electrical resistivity.

Electrical resistivity is a non-invasive surface based geophysical technique that is capable of identifying contrasting subsurface physical properties; specifically, electrically conductive material, relative to resistive native soil. At the 216-U-8 Crib, high nitrate concentrations (from the release of nitric acid [HNO3] and associated uranium and other fission products) were detected in 1994 and 2004 boreholes at various depths beneath the base of the crib. These contaminant concentrations were directly correlative with the presence of anomalously low electrical resistivity responses delineated during the summer 2010 geophysical survey.

Results from the electrical geophysical survey have been used to locate additional boreholes that are planned for late fall 2010 to identify nitrate and radionuclide contamination: a) throughout the entire vertical length of the vadose zone (i.e., 82 m [270 ft] bgs) within the footprint of the Crib, and b) 15 to 30 m (50 to 100 ft) east of the Crib footprint, where contaminants are inferred to have migrated through relatively permeable soils.

Resistivity mapping provided a volumetric distribution of subsurface high conductivity zones located within the vicinity of the disposal cribs. When used in conjunction with the discrete borehole data, the resistivity information provides a continuous three-dimensional data rendering and serves as a basis to site future characterization boreholes that will likely intersect contamination both laterally and at depth.

The electrical resistivity survey consisted of three phases: Phase I employed magnetic gradiometry to identify metallic objects and anthropogenic features that may cause electrical interference; Phase II established a set of east-west and north-south reconnaissance electrical resistivity profiles (lines) across and adjacent to the Crib,; and Phase III collected information across a 300 m by 300 m (820 ft by 820 ft) grid of survey lines that were located based on the results of the Phase II survey.

The electrical resistivity survey benefitted from an electrode spacing of 3 m (9.8 ft), providing suitable resolution while allowing for a depth of investigation up to 90 m (295 ft), given the depth of groundwater at approximately 84 m (275 ft).

Evaluation of Copper and Nickel in Groundwater at a Shoreline MTCA Site

Troy Bussey, *PIONEER Technologies Corporation*

A case study of an empirical demonstration conducted for the soil-to-surface water pathway at a MTCA site located adjacent to Puget Sound will be presented. The empirical demonstration was conducted at an Agreed Order site in accordance with WAC 173-340-747(9). Even though copper and nickel were not initially considered constituents of interest based on historical operations at the site, copper and nickel concentrations in groundwater routinely exceeded the conservative surface water screening levels. A multiple lines of evidence approach and an analysis of regional background concentrations for copper and nickel were used to demonstrate that the copper and nickel concentrations detected in groundwater were not attributable to a site release.

Single-well Thermal Tracer Tests Using Distributed Temperature Sensing

Andrew Leaf, *Sound Earth Strategies, Inc. / University of Wisconsin-Madison Dept. of Geoscience*
David Hart, Wisconsin Geological and Natural History Survey
Jean Bahr, University of Wisconsin-Madison Dept. of Geoscience

Recent work on the Cambrian-Ordovician Aquifer System in the upper Midwest has revealed laterally extensive preferential flow zones in sandstone units that were previously characterized as homogenous and isotropic. Differences in recharge elevations and/or pumping stresses between aquifer units can produce vertical head gradients and ambient flow in multi-aquifer wells. Distributed temperature sensing (DTS) is a powerful new technology that allows for the rapid profiling of temperature using fiber optic cables. In two naturally flowing multi-aquifer wells near Madison, WI, single-well thermal tracer tests involving the injection of heated water were monitored with DTS. The results elucidate the ambient flow regimes of the wells in great detail, revealing fracture-dominated flow in some sandstone intervals and intergranular flow in others. Comparison of DTS data with down-hole video and other borehole geophysical logs shows diverging flow in both wells to be emanating from a cluster of bedding-plane fractures in the Wonewoc Formation. In addition to being stationary and synoptic, DTS is sensitive to a wider range of flow rates than traditional heat-pulse and spinner flowmeter techniques. As the cost of DTS continues to decrease, this method could become a standard tool in site investigations.

Assessment and Management of PCE in Redmond's Shallow Alluvial Aquifer

Elaine Dilley, *City of Redmond*

Amanda Balzer, City of Redmond

The City of Redmond operates five supply wells that provide approximately 40% of Redmond's drinking water. The supply wells are screened in a shallow unconfined alluvial aquifer located in downtown and industrial areas and are therefore rated moderately to highly vulnerable. Redmond's 1997 Source Water Assessment determined that the quality of water in the aquifer was excellent based on the fact that water samples from the five supply wells had been routinely collected and were generally in compliance with maximum contaminant levels for public water supplies. Over the next ten years, groundwater sampling was conducted predominantly at the supply wells.

In an effort to assess overall water quality in the shallow alluvial aquifer, the City established a Groundwater Monitoring Program in 2007. Redmond obtained access to monitor several privately-owned groundwater monitoring wells and gathered data from private investigations and clean-ups. Additionally, the City installed a network of groundwater monitoring wells to fill-in spatial data gaps, focusing upgradient of the supply wells and downgradient of known contaminated sites. Many of these sites were dry cleaners, so the groundwater sampling plan included analysis for volatile organic compounds. The results of several rounds of groundwater sampling indicated the presence of extensive low-level perchloroethylene (PCE) contamination.

In an effort to manage the PCE contamination, oversight and inspection were conducted. Oversight was conducted at sites where investigation and cleanup were taking place. Involvement was limited to active sites, primarily those already enrolled and actively participating in the Voluntary Cleanup Program (VCP), and City-owned properties. Focused inspection, technical assistance, and outreach were conducted at existing dry cleaning facilities, printing presses and auto body facilities to determine if they were contributing to the PCE contamination. Through inspection it was determined that the existing facilities were not significant contributors.

The inspection process highlighted a gap in information: business types were known, but the use of specific chemicals was still unknown. This led the City to initiate the collection of hazardous materials inventory statements in an effort to obtain more detailed information from businesses on the types and amounts of chemicals at each facility. The collection effort currently underway will result in identification of facilities that use chemicals of concern and optimize targeted outreach and groundwater monitoring.

Assessment of PCE in Redmond's shallow alluvial aquifer indicates that active cleanup sites and existing facilities do not completely account for the extensive PCE contamination and suggests that the main source is likely the number of uninvestigated historical dry cleaners. PCE has been detected in groundwater downgradient of several historical dry cleaners that are not currently enrolled in the VCP. Preliminary research into one uninvestigated dry cleaner led to the discovery of a documented release of PCE.

It is imperative to Redmond that contaminated sites are swiftly investigated and cleaned-up, particularly if the Environmental Protection Agency lowers the primary drinking water standard for PCE. Therefore, Redmond will pursue site activation at the Washington State Department of Ecology through initiation of Site Hazard Assessments and prioritization based on the Washington Ranking Method.

Geologic Carbon Sequestration Regulations in Washington State

John Stormon, *Washington Department of Ecology*

At the instruction of the 2007 Washington State Legislature, the State developed the Nation's first Underground Injection Control Well (UIC) regulation for the Geologic Sequestration of Carbon Dioxide, adopted on June 19, 2008.

In late 2010, EPA released final federal Underground Injection Control Well rules for Geologic Sequestration of Carbon Dioxide. The Federal Rules supersede Washington's Rules. Washington State now must either amend our rules and petition for delegated authority or allow EPA to permit all Carbon Sequestration projects in Washington.

The presentation will briefly compare the Washington and Federal UIC rules for Carbon Sequestration. The presentation will finish with any details available on Washington's strategy toward Federal Delegation.

The Wallula Basalt CO2 Sequestration Pilot Project

Pete McGrail, *Pacific Northwest National Laboratory*

Frank Spane, Pacific Northwest National Laboratory

Charlotte Sullivan, Pacific Northwest National Laboratory

Gretchen Hund, Pacific Northwest National Laboratory

Continental flood basalts represent one of the largest geologic structures on the planet and exist in regions of the U.S. (and other countries such as India) where sedimentary basin storage capacity is limited. Consequently, demonstration of commercial-scale storage in deep flood basalts is important in meeting global CO2 emissions targets.

The U.S. Department of Energy Big Sky Regional Carbon Sequestration Partnership completed drilling the world's first continental flood basalt sequestration pilot borehole to a total depth (TD) of 1253 m at a paper mill site near the town of Wallula located in Southeastern Washington State. Site suitability was assessed prior to drilling by acquisition, processing and analysis of a four-mile, five-line, three component seismic swath. Analysis of the seismic survey data indicated absence of major geologic structures that would preclude CO2 injection at the site. Drilling of Wallula pilot borehole was initiated on January 13, 2009 and reached TD on April 6, 2009.

Hydrogeologic information was obtained primarily during borehole drilling/advancement utilizing a progressive drill-and-test characterization strategy. Based on the comparative results from 10 test intervals, a candidate injection test zone was identified between the general depth interval of ~828 and 875 m bgs. Over this interval, three brecciated interflow zones were intersected and isolated for CO2 injection. The flow tops have relatively high permeabilities (75 to 150 millidarcies) and are bounded by thick flow interiors that have extremely low (microdarcy) permeabilities. The borehole configuration established at the Wallula pilot site provides a unique and very attractive opportunity to scientifically study the reservoir behavior of three connected reservoir intervals confined between primary and secondary caprock zones. In addition, laboratory studies of basalt reactivity with both CO2 dissolved in water and a water-wet supercritical CO2 phase indicate a very rapid ability to convert the CO2 to stable carbonate minerals. The pilot study is being uniquely configured with a downhole gas and fluid sampling tool to enable tracking of fluid chemistry evolution for comparison with model predictions.

Simulations of a 1000 MT open-borehole injection over a period of 14 days into the three brecciated zones show that most of the injected CO2 flows into the Slack Canyon #2 flow top due to its higher permeability. The increase in pressure in the well bore over hydrostatic is less than 760 kPa to achieve this injection rate and the radius of the injected supercritical CO2 increases to a maximum of 180 ft one year after the start of injection. No CO2 migration into the overlying Slack Canyon flow interior is predicted even after 1 year of simulation time. Based on these favorable simulation results, a permit application to inject 1000 MT of CO2 was submitted to Washington State Department of Ecology in February of 2010 and an injection permit issued in October 2010 after extensive review and public comment. Injection planning is current underway and is scheduled for completion in late spring of 2011. Coordinated public outreach efforts are in progress to maintain public involvement and support prior to injection.

Integration of Basalt Aquifer Geomodels for Evaluation of CO2 Sequestration Potential in the Columbia River Basalt Group

Charlotte Sullivan, *Pacific Northwest National Laboratory*

B. Peter McGrail, Pacific Northwest National Laboratory

New aquifer geomodels of the Columbia Basalt Group are a valuable component for evaluating sequestration potential for anthropogenic CO2 in areas where the basalts contain non-potable groundwater and are at depths greater than 800 m. Mafic continental flood basalts globally form an important, but under-characterized target for the sequestration of gigatons of man-made CO2, particularly where more conventional sedimentary targets are not available. Laboratory experiments indicate that chemically reactive Columbia River Basalts have the potential to mineralize a substantial portion of injected CO2, thus permanently sequestering this greenhouse gas. Battelle and the DOE Big Sky Regional Sequestration Partnership are currently conducting a pilot field test of the potential for sequestration and mineralization in the Grande Ronde Basalts at the Boise White Paper mill at Wallula, Washington. Injection of 1000 metric tons of food grade CO2 is scheduled for 2011. The GIS-based basalt aquifer geomodel constructed by the Oregon Water Science Center (USGS) provides a robust regional framework for constraining and extrapolating data from outcrops and from the suite of modern wireline logs obtained in the 4100 ft pilot well at Wallula. In addition, published basalt aquifer studies provide insight for possible compartmentalization of sequestration reservoirs. Aeromagnetic data indicate strong linear anomalies in the subsurface of the Pasco Basin; limited outcrops reveal dikes and associated faults. Basalt aquifer studies indicate that dikes may form either conduits for fluid migration or permanent barriers to flow, In this talk we review seismic, aeromagnetic, wireline, and hydrologic data to assess the subsurface geology and reservoir compartmentalization near the Wallula pilot project. The input of these data into numerical modeling and visualization tools is greatly refining our estimates of the sequestration potential of the continental flood basalts of the Columbia River Basalt Group, and is providing methodologies for evaluating basalt reservoirs around the world.

Hydrologic Test Characterization Results from the DOE Regional CO2 Partnership, Wallula Basalt Pilot Study

Frank Spane, *Pacific Northwest National Laboratory*

Paul Thorne, Pacific Northwest National Laboratory

During 2009, the U.S. Department of Energy's Big Sky Regional Carbon Sequestration Partnership completed drilling and characterizing the first pilot borehole for assessing the suitability of sequestering CO2 in deep basalt formations. In addition to the drilling and associated characterization of the pilot borehole, the field assessment program includes a sequence of subsequent activity phases, including 1) pre-CO2 injection monitoring/characterization (2009–2010), 2) injection of 1,000 tons of CO2 (Spring-Summer 2011), and 3) post-injection monitoring and evaluation (2011–2013). The pilot borehole is located in south-central Washington State, at the Boise White Paper Mill property at Wallula, Washington. The site selection was facilitated before drilling by conducting surface seismic surveys during 2007 and 2008. Analysis of the seismic survey data indicated a composite basalt formation thickness of ~8000 ft and a lack of major subsurface geologic structures (i.e., faults) in the vicinity of the well-site location. Drilling of the Wallula pilot borehole was initiated in mid-January, 2009, and reached a total depth of 4110 ft in early April, 2009. Detailed hydrogeologic characterization tests were conducted during the course of drilling the borehole and included 1) an extensive wireline geophysical log suite, 2) discrete rotary side-wall coring and XRF analysis of rock samples, 3) hydrochemical/isotopic groundwater analysis, and 4) detailed hydrologic testing for hydraulic property determination.

Based on hydrologic test results obtained during drilling, three basalt flowtop breccia zones were identified between the depth interval of 2716 and 2910 ft as having favorable characteristics to serve as the targeted CO2 injection reservoir. The tests showed that the targeted reservoir permeability conditions were adequate to accept the planned CO2 injection volume, that the caprock permeability would support long-term sequestration, and that the reservoir contains non-potable groundwater. The targeted injection reservoir occurs within the Grande Ronde Basalt and is situated stratigraphically below the massive Umtanum Member of the Grande Ronde Basalt, whose flow-interior section possesses regionally recognized low-permeability characteristics. The target injection zone reservoir provides a unique and attractive opportunity to scientifically study the geochemical reactive behavior of basalt formations to injected CO2 within three interconnected basalt flowtop intervals.

INSAR and Gravity Surveys of a Large Aquifer Storage and Recovery Site in Pendleton, OR: Application to Large CO2 Storages

Alain Bonneville, *Pacific Northwest National Laboratory*

Elsie Sullivan, Pacific Northwest National Laboratory

Essam Heggy, NASA Jet Propulsion Laboratory

Jeffrey Dermond, Pacific Northwest National Laboratory

Mark Sweeney, Pacific Northwest National Laboratory

Kyle Parker, Pacific Northwest National Laboratory

Christopher Strickland, Pacific Northwest National Laboratory

One of the main issues in the sequestration of large volumes of anthropogenic CO2 in the deep subsurface is to determine the field-scale induced displacements of fluids (mainly saline water) and their consequences on the mechanical behavior of the reservoir and surroundings. A quantifiable estimation of that displacement can be made by combining the robust, cost effective and repeatable geophysical techniques of microgravity and INSAR (Synthetic Aperture Radar INterferometry).

The determination of the density distribution of materials in the subsurface and its evolution with time potentially provides a cost effective monitoring technique to determine field-scale displacements of reservoir fluids induced by injection of liquid or gas. At the same time, the accurate measurement of temporal ground deformation reflects geomechanical responses and spatial changes. With micro-gravimeters and DGPS, very small gravity anomalies can now be mapped as well as their evolution with time. Displacements of the ground surface can also be measured very precisely through satellite radar interferometry (INSAR). Each of these methods has been implemented on a few occasions on active storage fields (natural gas storage or CO2 pilot sites) and recently with success for INSAR techniques at the commercial CO2 sequestration site at In Salah, Algeria. However, these technologies are largely uncalibrated for diverse environmental settings like vegetated or urban areas for example.

