Washington Hydrogeology Symposium

10th Anniversary

PROGRAM AND ABSTRACTS

WASHINGTON HYDROGEOLOGY SYMPOSIUM

Hotel Murano | Tacoma, Washington

April 14–16, 2015

www.wahgs.org

GENERAL SCHEDULE

Date	Activity
Monday *April 13*	**Field Trip: 35th Anniversary of the Mount St. Helens Eruption** *(all day)* **Workshop 1:** Well Drilling *(8am-4pm at Clover Park Technical College and USGS Warehouse)*
Tuesday *April 14*	**First Day of Symposium** **Opening Session and Keynote Talk** **Platform Presentations** **Exhibits** Lunch Provided **Poster Session and Reception** *(early evening)*
Wednesday *April 15*	**Second Day of Symposium** **Keynote Talk** **Platform Presentations** Lunch Provided **Exhibits and Posters** **Workshop 6**: Environmental Information Management (EIM) System Groundwater Tools *(2pm-2:40 pm)*
Thursday *April 16*	**Workshops** **Workshop 2:** Bioremediation Fundamentals and Applications *(8am-noon)* **Workshop 3: Characteristics and Remediation Technologies for Petroleum Releases** *(1pm-5pm)* **Workshop 4:** Natural Stress Impacts on Well-Level Response: Analysis and Removal Applications *(8am-4pm)*
Friday *April 17*	**Workshops** **Workshop 5:** Solute Transport Modeling: Ideal and Otherwise *(8am-4pm at USGS Water Science Center Office)*

CHAIRMAN'S WELCOME

Washington Hydrogeology Symposium — 10th Anniversary

Welcome to the 10th Washington Hydrogeology Symposium! We are pleased to convene this year's Symposium at the Hotel Murano in Tacoma, Washington in the shadow of Mt. Rainier and on the shores of Puget Sound. We hope the Symposium offers you an opportunity to learn about recent developments in the field of hydrogeology and connect with colleagues from across the Pacific Northwest.

We are excited to present a comprehensive technical program that covers new developments in hydrogeology throughout Washington State and beyond. Forty-nine platform and sixteen poster presentations cover a diverse suite of topics including contaminant fate and transport in groundwater, aquifer storage and recovery, and water rights and instream flows, to name a few. In addition to the technical program, six workshops are offered during the Symposium including: Well Drilling Workshop, Bioremediation Fundamentals and Applications, Characteristics and Remediation Technologies for Petroleum Releases, Natural Stress Impacts on Well Water-Level Response, Solute Transport Modeling, and Environmental Information Management (EIM) System Groundwater Tools. Symposium participants had the opportunity to attend the Monday field trip to Mt. St. Helens led by Dr. Tom Pierson of the U.S. Geological Survey Cascades Volcano Observatory during the 35th Anniversary of Mt. St. Helens 1980 eruption.

We are extremely privileged to welcome Dr. David Rudolph, professor of Earth and Environmental Sciences at the University of Waterloo and Dr. Melissa Rice, professor of Geology and Physics/Astronomy at Western Washington University, as keynote speakers for the Symposium. Dr. Rudolph was the 2013 Henry Darcy Distinguished Lecturer whose current research focuses regional groundwater flow systems, recharge dynamics, and vadose zone processes. Dr. Rice joined the faculty at Western Washington University in 2014 and her research in planetary science includes recent discoveries of water on Mars.

Please take time to visit our exhibitors who are showcasing state-of-the art data collection, analytical, and reporting solutions. We would also like to thank our sponsors who, through their generosity, have ensured the continuity of the Symposium's success and allowed the registration fee to continue to be offered at a very affordable price. A full list of our sponsors and exhibitors are included in the back of this program book.

On behalf of the 10th Washington Hydrogeology Symposium Steering Committee, I hope you spend several enjoyable and productive days at the Symposium and that you plan to join us again in 2017!

Sincerely,

Andy Gendaszek

2015 Symposium Chair

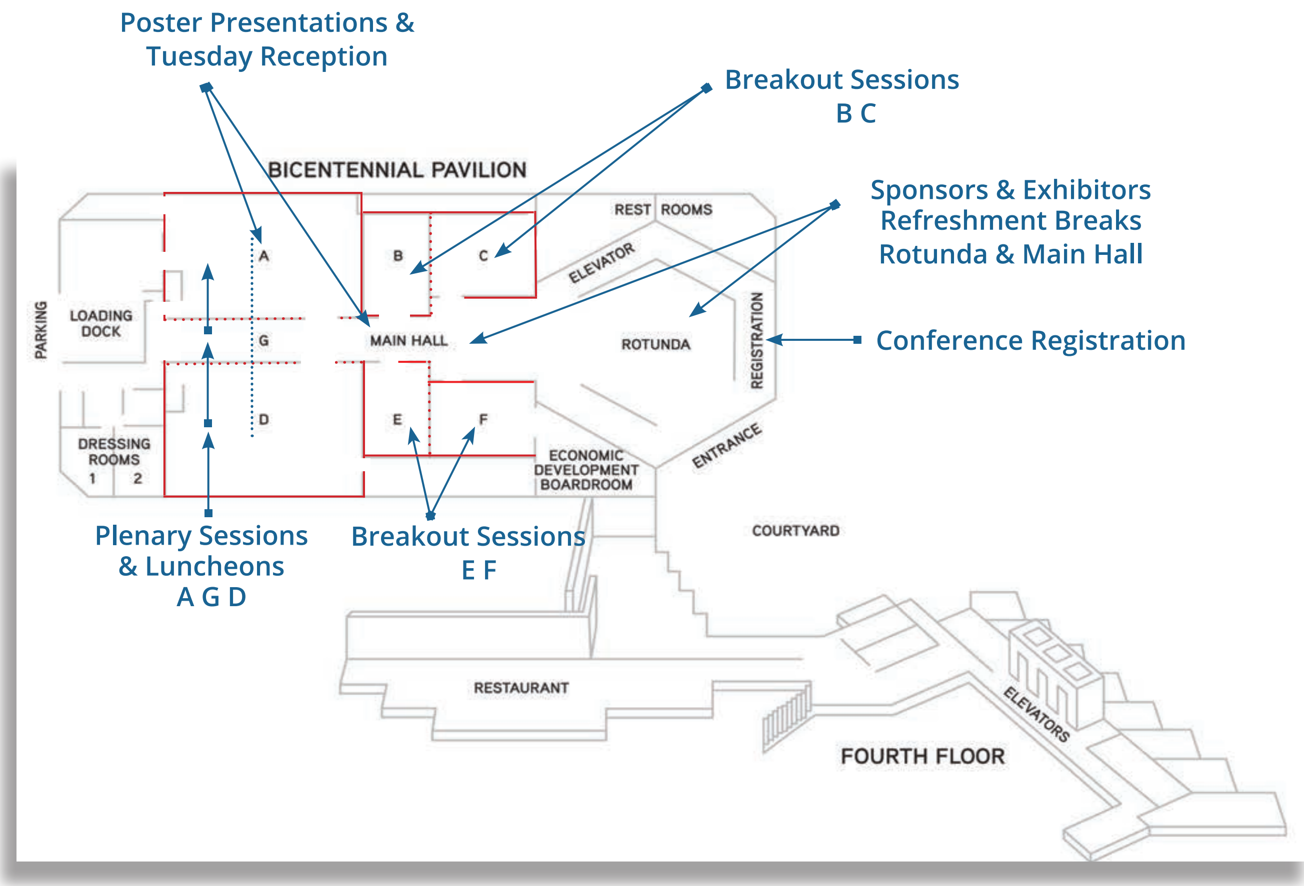
U.S. Geological Survey, Washington Water Science Center

10th Anniversary Washington Hydrogeology Symposium

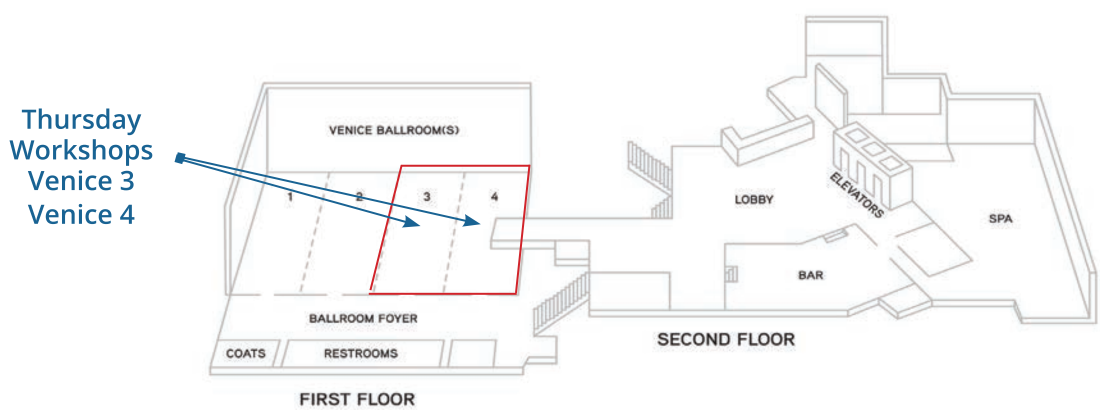
KEY LOCATIONS

Hotel Murano, Tacoma

Bicentennial Pavilion



Main Hotel



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GENERAL INFORMATION

Symposium Registration Booth

The Washington Hydrogeology Symposium Registration Booth is located in the Rotunda of the Bicentennial Pavilion. Staff will be available there to provide assistance and information throughout the Symposium.

Registration Hours

Tuesday, April 14 - 7:30 AM – 5:30 PM | Wednesday, April 15 - 8:00 AM – 4:30 PM | Thursday, April 16 - 8:00 AM - 1:30 PM

Name Badges

Your name badge is your entrance ticket to Symposium activities including sessions, breaks, lunches, and the Tuesday Poster Reception.

Symposium Sessions

Symposium sessions will be held in meeting rooms within the Pavilion. Thursday workshops (except for the Well Drilling and Solute Transport Modeling workshop) will be held in the lower ballroom level of the Hotel Murano's main building. Please refer to the hotel floor plans on page ii in this program book.

Presenters

Presenters in oral sessions should arrive at assigned presentation rooms at least 10 minutes before the session start time to load files onto the laptop provided. An audio-visual operator will be available if assistance is needed. Poster presenters may set up their poster any time on Tuesday morning or during the morning break at 10:15 AM. It is important that all posters are in place by the end of the afternoon break at 3:00 PM. You may leave your poster up until the end of the afternoon break on Wednesday at 3:00 PM. Plan to be available at your poster during the Tuesday Poster Session and Reception.

Meals and Refreshments

Lunch is provided on Tuesday and Wednesday. If you made a special meal request (vegetarian or other), please note that the lunch buffets each day will offer options to meet most dietary requirements.

Early morning coffee and pastries will be provided each day and beverages and snacks will be available during breaks.

Poster Reception

We hope you will join us at the Symposium Poster Session and Reception on Tuesday from 5:10-7:00 PM. View the 2015 posters, visit our sponsors and exhibitors, and enjoy food and beverages while networking with colleagues. During this event, we will hold the 2015 Symposium raffle.

Internet Access

Complimentary internet access is available in all meeting rooms, the lobby and the hotel restaurant. Overnight guests will receive a user name and password when they check in that can be used in their hotel room and in the meeting rooms. For those participants not staying in the hotel, please use the username: hydgeo and password: 2015. Questions about how to log in can be answered by hotel front desk staff persons and symposium staff at the Registration Desk.

Please note! Interested persons are welcome to join the Symposium Planning Committee. If you are interested in participating in the planning of the 11th Washington Hydrogeology Symposium scheduled for April 2017, please sign up at the Symposium Registration Desk. To kick things off, you will be invited to attend a free morning breakfast meeting on Wednesday, April 15, at 7:30 AM (RSVP only).

WIRELESS ACCESS

username: hydgeo
password: 2015

STEERING COMMITEE

Left to Right: Gary Walvatne, Rose Riedel, Donna Buxton, Andy Gendaszek, Chris Brown, Joel Purdy, Sue Kahle, Angie Goodwin, Mark Freshley, Roy Jensen, Ashley Cedzo

Not Pictured: Jean Doesburg, Vicky Freedman, Margo Gillaspy, Laurie Morgan, Robert Mitchell, Christin Neumiller, Sophia Petro, Jason Shira, Michelle Valenta Snyder, Tom Tebb, and Heidi Yantz

10th Washington Hydrogeology Symposium Steering Committee

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Vicky Freedman	Pacific Northwest National Laboratory, Vice-Chair
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Mary Jane Shirakawa Jan Kvamme	UW Conference Management University of Washington www.uwconferences.org

Tuesday, April 14, 2015 *all activities in Bicentennial Pavilion*		
7:30 AM	Check-in & Registration	
9:00 AM	**Opening Session** *(Room AGD)*	
	Welcome & Opening Remarks *Andy Gendaszek, 2015 Washington Hydrogeology Symposium Chair and* *Maia Bellon, Director, Washington State Department of Ecology* **Keynote Talk: Influence of Vadose Zone Dynamics on the Fate of Agricultural Nutrients** ***David Rudolph,*** *University of Waterloo*	
10:15 AM	Refreshment Break | Exhibits | Posters	
10:40 AM	**1A– Groundwater Availability** *(Room BC)*	**1B–Innovative Remediation Technologies I** *(Room EF)*
	Moderator: Sue Kahle	*Moderator: Donna Buxton*
	SVRP Aquifer and the Spokane River, Part 1: How the System Works *Dale Ralston, Ralston Hydrologic Services*	**Thermal treatment in the Duwamish Valley – a Detailed Look at Pre- and Post- Thermally Treated Soil and Groundwater** *Tom Colligan, FloydSnider, Inc.*
	SVRP Aquifer and the Spokane River, Part 2: Managing Pumping to Benefit Low River Flow *John Porcello, GSI Water Solutions*	**Biopolish of a PCE/TCE Source Zone Following Electrical Resistance Heating** *Clinton Jacob, Landau Associates*
	Assessment of Groundwater in Storage, Eastern Pasco Basin, Washington *Charles Heywood, US Geological Survey*	**Results of First Full Scale 1,4-Dioxane Synthetic Media Groundwater Remediation System** *Michael Dodson, GRS*
	Groundwater Modeling in Support of a Complex Water Rights Application, Bitterroot Valley, Montana *Gary Andres, NewFields*	**Accelerated Biodegradation of Petroleum and Chlorinated Contaminants Facilitated by an In Situ Colloidal Biomatrix** *Kristen Thoreson, Ph.D., Regenesis*
12:00 noon	**Hosted Luncheon** *(Room AGD)*	
1:20 PM	**2A–Aquifer Storage and Recovery I** *(Room BC)*	**2B – Innovative Remediation Technologies II** *(Room EF)*
	Moderator: Dave Nazy	*Moderator: Gary Walvatne*
	A Desktop Suitability Assessment of Aquifer Storage and Recovery (ASR) in Washington State *Maria Gibson, Oregon State University*	**Considerations for Horizontal Directional Drilling in Groundwater Remediation Applications in the Pacific Northwest** *Michael Lubrecht, Directed Technologies Drilling*
	ASR Feasibility in the Ahtanum-Moxee Subbasin: A Case Study with the City of Yakima *Andrew Austreng, Golder Associates*	**Horizontal Environmental Wells Case Histories** *James Doesburgh, Directed Technologies Drilling, Inc.*
	Shallow Aquifer Recharge to Meet Multiple Objectives in the Dungeness Basin *Amanda Cronin, Washington Water Trust*	**Opportunistic Use of Shallow Subsurface Aquitard Topography for LNAPL Plume Interception and** *Piper Roelen, Landau Associates, Inc.*
	Ongoing Evaluation of Aquifer Storage and Recovery, Columbia River Off-Channel Aquifer Storage Project *James Miller, GeoEngineers, Inc. and Guy Gregory, Washington Dept. of Ecology*	**Nineteen-Year Performance of a Surface Barrier at the Hanford Site** *Fred Zhang, Pacific Northwest National Laboratory*
2:40 PM	Refreshment Break | Exhibits | Posters	
3:00 PM	**3A–Aquifer Storage and Recovery II** *(Room BC)*	**3B–Carbon and Climate** *(Room EF)*
	Moderator: Dave Nazy	*Moderator: Ashley Cedzo*
	City of White Salmon ASR – Completing the Supply Puzzle *Joseph Morrice, Aspect Consulting, LLC.*	**Update of Post CO2 Injection Activities for the Wallula Basalt Carbon Sequestration Pilot Project** *Frank Spane, Pacific Northwest National Laboratory*
	City of Kennewick Aquifer Storage and Recovery Project: Developing a Cool Thermal Storage Zone in a Warm Aquifer *Phillp Brown, GSI Water Solutions Inc.*	**Warming Temperatures Threaten Water Supplies in the Pacific Northwest by Shrinking Mountain Glaciers** *Matt Bachmann, US Geological Survey*

Tuesday, April 14, 2015 *(continued)*		
3:00 PM	**3A–Aquifer Storage and Recovery II** *(Room BC - continued)*	**3B–Carbon and Climate** *(Room EF - continued)*
	Aquifer recharge as a water management tool in a bi-state alluvial fan system *Steven Patten, Walla Walla Basin Watershed Council*	**The Missouri Carbon Sequestration Project – A Model for State-wide Assessment of Carbon Sequestration Feasibility** *Gary Pendergrass, GeoEngineers, Inc.*
	Managed Aquifer Recharge in the Walla Walla Basin for Ecological and Agricultural Water Supply Enhancement Assessed Through Numerical Modeling *Jacob Scherberg, GeoSystems Analysis, Inc*	**A Retrospective of Contributions & Highlights of Water Resources on Vashon-Maury Island, King County, WA** *Sevin Bilir, King County Science and Tech Support Section*
4:20 PM	Refreshment Break | Exhibits | Posters	
4:30 PM	**4A–Contaminant Threats** *(Room BC)*	**4B–Groundwater Protection & Management** *(Room EF)*
SESSION 4	*Moderator: Michelle Snyder*	*Moderator: Angie Goodwin*
	A Case Study in the Development and Application of Multipurpose Tools for Aquifer Management *Richard Malin, Parametrix*	**Production Well Design: Engineering and Experience** *Eric Weber, Landau Associates, Inc.*
	Science-Based Approaches to Protecting Groundwater Quality from Stormwater Infiltation at UICs: Lessons Learned from Oregon *Matthew Kohlbecker, Oregon Dept of Environmental Quality*	**Permit-Exempt Domestic Well Use in Washington** *Tom Culhane, Washington State Department of Ecology*
5:10-7:00 PM	**Poster Session & Reception** *(Posters in AGD; Reception throughout Bicenenial Pavilion)*	
	Using Piper Diagram Two-Component Mixing To Show a Sewage Lagoon Leaked, *Phil Richerson, Oregon Department of Environmental Quality*	
	Oral histories of Puget Lowland tribes: Do some myths provide a cultural memory of catastrophic laharic floods from Mount Rainier, Washington? *Michelle Kearns, The Evergreen State College*	
	A Site-Specific Terrestrial Ecological Evaluation for Abandoned Mined Lands on a Watershed Scale, *Michelle Havey, Hart Crowser, Inc.*	
	The Washington Nitrate Prioritization Project, *Laurie Morgan, Washington State Dept. of Ecology*	
	Approach to examine uranium occurrence in groundwater in northeastern Washington State, *Sue Kahle, US Geological Survey*	
	Sediment and phosphorus inputs from perennial streams to Lake Whatcom, Northwestern Washington State, *Robert Mitchell, Western Washington University*	
	Calibration of a Hydrologic and Dynamic Glacier Model to the Nooksack River Basin Using Gridded Surface Climate Data, *Ryan Murphy, Western Washington University*	
	The Relationship Between Saturated Hydraulic Conductivity and Grain-Size Distribution of Glacial Outwash Deposits within the Puget Lowland, Washington, *Lam Nguyen, Associated Earth Sciences, Inc.*	
	Reassessing dairy nutrient management plans to evaluate nitrate concentrations leached through agricultural soils in Whatcom County, Washington, *Sarah Gregory, Western Washington University*	
	Investigation of Phosphorus Loading and Cycling at Waughop Lake (Pierce County): The Most Toxic Lake in Western Washington, *Halle Peterson, University of Puget Sound Geology Dept.*	
	Hydrogeologic Framework for the Puyallup River Watershed and Vicinity, Pierce and King Counties, Washington, *Wendy Welch, US Geological Survey*	
	Sediment and Sediment-Bound Toxic Chemical Loads from the Green River to the Lower Duwamish Waterway, Washington, *Kathy Conn, US Geological Survey*	
	Hydrogeology of the Eastern Pasco Basin, Washington, *Theresa Olsen, US Geological Survey*	
	Preparations of HAZUS Landslide Susceptibility Maps for Island, Skagit and San Juan Counties, Washington, *Yuyang Zou, Washington State Department of Natural Resources*	
	Age of The Bonneville Landslide and the Drowned Forest of the Columbia River, Washington, USA—From Wiggle-Match Radiocarbon Dating and Tree Ring Analysis, *Nathaniel Reynolds, Cowlitz Indian Tribe*	
	A Hydrologic Assessment of Instream Flow Standards in Washington State, *Roy Jensen, Hart Crowser, Inc.*	
	Database Population and Geospatial Modeling of the Hydrostratigraphy at an Active Landfill in King County, WA., *Sevin Bilir, King County Science & Technical Support*	
	RRAWFLOW: Rainfall-Response Aquifer and Watershed Flow Model, *Andrew Long, US Geological Survey*	

Wednesday, April 15, 2015		
8:00 AM	Registration Desk Opens	
9:00 AM	**Keynote Talk** *(Room AGD)*	
	The History of Water and Habitability at Gale Crater, Mars: New Discoveries from NASA's Curiosity Rover ***Melissa Rice,*** *Planetary Science, Western Washington University*	
10:00 AM	Refreshment Break | Exhibits | Posters	
10:20 AM	**5A–Instream Flow I** *(Room BC)*	**5B–Geochemical Characterization and Sensors** *(Room EF)*
SESSION 5	*Moderator: Roy Jensen*	*Moderator: Heidi Yantz*
	Instream Flow Policy and Legal Implications *(30 minutes)* *David Christensen, Washington Department of Ecology*	**Uranium millsite hydrogeology, Chamokane Basin, Ford, Washington** *Dr. John Riley and Bryony Stasney, WA State Department of Health, Office of Radiation Protection*
	Instream Flow Science *(30 minutes)* *Jim Pacheco, Washington Department of Ecology*	**Hexavalent chromium sensor developed for real-time in situ groundwater monitoring** *Kenton Rod, Freestone Environmental Services Inc.*
	Legal History of Instream Flows *(30 minutes)* *Jennifer Holderman, Washington Dept of Ecology*	**Geochemical Studies of Surface Water/Groundwater Interactions in Central Washington** *Carey Gazis, Central Washington University*
		Marine streamer electrical resistivity characterization of riverbed sediment contamination, Coeur d'Alene River, *Nigel Crook, hydroGeophysics Inc.*
11:40 AM	**Hosted Luncheon** *(Room AGD)*	
1:00 PM	**6A– Instream Flow II** *(Room BC)*	**6B – Data Collection and GIS** *(Room EF)*
SESSION 6	*Moderator: Roy Jensen*	*Moderator: Michelle Snyder*
	A Hydrologic Assessment of Instream Flow Standards in Washington State *Roy Jensen, Hart Crowser, Inc.*	**King County Groundwater Protection Program volunteer data collection efforts** *Eric Ferguson, King County DNRP*
	The Wild West Comes to Western Washington – Implementing the Dungeness Instream Flow Regulation *Michael Gallagher, Department of Ecology*	**Systematic Identification of Potential Groundwater Recharge Sites Using Geographic Information Systems** *James Bush, Brown and Caldwell*
	Panel Session: Instream Flow Program in Washington *Panel Members:* *Jim Pacheco, Washington Department of Ecology* *Mike Gallagher, Washington Department of Ecology* *F. Michael Krautkramer, Robinson Noble* *Moderator: Roy Jensen, Hart Crowser*	**Advancing Methods to Parameterize Emergent Vegetation Variables for Coastal Impact Models** *Chad Stellern, Western Washington University* **Workshop: Environmental Information Management (EIM) System Groundwater Tools Workshop** *Christine Neumiller, Washington Department of Ecology (40 minutes)*
2:40 PM	Refreshment Break | Exhibits | Posters	
3:00 PM	**7A–Nitrates** *(Room BC)*	**7B–Modeling** *(Room EF)*
SESSION 7	*Moderator: Tom Tebb*	*Moderator: Vicky Freedman*
	Indicators of Nitrate Groundwater Contamination Sources *Melanie Redding, Washington State Dept of Ecology*	**Conceptual Model for the Kitsap Peninsula, Kitsap, Mason, and Pierce Counties, Washington** *Lonna Frans, U.S. Geological Survey*
	Nutrient Transport in Groundwater *Llyn Doremus, Washington Department of Ecology*	**Using MODFLOW to Predict Impacts of Groundwater Pumpage to Instream Flow: Upper Kittitas County, WA** *Zoe Futornick, Central Washington University*
	Assessment of manure management strategies impact on nutrient loading to the Sumas aquifer in Whatcom County Washington *Andrew Spanjer, US Geological Survey*	**Groundwater/Surface-Water Interactions and Detecting Cold-Water Refugia in Streams of the Pacific Northwest** *Andrew Gendaszek, US Geological Survey*
	Lower Yakima Valley Dairies Address Nitrate Contamination of Drinking Water Aquifer *Rene Fuentes, U.S. Environmental Protection Agency*	**Advanced Simulation Capability for Environmental Management; A Workflow for Subsurface Simulation** *Vicky Freedman, Pacific Northwest National Laboratory*
4:20 PM	2015 Symposium Presentations Adjourn	

Thursday, April 16, 2015	
8 AM - 12 PM	**Bioremediation Fundamentals and Applications**
	Workshop Presenter: **Troy Fowler,** Bioremediation Specialists L.L.C.
	Room: Venice 3, Hotel Murano
1 PM - 5 PM	**Characteristics and Remediation Technologies for Petroleum Releases**
	Workshop Presenters: **Troy Fowler,** Bioremediation Specialists L.L.C. **Kirk O'Reilly,** Exponent, Inc.
	Room: Venice 3, Hotel Murano
8 AM - 4 PM	**Natural Stress Impacts on Well Water-Level Response: Analysis and Removal Applications**
	Workshop Presenters: **Frank Spane,** Pacific Northwest National Laboratory **Rob D. Mackley,** Pacific Northwest National Laboratory
	Room: Venice 4, Hotel Murano

Friday, April 17, 2015	
8 AM - 4 PM	**Solute Transport Modeling: Ideal and Otherwise**
	Workshop Presenters: **Christopher Neville,** S.S. Papadopulos & Associates, Inc. - Waterloo, Ontario **Brad Bessinger,** S.S. Papadopulos & Associates, Inc. - Portland, Oregon
	Location: USGS Water Science Center Office, 934 Broadway, Suite 300, Tacoma

David Rudolph, Ph.D., P.E.

Professor, Department of Earth and Environmental Sciences and Department of Civil and Environmental Engineering, University of Waterloo, Ontario, Canada

Title: Influence of Vadose Zone Dynamics on the Fate of Agricultural Nutrients

Elevated levels of nutrients in groundwater worldwide have been associated with leaching of excess fertilizers from agricultural land use practices. Considered a regional, non-point contaminant source, the fate and transport of agricultural nutrients such as nitrate leaching from farm lands is complicated by surface and subsurface heterogeneity, diversity in land use practices, transformation processes and climatic seasonality. Nutrient management strategies, often referred to as nutrient Best Management Practices (BMPs) are being implemented on agricultural landscapes around the world; however there is a paucity of science-based evidence that can be used to quantify their effectiveness. This is primarily due to the intrinsically long time lags between the implementation of the BMP and the subsequent impact on a public supply well. Surface applied nutrients must first migrate through the unsaturated zone, which can significantly influence the timing and distribution of the nutrient species arriving at the water table. In many cases, performance assessment relies heavily on predictive simulations. In this presentation, the role of the vadose zone in influencing the fate and transport of nitrate will be examined within the context of quantifying BMP performance, aquifer vulnerability and related modeling challenges. Applications from actual field sites will be used for illustrative purposes.

David Rudolph, Ph.D., PE, a geological engineer, is a professor in the Department of Earth and Environmental Sciences and cross-appointed to the Department of Civil and Environmental Engineering at the University of Waterloo. He specializes and teaches in the areas of regional hydrogeology and groundwater protection and management. Rudolph's areas of research activity include field investigation and numerical modeling related to groundwater flow and contaminant transport with a focus on regional groundwater flow systems, recharge dynamics, and vadose zone processes. Specific research applications have focused on assessing the impacts on water quality from agricultural land-use practices. He works extensively in areas related to the regional management of groundwater resources and he has participated with municipal authorities both nationally and internationally, primarily throughout Latin America in the development of groundwater protection and management strategies.In addition, Rudolph heads a nationwide research team working on prioritizing risk to water quality from various agricultural practices and evaluating performance of beneficial management practices or BMPs. He recently served as executive director of the Water Institute at the University of Waterloo. Rudolph was the 2010 recipient of NGWA's M. King Hubbert Award for contributions to the field of hydrogeology and the 2013 NGWA Darcy Lecturer in Ground Water Science. Rudolph graduated from the University of Manitoba, and received his M.Sc. and Ph.D. from the University of Waterloo in hydrogeology.

Melissa Rice, Ph.D.

Assistant Professor, Planetary Science, Western Washington University, Washington, USA

Title: The History of Water and Habitability at Gale Crater, Mars: New Discoveries from NASA's Curiosity Rover

Our understanding of the history of water on Mars has undergone enormous changes in the past 60 years. In the 1950's, it was often taken for granted that Mars' surface was covered with vegetation, in addition to large canals – carved by intelligent beings – that delivered water from the poles to drying equatorial regions. When the first spacecraft arrived in the 1960's, photographs of a cratered, moon-like landscape dashed these hopes of a living Mars with abundant water. Subsequent orbiters, however, have revealed an increasingly complex geologic history of the Red Planet, including an ancient, possibly long-lived hydrologic cycle. We now know that Mars' surface is covered with the scars of massive outflows, dendritic drainage networks, sapping channels, gullies, aeolian fans, and deltas. Orbital spectrometers are also revealing a rich history of aqueous alteration as recorded in the mineralogy of the planet's oldest terrains.

Currently, NASA's Curiosity Mars rover is studying an ancient fluvio-lacustrine system in Gale Crater, where it has been exploring since August 2012. Analyses of the chemistry, mineralogy and sedimentology from Curiosity have led to the first confirmation of a once-habitable environment on Mars. This talk will provide an overview of the major results from Curiosity's mission to date, including some of the latest images acquired with the rover's 17 cameras, and how the rover's ongoing investigation is adding to our understanding of ancient Mars' dynamic hydrological cycle. Plans for NASA's next Mars rover mission, launching in 2020, will also be discussed.