We propose to field test and evaluate these techniques in an active large volume aquifer storage and recovery (ASR) project where sufficient geological data and documented time series exist to create realistic models of mass distribution and surface motion displacement for comparison with gravity and radar interferometry observations. The results will be used as analogs to CO2 storage sites with the appropriate scaling in volume and physical properties for CO2 injection, as well as direct examples of sites where CO2, dissolved in saline aquifer water will be injected.

We are presenting the first results of this coupled approach obtained on the basalt aquifer ASR project of Pendleton Oregon. Since 2003, the Oregon Water Resources Department and the City of Pendleton have installed several ASR wells into discontinuous basalt aquifers to a depth of about 333 m. From 23,000 to 1.9 million cubic meters per year are withdrawn from the Umatilla River and are injected from January through June. The project then recovers, or produces, about 1.7 million cubic meters per year from June through November. Three micro gravity and differential GPS surveys made in June, August and October 2010 and a 2010 time series of ALOS L-band interferograms seem to confirm that temporal ground deformation can be observed and measured. We present these data and our calibration approaches and will discuss their implications for geomechanical modeling in such a geological context.

Monitoring Functional Genes to Evaluate the Effectiveness of EOx at Gasoline-Impacted Sites

Gary Birk, EOS Remediation, Raleigh, NC

Greg Davis, Microbial Insights, Rockford, TN

Holly Parsons, American Environmental Corporation, Indianapolis, IN

Meichin Yeh, EOS Remediation, Narashino City, Chiba Japan

***Sheri Knox**, EOS Remediation, Raleigh, NC*

Evaluation of corrective actions designed to enhance biodegradation of petroleum hydrocarbons and fuel oxygenates should include chemical, geochemical, and microbiological lines of evidence. Monitoring and analysis of trends in dissolved benzene, toluene, ethylbenzene, xylene (BTEX) and methyl tert-butyl ether (MTBE) concentrations are routinely used to document contaminant loss and provide an indicator of enhanced biodegradation. Likewise, monitoring geochemical parameters to document changes in availability of electron acceptors such as dissolved oxygen (DO) can provide a second indicator of enhanced biodegradation. However, the potentially most direct line of evidence to evaluate the ability of a remediation technology to stimulate biodegradation is to quantify the specific genes encoding enzymes responsible for biodegradation of the contaminants of concern. The calcium-based bioremediation product EOx™ was used to address impacted groundwater at a gasoline impacted site in central Indiana. CENSUS quantification of phenol hydroxylase and toluene dioxygenase was employed to monitor microbial populations responsible for BTEX biodegradation and to evaluate the effectiveness of EOx™ for promoting aerobic biodegradation. Overall, traditional groundwater analyses combined with monitoring select aromatic oxygenase genes provided the three lines of evidence needed to demonstrate the effectiveness of enhanced aerobic bioremediation at this site. Data from a CPC Service Station located in Kaohsiung, Taiwan will also be discussed.

Using Groundwater Recirculation to Obtain Rapid, Site-wide Biodegradation of Petroleum Hydrocarbons or Chlorinated Solvents

Brian Timmins, *ETEC, LLC*

Using a groundwater recirculation approach to implement bioremediation is not a new technology, but it has often been challenging to utilize for successful remediation due to a range of issues that are associated with this process. Historically, mineral or biological fouling of equipment components has caused operational issues that have prevented this approach from being implemented. Furthermore, geological/hydrogeological conditions were not always well-characterized and understood, sometimes resulting in unsatisfactory remediation results. Additionally, system operators typically had limited experience with biological processes, and did not understand the technology limitations and optimal microbial conditions required to make this an effective remedial alternative. Finally, few practitioners fully understand the terminal electron acceptor process, and how this predictable and reliable sequence can be used to make ongoing system and amendment loading adjustments. Making enhanced bioremediation successful using a groundwater recirculation approach requires a combination of properly-designed equipment/infrastructure, the right mass/concentration of biological amendments, field experience with in situ amendment delivery, and consistent and proper interpretation of groundwater data throughout system operation.

This presentation will cover the design considerations with this technology, specifically how lithology, aquifer productivity, above-ground buildings/infrastructure, and remedial goals affect the degree of infrastructure required. Also covered will be the limitations of bioremediation (go or no go decision process), the mass balance considerations with any type of biological amendment, and the most common reasons why this technology fails to reach remedial goals at some sites. This information will be used to show how theoretical calculations usually mislead practitioners, and how practitioners should be using empirical data and 'field calls' to ensure optimized biological conditions are achieved and maintained. Lastly, we will show calculations why a dissolved oxygen only approach is generally not appropriate for the majority of petroleum hydrocarbon impacted sites.

Two case studies will be shown to demonstrate how this technology can be used to rapidly remediate either petroleum hydrocarbons or chlorinated solvents in the saturated zone. Site-specific conditions and design considerations for each site will be discussed (lithology, above ground buildings/infrastructure, natural attenuation and groundwater quality data, injection/extraction well design, etc.), as well as performance monitoring data and implementation costs. The presentation will also demonstrate correct interpretation of the empirical data collected from these sites to make adjustments using the programmable logic controlled systems to optimize ongoing in situ treatment. The results from both of these projects demonstrate that, even with differing site lithologies, contaminant types/concentrations, and plume size, enhanced bioremediation using a groundwater recirculation approach is an extremely fast, complete, and cost-effective approach when applied correctly.

Accelerated Site Cleanup Using a Sulfate-Enhanced In Situ Remediation Strategy

Gary Birk, EOS Remediation, Raleigh, NC

***Sheri Knox,** EOS Remediation, Raleigh, NC*

Meichin Yeh, EOS Remediation, Narashino City, Chiba Japan

Soil and groundwater clean-up is critical to sustainable business practices across many industries. The conventional wisdom for remediation of aquifers contaminated with petroleum hydrocarbons (PHCs) is to add oxygen. A paradigm shift in the remediation of petroleum hydrocarbons has occurred that employs a sulfate-enhanced in situ remediation strategy.

It was once thought that aromatic hydrocarbons do not biodegrade under anaerobic conditions. However, the importance of naturally occurring anaerobic oxidation processes in the biodegradation of PHCs is now firmly established and is considered the dominant driving force in natural attenuation of PHCs in the subsurface. Sulfate reduction and methanogenesis appear to be the dominant natural degradation processes at most sites (Wiedemeier et al., 1999). A recent British Petroleum/EPA study (Kolhatkar et al., 2000) has concluded that most hydrocarbon plumes are anaerobic and depleted of sulfate. Other studies such as Wilson et al. (2002) showed that of these natural anaerobic processes, sulfate reduction accounts for most of the degradation. Cuthbertson et al. (2006) presented case studies that demonstrated the benefits of adding electron acceptors such as EAS™ (U.S. Patent # 7,138,060) to stimulate the biodegradation of petroleum contaminants in groundwater under field conditions at various sites.

The availability of electron acceptors controls the rate of in situ biodegradation. In the presence of petroleum hydrocarbons, terminal electron acceptors are depleted at a rate significantly higher than can be naturally replenished, thus inhibiting biological degradation. The introduction of additional electron acceptors to the subsurface can accelerate the rate of biological degradation (Cuthbertson et al., 2009).

Based on a solid body of published scientific evidence, adding electron acceptors such as EAS™ to groundwater will aid in increased degradation. EAS™ addition will stimulate biodegradation by providing a soluble, readily available electron acceptor. In the presence of elevated sulfate (SO4-2), anaerobic groundwater bacteria use the PHCs for carbon and energy while mineralizing the hydrocarbons to carbon dioxide (CO2) and water (H2O).

Optical DO Technology Provides Real-Time Measurement Solution for Groundwater Remediation

Bill Mann, *In-Situ Inc.*

Groundwater remediation sites using the EPA Triad Approach rely on instruments that provide real-time measurement technologies. With these technologies, remediation specialists can track remedial progress and adapt treatment protocols as new data becomes available. Real-time measurement and reporting help technicians complete remediation more quickly, safely, and at a lower cost than with the use of traditional approaches.

Chemical oxidation (ISCO), chemical reduction (ISCR), and biosparging methods require the measurement of dissolved oxygen (DO) and parameters like pH/ORP, conductivity, temperature, and level/pressure. These treatment methods require sensors and instruments that can withstand a variety of conditions. Remediation specialists also require water quality sondes that are less than two inches in diameter for deployment into monitoring wells. Sondes that monitor and log data at user-defined intervals can minimize grab sampling – a time-consuming process that can expose technicians to highly reactive chemicals.

Optical-based DO technology enhances real-time, in-situ monitoring of treatment progress. Optical DO sensors can be deployed into a monitoring well and left unattended to measure and log DO. Remediation specialists can download data without removing instrumentation from the well, or they can connect a sonde to a telemetry system for remote data access. To further automate a treatment system, monitoring instruments can be used to regulate pumps or controls, which optimizes chemical and oxygen usage.

Optical sensors respond quickly to changes in DO and require minimal maintenance and infrequent calibrations. The durable sensing element extends operational life. Additionally, optical DO sensors do not require conditioning, do not consume oxygen as part of an electrochemical reaction, and do not require sample flow for accurate readings. Optical sensors are especially accurate below 2 ppm. With optical technology, maintenance and material costs are drastically reduced, and site visits are minimized. This paper will discuss the use of optical technology for groundwater remediation projects, a case study, and EPA approval of an optical DO method.

Development of a 3,500-gpm Groundwater Supply for the Lower Elwha Klallam Tribe's New Salmon Hatchery

Joel Purdy, *GeoEngineers, Inc.*

James Miller, GeoEngineers, Inc.

As part of the Elwha River Ecosystem Restoration project related to the removal of the Elwha and Glines Canyon Dams from the Elwha River, the Lower Elwha Klallam Tribe is constructing a state-of-the-art salmon hatchery along the Elwha River on the northern Olympic Peninsula. The water supply for the new 16-million-dollar hatchery, slated to be completed by the spring of 2011, is designed for the use of 3,500 gallons per minute of pathogen-free groundwater. Four 12-inch-diameter production wells, located between approximately 150 and 900 feet from the Elwha River, were drilled to depths between 100 and 120 feet using cable-tool and reverse-circulation rotary drilling techniques. Layered alluvial deposits were encountered, consisting of a complex mixture of silt, sand, gravel and cobbles.

Step- and constant-rate testing was conducted on the four new production wells plus one existing well to evaluate pumping capacities, well efficiencies, wellfield drawdown interference and aquifer characteristics such as transmissivity and storativity. A network of pressure transducers and dataloggers were installed to monitor water levels in the Elwha River, four new production wells, an existing 6-diameter domestic-supply well, and an existing production well that was installed in 2001. Traditional techniques were used to evaluate aquifer characteristics. Analysis of the pumping test information was complicated by rapid responses of groundwater levels in the shallow aquifer to variable Elwha River stage, recharge events, and, potentially, recirculation of discharge water from pumping tests.

The Potential to Augment Stream Flow using Ground Water, Bertrand Creek, Northwest Whatcom County, Washington

Bridget August, *Associated Earth Sciences, Inc.*

Charles Lindsay, Associated Earth Sciences, Inc.

David Baumgarten, Associated Earth Sciences, Inc.

Bertrand Creek is a small lowland stream that flows from southern British Columbia, Canada, southward through Whatcom County, eventually discharging to the Nooksack River approximately 2 miles southwest of the city of Lynden, Washington. Summer and fall flows in Bertrand Creek are typically less than the current in-stream flow requirements under Washington Administrative Code (WAC) 173-501-030. Associated Earth Sciences, Inc. (AESI) assisted the Bertrand Watershed Improvement District (WID) in evaluating potential options for improving summer and fall stream flow in Bertrand Creek. We evaluated the potential to augment stream flow in the upper reaches of Bertrand Creek with ground water obtained from a shallow aquifer that underlies the surrounding area which has a limited hydraulic connection to the creek. Based on explorations completed for the study, the project site appears to be underlain by a regional, locally unconfined shallow aquifer located within the Sumas glacial outwash sediments. Where encountered on the project site, the outwash aquifer is generally underlain by fine-grained glaciomarine drift comprised mainly of silt. AESI assisted the WID in installing and testing a stream flow augmentation well (AW-1) and completed an analysis of potential stream flow depletion in Bertrand Creek from the operation of AW-1 and two proposed augmentation wells (AW-2 and AW-3) located on property adjacent to Bertrand Creek. The stream flow augmentation wells are proposed to supply roughly 1,200 gallons per minute (gpm), approximately 2.7 cubic feet per second (cfs), to the upper reaches of Bertrand Creek. Under the proposed plan, each well would be pumped at approximately 400 gpm (0.89 cfs) for a period of up to 5 months in the summer and early fall to augment flow in Bertrand Creek. Aquifer testing results of well AW-1 indicated that pumping of the augmentation wells could cause a minor reduction in base flows to Bertrand Creek. In order to estimate the net gain in stream flow in Bertrand Creek from flow augmentation with ground water, AESI utilized the United States Geological Survey (USGS) STRMDEPL08 computer program. The stream depletion modeling indicates that a maximum 60 percent of the augmentation water routed to Bertrand Creek would be lost as depletion at the end of the 5-month period simulated, due to pumping the three augmentation wells at distances ranging from 1,200 feet to 3,000 feet away from the stream channel.

Numerical Simulation of the Groundwater-Flow System in the Chambers-Clover Creek Watershed and Vicinity

Ken Johnson, *U.S. Geological Survey*

Mark Savoca, U.S. Geological Survey

Burt Clothier, Robinson Noble, Inc.

A numerical groundwater-flow model was developed to contribute to an improved understanding of water resources in the Chambers-Clover Creek Watershed (CCCW). The study area covers about 491 mi2 in western Pierce County, Washington, and was selected to include major hydrologic features that could be used as regional model boundaries during development of the numerical flow model of the CCCW and vicinity. The study area is bounded to the northeast by the Puyallup River, to the southwest by the Nisqually River, and extends northwest to Puget Sound, and southeast to Tanwax Creek which approximates the southeastern extent of the majority of water-bearing hydrogeologic units. The study area is underlain by a northwest thickening sequence of unconsolidated glacial (till and outwash) and interglacial (fluvial and lacustrine) deposits. Sedimentary and volcanic bedrock units underlie the unconsolidated deposits, and crop out in a few areas within deeply incised river valleys along the southern and southeastern margin of the study area.

Groundwater flow was simulated using the groundwater-flow model, MODFLOW-2000. A finite-difference model grid consisting of 146 rows, 132 columns, and 11 layers was used to represent the groundwater-flow system. Each model cell has a horizontal dimension of 1,000 by 1,000 feet, oriented to align with the major river valleys and Puget Sound, and with the thickness of model layers varying throughout the model area. The model was calibrated using monthly water levels in 127 water wells and base flow measurements conducted at 50 stream cross-sections. Field data collection occurred at these sites between September 2006 and September 2008.

The model simulates both steady-state and transient conditions. Steady-state condition simulates average recharge, discharge, and water levels for the study period (September 2006–September 2008). The transient simulation period (March 2007–September 2008) was divided into 18 monthly stress periods to represent temporal variations in recharge, discharge, and other groundwater-flow system processes. Several model simulations were selected by stakeholders and USGS to demonstrate model performance and to provide representative examples of how the model may be used to evaluate the effects of potential changes in groundwater withdrawals, consumptive use, and recharge on groundwater levels and stream baseflows.

Riddle Me This! OR The Case of the Bastard Beach

Mike Krautkramer, *Robinson Noble, Inc.*

John Noble, Robinson Noble, Inc (Emeritus)

Burt Clothier, Robinson Noble, Inc.

Every once in awhile during a career in the geologic sciences, we come across something that just does not fit into the interpretation of the world with which we have become comfortable. We at Robinson Noble recently experienced such a moment and desire to share the quandary with the geologic community of which we are proud to be part. The point of the presentation is to deliver the observations and to stimulate thought and discussion on the matter. Such discussion can serve as an impetus for all to reexamine our interpretation of the history of the Puget Sound region and the processes that gave it form. Perhaps there is something new to learn.

The long-held description of the Puget Sound geologic history asserts that the first incursion of marine environments into the Puget Sound area occurred after the recession of the Puget Lobe at the end of the Vashon Glaciation. Most interpretations discuss sea levels no more than 300 feet below those of the present. Further, recent interpretations by Troost and Booth suggest the carving of valleys and the Sound itself occurred as erosion by sub-glacial drainage processes, a concept new to many of us.