Melissa Rice is an Assistant Professor of Planetary Science at Western Washington University, where she teaches in the Geology Department and the Physics/Astronomy Department. Her research focuses on the sedimentology, stratigraphy and mineralogy of planetary surfaces; the current aim of her work is to help constrain the habitability of ancient environments on Mars. She is a collaborator on the active NASA Mars Science Laboratory (MSL) Curiosity and Mars Exploration Rover (MER) Opportunity missions. Dr. Rice received her Ph.D. in 2012 in the Department of Astronomy at Cornell University, with minor concentrations in Geology and Science Communication. From 2012-14, she was a Postdoctoral Scholar in the Division of Geological and Planetary Sciences at the California Institute of Technology.

Oral Abstracts

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Poster Abstracts

pages 57-80

SVRP Aquifer and the Spokane River, Part 1: How the System Works

Dale Ralston, Ralston Hydrologic Services
Gary Johnson, Ralston Hydrologic Services
John Porcello, GSI Water Solutions

The Spokane Valley – Rathdrum Prairie (SVRP) aquifer and the Spokane River form an interconnected water resource system in northern Idaho and eastern Washington. About half of the recharge to the aquifer comes from the Spokane River in the reach from Coeur d'Alene Lake in northern Idaho to about Greenacres in eastern Washington. The river is perched above the aquifer in this reach. Most of the aquifer's discharge to the Spokane River occurs in the reach from about Greenacres to downtown Spokane. The Post Falls Dam provides water level control for Coeur d'Alene Lake and thus controls surface flow releases during the summer and fall months.

The aquifer is used as the sole water supply source for municipal, domestic, industrial, and irrigation uses in both Idaho and Washington. Production wells have very high yields because the aquifer is composed primarily of coarse-grained sedimentary deposits that have very high hydraulic conductivity. Despite increased urbanization and population in the valley, groundwater levels in Idaho and extreme eastern Washington were higher in 2014 than during the majority of the past 70+ years of record.

The primary water resource problem in the area is a period of low flow in the Spokane River that occurs in the fall of many years, as measured at the Spokane gage. The river flow at Spokane is comprised of discharge from the Post Falls Dam and groundwater gain from the SVRP aquifer. Low flows in the Spokane River are not associated with long-term water-level decline in the aquifer, but instead result from three factors: 1) the temporal pattern of water release from the Post Falls Dam, 2) the timing of effects from upstream aquifer recharge events, and 3) the timing of effects from groundwater pumping at sites throughout the aquifer. Hydrograph analysis coupled with response-function analysis of recharge events from different segments of the river has led to a greater understanding of the river/aquifer system and provides a predictive tool for the occurrence of extreme low-flow events.

SVRP Aquifer and the Spokane River, Part 2: Managing Pumping to Benefit Low River Flow

John Porcello, GSI Water Solutions
Gary Johnson, Ralston Hydrologic Services
Dale Ralston, Ralston Hydrologic Services

The Spokane Valley - Rathdrum Prairie (SVRP) Aquifer is a Sole Source Aquifer that provides drinking water to more than 500,000 people in Spokane County, Washington, and in Boundary and Kootenai Counties, Idaho. The aquifer is highly permeable, consisting of Missoula Flood Deposits that have hydraulic conductivity values estimated to be on the order of 10,000 feet per day or higher in some areas. Historically, the Spokane River has experienced declines in its annual 7-day summer low flow, despite the absence of any measurable long-term groundwater level declines or any discernible changes in rainfall in tributary valleys. Three approaches have been identified to address the declining low-flows: (1) increasing the discharge from the Post Falls Dam on Coeur d'Alene Lake, which is the headwaters for the Spokane River; (2) artificially recharging the aquifer to increase the base flow during the critical low-flow periods; and (3) relocating groundwater pumping to strategic locations and at specific times to allow greater flow in the river in the gaining reaches during the critical low-flow period.

This presentation discusses two independent studies conducted by separate researchers who evaluated the relocation idea, using two different groundwater models of the entire aquifer system that were originally constructed for other purposes. The study by Ralston Hydrologic Services for the Idaho Water Resource Board used a finite-difference model that was developed for regional water resources evaluations by the U.S. Geological Survey, the Idaho Department of Water Resources, the Washington Department of Ecology, the University of Idaho, and Washington State University. This study included development of a spreadsheet tool using transient response functions to predict the impacts of production wells on groundwater discharges to the river. This study also evaluated historical river gaging data to identify time-lag responses of the aquifer to variations in river flows, as controlled by releases from Post Falls Dam.

The study by GSI Water Solutions used a higher-resolution finite-element model that was designed and developed for the water providers in Washington (the Spokane Aquifer Joint Board) to support wellhead protection planning activities and well field operational assessments. This study evaluated the potential benefits to the river of operating existing wells differently during the three months leading to and ending with the 7-day critical low-flow period. This study focused specifically on operational changes to certain existing wells that some of the water suppliers in Washington identified might be feasible to implement for 1 to 3 months, given their current network of production wells and the operational constraints of their water distribution and storage systems.

The results of the two studies using different models are similar and highlight to decision-makers the strong linkage and temporal responses of the river/aquifer system. These studies also provide tools that allow for detailed evaluation of alternative groundwater pumping schemes as an approach to mitigating problems of critical low flow in the Spokane River.

Assessment of Groundwater in Storage, Eastern Pasco Basin, Washington

Charles Heywood, US Geological Survey
Sue Kahle, US Geological Survey
Erick Burns, US Geological Survey
Theresa Olsen, US Geological Survey
James Patterson, US Geological Survey

The Miocene Columbia River Basalt Group and younger sedimentary deposits of lacustrine, fluvial, eolian, and cataclysmic-flood origin compose the aquifer system of the Pasco Basin in eastern Washington. Irrigation return flow and canal leakage from the Columbia Basin Irrigation Project has recharged this aquifer system under parts of the Pasco Basin since 1952. Groundwater levels in the sedimentary overburden have risen substantially in some areas of the Pasco Basin, which contributes to landslides along the Columbia River and septic system failures, among other problems. State and local water resource managers are considering extraction of the additional stored groundwater to supply increasing demand, as well as possibly mitigating problems caused by the increased water levels. To manage future groundwater allocations, an assessment of increased groundwater storage is required. The U.S. Geological Survey developed a transient groundwater model of the Pasco Basin that quantifies changes in groundwater flow and storage, and can predict the effects of future withdrawals on groundwater levels. The model utilizes a 1-km finite difference grid with MODFLOW-NWT and is constrained by 846 well logs in the study area. Seven model layers represent five overburden hydrogeologic units and two underlying basalt formations. Head-dependent flux boundaries represent the Columbia and Snake rivers to the west and south, respectively, underflow to/from adjacent areas to the northeast, and discharge to agricultural drains and springs. Specified flux boundaries represent discharge through groundwater withdrawal wells and recharge from "natural" and anthropogenic sources, including irrigation return flow and leakage from water-distribution canals. The model was calibrated with the parameter-estimation code PEST to groundwater levels observed from 1907 through 2013 and discharge to springs and agricultural drains. The simulated increase in groundwater storage since predevelopment represents the contribution of anthropogenic sources to the aquifer system. The model can be used to evaluate the efficacy of groundwater withdrawals in reducing groundwater levels near landslide-prone areas.

Groundwater Modeling in Support of a Complex Water Rights Application, Bitterroot Valley, Montana

Gary Andres, NewFields
Karl Uhlig, WGM Group
Ross Miller, Mountain Water Company

Groundwater modeling was conducted to support a Beneficial Use Water Rights Application for a site along the Bitterroot River in Montana. The application quickly expanded into a complex process of Change Applications to mitigate predicted river depletion, and provides an example of how complex water rights applications are becoming.

Initial model simulations of a proposed wellfield for a housing development showed depletion, or reduction of groundwater flow into the Bitterroot River. Because the Bitterroot River is in a closed basin where new surface water rights or further reduction in river flows due to groundwater uses are prohibited, these depletions were unacceptable by the State Department of Natural Resources and Conservation (DNRC). Bitterroot River depletion was exacerbated by the fact that non-consumed domestic water from the development would be piped north for treatment and discharged into the Clark Fork River instead of being treated on site and discharged to the Bitterroot River.

To offset the predicted depletion, mitigation efforts were crafted that involved retiring a nearby private well, retiring several irrigation water rights that divert water from a nearby stream, and using a water right owned by Missoula's water purveyor, Mountain Water Company (MWC), for some of the development's water needs.

Modeling consisted of modifying an existing MODFLOW model of the Missoula Aquifer to incorporate components of the proposed water right, and to run in monthly-time steps. Model simulations of the pre-application, proposed pumping, and proposed pumping with mitigation conditions were developed. River cell fluxes, used to represent the Bitterroot and Clark Fork rivers, were used to quantify and locate net and seasonal effects to the river.

Simulating the retired agricultural rights was complicated because these derive water from Miller Creek, which otherwise would infiltrate and recharge groundwater. Calculations were made to estimate the distance downstream the non-diverted water would travel before infiltrating, and those locations in the model were populated with injection wells. Once the various scenarios were set up, the modeling process involved iterations of running the model, tallying the depletions, and making revisions as needed.

The initial application predicted some depletion in the Bitterroot River even with mitigation efforts. MWC submitted a new application that fully mitigated depletions by reducing the proposed pumping and replacing the reductions with water from an existing un-perfected permit held by MWC. Permitting was then complicated by potential depletions during low flow years to instream flow rights on the Bitterroot River held by Montana Department of Fish, Wildlife and Parks (DFWP). MWC reached an agreement with DFWP by providing additional mitigation water, however DNRC deemed the additional mitigation was not necessary and thus not a "beneficial use", leaving MWC stuck between two state agencies in disagreement with each other.

Ultimately, the water right was obtained by entering a private agreement with DFWP to retire additional water rights in the future to mitigate the instream rights. Should the DNRC decide the additional mitigation water is not a "beneficial use", then those water rights would be terminated instead of being changed to mitigation.

Thermal treatment in the Duwamish Valley - a Detailed Look at Pre- and Post- Thermally Treated Soil and Groundwater

Tom Colligan, FloydSnider, Inc.

Remediation of the Fox Ave site, a DNAPL site located in south Seattle about 130 yards from the Duwamish Waterway, used Electrical Resistance Heating (ERH) to treat 42,000 cubic yards of solvent-contaminated soil which were discharging PCE, TCE, cis-dichloroethene, and vinyl chloride to the Waterway via seeps and upwelling groundwater. Sediments and biota of the Waterway were unaffected by groundwater and seep discharges, however. The ERH project was completed in May 2013 with extensive sampling of soils and groundwater both pre- and post- ERH to document treatment effectiveness. For soil, results indicate ERH reduced on average PCE and TCE concentrations by 99%. For groundwater, PCE and TCE concentrations were reduced by a similar amount, 98%. ERH was less effective in removal of daughter product from groundwater, however, with cis-dichloroethene and vinyl chloride reductions averaging between 77% and 51% respectively. The design and application of bio-polish to further treat the residual VOCs in the thermally-treated areas is the subject of the follow-on presentation.

Biopolish of a PCE/TCE Source Zone Following Electrical Resistance Heating

Clinton Jacob, Landau Associates
Brandon Duncan, Landau Associates

Source zone aquifer bioremediation is being conducted at the former Great Western Chemical site in the Georgetown neighborhood of Seattle, WA. This bioremediation project constitutes a "biopolish" following aggressive source zone mass reduction achieved through electrical resistance heating (ERH). ERH and biopolishing were implemented following the earlier use of other remedial technologies with limited success, including groundwater pump and treat, soil vapor extraction, dual phase extraction, and chemical oxidation.

Between the 1960s and 2000, chemical packaging and distribution activities resulted in aquifer contamination with chlorinated solvents tetrachloroethene (PCE) and trichloroethene (TCE) and their biodegradation breakdown products cis-1,2-dichloroethene (cDCE) and vinyl chloride (VC); reductive dechlorination to cDCE and VC resulted from naturally reduced aquifer conditions. Prior to ERH, dense non-aqueous phase liquid (DNAPL) was observed in site wells and PCE/TCE in groundwater approached solubility limits at depths up to 65 ft BGS. Lower concentrations of these contaminants extended approximately 500 ft to the Duwamish Waterway. The Lower Duwamish Waterway is a Superfund site due to accumulation of various contaminants in river sediments; however, due to their physical characteristics, the contaminants from this site do not accumulate in sediments.

ERH, completed in May 2013, resulted in substantial reduction of source zone contamination and elevated aquifer temperatures. ERH removed approximately 10,000 lbs of chlorinated solvents and removed approximately 99 percent of the PCE/TCE mass in source soils. Soil and groundwater temperatures increased to around 100ºC during ERH. Prior to bioremediation, total chlorinated volatile organic compound (cVOC) concentrations remaining in the area targeted for biopolish ranged from below reporting limits to 55 mg/L and averaged 3 mg/L. It was 20 months following ERH before the source zone aquifer cooled to below 35ºC.

Bioremediation activities began with injection of electron donor substrates and other amendments in July 2014 and January 2015. Approximately 130,000 gallons of injection solution consisting of water mixed with vegetable oil, sugar, and ferrous sulfate was injected to 11 deep and 8 shallow wells. Shallow and deeper water bearing zones are partially separated by a thin, discontinuous silt unit at approximately 15 BGS. Injection wells target a 70-ft deep treatment zone approximately 100 ft by 150 ft. The injection volume is designed for 12- to 15-ft radii of injection (ROI) for each well. Deep wells, which exhibited resumed production of VC following ERH, did not require bioaugmentation. Conversely, very little VC production was observed in shallow wells. Therefore, shallow wells were bioaugmented with groundwater from elsewhere at the site containing elevated cell counts of the Dehalococcoides (DHC) bacteria responsible for conversion of cDCE to VC. Injection of shallow zone wells was delayed until groundwater temperatures cooled to approximately 35 ºC, which is generally considered the maximum desired temperature for effective bioaugmentation and proliferation of DHC. Warm aquifer temperatures increase the reaction rate for biotic and abiotic degradation processes. Initial results are evaluated using quarterly monitoring data.

Results of First Full Scale 1,4-Dioxane Synthetic Media Groundwater Remediation System

Steven Woodard, ECT
Louis Burkhardt, Raytheon
presented by Michael Dodson, GRS

Background/Objectives

This paper describes the objectives, design, implementation and operation of the first full scale Synthetic Media system for 1,4-dioxane treatment. The site is located in Waltham, Massachusetts and was designed to treat 15 gpm of contaminated groundwater containing approximately 20 µg/l of 1,4-dioxane and 3,000 µg/l of chlorinated volatile organic carbon (cVOC) compounds. The treatment system is part of a larger, 100-gpm hydraulic control remedy. A modular system design was provided to allow for future relocation to an underground parking garage for a new apartment complex. The objectives of the remediation system are to: (1) provide long-term contaminant migration control; and (2) learn from this smaller system in anticipation of replacing the existing 100-gpm air stripper treatment system operating at an up-gradient location.

Approach/Activities

A new technology had to be selected, since the existing air stripper does not remove 1,4-dioxane. Synthetic media, specifically AMBERSORBTM 560, was identified as the technology more capable of improving operational reliability than other 1,4-dioxane treatment technologies. This new technology also facilitated compliance with tight permit limits (1,4-dioxane less than 3.0 µg/L during the design phase, now less than 0.3 µg/L), while simplifying process design and reducing long-term operating costs. The full scale system design was based on the results of extensive bench and pilot testing. Water is pumped in an up-flow mode through multiple synthetic media vessels operated in series, i.e. lead-lag-polish operation. The 1,4-dioxane and other contaminants preferentially adsorb to the media, as with granular activated carbon systems. Steam regeneration is performed in the vessel, in a down-flow mode.

Results/Lessons Learned

Influent 1,4-dioxane concentrations have ranged from 8 to 60 µg/L during the first 29 months of operation. Effluent concentrations have been consistently non-detect, at less than 1.6 µg/L (and more recently less than 0.04 µg/L), other than one brief period during startup. The other contaminants, total cVOCs, have been consistently removed to non-detect levels (less than 1.0 µg/L) for the entire 29-month operating period.