In a recent drilling project in the Puyallup Valley for the City of Sumner, we encountered a marine beach deposit at an elevation of about 400 feet below sea level. These sediments are a mix of gravel, sand and shells reminiscent of many beaches of modern Puget Sound. Many of the larger gravel clasts had barnacles attached that looked as if they had been plucked from the Sound yesterday. The deposit is replete with shells of many types some completely intact.

This implies that either the recent deposition of marine sediments in the Puyalllup Valley reach much deeper than previously thought, or there is an older marine chapter in the history of the area that has, as yet, been unread. Either way there is an opportunity for us to learn. If post-Vashon, the presence of these ancestral beach deposits imply a sea level at the time of deposition lower than most now discuss. Further, the existence of a deep canyon beneath the current position of the Puyallup River raises questions of stratigraphy and depositional process that intrigue the authors and could be far reaching.

A deep canyon would suggest the sub-glacial erosion posited by Troost and Booth was substantial in the valleys. It also raises some weighty questions with regard to the ice physics and sediment transport of the setting. What did the presence of canyons do to the movement of the glacial ice? Assuming the ice filled these canyons as they were cut, did such drainages act more like pipes than like rivers? If so, how much of our normal-think as to sediment transport would apply? Or, Does this deposit indicate an earlier pre-Vashon marine environment?

Conceptual Models for Predictive Simulations of Soil Desiccation at the Field Scale

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Soil desiccation is a potential remediation technology for contaminants located in the deep vadose zone at the Hanford Site in southeastern Washington State. In soil desiccation, a dry barrier is established between a contaminant plume in the vadose zone and the water table by injecting dry gas and then removing the vapor. Since the performance of the soil desiccation technology is impacted by both physical and chemical heterogeneities in the subsurface, the level of detail necessary for representing heterogeneities in numerical models is investigated. Several different conceptual models are developed based on sparse site-specific data, and different discretization schemes are used to represent the conceptual models. Results demonstrate that in some cases, highly resolved representations of the physical heterogeneities are needed to predict contaminant transport behavior. However, more simplistic, coarser representations of heterogeneities are also shown to be sufficient to capture important features and subsequent contaminant transport behavior. By reducing the computational requirements for simulation execution, improvements in risk and uncertainty quantification result because a larger number of simulations can be executed for analysis.

Radionuclide Immobilization and Flow Path Modifications by Dissolution and Secondary Precipitates

Guohui Wang, *Pacific Northwest National Laboratory*

Wooyong Um, Pacific Northwest National Laboratory

Leaking of caustic (hyper-alkaline) radioactive wastes, generated from plutonium production during the Cold War and stored in underground storage tanks at Hanford Site (Richland, WA), has been detected in the subsurface. The caustic wastes leachate induce mineral dissolution and subsequent secondary precipitation in the sediments, which influence the fate and transport of contaminants through pore structure changes and coprecipitation/sorption of radionuclide on the neo-formed secondary precipitates. The objective of this study is to investigate the combined effects of mineral dissolution and precipitation on transport of radioactive 90Sr using stable Sr as surrogate in the subsurface. A series of saturated columns filled with pure quartz or Hanford course sands using simulated tank caustic leachate spiked with Sr are carried out under elevated temperatures. The pore structure changes in the packed column before and after contact with the caustic solution are observed through the pore structure images collected by the X-ray Microtomography (XMT) system, and the related changes in the effective pore water volume can be quantified via the pore water distribution function through image analysis (measured pore radius) using 3DMA-Rock software. The caustic leachate-dissolved Si from primary silicate minerals reacts with Al and Na to form secondary precipitates such as cancrinite or sodalite which is feldspathoid aluminosilicate mineral on the surfaces of packed mineral grains. Strontium can coprecipitate and/or be incorporated into the cage structure during the secondary precipitates forming. Newly formed precipitates tend to possess higher specific surface areas and therefore may provide additional sorption sites for removal radionuclides. As expected, the transport of Sr is much retarded in caustic leachate columns and geochemically agrees well with Al, Si breakthrough curves. The comparison of nonreactive tracer (Br) breakthrough curves before and after caustic leachate flooding also indicates the column hydrodynamic changes due to different flow path resulting from altered pore structure.

Technetium-99 and Uranium-238 Contamination on Sediments in the BC Cribs and Trenches Area

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Jeff Serne, Pacific Northwest National Laboratory

Michael Truex, Pacific Northwest National Laboratory

Two key radioactive contaminants, technetium-99 and uranium-238, along with other trace metals were determined in water and acid extractions of the collected core sediments from new borehole 299-E13-65 (C7047). The water-extractable technetium-99 concentrations in borehole C7047 show elevated technetium-99 concentrations occurring at the same locations as elevated nitrate with maxima of 73 pCi/g, 73 pCi/g, and 64.5 pCi/g (4.3 x10-3 µg/g, 4.3 x10-3 µg/g, and 3.8x10-3 µg/g) at 29 ft, 39 ft, and 60 ft bgs, respectively. Because they are both mobile contaminants, the concentration profile of nitrate and technetium-99 occurs at the same place and distributes in a similar pattern in the Hanford vadose zone. The same sediments contain elevated water-extractable uranium-238 as high as 1.29 μg/g of dry sediment at the depth of 33.2 ft bgs. Highly elevated uranium-238 concentrations are found in the depth region of 33 ft to 40 ft bgs where high moisture and elevated pH levels are found because of the presence of fine-grained silty beds. The concentrations of technetium-99 in acid extracts of C7047 are very similar to those of technetium-99 in water extracts. However, much higher concentrations of uranium-238 were found in acid extracts of C7047 sediments with a maximum value of 3.36 µg/g at 33.2 ft bgs, which is indicative of the presence of uranium (co)precipitates or uranium occlusions within mineral structure.

Compared to water-extractable technetium-99 and uranium-238 concentrations of nearby borehole 299-13E-62 (C5923), C7047 sediments show a similar distribution of technetium-99 between two boreholes except for higher concentrations of technetium-99 at the depths of 22 ft to 33 ft bgs in C7047 and 36.8 ft and 45.5 ft bgs in C5923. Much higher uranium-238 concentrations in water extracts of C7047 sediments suggest that high uranium contaminants still remain in the uranium-recovery wastes disposed of in the cribs. Higher values of pH, EC, and ionic strength in the two lobes (25-33 ft and 46-60 ft bgs), and elevated concentrations of water-extractable technetium-99 and nitrate at shallow depths (25 ft and 33 ft bgs) of C7047 sediments are attributed to the greater volumes of caustic wastes that have contaminated the C7047 sediments through lateral spreading after being disposed of in the cribs which are located closer to C7047 than C5923. The total and water-leachable concentrations of key contaminants as a function of depth and distances from the footprints of inactive disposal facilities can be used to update contaminant-distribution conceptual models and to provide more data for improving baseline risk predictions and remedial alternative selections.

Multiple Remediation Approaches Demonstrate Cumulative Effectiveness in Treating Tetrachloroethene

Troy Fowler, *Hart Crowser, Inc.*

Craig Dockter, Hart Crowser, Inc.

Brian Timmins, ETEC, LLC.

The former Springvilla Dry Cleaners site used a tiered remediation approach to cost-effectively address significant residual tetrachloroethene (PCE) mass distributed across more than 80,000 cubic yards of soil and two aquifers. Five sequentially implemented remediation approaches were used to mitigate on-site and off-site risk and allowed for monitored attenuation after three years of aggressive treatment. This tiered approach maximized remediation effectiveness and long-term reliability while dramatically shortening time frames by 20 years and reducing costs by $2 million.

Initially, source area soil beneath the former cleaners was excavated and treated by ex situ soil vapor extraction. An infiltration gallery was installed in the source area excavation. Permanganate salts were injected to chemically oxidize residual contamination in the shallow aquifer in the vicinity of the source removal. Sub-slab soil vapor extraction was used temporarily to mitigate vapor intrusion risks posed by contamination remaining under the building until broader treatment could be completed.

Following initial source area work, in situ reductive bioremediation was implemented to address remaining site contamination. Based on the estimated treatment area pore volume of 4 million gallons, a groundwater recirculation system was used to deliver bioremediation amendments within a treatment cell and to maintain hydraulic control of the plume. During initial recirculation, PCE groundwater concentrations were observed up to 1,300 µg/L in the silty-sand shallow aquifer and 930 µg/L in the sandy-gravel intermediate aquifer. Due to the plume size, a "treat and hold" strategy was adopted to efficiently remediate the site in stages. A combination of CarBstrate™, complex lactates, and nutrients were recirculated to achieve initial PCE dechlorination, control biological fouling of injection locations, and improve amendment distribution across the shallow and intermediate depth treatment cells. Once PCE dechlorination within a treatment cell was largely complete, emulsified oil products were then deployed to maintain reductive activity and the recirculation treatment cell modified to address different areas.

Approximately 54,000 pounds of electron donor amendments were introduced during the 24 month recirculation system operation period and 6,300 pounds of emulsified oil concentrate were injected under the building's concrete slab to ensure complete treatment of the shallow aquifer under the building. Project costs are anticipated to total $1 million dollars for 3 years of aggressive remediation. Approximately 25 percent of project costs were to deliver amendment into the subsurface. Traditional pump and treat remediation, instead of reductive bioremediation, would have added an estimated $2 million and 20 years to reach the monitored attenuation remedy stage.

Donor Borings: Novel Use of Electron Donor Backfill for Bioremediation of a TCE Source Zone

Christophe Venot, *Landau Associates, Inc.*
Clint Jacob, Landau Associates, Inc.
Jerry Ninteman, Landau Associates, Inc.
Y. Nicholas Garson, The Boeing Company
Alan Sugino, The Boeing Company
Daniel McCormack, The Boeing Company

This presentation will discuss the design, construction, and treatment results of "donor borings" installed for treatment of a trichloroethene (TCE) source zone at an aerospace manufacturing plant in Everett, Washington. The source zone exists within a low permeability portion of an unconfined, advance outwash aquifer of sand to silty sand extending from 10 to 45 ft below ground. A prior attempt to stimulate biological treatment through injection of electron donor injection fluid was largely unsuccessful due to tight aquifer conditions.

Anaerobic bioremediation of TCE is accomplished through the addition of organic carbon substrates which serve as electron donor for biologically mediated reductive dechlorination of TCE and breakdown products. Electron donor is used by native aquifer bacteria for reductive dechlorination and to create the highly reducing aquifer conditions required for complete degradation of TCE and breakdown products. Reductive dechlorination of TCE results in the removal of chlorine atoms and the formation of sequential degradation products cis-1-2-dichloroethylene (cDCE), vinyl chloride (VC), and non-toxic end products ethene and/or ethane.

The donor boring approach is similar to the more common mulch biobarrier approach, except that 1) donor backfill is placed in closely spaced borings instead of in a trench and 2) more donor substrate is emplaced to achieve a downgradient treatment zone, not just treatment of water passing through the barrier. Closely spaced, offset rows of donor borings are constructed perpendicular to groundwater flow to form a "picket fence" of emplaced donor that is distributed to the downgradient aquifer as groundwater flows between the borings.

Thirteen donor borings in three staggered rows were backfilled with a granular slurry of LactOil™ (vegetable oil and ethyl lactate), cheese whey, and pea gravel. The backfill design was developed through bench testing and field installation pilot testing to arrive at a mix with high donor content, adequate density to overcome heaving sands during installation, and structural integrity of the backfilled boring. Off-spec whey, not suitable for human consumption, was used in the donor backfill; due to metal filings in the whey, it was classified for use as a low-grade animal feed. Use of off-spec whey helped the facility achieve its sustainable remediation objective of materials reuse and reduction of natural resources consumption.

Enhanced Anaerobic Bioremediation of Petroleum by Nitrate Injection: Pilot- and Full-Scale Results

Clinton Jacob, *Landau Associates*

Martin Valeri, Landau Associates

James Bet, The Boeing Company

Jennifer Parsons, The Boeing Company

This presentation will discuss the results of a pilot test and full scale treatment of petroleum hydrocarbons using enhanced anaerobic biodegradation at an aerospace manufacturing facility in Seattle, Washington. In 1985, a former underground storage tank (UST) was punctured and released approximately 800 gallons of unleaded gasoline to the shallow unconfined aquifer. Following UST and soil removal, and recovery of 500 to 600 gallons of floating product, elevated concentrations of TPH-G (270 mg/L) and benzene (5000 µg/L) persisted in groundwater. A pilot test using Oxygen Release Compound to stimulate aerobic bioremediation was ineffective due to naturally high organic carbon in the aquifer and naturally anaerobic aquifer conditions.

Enhanced anaerobic bioremediation was successfully pilot tested in 2007. By this approach, bacteria metabolize petroleum hydrocarbons as the electron donor and added nitrate as the electron acceptor to obtain energy. Baseline aquifer redox conditions were mildly reduced (i.e. nitrate- to sulfate-reducing), conditions conducive to anaerobic biodegradation with nitrate. A solution of ammonium nitrate fertilizer was injected to the most contaminated well located in the former tank pit. The single pilot test injection resulted in a TPH-G concentration reduction of 49 percent from baseline (51 mg/L to 26 mg/L) and a 77 to 98 percent decrease in BTEX compounds. The most significant decrease in contaminant concentrations was observed during the first and second months post-injection when nitrate aquifer concentrations were highest. Injected nitrate was consumed in 3 to 4 months followed by rebounding contaminant concentrations due to a return of groundwater concentrations to equilibrium with substantial sorbed and/or NAPL mass present in the aquifer.

Full scale treatment was performed in 2008 through 2010 with 6 injections of nitrate solution occurring to two injection wells. Effective treatment has been evidenced by decreases in contaminant concentrations to the lowest levels since monitoring began, with TPH-G and BTEX decreasing 91 to 99 percent compared to baseline. Some rebound of contaminant concentrations continues to occur upon depletion of nitrate in the aquifer and nitrate injections will continue, as needed, to treat remaining aqueous-, sorbed-, and/or NAPL-phase contamination.

Multiple-Tiered Remediation Approach to Prevent Concentration Rebound at an Active Fueling Station

Craig Dockter, *Hart Crowser, Inc.*

Troy Fowler, Hart Crowser, Inc.

An active fueling station in eastern Oregon is performing remediation of free-phase product (product) and dissolved-phase hydrocarbons extending over two city blocks. Remedial efforts began in March 2008 to address the approximately 7 acre product plume. A liquid-ring pump was used to extract product, shallow groundwater, and soil gas from 14 locations by cycling between multi-phase and soil gas only to maximize mass removal and minimize groundwater treatment. Oxidative bioremediation was incorporated into the remedy in September 2009 by using existing infrastructure to recirculate groundwater and deliver amendments to areas where product had been removed. Oxidative bioremediation was expanded to include slug-injections in March 2010. The physical extraction-bioremediation multi-tiered approach is designed to accelerate remediation of dissolved-phase hydrocarbons in the saturated zone, while reducing the mass of adsorbed-phase hydrocarbons to prevent concentration rebound at the completion of system operation.

Prior to remedy startup, product was detected in 14 of 30 monitoring wells with a maximum thickness of 1.39 feet. After 33 months of operation, product is no longer present in any of the 30 monitoring wells. Approximately 28,200 pounds of petroleum has been physically removed through vapor and groundwater extraction, with an additional 2,900 pounds biologically oxidized through December 2010.

Issues Related to the Attenuation Processes to Remediate Metals and Radionuclides in Groundwater

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Carl Sprang, Colorado Department of Public Health and Environment

Many sites across the United States have groundwater contaminated with metals or radionuclides - often at low levels, but above standards. In the Washington State, Hanford federal facility is one those sites where groundwater is contaminated with both metals and radionuclides. Most potential engineered remedies are too costly or otherwise impracticable. In contrast, attenuation-based remedies rely on natural processes to sequester the contaminants of concern and are therefore less aggressive and invasive, and are typically less costly. Attenuation of metals and radionuclides involves more complicated or interdependent sets of processes and has rarely been applied. Because technical guidance specifically addressing the use of attenuation-based remedies for metals and radionuclides has only recently been available, the application of attenuation remedies for metals and radionuclides has been inconsistent.