There were several key lessons learned during first full scale application of synthetic media for 1,4-dioxane treatment. The full miscibility of 1,4-dioxane in water made it more difficult to regenerate the media than anticipated, and higher steam temperatures are required to completely regenerate the media via dehydration. Steam regeneration system sizing must consider local boiler requirements, which can vary across the country. Finally, materials of construction/metallurgy in certain system components must account for the low pH of the condensate, typically in the 1.0 to 1.5 range, from the regeneration of chlorinated VOCs.

Accelerated Biodegradation of Petroleum and Chlorinated Contaminants Facilitated by an In Situ Colloidal Biomatrix

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Enhanced biodegradation and monitored natural attenuation (MNA) are effective, widely-used tools for elimination of organic contaminants in groundwater. The timeframe for treatment by these methods is on the order of months to years, during which time the contaminants are biodegraded to non-toxic end products. To significantly improve remediation performance beyond that of traditional enhanced bioremediation, a new in situ technology has been developed that accelerates biodegradation and drastically shortens the timeframes for reaching groundwater treatment goals.

This presentation demonstrates the efficacy of a colloidal in situ remediation agent that consists of highly sorptive activated carbon particles (1-2 microns in size) stabilized to transport widely through an aquifer upon injection. The stabilized colloids deposit on soil surfaces, forming a biomatrix that traps contaminants and accelerates their degradation. Some advantages of this approach include a rapid drop in groundwater concentrations, along with the ability to stop plume migration and protect sensitive property boundaries or environmental receptors. It is hypothesized that the protective effects of the colloidal agent last many years after its application.

Microcosm studies were performed to evaluate the biodegradation of both benzene and PCE in the presence of the colloidal biomatrix material. Contaminant concentrations in water were monitored weekly over the course of the studies by static headspace using GC-FID or GC-ECD methods. In both studies, the colloidal agent facilitated >90% destruction of contaminant within 28 days compared with controls. To further the understanding of the process, full-bottle extraction methods were developed to measure contaminant mass across all phases in the bottles (soil, water, and colloidal sorbent). The extraction techniques confirmed that colloidal agents rapidly reduced groundwater contaminant concentrations via sorption (70-90% in the first 24 hours), and subsequently accelerated biodegradation of the contaminants. All conditions were run in triplicate and results analyzed for statistical significance.

The performance of the colloidal biomatrix material will be reviewed in detailed comparison with sterile and live control samples, as well as those treated with traditional enhanced bioremediation methods. Benefits of the colloidal technology will be discussed, including advantages for treatment of sites exhibiting matrix back-diffusion of contaminants. A summary of performance in multiple field applications will also be presented.

A Desktop Suitability Assessment of Aquifer Storage and Recovery (ASR) in Washington State

Maria Gibson, Oregon State University
Michael Campana, Oregon State University

A large-scale Aquifer Storage and Recovery suitability assessment was conducted on 280 sites within Washington's 62 Water Resource Inventory Areas. Statewide suitability was evaluated using a two-pronged approach: a quantitative modified ASR metric and a qualitative site suitability assessment. The modified ASR metric, which is the ratio of an estimated injection rate and the aquifer's ability to accept this rate, indicates 24% and 29% of sites are marginally suitable and likely suitable for ASR, respectively. The site suitability assessment, which evaluates regulatory constraints, hydrogeologic parameters, and infrastructure considerations, in addition to climate change supply and demand projections for the Columbia River basin, indicates 51% of locations have between 40% to 60% ideal conditions suitable for ASR. Statewide storage potential of 500,000 acre-feet per year was realized, and sufficient suitability correlated with aquifers in the Puget Sound Lowland and the Columbia Plateau regional aquifer system. Although ASR suitability is highly site-specific, this technique can be used on a regional scale to provide rapid estimates of suitability and potential storage volume.

ASR Feasibility in the Ahtanum-Moxee Subbasin: A Case Study with the City of Yakima

Andrew Austreng, Golder Associates
Chris Pitre, Golder Associates

The City of Yakima, Central Yakima Valley, relies on a single Naches River surface water source for municipal water supply. This source may be reduced by drought conditions, water right curtailment, mechanical maintenance of the treatment plant, ice jams, and high turbidity during high flows. Climate change conditions are expected to further stress this supply, and the treatment plant may not be able to handle high turbidity conditions that may occur after a watershed forest fire. Existing backup groundwater wells are able to provide 50% of peak demand. The City is developing an Aquifer Storage and Recovery (ASR) program to permit additional groundwater sources to provide 100% backup capacity should the surface water source become unavailable.

The ASR program involves diverting water from the Naches River during low demand periods, treating the water to drinking water standards, delivering water through the City's distribution system to groundwater wells, for recharge into the Upper Ellensburg sandstone formation in the Ahtanum-Moxee Subbasin. Recharged water may then be withdrawn at later times for municipal use. The ASR program was assessed through development of a conceptual model, field testing and numerical modeling to support a groundwater reservoir ASR permit application.

A numerical groundwater flow model was developed to determine the recoverable quantity of recharged water. Modeling with the FEFlow finite element software package was conducted to estimate residual increased storage above baseline aquifer conditions. Recharged water that did not remain in storage was simulated to discharge to the Yakima River, providing increased streamflow.

Although water recharged and recovered met safe drinking water quality standards, All Known, Available and Reasonable Treatment (AKART) analysis was completed to address water quality concerns in the context of the antidegradation of groundwater rule (WAC 173-200). The primary concern was the presence of disinfection byproducts from chlorination. It was recommended to allow a variance.

ASR tests were conducted on two wells, one retrofitted for ASR and the other built with ASR functionality. Clogging during recharge occurred in one well (e.g., 25% loss of well efficiency), which was fully reversed during post-recharge pumping. No clogging effects were observed in a second well. The differences in clogging were attributed to (1) differences in distribution system materials, (2) pre-recharge flushing, and (3) control of flow patterns through valving during recharge. Water quality was monitored extensively to evaluate (1) compliance with drinking water standards, (2) disinfection by-products in the context of WAC 173-200, and (3) geochemical reactions that may affect operations. Water quality parameters are compatible with ASR operations.

ASR in the Ahtanum-Moxee Subbasin is feasible and capable of providing the backup groundwater supply capacity to the surface water source to provide the city with the reliability and redundancy needed for municipal supply in response to current and future conditions. Additionally, the City may be able to operate an ASR program to increase the Total Water Supply Available to water users in the Yakima Basin.

Shallow Aquifer Recharge to Meet Multiple Objectives in the Dungeness Basin

Amanda Cronin, Washington Water Trust
Peter Schwartzman, Pacific Groundwater Group

Regulation and management of groundwater use in the Dungeness Basin on Washington's Olympic Peninsula underwent a substantial change in January of 2013 when Department of Ecology's Dungeness Water Management Rule (WAC 173-518) went into effect. The most discussed and contentious element of this new rule is the requirement to mitigate for all new groundwater uses beginning in 2013. Under the rule, new surface-water uses are not allowed (with some small exceptions for environmental benefit) and mitigation is required for all groundwater uses including permit-exempt wells. The rule relies heavily on a groundwater model (developed for Ecology by Pacific Groundwater Group) to estimate how stream capture from new pumping wells is distributed among protected streams including the Dungeness River, two tributaries and seven independent streams that flow directly into the Strait of Juan De Fuca. Ecology's implementation of the rule requires no net annual baseflow impact to the regulated streams and zero flow depletion during critical periods (8/15-9/15) on the Dungeness River, 9/1-10/1 on small streams).

Providing water-for-water mitigation in Washington is a difficult prospect and is made even more challenging if mitigation is required to closely match the distribution of pumping impacts across multiple regulated streams. Traditionally the purchase and retirement of senior surface water-rights (most often irrigation rights) has been used to provide for mitigation for new groundwater uses. However, the small independent streams in the Dungeness rule area of WRIA 18 have few if any active water right uses that could be purchased, retired and used for mitigation. Washington Water Trust was tasked with setting up a mitigation bank in the Dungeness Basin to offset pumping impacts from exempt wells to the Dungeness River and protected streams. Shallow aquifer recharge (SAR) was determined to be the best solution for mitigating flow impacts in the small streams. SAR projects will be supplied with Dungeness River water available during the spring freshet and delivered via irrigation ditches. Several SAR sites are slated for construction in 2015.

The focus of the presentation will be on the use of shallow aquifer recharge to achieve the two primary water management goals of the Dungeness Basin: sustainable groundwater mitigation and flow restoration of the mainstem Dungeness River. We will provide an overview of the use of SAR as a source of mitigation and will describe use of the model to inform DWE's mitigation program and to calculate mitigation credits and debits. Designing and siting aquifer recharge projects for flow enhancement in the Dungeness River (i.e. habitat restoration) will also be covered.

Ongoing Evaluation of Aquifer Storage and Recovery, Columbia River Off-Channel Aquifer Storage Project

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Jon Rudders, GeoEngineers, Inc.
Chris Augustine, GSI Water Solutions, Inc.
John Covert, Washington Dept. of Ecology
Guy Gregory, Washington Dept. of Ecology

The Washington State Department of Ecology has been conducting an evaluation of the feasibility for aquifer storage and recovery (ASR) at a project site in Douglas County near the northwestern limits of the Columbia Plateau. If feasible, the project would store surface water from the Columbia River in aquifers of the Columbia River Basalt Group (CRBG). The study area is somewhat isolated topographically, with relatively limited local beneficial use of groundwater. Characterization of the CRBG and aquifer system so far includes construction of test and monitoring wells, down-hole video surveys, borehole geophysical logging, analyses of formation samples by X-ray fluorescence, groundwater chemical analyses, and aquifer testing and hydraulic analysis.

Subsurface explorations have encountered a layered aquifer system consisting of four major hydrostratigraphic units. These include, from youngest to oldest: (1) Wanapum Basalt, (2) Vantage Interbed, (3) Grande Ronde Basalt, and (4) pre-Miocene basement rocks. Within the study area, the Vantage Interbed is interpreted to be an aquitard, with water levels in the Grande Ronde Basalt-hosted aquifer generally about 15 to 25 feet lower than water levels in the overlying Wanapum Basalt-hosted aquifer. Surface exposures and test drilling indicate that the Grande Ronde Basalt aquifer is bifurcated in the study area by a mostly buried ridge of basement rock.

Within the project area to date, five test wells have been completed as open-hole borings to depths of up to 500 feet in the Grande Ronde Basalt. The uncased portions extend between depths of about 225 feet and 500 feet. Seven monitoring wells up to 600 feet deep have been completed within the Grande Ronde at varying distances from the test wells. In addition, two monitoring wells were completed within the overlying Wanapum Basalt aquifer and one monitoring well was completed within the Vantage Interbed. Aquifer testing consisted of step-rate pumping tests and 24- to 72-hour constant rate pumping tests at each of the five test well locations. An immediate hydraulic response was observed in Grande Ronde Basalt aquifer monitoring wells located near the pumping wells. No measurable drawdown as a result of test pumping has been observed in monitoring points within the Wanapum Basalt aquifer, or in Grande Ronde Basalt aquifer observation wells located a mile or more distant from pumping wells.

Analysis of the aquifer testing data to date indicates low-to-moderate transmissivity and good storativity for the Grande Ronde unit. The aquifer test data and groundwater gradients suggest that the Grande Ronde aquifer in the study area is highly bounded. Based on information obtained to date, there is good potential for regional scale storage, and a third phase of investigation is scheduled for 2015.

Considerations for Horizontal Directional Drilling in Groundwater Remediation Applications in the Pacific Northwest

Michael Lubrecht, Directed Technologies Drilling, Inc.
James Doesburg, Directed Technologies Drilling, Inc.

Horizontal wells and horizontal directional drilling (or HDD) are becoming more common as a remedy for contaminated sites. With proper well design and installation, horizontal wells have proven to be very effective in treating large groundwater volumes using treatment methods such as biosparging, air sparging or oxygen injection, and injection or recirculation of biological substrates. Similarly, HDD applications for groundwater supply for other uses, such as irrigation, oil and gas production support, and residential or municipal water supply, are more frequently being considered.

HDD technology has been in mainstream remediation use for nearly 15 years. Developed originally as a soil drilling technology, the industry has advanced to engage more challenging drilling projects. Other innovations in drilling fluid technology makes it possible to install more efficient horizontal wells that limit damage to the formation and improve recovery.

In the Pacific Northwest, horizontal wells have seen limited use, in comparison with other regions such as California, the Northeast, and the Gulf Coast. Our challenging drilling conditions and regulatory environment sometimes impose perceived barriers on the application of the technology.

This presentation provides insight into the use of HDD in the Pacific Northwest in both geological and regulatory contexts. The author shares experience with a variety of drilling conditions and drilling solutions for horizontal well installation in northwest geological settings. The presentation includes a summary of current regulatory hurdles for use of horizontal wells in Washington, and how to address those.

Horizontal wells often compare favorably to competing technologies for site cleanup and groundwater supply under a variety of circumstances. Better understanding of the technology may lead to more frequent consideration and utilization within the Northwest, with corresponding benefits.

Horizontal Environmental Wells Case Histories

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In the past 25 years horizontal environmental wells have been installed in every state in the U.S.. The reasons horizontal wells were chosen instead of vertical wells were typically because the sites to be remediated were either inaccessible using vertical technology or because the areas requiring treatment were so large that vertical wells were a more expensive choice. In the past 25 years, horizontal environmental wells were designed and installed for soil vapor extraction, groundwater extraction, dual phase extraction, groundwater barrier wells, air sparging, in-situ chemical oxidation, in-situ heating, and nutrient injection. These wells have shown that this technology can be a valuable tool for scientists and engineers working in the remediation field today.

This paper will discuss three case studies: long horizontal air sparge wells at air fields; below ground recirculating wells, and emulsified vegetable oil injection wells. We will discuss the cost differential between vertical and horizontal systems and the effectiveness of the treatment deployed.

Opportunistic Use of Shallow Subsurface Aquitard Topography for LNAPL Plume Interception and Recovery

Piper Roelen, Landau Associates, Inc.
Tom Briggs, Landau Associates, Inc.
Clint Jacob, Landau Associates, Inc.
James Raspen, Landau Associates, Inc.
Bryce Robbert, Avista Corporation

In December 2013, during a regular fuel inventory check at their Kettle Falls Generation Station facility, Avista Corporation identified a rapid release of approximately 10,000 gallons of diesel fuel to the subsurface. The release was traced to a corroded underground distribution pipeline. Subsequent investigations determined that the released diesel migrated vertically beneath the pipeline until it reached a silt aquitard approximately 20 ft below ground surface. The fuel then appeared to migrate dowgradient along the top of the silt unit, primarily through a sandy gravel layer immediately above the silt. A thin saturated zone, around 2 to 3 feet in thickness, was also observed seasonally within this sandy gravel layer. An unknown portion of the diesel plume was determined to be present beneath an enormous wood chip pile used by the facility as fuel for combustion-based power generation.

Landau Associates was contracted to complete additional site investigation activities and design and construct a remediation system. The work had to be completed during the facility's annual shutdown/maintenance period when the wood chip pile was relocated, providing access to the ground surface above the plume. Within an approximately 6-week period, Landau Associates completed delineation of a light non-aqueous phase liquid (LNAPL) diesel plume and an associated dissolved-phase plume, and designed and installed an LNAPL interception and recovery system. The investigation included collecting soil and groundwater samples using direct push equipment. During drilling, the topography of the shallow silt aquitard was mapped using depth to silt measurements and surveyed ground surface elevations. The topography of the silt unit, along with observations of diesel-impacted soil, was used to identify the approximate configuration, limits, and potential flow path of the plume. This data was used advantageously to design and construct a 205-ft-long interception trench that was keyed into the silt aquitard to create a physical barrier to the advancement of the LNAPL plume. A sump was installed at the end of the trench for recovery of LNAPL and contaminated groundwater. After aboveground product separation and activated carbon treatment, the groundwater is re-injected upgradient of the plume through an infiltration trench to increase flushing of the impacted area. Once active groundwater extraction was commenced in late July 2014, recovery of LNAPL in the aboveground separator was observed within 2 weeks. As of the end of September 2014, approximately 190 gallons of diesel fuel have been recovered.

Due to the relatively low mobility of diesel, diminishing or negligible recovery of mobile product is expected to occur after a relatively short time period. This condition would likely indicate that only residual LNAPL saturation remains in the smear zone and soil-groundwater matrix. At this stage, a non-toxic and biodegradable surfactant is planned to be introduced through the infiltration trench to reduce the interfacial tension and viscosity of the remaining diesel and flush it into the downgradient interception trench. The objective of the surfactant flushing would be to reduce the overall restoration timeframe for the site.

Nineteen-Year Performance of a Surface Barrier at the Hanford Site

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Mark Freshley, Pacific Northwest National Laboratory
Dawn Wellman, Pacific Northwest National Laboratory

Surface barriers have been proposed for use at the Department of Energy's Hanford Site to isolate certain radioactive waste sites that, for reasons of cost or worker safety, may not be exhumed. A surface barrier is an engineered cover that consists of components designed to contain, control, and retard the flow of water and the migration of radioactive contaminants in the subsurface. A surface barrier was constructed over a waste site (216-B-57) in 1994 using mostly natural materials. This barrier is one of several long-term (design life of 1000 years) surface barriers over a waste site in a semi-arid region of the United States. The 80 m by 40 m center portion of the barrier consists of a 2-m-thick layer of silt loam resting on a capillary break of coarser materials ranging in sequence from sand to gravel to basalt riprap. The vegetation growing on the cover consists of assorted shrubs and annuals typical of the surrounding shrub-steppe environment. To investigate the effect of a much wetter climate, the northern half of the barrier was irrigated from 1995 to 1997 so that the total amount of water falling on it was three times the average precipitation, while the southern half was exposed to natural precipitation conditions. To investigate the potential effects of a wildfire on barrier performance, the vegetation on the northern half of the barrier was burned by a controlled fire in 2008.

The barrier's hydrological and ecological performance and stability were monitored for 19 years, which is the time between completion of construction and end of the monitoring program in 2013. Extensive instrumentation was used to monitor the hydrological regime above, within, below, and around the barrier. Specifically, natural precipitation and irrigation were measured with rain gauges, runoff water with a runoff flume, soil water content within the barrier at 12 monitoring stations (each equipped with a neutron probe, a capacitance probe, and time domain reflectometry probes), and soil water pressure with gypsum blocks and heat dissipation units. Drainage through the barrier and the side slopes was measured with 12 water collection vaults, respectively, for 12 zones. Each drainage vault was equipped with a dosing siphon, a dose counter, a pressure transducer to measure the water level, and a tipping bucket to measure the inflow. The vegetation condition and species composition were assessed with both ground-based field surveys and aerial photogrammetry in selected years. The settlement and elevation of the barrier and the stability of the riprap side slope were monitored roughly annually. Overall, the barrier performed as or better than expected.

City of White Salmon ASR – Completing the Supply Puzzle

Joseph Morrice, Aspect Consulting, LLC
Timothy Flynn, Aspect Consulting, LLC

Municipal water systems face continual challenges providing safe, reliable water supplies for their communities. These challenges can include physical constraints, such as declining aquifer yield, and compliance with regulatory requirements, such as water right permitting and water treatment standards. This talk will provide a case study of the City of White Salmon water system and the potential for aquifer storage and recovery (ASR) to compliment other actions to meet both regulatory and physical challenges for the water system.

The City was historically served by a high quality surface water source from Buck Creek, a tributary of the White Salmon River. When compliance with increased surface treatment standards proved prohibitively costly the City, in partnership with the City of Bingen and Port of Klickitat, developed a new groundwater well field to replace surface supplies. The well field, brought online in 2002, was initially highly productive, but has shown significant decrease in yield over time. Additionally, the City faced shortages in the annual water supply authorized under their water rights, forcing a moratorium on new connections. The City instituted strict conservation measures, including restrictions on outdoor water use, but still faced a deficit in meeting demands under projected growth.

In response to these shortages in both source yield and regulatory authority, the City has initiated a series of actions to improve the reliability of supply. These include reactivating the surface water diversion, constructing a sand filtration plant to meet treatment standards, and securing a new, mitigated water right to increase capacity of the water supply system and the authorized surface water diversions. Concurrently, the City has been pursuing an ASR project to take seasonally available winter flows from the new treatment plant, inject treated water into the City production well that has shown the greatest decrease in yield, and recover water during peak summer demands. The ASR project is expected to increase the quantity and reliability of supply while reducing demand on summer flows in Buck Creek and the White Salmon River, an issue of concern to basin stakeholders. The ASR project is currently in the pilot testing stage, with injection, storage and withdrawal cycles planned for winter 2014-2015.

Initial mitigation for the City's new water right was provided by lease of a trust water right. In reviewing options to secure long-term mitigation instead of continuing the lease, the City contracted with a local irrigation district to buy water imported from the Lewis River drainage to the White Salmon River drainage. This water was imported via a canal originally constructed as mitigation for the effect of the irrigation district's diversion on operation of Condit Dam. With removal of the dam in 2011, the City was able to purchase water from the irrigation district, place the imported water into trust and establish a water bank to mitigate for new out-of-stream uses.

Combined, these efforts are putting the City on a path to a reliable and secure water supply to meet projected long-term growth in demands.

City of Kennewick Aquifer Storage and Recovery Project: Developing a Cool Thermal Storage Zone in a Warm Aquifer

Phillip Brown, GSI Water Solutions Inc.
Elizabeth Haas, GSI Water Solutions Inc.

The City of Kennewick collaborated with the Washington Department of Ecology to develop an Aquifer Storage and Recovery system in the City's rapidly expanding Southridge area. The City is storing treated drinking water from its Columbia River supply source and recovering that water to benefit the supply system operations and summer supply availability. In the project area, the deeper portions of the Wanapum Formation basalts are relatively undeveloped and the aquifer hydraulics were not well-defined. An exploratory drilling and testing program identified highly productive interflows that would support ASR storage zone development at economic rates at approximately 1,200 feet below ground surface. While the target storage zone exhibited relatively good background groundwater quality, the physical condition that had the greatest potential to limit the utility of the aquifer system for ASR development and municipal use was the background water temperature – approximately 28°C (84°F). The project team developed an ASR pilot testing program designed to quickly assess aquifer hydraulic response to recharge, potential changes in recovered water quality, aquifer thermal response to ASR, and the primary goal of assessing the City's ability to recover water cool enough for municipal use. That program was implemented in the spring and summer of 2014, and the results indicate ASR development at this location could be a significant benefit to the City and regional water management plans. The City is permitted to implement an operational-scale ASR cycle in 2015.

This presentation will outline the development stages of the City's ASR project, the analysis of hydraulic response data, and the Total Storage Volume (TSV) approach that the City is using for thermal storage zone development that balances the City's supply needs with thermal recovery efficiency.

Aquifer Recharge as a Water Management Tool in a Bi-State Alluvial Fan System

Steven Patten, WWBWC
Brian Wolcott, WWBWC
Troy Baker, WWBWC

Unlike many other aquifer recharge projects being implemented nationally and internationally, Walla Walla Basin alluvial aquifer recharge projects are not currently being implemented for aquifer storage and recovery (commonly referred to as ASR). Although some use of the improved aquifer is likely occurring at wells down gradient of the current aquifer recharge (AR) sites, the primary purpose is for public and regional benefit to restore the alluvial aquifer and enhance and/or support groundwater contributions to instream flow thereby maximizing the aquifer's potential with multiple benefits for aquatic life, recreational water use, domestic use, and irrigation use.

With agricultural (irrigation demands) and urban development (construction of flood control levees), the hydrology of the Walla Walla Basin has been fundamentally changed. These changes have contributed to the listing of two fish species under the ESA, a declining alluvial aquifer, reduction in spring flows and reduced stream flow in streams that have high rates of channel bed seepage. Aquifer recharge simulates the historic floodplain functions in the Walla Walla Basin that have been lost due to development.

Starting in 2003, the Walla Walla Basin Watershed Council (WWBWC) partnered with local irrigation districts to develop aquifer recharge pilot projects. The Johnson aquifer recharge site has operated since the spring of 2004 and currently has an infiltration rate of ~16-17 cfs into ~2.5 acres of infiltration basins and 4 infiltration galleries. Aquifer recharge at the Johnson site has resulted in improvements to both the surface water and groundwater systems. Down-gradient well data indicate increased aquifer storage. After being dry for decades, Johnson spring-creek began to have seasonal flows in 2005. These seasonal flows are a direct result of aquifer recharge activities. The WWBWC has expanded the aquifer recharge program to 10 sites and is planning for additional projects in the near future.

These aquifer recharge projects have undergone extensive water quality monitoring before, during, and after operations. These data have demonstrated that contaminants are not being introduced to the alluvial aquifer through aquifer recharge operations and that groundwater degradation is not occurring as a result of these projects. In several cases water quality parameters in the groundwater system improved as a result of aquifer recharge activity.

The bi-state nature of the Walla Walla basin adds to the complexity of the WWBWC's AR program. Water management laws, concerning both water rights and water quality, vary significantly from Washington to Oregon. The WWBWC's aquifer recharge strategic plan is structured to address groundwater conditions within the hydrologic boundaries (i.e. the Walla Walla Watershed) rather than political boundaries.

Managed Aquifer Recharge in the Walla Walla Basin for Ecological and Agricultural Water Supply Enhancement Assessed Through Numerical Modeling

Jacob Scherberg, GeoSystems Analysis, Inc
Steven Patten, Walla Walla Basin Watershed Council
Troy Baker, Walla Walla Basin Watershed Council
Jason Keller, GeoSystems Analysis

The Walla Walla Basin, a semi-arid region of Eastern Washington and Oregon, USA, is faced with the challenge of providing water required for agricultural production while maintaining stream conditions that support several endangered salmonid populations. There is an agreement between stakeholders to maintain 25 ft^3/second in the Walla Walla River which effectively limits withdrawals for irrigation over the summer months. As a result, groundwater is relied upon to support agricultural production, increasing demand on an underlying gravel aquifer system that has experienced groundwater level declines for over 60 years.

In 2004 the Walla Walla Basin Watershed Council initiated a managed aquifer recharge (MAR) program in which water is diverted from the Walla Walla River during winter/spring months into infiltration basins and galleries to recharge the gravel aquifer system. The primary goals of the MAR program are to stabilize aquifer levels while increasing the availability of groundwater for summer irrigation and providing ecological benefits such as enhancing off channel tributaries though return flows, providing thermal refuge for fish. A key component to the MAR program has been the application of the numerical groundwater-surface water model, Integrated Water Flow Model (IWFM), to simulate hydrological conditions in the basin. The calibrated model has been applied as a planning tool to provide a quantitative analysis of basin wide water use and evaluate the ability of MAR to mitigate declining groundwater levels. Model results have illustrated that the water resources within the basin are sufficient to stabilize aquifer levels, supply irrigators, and support fisheries if aquifer recharge is applied over the winter and spring months and groundwater is used for summer irrigation. Without MAR the model predicts continued groundwater declines. More recent modeling has focused on identifying an optimal strategy for MAR within the Walla Walla Basin. This includes evaluating the distribution of recharge facilities with consideration of the concurrent goals of aquifer stabilization, stream enhancement, and irrigation supply. The model is also used to assess the amount of recharge water required for efficacy of the MAR program and to address the challenges of retaining recharged water in the highly permeable gravel aquifer so that it is available when surface water resources are limited.

Update of Post CO_2 Injection Activities for the Wallula Basalt Carbon Sequestration Pilot Project

Frank Spane, Pacific Northwest National Laboratory
Pete McGrail, Pacific Northwest National Laboratory
James Amonette, Pacific Northwest National Laboratory
Chris Thompson, Pacific Northwest National Laboratory
Darrell Newcomer, Pacific Northwest National Laboratory

Continental flood basalt provinces represent some of the largest geologic formational structures in the world and occur within regions of the U.S. (and other countries such as India) where subsurface sedimentary basin storage capacity is limited. Consequently, demonstration of commercial-scale subsurface storage within deep flood basalts is important in meeting global CO_2 emission targets.

In 2009, the U.S. Department of Energy Big Sky Regional Carbon Sequestration Partnership completed the drilling and detailed characterization of the first continental flood basalt CO_2 sequestration pilot borehole to a total depth of 4,110 ft. The basalt pilot borehole is located at the Boise White Paper Mill property near the town of Wallula in southeastern Washington state. The pilot well characterization program included reconnaissance-level hydrologic tests on selected basalt interflow reservoir zones and flow-interior/caprock intervals during and after completion of the borehole drilling activities to support selection of a candidate injection reservoir for subsequent CO_2 sequestration studies. Based on the results of the active borehole characterization program, an injection reservoir was identified between a depth interval of 2,716 and 2,870 ft that met CO_2 injection objectives and Washington state permit requirements.

Following well completion activities in June 2009, baseline reservoir zone pressure was monitored over an extended period (July 2009 through December 2010) to evaluate long-term seasonal and short-term, temporal reservoir response dynamics to natural and human-related stress activities. After baseline pressure monitoring was completed, a series of hydrologic reservoir well tests were conducted in 2011 and 2012 to assess the possible effects of well completion activities on the injection reservoir, to determine intermediate-scale reservoir hydraulic properties, and to detect presence of any hydrologic boundaries in the reservoir. Based on the favorable hydrologic test results, the project was accepted by the Department of Energy to proceed with CO_2 injection and post-injection monitoring in 2013.

During the 2013 field pilot injection phase, 977 metric tons of CO_2 were injected into the basalt reservoir over a continuous, 24 -day period in July and August. Downhole injection pressures were maintained at a level of <400 psi above static pre-injection reservoir levels. Post-injection surface monitoring and downhole reservoir pressure monitoring and fluid sampling for geochemical reaction characterization is scheduled to continue until completion of the field pilot study in July 2015. Chemical analysis of fluid samples collected to date show elevated concentrations of Ca, Mg, and Fe and isotopic shifts that are consistent with chemical reactions between the basalt and injected CO_2. Final planned post-injection field activities include: detailed wireline logging for determining the location of injected CO_2 within the injection reservoir; side-wall coring for assessing CO_2 geochemical reaction products with the host basalt; and hydrologic testing for evaluating possible reservoir permeability changes associated with the CO_2 injection. Following completion of the final post-injection characterization activities, the pilot well will be decommissioned.

Warming Temperatures Threaten Water Supplies in the Pacific Northwest by Shrinking Mountain Glaciers

Matt Bachmann, US Geological Survey

Receding maritime glaciers in the Pacific Northwest confer a strong resistance to climate change impacts on the timing but not peak flow rates of the streams and rivers into which they melt. Since 1957 the U.S. Geological Survey has been measuring glacier mass balance and immediate downstream hydrology at South Cascade Glacier in Washington State, and this multi-decadal record exhibits significantly less hydrologic disturbance in the glacially supported Cascade River than in an adjacent non-glaciated basin. The average timing of peak base flow at the Middle Tarn gaging station (12181090) below South Cascade Glacier now occurs 3 days earlier than it did 56 years ago, but occurs 24 days earlier on the adjacent non-glaciated Salix Creek gage (12181200). Baseflow separation was conducted using a recursive digital filter following Eckhardt 2005 and records from multiple sites were collated using a double mass analysis after Linsley et al. 1980. Summer temperatures have risen 3.5 degrees Celsius at South Cascade Glacier since 1957, resulting in a net mass loss of approximately 45% of glacier ice volume. As Northwest glaciers continue to recede in future years, hydrological impacts from a warming climate which are currently moderated by glacial contribution to streamflow are anticipated to materialize, resulting in earlier and more severe peak flows in rivers in the North Cascades.