In order to facilitate the acceptance of attenuation-based remedies for metals and radionuclides, the Interstate Technology and Regulatory Council (ITRC) has developed a technical and regulatory guidance document, which builds upon the EPA's new Technical Framework Documents and emerging policy directive. To determine the specific approach of this document, ITRC conducted a web-based survey of state regulators and stakeholders to determine the existing state of knowledge and acceptance regarding the application of attenuation processes as a remedy. Stakeholders may be concerned that attenuation-based restoration of radionuclide and metal contamination may require a more detailed characterization of the site or that attenuation will require extensive long-term monitoring to ensure public health and ecological parameters are met. Attenuation, perhaps more than other environmental restoration techniques for metals and radionuclides, depends strongly on balancing relationships between the contaminated media and the geo-chemical (and perhaps ecological) situation at a specific site (or portion of site) during a specific period of time: a dynamic stasis of sorts. Significant uncertainties in attenuation cleanup efficacy and timelines may conflict with stakeholder expectations.

Foam: Reactant Transport Media for In-Situ Immobilization of Radionuclide and Metallic Contaminants

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Lirong Zhong, Pacific Northwest National Laboratory
***Martin Foote**, MSETA*
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The U.S. Department of Energy (DOE) is currently addressing issues related to remediation of Cr, U and Tc contamination in the deep vadose zone at the Hanford Site in Washington State. One of the transformational technology alternatives being considered by the DOE, is the use of foam for subsurface delivery of remedial amendments to immobilize contaminants in-situ. Foam injection technology for Enhanced Oil Recovery has well-established pedigree. Use of surfactant foams have also been explored for mobilizing DNAPL from sediments. However, until now, the novel concept of using RCM for in situ immobilization of contaminants in the deep vadose zone has not been explored. This presentation will provide the results of a multi-agency investigation to develop robust stable foams for delivering reductive and/or precipitating reactants to deep subsurface environments. Results will be presented quantifying the quality, stability, bubble size distribution, surface tension and viscosity of foam delivery technology in the presence of remedial amendments (polyphosphate and polysulfides). Results from a series of scaled-up reactant carrier foam injection tests, to evaluate the efficacy of this technology for potential deep vadose zone remediation, will also be discussed.

Removal of Heavy Metals in Acid Mine Drainage using Carbonate Cancrinite and Sodalite

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Korea Institute of Science and Technology

Wooyong Um, Pacific Northwest National Laboratory

Acid mine drainage (AMD) is a serious threat to the environment and human health. The pH of AMD is generally acidic and AMD contains high concentrations of heavy metals such as iron, manganese, aluminum, arsenic, lead, cadmium, zinc, and copper, which are not naturally biodegradable. AMD is usually treated by alkaline materials such as fly ash, lime, or soda ash to precipitate heavy metals as metal hydroxides when the acid pH in the AMD is neutralized by alkaline materials. However, there are some disadvantages to using these materials as sorbents because they have low reaction rate and removal capacity. Use of alkaline materials also produces huge amounts of secondary wastes after the remediation process. In this study, the feldspathoid minerals carbonate cancrinite and sodalite were applied to treat heavy metals in synthetic AMD based on a recipe found in Gangwon Province in South Korea. Carbonate cancrinite and sodalite are alumino-silicates that have a cage structure like zeolite and a pH buffering capacity because of the presence of carbonate. Because of their high sorption capacity to remove heavy metals in solution and acid neutralization capacities, they could be alternative sorbent materials for treating AMD. We synthesized carbonate cancrinite and sodalite and characterized the properties with XRD and SEM-EDX. To test acid the neutralization capacities and acid stability of carbonate cancrinite and sodalite minerals, the dissolution rates of Al and Si were observed at low pH and the pH titration of synthetic AMD was carried out with or without the presence of carbonate cancrinite and sodalite. The remediation capacity of these materials to remove heavy metals found in synthetic AMD was also tested in batch sorption and kinetic experiments under varying conditions of metal concentrations. The mechanisms of the remediation process were studied and the stability of the materials was tested to increase our understanding of heavy metal sorption and desorption. Carbonate cancrinite and sodalite, which possess a fast sorption capacity for removing heavy metals and a pH neutralizing capacity, can be used as efficient sorbents in AMD environments.

Resin Testing to Recover Technetium-99 and Uranium from 200 West Area Groundwater, Hanford Site, Richland, Washington

Mark E. Byrnes, *CH2M HILL Plateau Remediation Company*

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Ron Smith, Pacific Northwest National Laboratory

CH2M HILL Plateau Remediation Company (CHPRC) is currently constructing the 200 West Area groundwater treatment facility at the U.S. Department of Energy's Hanford Site, north of Richland, Washington. Pump-and-treat is the remedial action selected under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 Record of Decision for the 200-ZP-1 Operable Unit. The treatment design is based, in part, on the removal of selected contaminants of concern using various sorbent media. CHPRC has requested the support of Pacific Northwest National Laboratory to perform treatability testing to quantify the ability of selected ion-exchange (IX) resins (Purolite A530E, Purolite A532E, and ResinTech SIR 110HP) to adsorb technetium-99 and second set of IX resins (Dowex 21K, Dowex 1, Purolite PFA600/4742, and ResinTech SIR-1200) to adsorb uranium from 200 West Area groundwater. Batch isotherm tests are scheduled to be performed initially, followed by continuous-flow column adsorption testing. Groundwater from extraction well 299-W19-36 was used to support all of the testing because this well has elevated concentrations of both technetium-99 and uranium. The test results will be used to select the most cost-effective resin for future use in the new 200 West Area groundwater treatment facility. The results from this testing are being collected at this time and will be presented at the symposium.

Use of Reclaimed Water for Watershed Enhancement

Sally Brown, *University of Washington*

Rebecca Singer, University of Washington

Municipal effluent from wastewater treatment plants is the largest point source discharger into Puget Sound. A number of watersheds in Puget Sound have been identified with stream flow below critical levels during summer months. Ecological and agricultural use of reclaimed water would reduce direct discharge into Puget Sound and replenish flows in compromised watersheds. Current State requirements for groundwater recharge using reclaimed water are in excess of Class A requirements for irrigation. It is likely that indirect recharge by using irrigation areas as surface spreading basins will effectively treat water to meet State groundwater requirements. Research is being conducted to test the potential for soils in impacted watersheds to serve as a tertiary treatment system. Fate of nutrients, heavy metals, and endocrine disrupting compounds are being monitored in a greenhouse study. Two types of Class A reclaimed water are being added to intact columns collected from an Alderwood soil. The second phase of the test will add water to an Everett soil. Both sand filter water and water from a membrane bioreactor are being tested. Water is being added to soil at 1,2 and 4x the irrigation requirements. Irrigation is being done with and without plants. Impact on soils and water quality are being measured. This approach offers the potential for maximizing benefits associated with reclaimed water while simultaneously protecting water quality in streams.

The Role of Groundwater in the Nile Valley Landslide, Yakima County, Washington

Thomas C. Badger, *Washington State Department of Transportation Geotechnical Division*

Eric L. Smith, Washington State Department of Transportation Geotechnical Division

Steve M. Lowell, Washington State Department of Transportation Geotechnical Division

On October 11th, 2009, a very large translational landslide destroyed more than 2000 ft of State Route 410 along the Naches River near the community of Nile, which is located on the semi-arid eastern slope of the Washington Cascades about 25 miles northwest of Yakima. A forensic investigation was completed in the following months to characterize the failure mechanics of the landslide, evaluate its post-failure stability, and develop remedial options to reestablish the highway around or across the landslide. Notwithstanding the landslide's dramatic size and deformation features, the investigation revealed a fascinating evolution of failure: an initial shallow failure within the unconsolidated surficial deposits, followed by failure within a 250-ft-deep, adversely dipping, claystone interbed between two Grand Ronde Basalt flows. The shallow failure zone consists of a very weak, saturated, clay-rich zone located along the contact between the unconsolidated surficial deposits and the underlying bedrock. A deep unconfined aquifer influences the stability of this shallow failure zone, which to date has shown no response to precipitation. The deep failure zone is influenced by a highly pressurized confined aquifer, which yields strong artesian flows of up to 150 gpm with a piezometric surface up to 135 feet above the ground surface. Some responsiveness to precipitation has been observed in the deep confined aquifer.

Preliminary Lahar Hazard and Loss Estimations for Mount Rainier, Washington

Recep Cakir, *Department of Natural Resources - Geology and Earth Resources*

Timothy J. Walsh, Department of Natural Resources - Geology and Earth Resources

Mt. Rainier located about 20 miles southeast of the Seattle-Tacoma metropolitan area is an active and most dangerous volcano in the Cascade Range. In the last 10,000 years, there have been more than 60 lahars or debris flows that have traveled at least as far as 70 miles downstream to the valleys. Among all other volcanic hazards, it is generally accepted that lahars are greater threats to the communities and critical structures downvalley from Mount Rainier.

Washington State Department of Natural Resources (DNR)-Division of Geology and Earth Resources (DGER) currently runs a USGS-funded pilot project to estimate direct and indirect losses of various lahar hazard scenarios for Mount Rainier. We ran LAHARZ, a GIS-based computer program distributed by the USGS Cascade Volcano Observatory, to delineate potential hazard zones based on various volumes of lahars identified earlier and available digital elevation model. We then ran HAZUS-MH, a GIS-based software, distributed by the FEMA, to estimate losses (based on earthquake, flood or hurricane models) in the lahar hazard zones crossing the surrounding counties. Preliminary results of our ongoing project which extensively use the LAHARZ and HAZUS-MH methodologies will be shown for the major drainages emanating from Mount Rainier.

When Push Comes to Shove: Stream Channel Relocation by Lahars as Documented using Sub-fossil Trees

Kenneth Cameron, *Oregon Department of Environmental Quality*

Old Maid's Flat on Mt. Hood, Oregon, has received the bulk of eruptive debris produced by the mountain during its last two major eruptive periods. This fines-deficient debris generally forms a very well-drained xeric soil profile over time and vegetation is restricted to drought-resistant trees and shrubs. The exception to this is in the immediate vicinity of incised stream channels where water-loving trees, such as cedars, can survive.

In the area of Old Maid's Flat between Ramona Creek and the Muddy Fork of the Sandy River the usual vegetation cover of lodge pole pine, kinnikinnick and moss is spotted by sub-fossil snags up to 1.5 meters in diameter and over 30 meters tall. These snags are old-growth cedars, which are rot resistant due to their high tannin content. There are also numerous cylindrical shafts, known as tree wells, where trees, perhaps more easily decayed Douglas fir or hemlock, were buried by eruptive debris and have rotted away. Sounding the wells to their root base gives the thickness of the channel fill. At least two wells have been sounded at 6 meters and others at 4 to 5 meters.

From their size and inferred age the cedars must have colonized water-rich zones in lahar deposits from the Timberline Eruptive Period 1400 to 1800 years ago, and were buried and killed by material from the Old Maid Eruptive period 200 to 210 years ago. Due to their need for a wet micro-climatic niche in an otherwise xeric area, the cedars must have been growing in the immediate vicinity of a continual source of water, probably along an ancestral channel of the Muddy Fork or Ramona Creek. The locations of snags and wells were surveyed using a handheld GPS receiver and plotted on DEM and LIDAR maps hoping they would trace a now buried channel. Instead of a single channel, the plots show three linear concentrations, apparently previous channel orientations of the Muddy Fork.

My interpretation of the sequence of events starts with filling of the valley during the Timberline Period by lahars and pyroclastic flows, forming a hydrostatic level surface in the area of the modern location of the Muddy Fork and Ramona Creek. The Muddy Fork was temporarily dammed, creating a small lake or marshy area as seen by well sorted, fine-grained sediments and a dense stand of sub-fossil tree snags.

The lake breached the debris dam and formed at least three sub-parallel, possibly anastomosing, incised channels across the flat depositional surface. A water-loving flora colonized the channels, eventually producing a micro-environment including cedars and possibly other conifers. Lahars from the Old Maid Eruptive Period crossed the Timberline-aged surface, filling the channels and killing the trees. The channel of the Muddy Fork was pushed against the north side of the valley, cutting through the hummocky terrain of a landslide deposit (as interpreted from LIDAR images) forming the modern channel.

Large Seafloor Mounds in Hood Canal: Possible Earthquake-Induced Landslides

Timothy Walsh, *WA DNR, Division of Geology and Earth Resources*

Recep Cakir, WA DNR, Division of Geology and Earth Resources

Robert Logan, WA DNR, Division of Geology and Earth Resources (retired)

Two large seafloor mounds in southern Hood Canal, Washington, located directly off the mouths of the Dewatto and Little Dewatto Rivers, have previously been interpreted as dredge spoils or as drumlins. It was previously shown that they were embedded too deeply in the substrate to be dredge spoils, and we demonstrate that their shapes are inconsistent with Puget Lowland drumlins, which are larger and more streamlined than the Dewatto mounds. Suggestions that the mounds may be natural gas seeps are dispelled by the coarseness of the observed mound material and the lack of vent features. We made direct visual observations on these two mounds by using a remotely operated vehicle (ROV) operated from a small boat navigated by the Washington Department of Fish and Wildlife. In addition, we have been mapping the adjacent uplands aided by high resolution LiDAR imagery.

The traversed mounds are mostly composed of well-rounded, cobble-sized clasts that appear much like compact Olympic provenance outwash gravels and tills found just above sea level in the bluffs of Dewatto Bay and in the submarine scarp at the mouth of the bay. While most other streams that empty into Hood Canal have deltas, both Dewatto River and Little Dewatto River lack deltas, suggesting submarine collapse of their deltas and implying relative recency. The inferred headwalls of both mounds are very steep, leaving little lateral support of the shoreline, that may be subject to future subaerial or submarine failures. One such failure has been mapped on the south shore of Dewatto Bay. These features are at the west margin of the Seattle and Tacoma fault uplift and the faults in the vicinity of Price Lake, all of which have been active in the last thousand years. We suggest that these features may be seismically induced and compare them to other inferred earthquake-induced landslides in the area. An intriguing swarm of shallow earthquakes occurred surrounding the northern mound in the early 1980's, and no similar earthquakes have occurred in the vicinity since.

Predicting Groundwater Gradients Adjacent to a Dam-Controlled River

Roy Jensen, *Hart Crowser, Inc.*

Angie Goodwin, Hart Crowser, Inc.

William Abercrombie, Hart Crowser, Inc.

The relationship of the stages of the Spokane River to groundwater gradients at a site located along the river in Washington State has been studied for over a year. The purpose of the study is to identify: (1) the conditions necessary for groundwater gradient reversals to occur; and (2) if the relationship between the river's stage and groundwater levels can be used to predict historical gradient reversals. The study is based, in part, on transducer data that recorded water levels at five-minute intervals in eight wells located from 125 to 1,400 feet of the river's edge and four river gage stations.

Flow in the Spokane River is controlled, in large part, by releases from Post Falls Dam, which was built in the early 1900s and is located upstream of the study site. Flows in the river are lowest during the summer and fall and highest in the spring. River levels near the site vary seasonally between 8 to 12 feet.

Groundwater beneath the study site is in a thick, unconfined aquifer, which consists primarily of gravel and sand. The aquifer is very productive and extremely permeable. Hydraulic conductivity of the aquifer ranges from 200 to 3,000 feet/day with groundwater travel times varying from 30 to 600 feet/day based on tracer tests and groundwater flow modeling. The local water table can vary seasonally by 10 to 17 feet.

The Spokane River and the local aquifer are hydraulically connected. In general, groundwater flow at the site is toward the river in a southwesterly (~240 degrees) direction. Short-duration groundwater reversals (~90 degrees) can occur during the spring peak flows. For reversals to occur, the river stage must increase by at least one foot and at rate of 0.1 foot per hour. The gradient reversal is maintained until groundwater has time to respond to the new equilibrium. Regression analysis between river stage, groundwater elevations, groundwater gradients, and flow direction indicate that strong correlations are present. The correlations between the river stage and groundwater levels in wells have R2 values of 0.98 to 0.99.

The authors developed a regression-based model to predict the historical occurrence of gradient reversals using available river stage records from the 1940s. Gradient reversals occurred during the majority of spring seasons, but were of relatively short duration.

Estimating Groundwater Discharge and Nutrient Loading to Lynch Cove, Hood Canal, WA

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Low dissolved-oxygen concentrations in the waters of Hood Canal, WA threaten marine life in late summer and early autumn. Eutrophication in the landward reaches of the Canal (Lynch Cove) has been linked to phytoplankton growth, which is controlled by nutrients (primarily nitrogen) that enter the Canal from various sources leading to subsequent oxygen depletion. Previous work has shown that seawater entering the Canal is the largest source of nitrogen; however, groundwater discharge may also contribute significant quantities, particularly during summer months, when increased nutrient availability in the Canal directly effects eutrophication. The amount of nitrogen entering Hood Canal from groundwater was estimated using direct and indirect measurements of groundwater discharge, analysis of nutrient concentrations, and estimates of denitrification in near-shore sediment. Our research employed multiple methods to identify and quantify groundwater discharge into Hood Canal. In areas with confirmed groundwater discharge, shore-perpendicular electrical resistivity profiles, manual and automatic seepage-meter measurements, and continuous radon measurements were used to characterize temporal variations in groundwater discharge over several tidal cycles. Combined groundwater fluxes using all methods ranged from 0.1 to 65 cm/day in the study area. These data demonstrate that groundwater discharge to Hood Canal is highly variable in space and time because of the local geology, the hydraulic gradients in the groundwater system adjacent to the shoreline, and a large tidal range of 3 to 5 meters. Although nitrogen concentrations in groundwater are generally low (average 0.5 mg N/L), the flux of groundwater discharge associated N may be large in some areas of the Hood Canal coastline as confirmed in recent thermal imaging conducted in September 2008 and 2009 that showed large areas of freshwater inputs. Therefore, a more refined understanding of the nutrient loads entering Hood Canal from submarine groundwater discharge, particularly in summer, is an important component of the overall nutrient budget in this system. Finally, groundwater fluxes of freshwater into Lynch Cove from these various field methods are being used to refine circulation models of Lynch Cove to better understand the periodic low oxygen events in Hood Canal.

Hydrogeologic Controls on Aquifer - Columbia River Interactions, 300 Area IFRC Project, Hanford Site, Washington

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Field-scale experiments are ongoing at the U.S. Department of Energy IFRC (Integrated Field-Scale Subsurface Research Challenge) site to determine the mechanisms responsible for a persistent uranium plume in the unconfined aquifer beneath the 300 Area. Sources of the uranium contamination are attributed to past discharges of liquid effluent to unlined disposal facilities associated with nuclear-fuel fabrication in the area. A key component in understanding the transport of uranium is a representative hydrogeologic model of the subsurface. To this end, within the IFRC a total of 38 monitoring wells were installed over a triangular well-field area approximately 70 m on a side. The base of the up to 10-meter thick unconfined aquifer lies atop a fine-grained fluvial-overbank facies of the Neogene Ringold Formation. Most groundwater flow within the aquifer occurs through a network of subsurface paleochannels eroded into the Ringold Formation filled with coarse-grained, complexly stratified, variably permeable Ice Age flood deposits (i.e., Hanford formation). The channel-fill deposits are in direct hydraulic communication with the nearby highly fluctuating Columbia River.

Based on hundreds of meters of drill core, as well as several large backhoe pits excavated into the unsaturated portion of the Hanford formation, the gravel-dominated flood deposits are known to be extremely heterogeneous and anisotropic. Saturated hydraulic conductivities for the Hanford formation range from 4,600 to 11,000 m/day. Flood deposits consist of discontinuous lenses of open-work sandy gravel separated by intervals with reworked Ringold mud coating and sometimes filling the voids between gravel clasts. Oversized, rounded boulders of compacted Ringold mud are dispersed as detrital rip-up clasts within the flood deposits. A low-K interval within the Hanford formation, identified via EBF (electromagnetic borehole flowmeter) testing is probably associated with one or more semi-confining, mud-rich lenses.

Complex flow hydrodynamics are a result of rapidly changing, high-frequency river-stage fluctuations adjacent to a heterogeneous, anisotropic, unconfined aquifer. Significant vertical well-bore flows were found to occur in IFRC wells screened across the low-K interval, especially during periods of dynamic river-stage fluctuation. Downward and upward ambient flow within the fully screened wells can result in mixing or exchange of groundwater vertically across the aquifer, impacting the representativeness of contaminant-uranium concentrations.

Aquifer-River Interactions: Implications for the 300 Area Uranium Plume, Hanford Site, Washington

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Recent efforts to further characterize uranium contamination in the subsurface beneath the Hanford Site's 300 Area have produced new insight on the dramatic influence that the Columbia River has on the characteristics of a plume in groundwater. The principal phenomena involve 1) hydraulic interaction between the aquifer and river hydrologic systems, and 2) changes to the near-river aquifer's geochemistry. Interaction is promoted by the highly permeable fluvial sediment that contains the water table and within which most contamination is found. New information that has become available includes results from comprehensive groundwater monitoring, hyporheic zone monitoring, and research results pertaining to the mobility of uranium (IFRC Project).

The persistence of a uranium plume in groundwater beneath the 300 Area has perplexed investigators since initial characterization of the problem in the early 1990s. Conceptual and computer simulation assumptions that have proved faulty are 1) no continuing source for resupplying the groundwater plume with uranium, and 2) oversimplification of the conceptual model for exchange between dissolved and solid forms of contaminant uranium. Part of the complexity associated with the persistence of the plume involves the dynamic environment in the aquifer created by fluctuations in Columbia River flow, particularly stage changes and their impact on the elevation of the water table. Investigators are now focusing on the periodically rewetted zone, i.e., the stratigraphic interval between high and low water table conditions, as being a principal element in the conceptual model for plume persistence.

At least two fundamental hydrologic conditions are responsible for the persistence of the plume. The first involves the continued resupply to groundwater of mobile contaminant uranium from the overlying vadose zone. This appears to occur at specific, limited locations, such as proximity to known liquid waste disposal sites and possibly waste sewer systems. New uranium is added to the plume during seasonal high water table conditions; this 'new' component of the plume migrates within a seasonal cycle to the Columbia River shoreline and disperses. The second condition occurs in the periodically rewetted zone away from suspected sources and manifests itself as a relatively constant level of contamination, in spite of rapid flow of groundwater through the area. This suggests some degree of sequestering of uranium in the zone. Both of these conditions are intimately related to fluctuations in Columbia River stage and the resulting water table fluctuations.

Soil Shaking Levels and Liquefaction Susceptibilities at Walla Walla and Aberdeen School Sites

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Timothy J. Walsh, Department of Natural Resources - Geology and Earth Resources

As part of work of Washington State School Seismic Needs Pilot Project, the Washington State Department of Natural Resources, Geology and Earth Resources conducted shallow seismic surveys at K-12 school sites of Walla Walla and Aberdeen school districts to determine how the shallow soil columns at the school sites will perform during an earthquake. For each site, we estimated Vs30m (average shear-wave velocity of top 30-meter of the soil column) to quantify shaking levels using the shallow shear-wave velocity (Vs) profiles, estimated using noninvasive seismic methods (shear-wave refraction, and multi-channel analysis of surface waves (MASW)). Along with determining the shaking levels, estimating the liquefaction susceptibility at each school site will be equally important to better determine the performance of the site during an earthquake. Water table information directly influences the susceptibility of the liquefaction. The deeper water table compared to the old shallower ones can significantly reduce the liquefaction hazard. Both estimated shaking levels and liquefaction susceptibilities will be used as inputs to FEMA HAZUS-MH earthquake model software to calculate the risk at each site.

State Agencies Collaborate in Evaluating Seismic Stability of an Unpermitted Dam

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The Washington State Department of Ecology Dam Safety Office (DSO) “has powers and duties, insofar as it may be necessary to assure safety to life or property, to inspect the construction of all dams, and to require changes in construction or maintenance.” The DSO continues to find dams that were built without complying with the applicable statutes, i.e., without a DSO review and approval of the plans (if any were ever prepared) and without inspection during construction. Such dams typically have inadequate spillways, seepage issues, seismic stability concerns, and maintenance lapses. When such a dam is found the DSO conducts a downstream hazard assessment and then evaluates the likelihood of the principal modes of dam failure. The seismic assessment of one such dam was done collaboratively with Department of Natural Resources Geology and Earth Resources (DNR) expertise and equipment.

Specifically, Multi-channel Analysis of Surface Wave (MASW) field testing was performed to image the embankment, abutments, and foundation. The resulting shear wave velocities were empirically correlated first to Standard Penetration N-values (N1,60) and then into the soil properties necessary in 3D, time history, dynamic analyses. The dynamic analyses (FLAC3D) utilize a hybrid bounding surface hypo-plasticity model to predict the time history of volumetric strains and the resulting pore pressure changes in the embankment phase of the model. The model output includes the displacements the embankment is predicted to undergo subject to earthquake scenarios deemed representative of the principal sources zones contributing to the probabilistic seismic hazard at the site.

MASW data interpretation is based on a level ground mathematical formulation (waves traveling in a principal stress plane). Concerns arose about extrapolating the process to the data interpretation of lines on the face of a 26.6 slope. To gain insight into this question, a second series of MASW testing was done on another dam that had been retrofitted with an engineered buttress. Extensive construction data exists on the prepared foundation and buttress fill. MASW lines were run parallel to the long axis of this dam at the crest and mid-slope (again inclined at 26.6). A blind comparison of the MASW imaging matched well with boring data along the embankment crest and survey data for the base of the buttress beneath the geophone line. For the limited purposes of the dam analysis, the MASW data interpretation scheme was deemed acceptable for both level and inclined surface geometry up to 26.6 degrees.

The dynamic modeling, if it shows the dam to have inadequate seismic stability, will include evaluating a number of practical schemes to achieve a suitable level of reliability. The results of this effort will be written up in a formal report. If the dam is deemed inadequate and the owner refuses to undertake remedial action, that report will become part of a DSO enforcement order to address the deficiency in specified timeframe.

Mapping the Extent of a Near-Surface, Low-Velocity, Saturated Zone using Microtremor Noise Recording

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The project is located along SR16 in Tacoma, Washington on the north slope of Nalley Valley. During construction of an access road for work on the TEB and WSP lines, an area of loose, wet soil was encountered. Severe pumping of the subgrade occurred and to maintain access to the area the Contractor placed a geotextile and up to 9 feet of quarry spalls. To map the extent of the loose wet soil, the Department conducted a subsurface investigation that consisted of six geotechnical test borings in conjunction with three geophysical lines that measured shear wave velocities using the refraction microtremor (ReMi) method. This method allowed for lower seismic velocity layers to be identified under higher velocity layers and for seismic data to be collected within a noisy construction environment. Geotechnical test borings were drilled to verify the seismic results and to obtain soil densities, ground water levels, and soil samples for laboratory testing. The test borings encountered silty sands with gravel and had soil densities ranging between very loose and very dense. The geophysical lines were positioned so averaged point sources along each geophysical line would be near some of the test boring locations. This allowed comparisons to be made between the test boring data and the geophysical data. The geophysical survey detected low shear wave velocity material from the surface to depths up to 17 ft below ground surface (bgs) with a few intermingled thin layers of higher velocity material. The test borings encountered loose wet soils between 11 and 17 ft bgs. In most cases the interpretation between the seismic data and the test boring data reasonably matched one another. Based upon the subsurface investigation the Project Office decided to excavate and replace the estimated 11,800 yds3 of loose wet soil. Limited equilibrium analysis was conducted for the construction of temporary cut slopes as steep as 1.5H:1V. Few geophysical options were available because the project was in an active construction site that was located along a heavily traveled highway with considerable background noise. The ReMi geophysical method was quick and easy to deploy and required little analysis time. The test boring data was consistent with the results obtained through the ReMi geophysical method and the quantity of the excavated material (12,430 yds3) was within approximately 5 percent of the estimated quantities. In addition, the depth of the loose wet soil encountered during excavation was also within 2 ft (≈10%) of that estimated.

Chinook Salmon Redd Distribution on the Cowlitz River, WA and Associated Habitat Features

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Julie Henning, Washington Deparment of Fish and Wildlife

Christopher Murray, Pacific Northwest National Laboratory

We investigated the spawning patterns of fall and spring Chinook salmon Oncorhynchus tshawytscha on the Cowlitz River, Washington using a unique set of fine- and coarse-scale temporal and spatial data. Coarse-scale spatial data (500 m – 28 km resolution) were collected from 1991-2009, and fine-scale spatial data (100 – 500 m resolution) were collected in 2008 and 2009 from bi-weekly helicopter flights over the lower Cowlitz River. We examined spatial patterns of Chinook salmon redd reoccupation among and within years in relation to segment-scale features, some of which have an impact on groundwater/surface water interactions. Depth discontinuities, channel bifurcation, and tributary junctions are directly related to groundwater flow in the hyporheic zone. Distance upstream, sinuosity, and channel gradient are all geomorphic factors that have been known to affect spawning distributions. Continuous surveys were used to provide a detailed look at the landscape, along with data from a digital elevation model (DEM), topographic maps and aerial photos. We used regression with a general linear model (GLM) to determine the relationship between habitat features and the redd locations from 2009 on a 500-m scale. Chinook spawned in the same sections each year with little variation among and within years and their redds were clustered ($P < 0.02$). Distance upstream, channel bifurcation, and sinuosity were associated with redd density on a 500-m scale. Channel bifurcation was positively associated with the occurrence of spawning in reaches in the Cowlitz River. These multiple channels are associated with hyporheic flow on a large scale which is critical for incubating salmon. Increased intragravel flow often occurs at the upstream and downstream ends of channel bars or islands where the river is slower and shallower. Determining the pattern of fall and spring Chinook salmon spawning within the Cowlitz River and its relation to habitat features is necessary for conservation and restoration.

Development of a Conceptual Chum Salmon Emergence Model for Ives Island

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Chum salmon Oncorhynchus keta are an ESA threatened species that spawn in the Ives Island side channel of the lower Columbia River downstream from Bonneville Dam. River managers must understand where chum salmon spawn and when sac fry are present within the riverbed so dam operations can be managed to protect the species. We engaged in a long term study of this spawning area to determine whether physicochemical characteristics of the hyporheic zone affect redd site selection and incubation timing of developing embryos, and how river management impacts these variables. During 2000-2001 we found that chum salmon spawned where the vertical hydraulic gradient (VHG) was positive and hyporheic water was significantly warmer than overlying river water, reducing the incubation time of chum salmon. This was confirmed during 2001-2004, when temperature and water surface elevation were monitored hourly. We also learned that hyporheic temperature and VHG were highly variable when large, frequent changes in river discharge occurred, potentially influencing chum salmon spawning site selection and emergence timing. An automated data collection system was developed to collect hourly real-time temperature and water surface elevations from paired river and hyporheic sensors at three locations within chum spawning habitat. The system, operational from 2003-present, uses piezometers installed in the hyporheic zone and the river. Temperature sensors and unvented pressure transducers were connected to a telemetry system located above the high water mark via approximately 700 feet of buried cable. From 2003-2010, data from the system were provided to management agencies and used to improve estimates of chum salmon emergence timing. During 2010, data collected from the real-time system were used to develop a conceptual model to predict the timing of chum salmon emergence. The model uses bed and river temperatures from the real time system to predict the cumulative percent distribution of chum salmon emergence during the incubation period, and then continually updates these predictions as temperature data are collected. Development of the chum emergence model required integration of temperature data from the real time system with historical temperature data from 2006-2007, when a large number of sensors were in place during the entire incubation period. A case study will be presented showing the application of the chum emergence model to redd locations from the 2009-2010 spawning season.

Poster Abstracts

Navigability Potential of Washington Rivers and Streams Determined with Hydraulic Geometry and GIS

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Using discharge and channel geometry measurements from U.S. Geological Survey streamflow-gaging stations and data from a geographic information system (GIS), regression relations were derived to predict river depth, top width, and bottom width as a function of mean annual discharge for rivers in the State of Washington. A new technique also was proposed to determine bottom width in channels, a parameter that has received relatively little attention in the geomorphology literature. These regression equations, when combined with estimates of mean annual discharge available in the National Hydrography Dataset, enabled the prediction of hydraulic geometry for any stream or river in the State of Washington. Predictions of hydraulic geometry were then compared to thresholds established by the Washington State Department of Natural Resources to determine navigability potential of these rivers within a GIS framework. The concept of navigability in rivers and streams in the State of Washington is the determinant factor in legal ownership of the watercourse, but, to date, the legal system has employed few quantitative techniques to aid in this determination.

Prediction of Sediment Yield from Swift Creek Landslide using the Distributed-Hydrology-Vegetation-Model

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Prediction of sediment yield from Swift Creek Landslide using the Distributed-Hydrology-Vegetation-Model.