Linsley, Ray K., Kohler, Max Adam, Paulhus, Joseph H., 1982, Hydrology for Engineers: New York, McGraw-Hill, 508 p.

The Missouri Carbon Sequestration Project - A Model for State-wide Assessment of Carbon Sequestration Feasibility

Gary Pendergrass, GeoEngineers, Inc.

With growing concern for greenhouse gas emissions and the prospect of new regulations being promulgated by the federal government, state environmental agencies and electric utility groups across the nation must find ways to reduce carbon emissions safely, effectively and economically. The President's Climate Action Plan mandates that US greenhouse gas emissions be reduced to 17 percent below 2005 levels by 2020, and new rules proposed by the US Environmental Protection Agency set performance standards designed to achieve this mandate. Under the proposed rules, new fossil fuel-fired power plants would be required to implement partial carbon capture and storage (CCS). Existing fossil fuel-fired power plants are not strictly required to implement CCS, but it is provided as an option if needed to achieve the required emission reductions.

The Missouri Carbon Sequestration Project was an important step toward Missouri utilities addressing this need, and the project serves as a model for state-wide assessment of carbon sequestration feasibility by state environmental agencies or electric utility groups.

The research project was led by City Utilities of Springfield, Missouri under a Cooperative Agreement with the US Department of Energy. The project's goal was to assess the feasibility of onsite carbon sequestration at Missouri power plant sites. Onsite sequestration avoids the time, expense, and risk involved in construction and operation of pipelines and compression stations necessary to transfer carbon dioxide from individual power plants to large, regional carbon sequestration sites in other states.

The project involved drilling four deep exploratory boreholes in various geological settings to assess the potential for carbon sequestration. The Lamotte Sandstone, the basal sandstone in Missouri that directly overlies Precambrian basement rock, was the target formation for geological sequestration of carbon dioxide. The Lamotte underlies most of the state, and is overlain by the Davis Formation, a very competent confining layer comprised primarily of shale.

Work included drilling exploratory boreholes into Precambrian basement rock, acquisition of continuous rock core from the confining layer and target formation, petrographic and mineralogical analysis, determination of porosity and permeability, hydrologic testing, pressure testing, determination of reservoir properties, and estimation of CO2 storage capacity.

Project partners included City Utilities, Ameren Missouri, Associated Electric Cooperative, Inc., The Empire District Electric Company, Kansas City Power & Light, the Missouri Department of Natural Resources, Missouri University of Science & Technology, and Missouri State University.

Funding was secured through two federal appropriations. Matching funds were provided by the participating electric companies.

The presentation will detail how the project was initiated and organized, how funding was secured, how the work was planned and executed, the research findings, the lessons learned, and how this process can be utilized by other states to assess carbon sequestration feasibility to meet emission reduction goals.

A Retrospective of Contributions & Highlights of Water Resources on Vashon-Maury Island, King County, WA.

Sevin Bilir, King County Science and Technical Support Section
Eric Ferguson, King County DNRP
Curtis DeGasperi, King County DNRP

To address water resource concerns on Vashon-Maury Island in the Puget Sound, King County has conducted extensive environmental monitoring and modeling beginning in 2001. Vashon-Maury Island is a designated Sole Source Aquifer with no hydrogeologic connection with mainland aquifers and all freshwater supplied by precipitation. On this largely rural island, human activities, such as groundwater withdrawals, small-scale crop and livestock farming, on-site septic systems, land clearing, and landscape maintenance practices are the dominant drivers impacting water resources. The monitoring program includes precipitation, stream flows, groundwater elevations, stream water quality, and groundwater quality.

Overall, water resources do not appear to be excessively impacted. Stream nitrate and bacteria levels are typical of rural streams in the Puget Lowland. Stream flashiness, an indicator of the impacts of land conversion on flow, is characteristic of many rural streams and varies according to annual weather patterns. Groundwater contour maps show some variability in water levels, especially around the larger water supply wells, with future population growth likely to slightly exacerbate this issue. The groundwater water quality is good overall, with ongoing attention warranted for nitrates. King County has conducted outreach activities to engage islanders, including establishing a formal Groundwater Protection Committee. Over time, islanders have become more knowledgeable about their water resources and the impacts that may reduce the availability for future use. Maintaining a strong program and close relationships with island residents is a long-term goal and challenge given budget constraints.

A Case Study in the Development and Application of Multipurpose Tools for Aquifer Management

Richard S. Malin, Parametrix
Michael J. Riley, Anchor QEA

The Port of Vancouver, USA (Port), is located in the Vancouver Lake Lowlands (VLL). The Pleistocene alluvial aquifer (PAA) underlying the lowlands is a critical resource to meet current and future drinking water, industrial, and natural resource demands of southwest Washington. Former industrial uses at and near the Port resulted in volatile organic compound contamination in the aquifer. Since 1998, the Port has been investigating and remediating contamination in this aquifer. In addition, local water supply agencies have been developing additional wellfields that tap this aquifer. Overall management of the aquifer is a critical issue for the Port, local water supply agencies, industrial water users, the Washington State Department of Ecology, and other stakeholders.

Critical aquifer management challenges associated with the VLL PAA involve the intersection of increasing water supply demands, continued industrial use and development, and the presence of volatile organic contamination associated with historical industrial use and handling. The productivity of the PAA and constraints (including Endangered Species Act issues) related to other water resources resulted in the VLL area being identified as the source to meet future drinking water demand. The Port and other industries in the VLL area serve as economic drivers for the region; several of the larger industrial businesses have significant water rights in the aquifer.

The development and application of aquifer management tools involved a series of iterative steps where information from one step served to inform other steps and was used to check and confirm prior steps. These steps include site characterization, including the development of characterization tools, and groundwater model development, testing, calibration, use, and updating.

The PAA in the VLL is highly transmissive, hydraulically connected to the tidally influenced Columbia River, has a flat potentiometric surface, and is highly influenced by pumping stresses. These features complicated determination of groundwater flow and the transport of contaminants. Detailed characterization was completed to properly assess the hydrogeologic parameters. Data collection included discrete-depth sampling, deployment of a pressure transducer network, use of stable isotope analysis, determination of historic and current production well pump rates, and site area and region depositional unit characterization. These data were used to support development of a groundwater flow and transport model. The model was initially used to understand how the contaminant plume evolved and to evaluate source control actions. It was then further enhanced to consider future water supply development in the VLL area, changes in pumping stresses in the model area, and evaluation of a pump and treat system to hydraulically control the contaminant plume. The model also served as a tool to evaluate observed conditions and to simulate future water supply development scenarios. The model development process allowed the model to be tested and calibrated multiple times using data over a period of years.

Science-Based Approaches to Protecting Groundwater Quality from Stormwater Infiltation at UICs: Lessons Learned from Oregon

Matthew Kohlbecker, Oregon Department of Environmental Quality

Infiltrating stormwater into subsurface soils using drywells, or Underground Injection Controls (UICs), is a technique commonly employed to manage stormwater runoff from roofs, municipal rights of way, and parking lots. To ensure protection of groundwater resources, UICs are regulated under the federal Safe Drinking Water Act and state of Oregon UIC rules that were developed when EPA delegated the program to the Department of Environmental Quality in 1984.

Oregon's approach to regulating stormwater UICs has resulted in perhaps the most comprehensive understanding of stormwater UICs in the nation. Specifically, an extensive stormwater quality dataset consisting of thousands of samples has been generated, which has been used to identify the type and concentrations of pollutants in stormwater runoff from parking lots and municipal rights of way with a high degree of confidence. In addition, pollutant fate and transport studies have been used to evaluate pollutant attenuation after discharge from a UIC. Taken together, this information is being used to evaluate the types of UICs that pose the greatest risk of adverse environmental impact (stormwater and other), and to inform strategies for groundwater protection.

This talk will present a regulatory framework for UICs, and discuss the modeling efforts and stormwater data with the objective of informing strategies for effective protection of the groundwater resource.

Production Well Design: Engineering and Experience

Eric Weber, Landau Associates, Inc.
Paul Querna, PQ Products, Inc.
Ben Lee, Landau Associates, Inc.

Groundwater supply accounts for approximately one-fourth of all fresh water use in Washington State (USGS 2010). Access to that groundwater is accomplished via more than 3,500 documented domestic, industrial, public, and irrigation supply wells and countless other undocumented and permit-exempt private supply wells (Ecology 2014). Efficient and sustained withdrawal of groundwater requires a thoughtful engineering approach and an understanding of regulatory constraints. We summarize a successful approach to well installation consisting of the following steps:

- Permitting
- PreDesign
    - Design Pumping Rate
    - Site Constraints
    - Hydrogeologic Constraints
    - Regulatory Constraints
- Drilling and Installation
    - Drilling Method
    - Casing
    - Screen Design
    - Installation
    - Development
- Well Testing
    - Step Test and Pump Selection
    - Water Quality

To illustrate each step in the process, we present a recent case study of the design and installation of an irrigation supply well in northern Okanogan County that was engineered to withdraw at a maximum authorized instantaneous rate of 1,200 gallons per minute.

Permit-Exempt Domestic Well Use in Washington

Tom Culhane, WA State Department of Ecology - Water Resources Program
Dave Nazy, WA State Department of Ecology - Office of Columbia River

Washington State's groundwater permit exemption allows some groundwater users to construct wells and apply water to beneficial use without first obtaining water right permits. One such category includes single-family homes or groups of homes that use no more than 5,000 gallons per day. The Department of Ecology (Ecology) investigated the increasing numbers of these permit-exempt domestic wells, and their associated consumptive use relative to other water uses. Analyses were conducted for wells that fall under the category of "self-supplied domestic use", which includes both permit-exempt domestic wells and a small number of Group B water system wells that use water under water right permits.

Two methods were used to estimate the increase in the number of permit-exempt domestic wells, including: one based on Ecology well construction data, and another based on a combination of WDOH Group A Public Water Supply system data and U.S. Census Bureau data. Study results suggest data from Ecology's well construction database provide the best estimates of the number of new permit-exempt domestic wells. Making various assumptions, we conclude approximately 17,200 permit-exempt domestic wells were drilled statewide from 2008 through September 4, 2014 - ranging from 17 wells in Garfield County to 1,238 wells in Okanagan County.

Consumptive water use estimates were based on 2005 USGS total water use estimates (Lane, 2009) and many assumptions. Some key assumptions regarding permit-exempt domestic wells included: all outdoor water use occurred within a 4-month irrigation season, indoor water use equals 57.1 gallons per day per person, and volumetrically 10 percent of indoor use and 80 percent of outdoor water use is consumptive. Based on these and other assumptions, Ecology estimates that statewide, during the irrigation season, self-supplied wells account for about 0.9 percent of the overall consumptive water use. However, according to our estimates even public water supply systems account for only about 4.6 percent of consumptive water use, and overall most consumptive water use is due to irrigation.

It is critical to view our study's consumptive use estimates in the context of method limitations. From a water management perspective, scenarios of greatest concern involve: (1) relatively small watersheds where many permit-exempt domestic wells are drilled in aquifers highly connected to small streams, (2) a considerable amount of outdoor watering, and/or (3) surface water depletion in endangered aquatic species habitat. Consumptive water use in areas with high concentrations of permit-exempt domestic wells was not specifically addressed during this study. However, based on our analysis one major conclusion is that the greatest return from a water management perspective will be gained by focusing on those areas where potential impacts are greatest.

Instream Flow Policy and Legal Implications

David Christensen, Water Resources Program, Washington Department of Ecology

Since the adoption of the Water Resources Act of 1971, Ecology has attempted to develop a water management framework that provides a reliable future water supply for community needs while protecting instream resources and values. Case law over the past twenty years, most recently the Supreme Court ruling in Swinomish v. Ecology in late 2013, have increased the challenge to balance needs from competing uses and users. Ecology has been evaluating how it can meet its water resource management mandates and comply with the restrictions identified by the court. Ecology has a significant challenge in protecting instream flows and senior water rights holders while not precluding all rural development.

A key part of the Swinomish decision includes a finding that Ecology erred in using the Overriding Consideration of Public Interest (OCPI) to justify creating reserves of water for use by people with private domestic wells because minimum instream flows were not being met. Prior to the Swinomish decision, Ecology weighed the community needs for continued limited rural development and invoked OCPI to allow for some impairment to instream flows. Ecology relied on an OCPI finding to establish reserves of water for future rural domestic uses (and other uses in some cases), because we could not make a finding of water availability for the reserves. Without reserves, adopting instream flow rules may preclude rural development if mitigation for stream flow impacts is not available. This has resulted in a development moratorium for many property owners in the Skagit watershed who cannot fully mitigate all water use impacts and uncertain legal status for some who have already developed their property.

Instream Flow Science

Jim Pacheco, Water Resources Program, Washington Department of Ecology

Washington receives a lot of precipitation. Unfortunately, it doesn't usually come when we need it the most, in the late summer and early fall. With water availability and water use in conflict, instream resources, such as fish and wildlife, recreation, and aesthetics, have suffered.

Establishing instream flows seeks to protect and preserve these resources. Instream flow science helps provides the quantifiable justification and legally defensible rationale for the instream flow. The Department of Ecology has used a number on methods to develop instream flow recommendations and rules. The preferred method is the Physical HABitat SIMulation model or PHABSIM, while most common approach has been the Toe-Width method. These models tell us what stream flow provides the most fish habitat and guides the discussion, but actual instream flow recommendations come from negotiations with many interested parties.

At times the instream flow is higher than the average flow in the stream. Stream flows vary from one year to the next. Because it usually takes a "wet" summer/fall to provide good fish habitat, the instream flow is set at those rare, but beneficial higher flow, in order to protect and preserve the resource available during those rare good habitat years.

Legal History of Instream Flows

Jennifer Holderman, Water Resources Program, Washington Department of Ecology

Since 1971, the Washington Legislature has directed the Department of Ecology to "ensure that available water supplies are managed to best meet both instream and offstream needs." From 1976 to 1985, the agency adopted 17 instream flow rules to achieve this legislative directive. Then in 1986 the legislature imposed a moratorium on instream flow rule making in response to criticism that a proposed rule set flows too low. Instream flow rulemaking efforts were reinitiated in 1997 through the passage of RCW 90.82, The Watershed Planning Act. This time around the legislature faced the controversy head on and directed Ecology to "develop a more thorough and cooperative method of determining what the current water resource situation is in each water resource inventory area of the state and to provide local citizens with the maximum possible input concerning their goals and objectives for water resource management and development."

Passage of this law led to the second wave of rule making when Ecology in partnership with local planning units adopted nine rules to meet both instream and out of stream needs. This momentum in part was stymied by the Governor issuing a rule making moratorium in 2011 with exception to essential rule making associated with public health and safety. The WRIA 18 Dungeness Basin instream flow rule was enacted in 2012 under the exception. Since the rule making moratorium was lifted in 2013 efforts to enact a rule in WRIA 25 and 26, the Grays-Elochoman and the Cowlitz Basin, have been halted by the Washington State Supreme Court decision Swinomish v the Department of Ecology, where the court found Ecology's approach to instream flow rule making overstepped their discretion.