Swift Creek discharges a large active landslide in a basin that is about 6.5 km2 with nearly 1000 meters of relief near the city of Everson in Whatcom County, WA. The slide yields large quantities of asbestos laden sediment that flows down Swift Creek, filling channels that frequently have to be dredged to prevent flooding and road damage. Swift creek also discharges into the Sumas River, which flows north in British Columbia, Canada. Recent studies performed by the US EPA show that the asbestos fibers found in the deposits pose health risks to those who live and work on or near the material. Because of the potential health risks of the asbestos, Whatcom County is facing complex challenges in mitigating the spoils near the base of the basin, and addressing the Sumas River transboundary issue. Monitoring Swift Creek has been difficult in the past due to the flashy nature of the stream and sporadic mass wasting. As a result, historic data regarding the watershed and the landslide are sparse in quantity and temporal consistency. To provide an aid for management decisions, we applied the distributed-hydrology-soil-vegetation model (DHSVM) and its accompanying sediment module to the basin to evaluate the impact of hydrology and mass wasting on sediment discharge in the creek.

Monitoring methods used in this study include turbidity threshold sampling, physical water samples, periodic discharge measurements and stage data; each with varying degrees of success. These data are being used with meteorological data from a nearby weather station to calibrate the DHSVM hydrology and sediment model. Because of limitations in the quality of the measured discharge data, calibration has been challenging. Preliminary results indicate an inconsistent relationship between the measured turbidity and modeled streamflow. Assuming measured turbidity values are accurate, these varying results indicate that mass wasting and erosion are not always synchronous with precipitation events, and may include random failures on the slide toe or snow melt events. We are currently performing simulations with the sediment module and correlating them with real time photographs of the slide toe to further investigate these possibilities.

A Combined Model for Estimating Soil Water Evapotranspiration

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Potential evapotranspiration (PET) and actual evapotranspiration (AET) are difficult to measure directly and to do so requires expensive instrumentation and methodology. An empirical model incorporating stable isotope mass balance, a version of the Penman-Monteith model and a reduction of PET to AET, was developed to estimate AET for a soil water flux study along a climate gradient on the eastern slope of the Cascades in Washington State. Model inputs included meteorological data, soil moisture and oxygen isotope data obtained from four different locations representing distinctly different hydrologic regimes along the climate gradient. Modeling indicated a direct correlation between site soil moisture contents and evaporation rates suggesting that soil moisture content is the major control on evaporation rate except during times of frozen upper soil zone and/or snow cover. Downward percolation was the greatest overall form of soil water loss as indicated by the combined model. The assumption that plants in drier windier areas transpire more efficiently was supported by modeled transpiration. Seasonal soil moisture flux trends portrayed by the combined model were similar to those portrayed by a simple isotope mass balance model in previous study by Robertson and Gazis (2006). Advantages of the combined model over using a simple isotope mass balance alone include the partitioning of non-fractionating soil moisture losses into transpiration and downward percolation and estimation of actual evapotranspiration. Despite some uncertainty in the modeled actual evaporation, transpiration, and downward percolation rate values, site-specific seasonal trends in each of the fore mentioned parameters could be portrayed with confidence. Understanding the relationship between recharge water isotope ratios and soil water isotope ratios with respect to soil water flux trends, as indicated by the combined model, has implications for paleoaltitude reconstruction studies.

Detection of Historical Pipeline Leak Plumes using Non-Intrusive, Surface-Based Geophysical Techniques at the Hanford Nuclear Site, Washington, USA

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Hanford site historical records indicate that ruptures in buried waste transfer pipelines were common between the 1940s and 1980s, which resulted in unplanned releases (UPR) of fluid at numerous locations. Current methods used to detect leaks have included visual observation of fluid on the ground surface, discrepancies in mass balance between and input and output locations, and encountering subsurface waste material in close proximity to a pipeline through excavation or drilling. Since these detection methods are so limited in resolution and effectiveness, it is likely that a significant number of pipeline leaks have not been detected. Therefore, a technology was needed to detect the specific location of unknown pipeline leaks so that characterization technologies can be used to identify any risks to groundwater caused by waste in the vadose zone.

A proof-of-concept electromagnetic geophysical survey was conducted at an UPR in order to image a historical leak from a waste transfer pipeline. The proof-of-concept survey was to assess if an innovative suite of electromagnetic techniques could be used to map elevated soil conductivity caused by these past releases in the presence of an even more electrically conductive metallic pipe. Extensive surface based geophysical characterization has been completed at several tank farms and waste sites within the Hanford 200 West and East Areas as part of the “Surface Geophysical Exploration” (SGE) program for Washington River Protection Solutions, LLC (WRPS). Experience on these projects demonstrates that geophysical technologies have the capability to provide an efficient and cost effective tool for leak detection.

Uranium and Other Chemical Contaminants Entering the Columbia River from the South Columbia Basin Irrigation Outfalls

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Mike Priddy, DOH

The Washington State Departments of Ecology and Health jointly investigated the nature and extent of uranium contamination in the irrigation outfalls to the Columbia River. An outfall is where unused irrigation water returns to the river. Six locations on the lower Columbia River were sampled, and the samples were analyzed for uranium and other chemical contaminants. This paper documents the results.

Uranium was found at elevated levels in all of the outfall samples. The highest concentration of uranium was found in the Ringold 1 site, which on further investigation turned out to be an outfall from a State-operated fish hatchery. The concentrations at this site are roughly one-third the United States Environmental Protection Agency drinking water standard. Nitrate was the only non-radiological contaminant detected.

Analysis of river water after each outfall does not indicate a significant increase in the uranium levels in the river from irrigation water.

This study estimates the total mass of uranium (the "total uranium" values were used for the calculation) entering the river from Franklin County along the Hanford boundary to be 1,765 kilograms. That is an order of magnitude greater than the Hanford estimated annual uranium discharge to the Columbia River from the 300-FF-5 Operable Unit in the 300 Area, which was150 kilograms for 2005. These values do not include the contribution from the fish hatchery, which would add significantly to the total. The ratio of isotopes of uranium found indicates it is of natural origin, and not the result of human activity.

Using NO3-N and NO3-O Isotope Ratios to Identify Nitrogen Sources and Cycling in the Palouse Basin

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Agricultural systems are a leading source of reactive nitrogen to aquatic and atmospheric ecosystem. Understanding how anthropogenic nitrogen sources are cycled during transport from agricultural systems to aquatic and atmospheric systems is essential to identify the sink(s) of missing nitrogen and improve nitrogen management. Here we use natural 15N and 18O isotope abundances of nitrate to determine the timing of nitrogen cycling process and to identify the source of nitrate discharged to Missouri Flat Creek from a 12 hectare tile drained section of the Washington State University Cook Agronomy Farm. The tile drained section of Cook Agronomy Farm is a typical tile drain system in the Palouse Region of Eastern Washington State where low lying sections of land are artificially drained to allow for agricultural use. Tile drains act as short cuts for agricultural runoff to leave the soil profile and flow into local streams. Previous research at the Cook Farm has shown that 5% to 20% of fertilizer nitrogen leaves the system as nitrate through the tile-drain (TD), assuming all nitrate in TD discharge is originating from synthetic fertilizer. Identifying the timing of nitrogen cycling events and identifying the source(s) of TD nitrate is the first step to reduce nitrogen loss to aquatic systems bordering agricultural land. Throughout the 5 year study period 18Onitrate ranged from -6.72‰ to 4.56‰ and averaged -1.26±1.48‰, indicating that nitrate-oxygen isotopes were not being enriched. Tile drain nitrate 15N varied seasonally from -0.48‰ in the winter to +9.24‰ during the summer with an average of +3.19±2.62‰. The lack of enrichment in nitrate-oxygen during the study period indicates that nitrification is the dominant nitrogen cycling process in the tile drained soil; denitrification would have resulted in enrichment of 18Onitrate similar to that of 15N. The expected 18Onitrate from nitrification based on the nitrification equation is -2.0‰, also supporting the claim that nitrification is the dominant nitrogen cycling process in the soil drained by the tile drain system. The large range of nitrate 15N overlaps the expected isotope values for nitrate from nitrified synthetic nitrogen fertilizers and soil organic nitrogen. Nitrate-nitrogen and nitrate-oxygen isotope abundances have shown that nitrate in high nitrate concentration TD discharge originates from nitrification of reduced nitrogen fertilizers and nitrate in low nitrate concentration TD discharge originates from nitrification of; 1) soil organic nitrogen, 2) biotically enriched reduced nitrogen fertilizers or 3) a combination of the two. These findings also suggest that missing nitrogen from the Cook Agronomy Farm could be lost as gaseous emission of NO and N2O during nitrification.

Nitrate Contamination in the Sumas-Blaine Surficial Aquifer

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Numerous groundwater studies by federal, state, and university groups conducted over the last four decades indicate elevated nitrate concentrations occur throughout much of the Sumas-Blaine surficial aquifer. The aquifer covers about 150 square miles in the northwest corner of Washington State, and is the only available drinking water source for roughly 15,000 rural residents of northern Whatcom County. A recent 2003-2005 sampling of 35 private domestic wells within agricultural areas of the aquifer showed that nitrate+nitrite-N concentrations exceeded the drinking water standard of 10 mg/L in over 70% of the sampled wells. In addition, concentrations appear to be increasing in almost a third of these wells.

There are multiple potential sources of nitrogen contamination locally including dairy farms, irrigated agriculture, and on-site sewage systems. The shallow depth to groundwater (less than 10 feet in most areas) and intensive overlying agricultural land uses make the aquifer extremely vulnerable to contamination. The aquifer is also relatively thin (25-50 feet thick) which provides limited opportunities for deeper drilling to avoid contamination.

Resolution of this long-standing problem is complicated by the fragmentation of state and local groundwater protection authorities, and will require the focused cooperation of numerous agencies and the local community to develop a holistic management approach to restore and protect groundwater quality.

Nitrate and What Else in Washington State's Ground Water

Laurie Morgan, *Washington Dept. of Ecology Water Quality Program*

Nitrate contamination of Washington State ground water isn't new, but has gained visibility in the last few years. Most recently, the Lower Yakima Valley nitrate contamination of ground water has garnered widespread attention and spurred the US EPA to take action under the Safe Drinking Water Act. In the Spring of 2010, the US EPA sampled 337 individual domestic wells (about 1% of the groundwater users in the valley) for nitrate. Of these, 21% exceeded 10 mg/L, the Maximum Contaminant Limit used in drinking water standards. In response, Yakima County is forming a Ground Water Management Area and is distributing treatment systems for the most impacted households.

Other largely agricultural areas in the State of Washington also have documented nitrate contamination of ground water.

The Columbia Basin Ground Water Management Area was formed in 1998 to address nitrate contamination and includes Adams, Franklin and Grant County, later adding Lincoln County. The sampling of 574 wells that followed found nitrate concentrations exceeding drinking water health standards (10 mg/L) in almost 1 out of every 4 sampled wells.

In response, the Columbia Basin Ground Water Management Area has been improving irrigation practices so that less nitrate is leached through to ground water and conducting nitrate soil tests to encourage less nitrate loading from fertilizer.

In Whatcom County, an International Task Force was formed in 1992 to coordinate efforts on nitrate contamination of ground water that has occurred both in the U.S. Sumas-Blaine Aquifer and in the Canadian Abbotsford Aquifer. Several studies have found widespread nitrates above 10 mg/L . For example, in one study, 27 out of 53 wells sampled above 10 mg/L (Erikson, 2000).

Nitrates in ground water above the health limit of 10 mg/L is widespread in various areas of Washington State. Sampling and statistical analysis help determine where elevated nitrates have been found.

Universities, county health departments, state agencies, the US EPA, USGS, public water supply purveyors, consultants and households all have sampled for nitrates in ground water. The most accessible data sets that can be brought together to fill in the statewide nitrate picture are from the USGS, Washington Dept. of Health Public Water Supply and Washington State Dept. of Ecology.

The USGS has used Logistic Regression statistical modeling based on public water supply well data to estimate the probability of elevated nitrate in ground water due to human activities in the Puget Sound region, the Columbia Basin and ultimately the entire state.

Nitrates can often be an indicator for other contaminants in ground water. If the source is fertilizer or manure, pesticides or antibiotics from animal manure could be present. If the source is from septic tanks, medicines and household products disposed down the drain could be present.

Determining the cause of nitrates in groundwater at a specific location at a specific point in time is difficult, but there are sampling techniques and observational methods that help.

Coping with nitrate in drinking water above the health limit is difficult and costly. There are regulatory and voluntary control options at several levels of government in various programs. It's challenging to coordinate these into a cohesive plan. Controlling overloading from nitrate sources is especially important.

Groundwater-Surface Water Interactions within the Surficial Aquifers of the Chehalis River Basin, WA

***Andrew Gendaszek**, U.S. Geological Survey*

The Chehalis River and its tributaries flow over widely distributed surficial aquifers, which consist of Pleistocene glaciofluvial deposits and modern alluvium. This complexity creates the potential for significant exchanges of groundwater and surface water. Previously mapped geologic units were grouped into hydrogeologic units to construct hydrogeologic cross-sections to show the vertical and horizontal extents of the surficial aquifers within the Chehalis River Basin. Generalized groundwater flow paths and vertical gradients during late summer were determined from groundwater levels measured in over 250 wells within the surficial aquifers in August and September, 2009. Thirteen additional wells near the Chehalis River were monitored throughout the 2010 water year; six of these wells were monitored at monthly intervals and the other seven wells were instrumented with pressure transducers recording at 15-minute intervals. These data together with river stage measurements recorded at U.S. Geological Survey gaging stations show the temporal and spatial characteristics of the connection of the Chehalis River to the shallow aquifers over which it flows. During August, 2010, near-simultaneous streamflow measurements (a seepage run) were made at 41 locations along the Chehalis River and its tributaries. The seepage run data reveal alternating gains and losses along the mainsteam Chehalis; the largest surface water gains, however, both in total and as a percentage of streamflow were measured in the Black River. A 1000-m section of Fiber Optic Distributed Temperature Sensor (FO-DTS) was deployed coincident with the August 2010 seepage run in the vicinity of the USGS Grand Mound streamflow gage on the Chehalis River. No discrete temperature anomalies were recorded by the FO-DTS survey suggesting that, in this reach, groundwater inputs are relatively diffuse agreeing with the seepage run data representing a larger spatial scale.

Hydrogeologic Framework of the Chamokane Creek Basin, Stevens County, Washington

Sue Kahle, *U.S. Geological Survey Washington Water Science Center*

Matt Ely, U.S. Geological Survey Washington Water Science Center

Chamokane Creek basin is a 179 mi2 area that borders and partially overlaps the Spokane Indian Reservation in southern Stevens County in northeastern Washington State. Primary aquifers within the basin are part of a sequence of glaciofluvial and glaciolacustrine fill within an ancient paleochannel eroded into Miocene basalt and Cretaceous to Eocene granite. Chamokane Creek has a mean annual discharge of 62.5 cubic feet per second (ft3/s) and is tributary to the Spokane River.

In 1979, all water rights in the Chamokane Creek basin were adjudicated by the United States District Court requiring regulation in favor of the Spokane Tribe of Indian's senior water right. A court-appointed Water Master regulates junior water rights when the mean daily 7-day low flow falls below 24 ft3/s in Chamokane Creek; regulation has been necessary in two of the past 8 years (2001 and 2008). Additionally, the basin is closed to further groundwater or surface-water appropriation, with the exception of permit-exempt uses of groundwater.

The Spokane Tribe and the State of Washington are concerned about the effects of future groundwater development within the basin and the potential effects of this growth on Chamokane Creek. In order to evaluate these concerns, the U.S. Geological Survey (USGS) is conducting a study with the primary goals of describing the groundwater and surface-water system of the valley-fill deposits of the basin and assessing the effects of potential increases in groundwater withdrawals on groundwater and surface-water resources.

An analysis of the hydrogeologic framework within the Chamokane Creek basin has been done using well logs, geologic mapping, and field observations. Water levels in wells, stream-discharge measurements, and meteorological data have been collected in order to characterize the movement of water over time. Current and historic satellite data from the USGS Earth Resources Observation and Science Center were used to conduct a land-use/land-cover change analysis of the basin. The USGS coupled groundwater and surface-water flow model (GSFLOW) is being used to investigate the aquifer-creek interactions and simulate the effects of potential groundwater withdrawals and climate scenarios on Chamokane Creek.

Water Budget of Steilacoom Lake

Cameron Jasper, *Geology Dept, University Puget Sound*

Barry Goldstein, Geology Dept, University Puget Sound

Burt Clothier, Robinson Noble Inc.

This study will provide a water budget of Steilacoom Lake, which is located 5 miles south of Tacoma, Washington, during the period from late September 2010 to mid April 2011. The prime objective of this study is to determine the seepage from Gravelly Lake into Steilacoom Lake. Gravelly Lake is a kettle lake with no surface water outflow. Therefore, discharge from the lake is through aquifer “A-1” (as defined by Savoca et al, 2010). This aquifer is composed of well-sorted gravels and sands of the Vashon recessional outwash deposits, locally less than 75 feet in thickness. Groundwater recharge to Gravelly Lake comes, in part, from the deepest aquifer “A-3” which is confined above by Vashon till. The till underlies Steilacoom Lake, so calculating the groundwater inputs to Steilacoom Lake from Gravelly Lake will give us insights into groundwater flows between the two aquifer systems. To calculate the groundwater flow into Steilacoom Lake, the sum of all hydrologic inputs and outputs for Steilacoom Lake is required. The water budget for Steilacoom Lake can be expressed as: (Clover Creek inflow) + (Ponce de Leon Creek inflow) + (east and west groundwater inflow) + (unknown Gravelly Lake groundwater inflow) = (Steilacoom Lake evaporative loss) + (Chambers Creek outflow) + (ΔStorage Steilacoom Lake). Using a standard Price AA flow meter, weekly discharge measurements of Clover Creek, Ponce de Leon Creek and Chambers Creek will be collected to provide the two surface inputs and the one surface output term of the water budget. Precipitation and evaporation data will be provided collected from local NOAA sources. Groundwater data from Savoca et al (2010), supplemented by our own measurements from Lakewood Water District Well “V” (located one mile southwest of Steilacoom Lake) will allow an estimate of the east and west groundwater input into the lake. Hydrographs will be created for each lake and our analysis will compare the calculated changes in storage for each lake with the measured inflow and outflows. We expect that the change in storage in Gravelly Lake can be quantified as groundwater flow through the “A-1” aquifer, and thus give us an estimate of the subsurface water movement from Gravely Lake into Steilacoom Lake.

Using MODFLOW to Predict Impacts of Groundwater Pumpage to Instream Flow: Upper Kittitas County, WA

Zoe Futornick, *Central Washington University*

Carey Gazis, Central Washington University

Surface waters in the Yakima River Basin in central Washington are considered over allocated. Since 1960, new water demands have been met through groundwater withdrawals, with most groundwater users holding a later priority date than senior and junior surface water users. As a result, in 2007, the Washington State Department of Ecology (WaDOE) was petitioned to unconditionally withdraw future groundwater appropriations until more is known about potential effects from groundwater withdrawals on instream flow. WaDOE instead presented a Memorandum of Agreement to Kittitas County (upper Yakima River Basin), which included stipulations for a groundwater study in the county. As of October 2010, an emergency rule is in effect that establishes a withdrawal from appropriation of all unappropriated groundwater in Upper Kittitas County (Washington Administrative Code 173-539A-010).

The United States Geological Survey (USGS) has already extensively studied and modeled groundwater availability in the Yakima River Basin for the period October 1959 through September 2001, but the Upper Kittitas County region is not well represented in this model because bedrock units in that part of the basin are not delineated. This study constitutes a Master of Science thesis, which was done in collaboration with the USGS, and takes advantage of data from the USGS Yakima River Basin study. This study uses the finite difference model, MODFLOW, to investigate groundwater – surface water interactions in Upper Kittitas County in order to understand how present and potential groundwater withdrawals impact instream flow. Based on the current USGS Yakima River Basin model, an Upper Kittitas County scale model was extrapolated into a 246 column by 195 row grid, with 1,000 foot grid cells, and five layers representing three basin fill units, basalt, and bedrock. The model is populated with information including hydrogeologic unit characteristics, groundwater levels, groundwater use, and groundwater recharge for the period October 1959 through September 2001. The model will be updated with similar data through September 2010. Bedrock characteristics will also be enhanced.

Once calibrated, the model will be used to assess impacts of exempt well pumpage on instream flow by running scenarios in which exempt well pumpage is turned on or off. In addition to quantifying the overall impact of pumpage on stream discharge, the model can be used to examine how these impacts vary spatially (e.g. on gaining versus losing reaches) and with time. If this model is realistic in its predictions, it will be made available as a water management tool, and may be adapted in other similar settings.

Groundwater Flow Model of Bainbridge Island, Kitsap County, Washington

Lonna Frans, *U.S. Geological Survey*

Matthew Bachmann, U.S. Geological Survey

Groundwater is the sole source of drinking water for the population of Bainbridge Island. Increased use of groundwater supplies on Bainbridge Island as the population has grown over time has created concern about the quantity of water available and whether saltwater intrusion will occur as groundwater usage increases. A groundwater-flow model was developed to aid in the understanding of the groundwater system and the effects of groundwater development alternatives on the water resources of Bainbridge Island.

Bainbridge Island is underlain by unconsolidated deposits of glacial and non-glacial origin. The surficial geologic units and the deposits at depth were differentiated into aquifers and confining units on the basis of areal extent and general water-bearing characteristics. Eleven principal hydrogeologic units are recognized in the study area and form the basis of the groundwater-flow model.

A transient variable-density groundwater-flow model of Bainbridge Island and the surrounding area was developed to simulate current groundwater conditions. The model was calibrated to water levels measured during 2007 and 2008 using parameter estimation (PEST) to minimize the weighted differences or residuals between simulated and measured hydraulic head.

The calibrated model was used to make some general observations of the groundwater system in 2008. Total flow through the groundwater system was approximately 31,000 acre-ft/yr. The principal form of groundwater recharge was from precipitation and septic-system returns. Groundwater flow to the Island accounted for approximately 1,000 acre-ft/yr or slightly more than 5 percent of the recharge amounts. Groundwater discharge was predominately to streams, lakes, springs, and seepage faces (16,000 acre-ft/yr) and directly to marine waters (10,000 acre-ft/yr). Total groundwater withdrawals in 2008 were about 6.5 percent of the total flow.

The calibrated model was used to simulate predevelopment conditions, during which no groundwater pumping or secondary recharge occurred and currently developed land was covered by conifer forests. Simulated water levels in the uppermost aquifer were generally slightly higher at the end of 2008 than under predevelopment conditions, likely due to increased recharge from septic-returns and reduced evapotranspiration losses due to conversion of land cover from forests to current conditions. Simulated changes in water levels for the extensively used Sea-level aquifer were variable, although areas with declines between zero and 10 feet were common and can generally be traced to withdrawals from public-supply drinking wells. Simulated water-level declines in the deep (Fletcher Bay) aquifer between predevelopment and 2008 conditions ranged from about ten feet in the northeast to about 25 feet on the western edge of the Island. These declines are related to groundwater withdrawals for public-supply purposes.

The calibrated model was used to also simulate the possible effects of increased groundwater pumping and changes to recharge due to changes in land-use and climactic conditions between 2008 and 2035 under minimal, expected, and maximum impact conditions. Drawdowns generally were small for most of the Island (less than ten feet) for the minimal and expected impact scenarios, and were larger for the maximum impact scenario. No saltwater intrusion was evident in any scenario by the year 2035. The direction of flow in the deep Fletcher Bay aquifer was simulated to reverse direction from its predevelopment west to east direction to an east to west direction under the maximum impact scenario.

Collection of New Geothermal and Hydrothermal Data for Washington State

Jessica Czajkowski, *Wash. State Dept. of Natural Resources Division of Geology and Earth Resources*

Jeff Bowman, Wash. State Dept. of Natural Resources Division of Geology and Earth Resources

David Norman, Wash. State Dept. of Natural Resources Division of Geology and Earth Resources

The Department of Energy has recently initiated the construction of a national geothermal database by the nation's state geological surveys. The Washington State Department of Natural Resources Division of Geology and Earth Resources (DGER) is responsible for development of Washington's geothermal database. The aim of the project is to facilitate more development of both high and low temperature geothermal energy.

Exploration and development for geothermal energy relies heavily upon a wide variety of data types, which include data from geotechnical subsurface catalogs, thermal wells, monitoring wells, temperature gradient wells, oil and gas well records, thermal springs, and water chemistry. Other data include geophysical and geologic maps, whole rock chemistry, seismicity, active faults, age dates, and crustal stress data. Derivative products from this data include aquifer temperature maps and low-temperature geothermal potential maps. Within three years, Washington's relevant data will be gathered and made available to the public via the National Geothermal Database and the DGER Washington State Geological Information Portal site http://www.dnr.wa.gov/ResearchScience/Topics/GeosciencesData/Pages/geology_portal.aspx .

Current projects of the DGER team as part of this grant include gathering of water well temperature data, inventory and extraction of data from oil and gas well records, updating active fault data, and accurate location of earthquake hypocenters statewide. One of our aims is to gather new sources of hydrogeologic data for use in our current and future projects, as well as gather expertise in ways to best serve those who will likely use this data in the future.

Geochemical Constraints on Groundwater Recharge in the Royal Slope Area, Grant County, Washington

***Zoe Weis**, Central Washington University*

Carey Gazis, Central Washington University

Dimitri Vlassopoulos, Anchor QEA

Groundwater levels in Columbia River Plateau aquifers have been declining over the past 25 years (Snyder and Haynes, 2010). Stratigraphic and structural features of the Columbia River Basalt Group (CRBG) do not allow for rapid groundwater recharge, and groundwater mining is a pressing concern for those who rely on this resource. The Columbia River Ground Water Management Area (GWMA) investigates all groundwater issues in the counties of Lincoln, Grant, Adams, and Franklin. Groundwater is the predominant source of water for this area, and it is primarily used for municipal and agricultural purposes (Stoker, 2009). Groundwater geochemistry is a record of its source, residence time, water-rock interactions, and groundwater mixing. Geochemistry can be a powerful tool for delineation of the groundwater's age, recharge source, flow path, and intra aquifer mixing (e.g., Vlassopoulos et al. 2009). This information is essential for development of a conceptual groundwater model.

The Royal Slope area lies between the Frenchmen Hills and Saddle Mountains, two east-west trending anticlines that act as barriers to groundwater flow. The study area extends from the Columbia River east to Othello, WA and is primarily agricultural land that draws on both surface water (delivered via canals) and groundwater to irrigate. The area is of interest because there is evidence that groundwater collected from some wells in the area contains a significant percentage of modern water (Vlassopoulos et al., 2009) and thus the associated aquifers may be recharged to some degree by the canals and the Columbia River.

The CRBG aquifers are a series of planar-tabular (or strataform) vertically stacked, highly compartmentalized, water-bearing units within the interflow zones between individual basalt lava flows. CRBG geology (including stratigraphic and structural features) fundamentally control groundwater flow and recharge. Many wells in the Royal Slope area draw on aquifers within the Wanapum Basalt unit. The Wanapum unit is bounded on the top and bottom, respectively, by the Saddle Mountain and Grande Ronde Basalt units, which limit vertical groundwater movement into and out of the Wanapum. The Wanapum Basalt aquifer system is open to recharge in the areas where the Wanapum unit is close to the surface or where folding, faulting and erosion have exposed it.

In this study, several different types of geochemical analyses (major ion, trace element, stable isotope, CFC concentrations) were performed on groundwater from 20 wells in the Royal Slope area to investigate aquifer recharge in this region. These samples were collected by GWMA in summer, 2010 as part of a larger comprehensive study of the GWMA region. Preliminary results of these analyses will be presented. A variety of methods, including multivariable statistics and transport and mixing models, will be used to constrain the source, recharge rates and degree of mixing of groundwater in the Royal Slope area and thus determine the extent to which Columbia River water is recharging the aquifers in this region.

Geohydrology of the City of Blaine Ground Water Management Area, Whatcom County, Washington

Charles Lindsay, *Associated Earth Sciences, Inc.*

Bridget August, Associated Earth Sciences, Inc.

The City of Blaine (City) Ground Water Management Area (GWMA) encompasses roughly 30 square miles in the northwest portion of Whatcom County and was officially designated by the Washington State Department of Ecology (Ecology) on April 25, 1989. The City currently provides municipal water to a total population base of approximately 13,500 from 13 production wells located within the GWMA. The production wells are up to approximately 800 feet deep and are completed within three separate aquifer units (Perched, Intermediate and Deep Aquifers). The recharge areas for the Perched and Intermediate Aquifers appear to include the northwest portion of Whatcom County. However, the recharge area for the Deep Aquifer appears to extent a significant distance into southern British Columbia. Each aquifer has a unique ground water flow direction and chemistry, and a variable degree of continuity with surface water. The Deep Aquifer exhibits flowing artesian conditions in many areas and Carbon 14 age-dating of soil samples obtained from deep well indicates that the aquifer likely includes Olympia-Age and older sediments. The development and protection of the aquifers for municipal water supply purposes has presented challenges due to their variability in depths, water quality, recharge areas and continuity with surface water.

Groundwater Testing in an Unconfined Aquifer in Support of Water Rights Mitigation in North Bend

Jay Pietraszek, *Golder Associates Inc.*

Michael Klisch, Golder Associates Inc.

Nicole DeNovio, Golder Associates Inc.

The City of North Bend (City) was recently granted a new groundwater right by the WA State Department of Ecology. In order to meet water system demand projections over the next 50 years, the City installed a high-capacity production well in the shallow unconfined aquifer that underlies the North Bend valley. Groundwater withdrawn by the new well is in direct hydraulic continuity with the Snoqualmie River, and new appropriations in the Snoqualmie River basin are subject to instream flow restrictions. The City's mitigation for the new appropriations involves multiple sources of river flow augmentation, including trans-basin diversions. Flow augmentation is required when stream depletion occurs during periods when instream flows are not met at any of three control points on the Snoqualmie River. Aquifer parameters including transmissivity and storativity are critical inputs to determine the stream depletion resulting from groundwater withdrawals. In the Fall of 2010 the City performed a aquifer test on the production well. The purpose of the aquifer test was to quantify aquifer parameters in order to validate and refine the stream depletion predictions and the mitigation algorithm. Because the production well is plumbed into the City's water system, pumped groundwater was routed through the water system and discharged at hydrants more than a mile down gradient of the production well. Groundwater levels were monitored at multiple points near the pumping well and river levels were monitored in both the South Fork and Middle Fork of the Snoqualmie River. This poster provides an overview of the City's mitigation design and presents the results of the recent aquifer testing.

Logistical Considerations for Installing and Testing Large Diameter, High Flow Rate Wells

Stan Thompson, *Associated Earth Sciences, Inc.*

The Chief Joseph Hatchery project required a series of ground water production wells to deliver as much as 50 cubic feet per second (cfs) of process water for a new fish hatchery to be located immediately downstream of Chief Joseph Dam on the Columbia River. This phase of the project involved drilling, installing and testing five, 20-inch diameter, steel-cased water supply wells advanced to maximum depths of 200 feet, using cable tool drilling methods. The subsurface materials are interpreted to be Missoula flood deposits, and included sand, gravel, cobbles and numerous basaltic and granitic boulders in a silt matrix (upper flood deposits) over open-work (low silt and clay content) gravel with cobbles and sand (lower flood deposits). The wells were completed with between 30 and 40 feet of 18-inch diameter wire-wrapped stainless steel screens. Stepped- and constant-rate aquifer testing involved pumping at maximum flow rates of 4,000 to 5,600 gallons per minute, using a line-shaft turbine pump. Water was discharged into Rufus Woods Lake through as much as 2,000 feet of piping. Some difficulties included drilling through boulder fields, which was extremely hard on the drilling equipment and very slow; long runs of discharge piping, often with leaks at fittings; datalogger reading fluctuations, up to 7 feet at higher pump rates; and monitoring multiple activities, at times including two drill rigs and a well development rig, across a large site.