Uranium millsite hydrogeology, Chamokane Basin, Ford, Washington

Dr. John Riley and Bryony Stasney, WA State Department of Health, Office of Radiation Protection

This presentation describes the hydrogeology of the Dawn Mining Company (DMC) uranium millsite, located within the Chamokane Creek basin, near Ford, Washington. Since the 1980s, DMC has characterized the physical and chemical characteristics of site hydrogeology, has conducted various corrective actions and continues to monitor and assess groundwater and surface water as components of the ongoing closure of the millsite, under the regulatory authority of Washington State Department of Health (WDOH). The WDOH Office of Radiation Protection has delegated authority from the Nuclear Regulatory Commission (NRC) to regulate uranium mills under the NRC's Agreement State Program. As a result of past tailings disposal and ore stockpiling at the site, some constituents (primarily uranium and sulfate) are elevated in areas of the uppermost aquifer below the site. Drilling over the last five years has provided DMC and WDOH with detailed hydrostratigraphic information, confirming that the upper unconfined aquifer is underlain by low permeability silts and clays which in turn overlie a confined aquifer. Groundwater and surface water monitoring indicate that there is an upward groundwater flow gradient from the lower to upper aquifer and that the upper aquifer discharges into Chamokane Creek, along the northern boundary of the millsite. The improved understanding of site and basin hydrogeology will support DMC's and WDOH's future decisions for millsite closure.

Hexavalent chromium sensor developed for real-time in situ groundwater monitoring

Kenton Rod, Freestone Environmental
Kimberly Schuyler, Freestone Environmental
Stephen Hall, Freestone Environmental

Hexavalent chromium, a known carcinogen which exists as chromate in groundwater, is a contaminant of concern at multiple industrial and Department of Energy (DOE) sites across the United States. This ion is used in stainless steel production, textile dyes, tanning, wood preservation, conversion coatings, and as a corrosion inhibitor. For example, it was used at DOE Hanford Nuclear Reservation in Washington state to inhibit corrosion and, due to leaks and spills, has resulted in chromate release to the groundwater in concentrations above the Environmental Protection Agencies standard of 100 µg L-1 as total chromium. Chromate (CrO42-) is an oxyanion which forms weak outer sphere complexes with geomedia and its adsorption can often be suppressed by other co-anions. As such, it is readily transported with groundwater through the subsurface to receptors such as river biota and to potable water wells. Field sampling of wells for chromate plume monitoring can be costly and time consuming. To reduce sampling cost and improve characterization, a sensor was developed for continuous monitoring in wells (≥2-in diameter) or water bodies, with data transmitted via automated technologies. It uses near-ultraviolet absorption photospectroscopy to measure chromate and detection limits are comparable to those obtained with the widely used diphenylcarbazide colorimetric method. Turbidity, caused by colloidal material suspended in natural water, can interfere with the chromate measurement and is automatically compensated within the instrument.

Testing of the sensor in laboratory and field has yielded encouraging results. Laboratory experiments, using 900 µg L-1 NaHCO3 water to simulate ionic strength of natural waters, were conducted to test measurement reliability. Chromate was introduced to test samples by pipetting suitable aliquots of Cr6+ standard solution. One series of tests was designed to determine the effect of a large number of repeated measurements on instrument performance in terms of measurement noise and systematic drift. These tests were conducted in triplicate, using multiple chromate concentrations and three nominally identical sensors. Concentrations of solutions were verified by independent measurement using a Hach DR 2800 spectrophotometer at 540 nm. Sensor results were analyzed based on a paired Student t-test. Sensor measurements consistently yielded concentrations that correlate well with known concentrations (r2 = 0.99), for samples with 0 - 660 µg L-1 as Cr6+. The coefficient of variation is 4% to 8% for sample concentrations over 200 µg L-1. The coefficient of variation was 18% at a concentration of 30 µg L-1. Initial results of sensors deployed to the field showed a relatively stable chromate concentration over a two week period within 15% of the point measurement of 126 µg L-1.

Geochemical Studies of Surface Water/Groundwater Interactions in Central Washington

Carey Gazis, Central Washington University
Renee Holt, Central Washington University
James Patterson, Central Washington University
Sarah Taylor, Central Washington University
Zoe Weis, Central Washington University

Rainfall in central Washington ranges from >260 cm at the crest of the Cascade Mountains to <20 cm in the rain shadow 160 km to the east. Because of this rainshadow effect, the principle source of irrigation water for the agricultural regions in central Washington is Cascade and Rocky Mountain snowmelt. Water availability is limited and heatedly debated; issues of groundwater withdrawal impacts on surface water, groundwater mining, and groundwater quality exist. Geochemical studies of groundwater from three areas in central Washington present contrasting stories of water use and groundwater/surface water interactions.

Most of central Washington lies within the Columbia River Basalt Province, regionally extensive basalt flows interbedded with sedimentary layers that serve as the main water-bearing units. The Columbia River Basalts extend to approximately 80 km east of the Cascade crest; west of this terminus, the hydrogeologic framework is a complex geometry of older bedrock, in which fractures control much of the groundwater flow.

The three study areas presented here are: 1) upper Kittitas county, located in the fractured bedrock adjacent to the Cascade crest, where water is limited due to aquifer transmissivities but agricultural water demands are low; 2) the Ellensburg area, a sedimentary basin in a basalt syncline, where irrigation is primarily accomplished using surface water; 3) the Royal Slope region to the east of the Columbia River, where extensive irrigation is accomplished using groundwater drawn largely from basalt aquifers as well as surface water. A variety of geochemical techniques, (major ion, trace element, stable isotope, and Sr isotope analyses) were combined with principal component analysis to decipher different groundwater types and their connectivity with surface water in these study areas. Stable isotope analyses generally differentiate three types of water in central Washington: 1) groundwaters that are heavily influenced by irrigation water, often with elevated nitrate concentrations; 2) shallow groundwater that is isotopically distinct from irrigation water; 3) ancient groundwater that is isotopically lighter than modern waters, usually found in the deeper basalt aquifers. Groundwater geochemistry and patterns of groundwater/surface water interactions depend on aquifer lithologies, characteristics, and depths; groundwater residence times; geologic structures and fracture orientations; and timing and source of irrigation water.

Marine streamer electrical resistivity characterization of riverbed sediment contamination, Coeur d'Alene River, ID

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Brian Cubbage, hydroGeophysics Inc

The electrical resistivity method has proven itself to be a useful tool for assessing many geotechnical and environmental properties, including porosity of soils, rock hardness, and delineation of contaminated sediments. The method provides a cost efficient way for continuous characterization across a site, reducing the uncertainty introduced by simply interpolating between available borehole and core data. One electrical resistivity deployment arrangement, marine streamer resistivity, involves towing an array of electrodes behind a boat at a constant speed and continuously collecting a series of measurements. In addition, the water depth and temperature are measured by a depth sounder and positional data is provided by a GPS. This data is merged and then modeled to produce a cross-section of electrical resistivity along the length of the boat track, allowing many kilometers of data to be collected daily. This can significantly reduce the number of boreholes or coring locations required in marine or waterborne surveys. We present a case study of the marine streamer resistivity method for mapping contaminated sediment in the Lower Basin of the Coeur d'Alene River, ID. The Lower Basin is part of the Bunker Hill Mining and Metallurgical Complex Superfund site. The riverbed of the Coeur d'Alene River in the Lower Basin is contaminated with heavy metals, including lead from historical mining in the region. The riverbed consists of a contaminated silty-sandy layer, containing lead at concentrations ranging between 500 and 50,000 mg/kg or more, zinc concentrations are similar, with other heavy metals also present at elevated levels, overlying native silts and clays. A half mile section, near River Mile 157, was surveyed and a number of coring and geotechnical testing transects were collected along this section to enable validation of the electrical resistivity measurements.

A Hydrologic Assessment of Instream Flow Standards in Washington State

Roy Jensen, Hart Crowser, Inc.

The Washington State Department of Ecology (Ecology) is obligated by state law to a process for establishing minimum stream flows, commonly known as instream flows, in rivers and streams that protect and preserve stream resources. Instream flows can be established based on fish, wildlife, scenic, aesthetic, and other environmental values. As of 2014, instream flow regulations have been established in 26 of the 62 watersheds, or WRIAs, in Washington. In this paper, we will review the regulatory and technical basis that is used to develop and establish instream flows in Washington State.

Establishing instream flows is just one part of a comprehensive process of regulating water resources in a watershed. The first instream flow standards were first established in the Nooksack WRIA in the early 1970s. The process of establishing instream flows varies with watershed-specific conditions and has evolved over time with changes in regulatory and technical policies.

The primary goal of establishing an instream flow standard is to establish minimum stream conditions that are protective of the resources established for the stream. Fish habitat is the principal resource considered in establishing instream flows. It is assumed that if fish habitat is protected, then other resources will also be protected. Fish habitat factors are translated to stream flow as recorded at a specific compliance stream gage location. In theory, historical stream flows are not used as the basis for establishing instream flows. In practice, instream flows are set based on resource goals and then modified to reflect actual stream flow conditions. Established instream flows typically vary seasonally during the year. Instream flows are higher during periods of high stream flow and lower than periods of low stream flow. In some regulatory statutes, baseflow is equated with instream flow. Instream flows are not baseflows as commonly understood in hydrologic sciences.

Historical stream flows as recorded at compliance stream gages were compared to the established instream flow standards. Generally, recorded minimum stream flows drop below the established instream flow standard for periods of up to 1 to 4 months. Available stream flow data suggest that, with few exceptions, stream flows averages are generally steady. There may be continuing pressure on stream flows due to increasing water demand and climate changes.

Instream flows cannot be established for all streams in a watershed because of the absence of historical stream flow data. There is a challenge in maintaining the current stream flow monitoring network due to financial pressures on government resources. The US Geological Survey, Ecology, Tribes, and Counties should be provided the resources to maintain and even expand the current stream monitoring system because of the importance of stream flow monitoring in assessing the health of watersheds.

The Wild West Comes to Western Washington - Implementing the Dungeness Instream Flow Regulation

Michael Gallagher, Department of Ecology

The last 11 miles of flow of the Dungeness River exits the Olympic Mountains and flows north across a large alluvial fan prior to final drainage into the Strait of Juan de Fuca. This alluvial fan is approximately 60 miles square in area and includes over 4,800 individual water wells. This is approximately 1% of all water wells in Washington. In addition, this area receives on average approximately 15 inches of annual precipitation.

The alluvial fan area is underlain by three distinct aquifers, commonly known as the Shallow, Middle and Deep Aquifers. These three aquifers are separated by two confining layers.

The Dungeness Water Management Rule (the rule) was adopted by the Washington Department of Ecology (Ecology) on November 16, 2012 and took effect on January 2, 2013. The rule is intended to guide water use planning and decision-making for new water users in the Dungeness Watershed, and set policies to help protect the availability of water supplies for current and future needs of people and the environment. Two of the biggest changes are the formal closing of surface water to new appropriations and the requirement that all new groundwater uses mitigate their water use to offset the impact to streams within the watershed. All new water users, including permit-exempt well users, are covered by new requirements under the rule. Every new water user will need to offset the impact of their consumptive water use on surface water.

The rule also sets instream flow levels for the mainstem Dungeness River and its tributary Matriotti Creek, and seven smaller streams: Bagley Creek, Siebert Creek, McDonald Creek, Meadowbrook Creek, Cassalery Creek, Gierin Creek and Bell Creek. In addition to the instream flow levels, small amounts of water are set aside in each subbasin listed above for in-house domestic use. This rule was adopted to implement Ecology's obligations under the 2005 Elwha Dungeness Watershed Plan and the rule enacts recommendations made in the Plan.

Ecology adopted this rule under the authority of the Watershed planning (chapter 90.82 RCW), Water Resources Act of 1971 (chapter 90.54 RCW), Water code (chapter 90.03 RCW), Regulation of public groundwaters (chapter 90.44 RCW), Minimum Water Flows and Levels Act (chapter 90.22 RCW), and Water resource management (chapter 90.42 RCW); and in accordance with the Administrative Procedure Act (chapter 34.05 RCW)

This rule applies to the use and appropriation of surface and groundwater in the Dungeness River watershed begun after the rule's effective date. The rule does not affect:

(a) Existing surface and groundwater rights established prior to adoption of the state surface water and groundwater codes, or by water right permit issued under state law;

(b) Existing groundwater rights established under the groundwater permit-exemption where regular beneficial use began before the effective date of this chapter;

(c) The ability to serve water to a parcel that is part of a group domestic use under the groundwater permit exemption, provided the new use begins within five years of the date water was first regularly and beneficially used by one or more parcels in the group, and;

(d) Federal and tribal reserved rights.

The instream flows established in the rule are necessary to meet the water resource management objectives of the Elwha-Dungeness watershed plan and are considered water rights and are to be protected from impairment from any new water rights commenced after the effective date of this chapter and by future water right changes and transfers. All future new surface and groundwater appropriations, other than

rainwater collection, shall measure withdrawals. Installed water meters must meet specifications available from Ecology.

Ecology has been implementing the Dungeness Instream Flow Rule for over two years now. For part of the rule area, generally land below the irrigation diversions, both indoor domestic water and outdoor water is available for new water users upon payment of one-time mitigation fees. In another part of the rule area, generally land located upgradient of the irrigation diversions, only indoor domestic water is available.

To assist new water users with obtaining required water mitigation, Ecology and Clallam County have contracted with Washington Water Trust to establish the Dungeness Water Exchange. The Exchange has two primary programs: a stream flow restoration program and groundwater mitigation program.

This presentation gives an update on implementation of the Dungeness Water Management Rule.

King County Groundwater Protection Program volunteer data collection efforts

Eric Ferguson, King County DNRP

The King County Groundwater Protection Program has implemented three volunteer data collection efforts on Vashon-Maury Island since 2001. In 2015, four of these volunteers will be starting their 15th year of self-monitoring. These records are some of the longest water level data for Vashon-Maury Island.

Initial volunteer data collection was part of a 12 month study to gather additional water level data. This initial study piqued the interest of many island residents. King County was able to get commitments from 27 individuals wanting to participate. After 18 months, the number of volunteers dropped dramatically.

A second volunteer data collection effort involved reporting water usage for permit-exempt well users. Eight exempt well users allowed meters installed on their water systems. Volunteers eagerly self-reported data on a regular basis. As with the other volunteer self-monitoring program, participation/reporting dropped off for most of the participants. Currently, King County maintains regular participation and usage data delivery from three permit-exempt well volunteers and two Public Water Systems: one small Group A and one Group B.

The County's most recent effort to solicit volunteer data collection involves Group A public water systems on Vashon-Maury Island. King County and the Vashon-Maury Island Groundwater Protection Committee requested water level data sharing with island purveyors and offered to provide equipment to help establish a regular self-monitoring program. Response to this offer has been slow, especially when compared to previous efforts.

Data from these volunteers monitor three different aquifer zones of Vashon-Maury Island. 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. Decreasing and increasing water level trends are present for a few sites. Water usage, to date, ranges from less than 30 gallons per day (GPD) to over 1,000 GPD per connection. As expected, most volunteers consume more water during dry periods and less water during wet periods.

Volunteerism for data collection events have overall reduced over the last decade. King County continues to work with a small number of island volunteers in maintaining this effort. Future efforts to increase volunteerism will rely heavily on island resident interests, local purveyor support, and funds to support related efforts.

Systematic Identification of Potential Groundwater Recharge Sites Using Geographic Information Systems

James Bush, Brown and Caldwell
Jonathan Turk, Brown and Caldwell

The LOTT Clean Water Alliance of Thruston County, Washington (LOTT) plans to expand their groundwater recharge capacity as part of their greater effort to expand beneficial water reuse. Identifying locations that are suitable to surface recharge is challenging due to the great number of natural, financial, and human factors that contribute to the success of a recharge site. Identification is further complicated by the large size of LOTT's service area and the dynamic nature of several critical factors.

Geographic Information Systems (GIS) were employed to discretize Thurston County into 0.01 square mile cells and calculate each cell's favorability with respect to each factor. An overall recharge favorability for each cell was then calculated as the weighted sum of the individual favorabilities for each cell. Weighting was determined through a comparative process that incorporated physical hydrogeology and LOTT's community values. Overall recharge favorability maps were then generated along with topical maps illustrating the effects of different subsets of factors, such as physical factors affecting infiltration. The maps were used to determine focus areas that can be monitored for advantageous property transactions.