Hydrogeology and Seawater Intrusion Characterization of Guemes Island, Washington

Devin O'Reilly, *Geology Department, Western Washington University*

Robert Mitchell, Geology Department, Western Washington University

Guemes Island is a 21 square kilometer island north of Anacortes in Skagit County, Washington. A rural community of over 500 lives year-round on the island, which has a seasonal population in excess of 2200. Guemes Island is dominated by a gently rolling topography underlain by successive glacial deposits, with Guemes Mountain in the southeast compromising the only bedrock exposure. Our study focuses on the central, more sparsely populated southwest core of Guemes Island where two aquifers provide the majority of groundwater for island residents; the Vashon advance outwash is situated above sea level and the Double Bluff Drift, a productive heterogeneous unit, is typically encountered below sea level. Recharge potential to the aquifers is limited by both a low annual precipitation and the presence of Vashon till, a relatively impermeable dominant surficial material. Indications of seawater intrusion have been encountered in several low-lying, nearshore neighborhoods where the majority of island residents live. In 1997, the US EPA designated the Guemes Island aquifer system as a Sole Source Aquifer. Our goal is to characterize the hydrostratigraphy and develop a groundwater flow and seawater intrusion model for the study area to assist Skagit County's water resource management. To characterize the hydrostratigraphy, we examined 35 well logs to identify sub-units within the generalized stratigraphy developed as part of a USGS study (Kahle and Olsen, 1995). About 15 of these wells were selected for seasonal static-water level measurements, water chemistry analysis, and precise GPS-derived elevations and positions. The well log data are being used to construct a conceptual model using Aquaveo's Groundwater Modeling System (GMS). Preliminary results indicate a heterogeneous stratigraphy that is being refined for modeling purposes. Our conceptual model will be used along with static-water levels measurements and derived hydraulic conductivity and recharge estimates to calibrate a GMS-constructed MODFLOW groundwater flow model. Ultimately, our flow model will be coupled with the USGS program SEAWAT and water chemistry data to assess groundwater flow and seawater intrusion on the island both currently and under potential future development scenarios.

Groundwater Response to Increased Tidal Flux after Installation of Self-Regulating Tidegates

Karen Rittenhouse Mitchell, *Swinomish Indian Tribal Community*

Todd Mitchell, Swinomish Indian Tribal Community

Tidegates regulate the flow of water between fresh- and saltwater bodies, generally to preserve upland land uses including agriculture. Conventional tidegates permit freshwater drainage and discharge to an adjacent saltwater body only at low tide, preventing saltwater from inundating upland areas. Self-regulating tidegates (SRTs) permit a portion of the tidal prism to pass landward through the dikes, restoring fish passage and estuarine function while protecting the uplands from full tidal inundation. The installation of SRTs has been controversial due to concerns that increased tidal flux may raise water tables behind the dikes, increase saltwater influence, and negatively impact land use.

In 2003, the Swinomish Tribe and Skagit River System Cooperative initiated a study of the impacts of SRTs on adjacent agricultural lands at a site on the Swinomish Reservation near LaConner, Washington. Sixteen monitoring wells were installed at eight stations along relict slough channels and artificially maintained drainage channels behind the dike on the west bank of the Swinomish Channel. Stream flow from Fornsby Creek is conveyed through the southern channels. Surface water levels were monitored in the channels adjacent to each monitoring station as well as on both sides of the dike at the location of existing and proposed tidegates. Two existing conventional tidegates were replaced with SRTs; one of these was operated as a conventional tidegate to provide a control for subsequent analysis. An additional SRT was installed at a third site replacing plugged and abandoned tidegate tubes.

Installation and operation of SRTs at the study site has increased water levels within the channels as expected, however the adjacent local groundwater table was not significantly elevated by the increased tidal flux. Some monitoring wells adjacent to the channels show a sympathetic but significantly damped response. Wells located closest to the surface water channels (~50 ft) and near the downstream end closest to the tidegate show the greatest response, while wells located further from the surface water channels (>125 ft) and/or further upstream from the tidegate typically show little or no increase in water levels post-SRT installation. All wells show tidal influence on water levels.

Sympathetic groundwater response to the increased tidal flux seen in water table elevations is corroborated by groundwater quality data. Impacts to water quality have been laterally limited to about 50’ from the surface water channels. Salinity has increased in wells situated within restored areas and in areas where there was no previous surface water flow. Conductivity and chloride concentrations within surface water channels and in the Swinomish Channel are approximately equal both before and after SRT installation. Salinities decreased in most areas, possibly due to increased flow and drainage of water in the project area through the SRT.

Elemental and Stable Isotope Composition of Gravelly Lake (WA) Sediment Cores: A 150-year Record of Anthropogenic Environmental Impacts

***Mary Koenig**, University of Puget Sound*

Paul Woodward, University of Puget Sound

Kena Fox-Dobbs, University of Puget Sound

Jeff Tepper, University of Puget Sound

Lake sediments are an archive of environmental history. They preserve a range of biogeochemical data, including element concentrations of silica, carbon, phosphorus, and nitrogen, as well as isotopic data (specifically carbon and nitrogen) that provide a history of the changes in the environment. Such information allows us to reconstruct a high-resolution (<5-10 year) record of conditions in and around the lake. Once this timeline is established we can track changes in nutrient inputs to the lake (e.g. pollution), and sources of organic material (terrestrial vs. aquatic vegetation). We can also gain site-specific information about ground water contamination, and natural and anthropogenic (human) influences including land use changes (e.g. development, forest fires). South Puget Sound has numerous lakes but few have been studied. Gravelly Lake, located in Lakewood, Washington, is unique in that it is entirely spring-fed with no surface water inputs. The lake covers 160 acres with a maximum depth of 55 ft. Until now there has been no detailed study of sediment core records derived from the lake.

Coring done in May 2010 provided us with 1.5 meters of sediment. Using Pb-210 we dated the top of the core, which yielded a date of c. 1846 at 44 cm depth. The sedimentation rate was approximately 2 mm./yr. during the 19th Century, and then steadily increased over the 20th Century to approximately 5 mm./yr. Carbon and nitrogen elemental and isotopic data were relatively constant prior to 1840. Around 1840 there was a sudden shift in all organic data sets. Carbon and nitrogen contents and $\delta15N$ values increase, while $\delta13C$ values and C/N ratios decrease. An increase in C and N concentrations show an increase in nutrient supply and a decrease of C/N indicates a shift from terrestrial to aquatic organic source material, specifically algae. The 8 per mil increase in $\delta15N$ values indicate enhanced biological cycling of available organic material. Additionally, during that time period there is a sharp increase in biogenic silica. Co-occurring changes in organic biogeochemistry likely result from an increase in productivity.

Land use changes occurred in the Lakewood area around 1840. Prior to this time, Native Americans used burning to maintain an open prairie. In 1833, upon arrival of the Hudson Bay Company, there was permanent European settlement and the presence of livestock adjacent in the Lakewood area. The corresponding changes in lake productivity may reflect the resulting increase in nutrient supply to the lake.

Glacier Modeling in Support of Mass Balance Observations at South Cascade Glacier, Washington

William Bidlake, U.S. Geological Survey - WAWSC

***Edward Josberger,** U.S. Geological Survey- WAWSC*

The long-term USGS measurement and reporting of mass balance at South Cascade Glacier was assisted in balance years 2006 and 2007 by a new mass balance model. The model incorporates a temperature-index melt computation and accumulation is modeled from glacier air temperature and gaged precipitation at a remote site. Mass balance modeling was used with glaciological measurements to estimate dates and magnitudes of critical mass balance phenomena. In support of the modeling, a detailed analysis was made of the "glacier cooling effect" that reduces summer air temperature near the ice surface as compared to that predicted on the basis of a spatially uniform temperature lapse rate. The analysis was based on several years of data from measurements of near-surface air temperature on the glacier. The 2006 and 2007 winter balances of South Cascade Glacier, computed with this new, model-augmented methodology, were 2.61 and 3.41 mWE, respectively. The 2006 and 2007 summer balances were -4.20 and -3.63 mWE, respectively, and the 2006 and 2007 net balances were -1.59 and -0.22 mWE.

WORKSHOPS

AND

FIELD TRIPS

‖ WORKSHOPS ‖

WORKSHOP 1

Critical Thinking in the Interpretation of Pumping Tests

Thursday, April 28, 2011, 8:00 AM - 5:00 PM

The objective of this one-day short course is to hone the critical thinking skills of practicing groundwater professionals responsible for interpreting data from pumping tests in natural complex settings. The course takes a rigorous yet practical approach towards the interpretation of aquifer response and the estimation of representative aquifer properties from aquifer tests. The lectures and discussion are designed to go beyond the nuts-and-bolts of aquifer test analysis, to address concepts of diagnosis of aquifer response and assessment of the reliability of parameter estimates. The course is not devoted to any particular computer-assisted interpretation package, rather it addresses the effective use of these packages. Attendees will be provided with comprehensive, detailed course notes. These notes are intended to be formal technical documents that will serve for subsequent self-study.

Leaders and Contacts: Chris Neville, cneville@sspa.com

Location: Two blocks north of Hotel Murano at USGS Washington Water Science Center, 934 Broadway, 3rd floor, Columbia Conference Room. For directions see: http://wa.water.usgs.gov/directions.html

WORKSHOP 2

Well Driller and Ecology Well Report Database Workshop

Thursday, April 28, 2011, 8:00 AM - 4:00 PM

For the second time, the WA Hydrogeology Symposium is offering this workshop to provide 2.0 hours of continuing education units (CEUs) for Washington rules and 2.0 hours of continuing education credits (CECs) for Oregon rules. Presentations will briefly discuss the state-specific laws governing the drilling of geotechnical holes, water wells and monitoring wells, including notices and reporting requirements for drillers, geologists, and engineers. The workshop will also offer classroom training on Ecology's new well report database. The workshop will also include an off-site drilling demonstration.

Leaders: Bill Lum, WA Dept. of Ecology, blum461@ecy.wa.gov, (360) 407-6648 and Marian Spath, WA Dept. of Ecology, mbru461@ecy.wa.gov, (360) 407-6650; Oregon Water Resources Department (to be determined).

Location: Venice 1

Contact: Heidi Bullock, hbullock@landauinc.com, (503) 542-1080

Special Considerations: Be prepared for the chill of spring in Western Washington. Sturdy shoes, sunglasses, sunscreen, jacket or sweater, and raingear are recommended.

WORKSHOP 3

EIM Database Workshop

Thursday, April 28, 2011, 1:00 PM - 2:30 PM

CANCELLED

This session will include a demonstration and Q&A session on the new Groundwater component of Ecology's Environmental Information Management (EIM) database. EIM is Ecology's main database for environmental monitoring data, containing 9 million records on physical, chemical, and biological analyses and measurements.

Leader and Contact: Chris Neumiller, cneu461@ecy.wa.gov

Location: Venice 3

FIELD TRIPS

FIELD TRIP 1

Late Quaternary Geomorphic Reworking of the Puget Lowlands Downstream of Mount Rainier: Implications for People and Salmon Living with the Rivers

Monday, April 25, 2011 7:30 AM to 6:00 PM

The geomorphic framework of the river network in the Puget Lowlands, downstream of Mount Rainier reveals a fascinating story of river reorganization that reflects the complex interactions between glaciation, volcanism, climate, and rivers. The relative youth of the landforms, none older than the late Pleistocene, affords us the opportunity to see the landscape modifications of the Puget Lobe of the Cordilleran ice sheet, ponded lakes and associated outwash features, and laharic sedimentation. And through it all, the rain kept falling, forcing rivers to incise, aggrade, combine, avulse, and find their way to the sea. These dynamic river networks have long been home to salmon and people. In contemporary times, however, the rivers have been altered and channelized, opening floodplains to development and impacting aquatic habitat. Mount Rainier and the surrounding Cascade Range continue to produce copious volumes of sediment that is transporting downstream. In addition, there is evidence to suggest that glacier retreat and larger hydrologic events in the coming decades will further exacerbate sedimentation and associated flooding in these lowland rivers. True to geomorphology's moniker, "the science of scenery," this field trip will show the landscape's 16,000-year response to ice, lahars, and flowing rivers. We will also cover how contemporary land use and policy decisions influence the region's rivers. In particular, we will discuss how early-twentieth century engineering philosophy resulted in channelization of many river sections and how the Endangered Species Act has changed the engineering equation. Finally, we will examine how sedimentation and flooding has affected today's network of rivers and discuss what impacts we might expect to see in the future. Transportation will be by van.

Leaders and Contacts: Chris Magirl, U.S. Geological Survey, magirl@usgs.gov, (253) 552-1617; Pat Pringle, Centralia College, ppringle@centralia.edu.

Special Considerations: Be prepared for the chill of spring in Western Washington. Sturdy shoes, sunglasses, sunscreen, jacket or sweater, and raingear are recommended.

FIELD TRIP 2

Coastal Geology of Tacoma area

Wednesday evening, April 27, 2011 5:30 PM to 9:00 PM

Back by popular demand for the fourth time, 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 surrounding of an evening buffet dinner cruise. Kathy Troost, Brian Sherrod, Bill Perkins, 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 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.

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Field Trip 2 continued

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. And for the modelers amongst us, the vertical and lateral heterogeneity typical of our region's deposits will also be visible from the vessel. Participants will receive a guidebook with color maps, images, and a geologic strip map with measured sections. This trip will include a buffet dinner, a keg of beer and a selection of non-alcoholic beverages.

Leaders and contacts: Kathy Troost, University of Washington, Department of Geological Sciences, ktroost@u.washington.edu, (206) 616-9769; Andy Gendaszek, U.S. Geological Survey, agendasz@usgs.gov, (253) 552-1612.

Cost: $85. Transportation is by charter vessel and includes beverage, buffet dinner, and guide book.

Where: The boat is docked within walking distance of the Hotel Murano. http://www.mygirltheboat.com/directions.htm

The Boat: "My Girl" is a 69 ft long U.S. Coast Guard certified vessel with a professional, licensed crew. The boat has inside seating for 75, a sun deck, enclosed aft deck, rest rooms, and more. We will have sunlight until about 8 PM. Learn more at http://www.mygirltheboat.com/

FIELD TRIP 3

Groundwater-Surface Water Interactions—Demonstration of Fiber Optic Distributed Sensing

Thursday afternoon, April 28, 2011, 1:30 PM 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.

Leaders and Contacts: Andy Gendaszek, U.S. Geological Survey, agendasz@usgs.gov, (253) 552-1612; Rick Dinicola, U.S. Geological Survey, dinicola@usgs.gov, (253) 552-1603; Chris Curran, U.S. Geological Survey, ccurran@usgs.gov, (253) 552-1614.

Special Considerations: Be prepared for the chill of spring in Western Washington. Sturdy shoes, sunglasses, sunscreen, jacket or sweater, and raingear are recommended.

FIELD TRIP 4

Water Treatment Systems in Tacoma: Tour of Both Sewage & Drinking Water Treatment Plants

Thursday afternoon, April 28, 2011, 1:00 PM to 5:00 PM

Tacoma is very green and innovative. We will ride in vans to 2 locations and tour the facilities at each location, guided by a City of Tacoma employee. Stops will include Tacoma's Sewage Treatment Plant on the northeast side of the Puyallup River and Tacoma's Drinking Water Treatment Plant near Howard Hanson Dam.

Leaders and Contacts: Sandy Williamson, U.S. Geological Survey (retired), cell 253-376-8273, sandeb2@gmail.com.

Special Considerations: Be prepared for the chill of spring in Western Washington. Sturdy shoes, sunglasses, sunscreen, jacket or sweater, and raingear are recommended.

FIELD TRIP 5

Hydrogeology of Beer and Wine Country in the Yakima Valley

Friday, April 29, 8:00 AM to Saturday, April 30, 6:00 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 two-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 some of the local brewery and wineries to taste, first hand, the fruits of this unique hydrogeologic system.

Leaders: George Last, Pacific Northwest National Laboratory, george.last@pnl.gov, (509) 371-7080; Matt Bachmann, U.S. Geological Survey, mbachmann@usgs.gov, (253) 552-1672; Bruce Bjornstad, Pacific Northwest National Laboratory, (509) 371-7223, bruce.bjornstad@pnl.gov.

Where: On Friday, the trip will depart from the Hotel Murano in Tacoma. Eastern Washington attendees are welcome to join the trip in route. On Saturday, the trip will end to allow for a 6:00 pm return to Tacoma.

Special Considerations: Be prepared for the chill and/or warmth of spring in Eastern Washington. Hiking shoes, water, sunglasses, sunscreen, jacket or sweater, raingear, and overnight accessories are recommended.

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