Advancing Methods to Parameterize Emergent Vegetation Variables for Coastal Impact Models

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Emergent wetland vegetation has been shown to mitigate coastal inundation and erosion hazards by reducing wave energy through friction (Shepard et al., 2011). Estuarine wetland habitats are seldom considered in coastal protection planning because predictive models require improved input data. Uncertainty remains in hydrodynamic wave models that quantify and forecast the protection potential of wetlands that assume vegetation parameters based on idealized flume experiments or wave sensor data. These data may not account for site-specific spatiotemporal variability (seasonality, senescence effects) within these complex systems. Improved vegetation data are required to refine models and improve understanding of non-linear interactions of vegetation, waves, and sediment transport/deposition that shape coastal geomorphology. The vegetation parameters (biomass, stem density, elasticity, etc.) that affect wave dissipation vary considerably in space and time and are difficult, time consuming and expensive to quantify. This study aims to advance current methodology to more efficiently measure vegetation parameters and facilitate improved hydrodynamic wave-vegetation modeling. Following side-on photography methods applied by Moller (2006), we are isolating biophysical characteristics of plants using horizontal digital photographs in conjunction with remote sensing. We hope to quantify and extrapolate vegetation characteristics affecting hydrodynamics and sedimentation across estuaries in Puget Sound. Additionally, using a handheld field spectrometer we are creating taxonomic spectral library of vegetation and substrates to assist in long-term vegetation monitoring with remote sensing efforts. Wave models will be analyzed for sensitivity to variations in vegetation parameters in order to isolate controlling characteristics reducing wave impacts alongshore. We have chosen to study Port Susan Bay (Stillaguamish Delta), a western Washington estuary that has experienced up to a kilometer of marsh retreat since the 1960s and exhibits highly stratified vegetation assemblages. This presentation will introduce our quantitative methodology and preliminary results. We hope to account for variability in vegetation biophysical characteristics and sediment trapping ability as the vegetation senesces to a winterized state. This monitoring effort will allow us to characterize the wave transformations across a transition from non-vegetated tidal flat to dense tidal marsh with respect to seasonality.

Workshop: Environmental Information Management (EIM) System Groundwater Tools Workshop

Christine Neumiller, Washington Department of Ecology

Overview of new, groundwater (GW)-related tools in the Dept. of Ecology's Environmental Information Management (EIM) System. Learn more about searching, mapping, charting, and downloading GW info; using EIM tools to determine X, Y, and Z well coordinates; and using the EIM map to search for GW-related reports. EIM contains GW monitoring data for 17,000 plus wells across Washington, with 350,000 continuous and discrete water level measurements, and 3 million GW quality results.

Indicators of Nitrate Groundwater Contamination Sources

Melanie Redding, Washington State Department of Ecology

Nitrate is the most prevalent groundwater contaminant. Unlike other contaminants, nitrate also has numerous sources. These include; human and animal waste, fertilizers and natural environmental sources from plants, geologic formations and precipitation. When groundwater nitrate contamination is detected, identifying the source of contamination can be problematic and contentious. The goal of indicator parameters is to use additional constituents to help distinguish the source. Currently there are many indicators including pesticides, isotopes, PPCPs, veterinarian pharmaceuticals, inorganic constituents, and other anthropogenic contaminants, such as caffeine, or spices.

The challenge is to identify a suite of inexpensive, available, reliable and proven indicators that react similarly to nitrate, with respect to mobility, persistence, and reactivity that can also project sources with a high level of certainty. The realm of indicator parameters is evaluated against these goals.

The most promising indicators were included in several on-going studies. Inorganic constituents, specifically chloride/bromide ratios, boron and ionic plots were used in to determine the effectiveness in identifying sources.

Nutrient Transport in Groundwater

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Steve Cox, USGS WA Water Science Center
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Nutrients that infiltrate through onsite septic systems to groundwater eventually discharge to surface water, potentially degrading surface water quality. Measurement of the actual nutrient contribution from groundwater to surface water is complicated by the variability of groundwater flow paths and the uncertainty in nutrient concentration generated by aquifer dispersion. Additional variability is introduced with the nutrient fate and transport in the aquifer (i.e. nitrate breaks down under anaerobic conditions, and phosphorus sorbs to sediment particles). To better determine whether infiltration from onsite septic systems is influencing the water quality of a receiving water body requires a more refined means by which to assess the quantity of nutrient discharging from groundwater to surface water.

Nutrient discharge to two lakes in Washington is being characterized using a combination of methods to delineate groundwater discharge zones: measuring nitrogen isotope (15N) ratios in aquatic plants; and distributed water temperature measurements in the shallow lake shorelines at the water sediment interface. Results are used to identify likely discharge areas, and those locations are sampled for nutrients and other constituents associated with septic effluent. At locations where septic influence is indicated by constituent analyses, nutrient flux rates from groundwater to surface water are assessed using direct flux measurements taken at the sediment water interface. Those flux rates are integrated with nutrient concentrations measured in groundwater to estimate a nutrient loading rate to the surface water body over time.

Nitrogen isotope ratios (15N : 14N) can be used as an indicator of septic sources. The 15N isotope fraction increases in organisms with increasing trophic level. During the metabolic process the 15N ratio (denoted as d15N) increases, generating higher d15N in the organism tissues and excretions, with an average individual trophic level increase in d15N of 3 (atmospheric d15N is set at 0 parts per thousand). For each step up in trophic level, higher ratios of d15N are consumed and thereby concentrated. For humans typical d15N ratios excreted range from 6-10 parts per thousand (ppt). The microorganisms breaking down wastes in onsite septic systems increase d15N further to levels of 10 - 20 ppt.

Aquatic plants (pondweed, Eurasian milfoil, Yellow Heart and others) growing in shoreline areas derive nutrients from groundwater discharging in the near shore root zone (the discharge zone). Nitrogen in groundwater infiltrated from onsite septic systems will reflect characteristics of the septic source (i.e. elevated d15N), and transport that characteristic nitrogen to the discharge zone. Plant uptake of those nutrients through their roots over time will be integrated in the nutrient characteristics of the plant tissue. As such, plant tissue 15N ratio measurements can be used to interpret the duration of nutrient discharge in the groundwater that plants are taking up through their root systems over time.

Using the d15N identified discharge zones, along with groundwater nutrient concentrations and flux rate measurements, groundwater transport and discharge of nutrients from onsite septic systems to surface water and the impact on water quality can be quantified at a local scale.

Assessment of manure management strategies impact on nutrient loading to the Sumas aquifer in Whatcom County Washington

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Steve Cox, US Geological Survey
Raegan Huffman, US Geological Survey
Nichole Embertson, Whatcom Conservation District

Watersheds throughout Washington State are heavily impacted by the intersection of population growth and agricultural use. Poorly managed agricultural practices, such as the over application of manure, leads to degradation of water quality in these areas with high levels of nutrient contamination potentially making its way into the groundwater. In Whatcom County Washington, this combination of heavy agricultural use and a shallow water table raised concerns about nutrient contribution from farmers fertilizing their fields. A three year cooperative study that is in its final phase is being conducted by the Whatcom Conservation District and US Geological Survey testing an alternative strategy for scheduling manure application. Previously permitted manure management was based on seasonally targeted application windows; the tested method, known as the Application Risk Management system (ARM), relies on a combination of field specific hydrology, crop growth requirements, and near-term environmental conditions (precipitation amount, temperature, etc.). To test the success of the ARM strategy, co-located groundwater wells and soil moisture lysimeters were installed to monitor for spatial and temporal changes in nutrient and coliform bacteria present in each of three fields currently used for feed growth (planted with grass). Groundwater wells and soil lysimeters were discreetly sampled on a 3-5 week cycle throughout the year. Soil moisture was sampled at different depths within the vadose zone. Groundwater chemistry was sampled both at the water table and an isolated zone 12 inches below by utilizing an inflatable packer. Variations in nutrient loading to the groundwater were observed vertically throughout the soil and water column and geographically throughout the fields. This talk will serve as an initial summary of results from this three year study. Discussion of seasonal and spatial variability of nitrate levels (the main nutrient of concern) will be addressed as well as an initial assessment of the different ARM strategies ability to reduce nitrate loading of groundwater below test plots.

Lower Yakima Valley Dairies Address Nitrate Contamination of Drinking Water Aquifer

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Sheila Fleming, U.S. Environmental Protection Agency
Eric Winiecki, U.S. Environmental Protection Agency

In March 2013 EPA signed an Administrative Order on Consent ("Consent Order") with several dairies ("Dairies") in the Lower Yakima Valley. The goal of the Consent Order is to address nitrate contamination in the drinking water aquifer that is beneath and downgradient of the Dairies' facilities. According to reports generated by the Natural Resources Conservation Service, the most prevalent surface soil type within the footprint of the Dairies is a silt loam. Most of the surface soils have a relatively high hydraulic conductivity. Soils in the vadose zone are generally sandy, with some gravel, silt and clay components depending on the location. The water table in the vicinity of the Dairies ranges from about 200 feet below ground surface (bgs) in the vicinity of the northern, upgradient wells, to about 35 feet bgs toward the southern, downgradient edge of the Dairies' footprint. Under the Consent Order, the Dairies are taking steps to control potential nitrate sources at their facilities. For example, the Dairies are assessing the hydraulic conductivity of their waste storage lagoons. To address excessive nitrate levels in their application crop fields, the Dairies have proposed measures such as ceasing or reducing nitrogen application in some fields, and transitioning some fields from a double crop of corn and triticale to alfalfa. The Dairies are installing automated irrigation water management systems in their application fields to reduce the migration of nitrate below the root zone. To monitor progress, the Dairies conduct sampling of groundwater and application field soils on a quarterly and semiannual basis, respectively.

Conceptual Model for the Kitsap Peninsula, Kitsap, Mason, and Pierce Counties, Washington

Lonna Frans, US Geological Survey
Wendy Welch, US Geological Survey

The Kitsap Peninsula covers approximately 787 square miles in the southern Puget Sound Lowland of Kitsap, Pierce, and Mason Counties in western Washington. The watershed is underlain by as much as 2,000 feet of unconsolidated sediments that are the result of multiple Pleistocene glacial and interglacial periods. Defining extents and thicknesses of the aquifers and confining units within these unconsolidated sediments is essential to understanding groundwater flow and interaction with surface-water features.

In October 2010, the U.S. Geological Survey (USGS) Washington Water Science Center in partnership with the Water Purveyors Association of Kitsap County began a project to characterize the water resources and create a numerical groundwater flow model of the Kitsap Peninsula. As part of that project, a more detailed conceptual model and hydrogeologic framework of the area was needed.

Four major elements were completed to construct the hydrogeologic framework. A digital surficial hydrogeologic map was compiled by merging existing 1:100,000 and 1:24,000 geologic maps. A dataset of more than 2,000 wells was assembled from the USGS National Water Information System database and hydrogeologic unit assignments were made incorporating surficial geology, drillers' logs, and previous investigations. Cross-sections were created to illustrate the likely correlations between hydrogeologic units across the entire study area. Finally, maps were created to show the extents of the hydrogeologic units and the interpolated elevations of the unit tops.

Hydraulic parameters were estimated for hydrogeologic units using available data from aquifer tests, drillers' reports and published values. Water-level maps were prepared for principal aquifers within the basin in order to better understand groundwater flow directions, and horizontal and vertical water-level gradients.

All available data were then used to construct a numerical flow model of the Kitsap Peninsula to assist water resources managers in managing the groundwater system.

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

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 of the discussions surrounding this issue, the Upper Kittitas Groundwater Rule has been in effect since 2010. Pumping from new domestic (i.e., permit-exempt or “exempt”) groundwater wells in Upper Kittitas County is not allowed unless mitigation is used to offset the groundwater use.

The United States Geological Survey (USGS) has already created a basin-wide model for the Yakima River Basin for the period October 1959 through September 2001; however, the hydrogeology of Upper Kittitas County is coarsely represented in the USGS model because individual bedrock units are not delineated. Based on the USGS Yakima River Basin groundwater-flow model (hereafter the YRB-GFM), an Upper Kittitas County groundwater-flow model (UKC-GFM) was extrapolated to refine the Upper Kittitas County modeled region. This new model constitutes an M.S. thesis, done in collaboration with the USGS. The UKC-GFM contains 246 columns and 195 rows, with 1,000 foot grid cells, and five layers representing three basin fill units, basalt, and bedrock; it is populated with model information for the period October 1959 through September 2001. Refinements to the UKC-GFM include: (1) using a newer version of MODFLOW (MODFLOW-NWT) with the new Newton Solver and the Upstream Weighting (UPW) Package. The YRB-GFM used MODFLOW-2005, the PCG2 Solver, and the Hydrogeologic-Unit Flow (HUF) Package; (2) incorporating zone arrays with multiple hydraulic properties into model bedrock layers; (3) extending streamflow-routing cells into smaller headland creeks; (4) changing simulated monthly reservoir stages from steady-state to time-variant; and (5) estimating new parameter values.

Once calibrated, the UKC-GFM was given scenarios to assess responses of the flow system to potential changes in stresses. These scenarios are: (1) Existing Conditions without All Pumping, (2) Decrease Recharge by Fifteen Percent, (3) Increase Pumpage by Fifteen Percent, and (4) Existing Conditions with Refined Domestic Pumpage. Scenarios were used to evaluate the impacts of stresses to the system for only the last ten years of pumpage because this is where the majority of data exists for the study area, and these are the calibrated years. Based on the UKC-GFM’s cumulative water budgets, the scenario with the greatest impacts to stream leakage is Scenario 2, where cumulative net outflows are 680,000 cubic feet per second (cfs) lower for stream leakage than in the base UKC-GFM. Scenario 1 results in the greatest amount of groundwater discharging to streams, with the cumulative outflow for stream leakage 6,600 cfs greater than in the base UKC-GFM.

Groundwater/Surface-Water Interactions and Detecting Cold-Water Refugia in Streams of the Pacific Northwest

Andrew Gendaszek, U.S. Geological Survey

During summer, groundwater discharge into streams typically cools and buffers diurnal temperature fluctuations of the surface water into which it discharges. Cold-water refugia for aquatic organisms, created and maintained in part by groundwater discharge, have been identified by water-resource managers as key elements to restore the health and viability of cold-water fishes like salmonids within the Pacific Northwest. The location and magnitude of groundwater discharge into a stream depends largely on the distribution of shallow aquifers in continuity with streams, in-channel and floodplain geomorphic conditions, and the relation of the hydraulic gradients of groundwater relative to surface water. Longitudinal temperature profiles were collected in several western Washington streams and rivers including the South Fork Nooksack River, Stillaguamish River, and small streams of the Swinomish Indian Reservation during summer baseflow conditions when the temperature contrast between groundwater and surface water is greatest. Temperature profiles were measured using two techniques: 1) fiber-optic distributed temperature sensing where near-streambed temperatures of kilometer-scale reaches were monitored at one-meter intervals over a week and 2) towing a data-logging temperature sensor along the streambed of 10-kilometer-scale reaches at ambient flow velocity to measure the diurnal warming of a parcel of water. These rivers and streams represent a variety of fluvial setting with corresponding differences in the magnitude and extent of groundwater discharge. The influence of hydrogeologic conditions, including the presence of underlying water-bearing and non-water-bearing hydrogeologic units, and reach scale and valley scale geomorphic conditions on groundwater discharge to streams is subsequently discussed.

Advanced Simulation Capability for Environmental Management; A Workflow for Subsurface Simulation

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The U.S. Department of Energy (USDOE) Office of Environmental Management (EM), Office of Soil and Groundwater Remediation, is supporting development of the Advanced Simulation Capability for Environmental Management (ASCEM). ASCEM is an open source and modular computing framework and modeling workflow that incorporates new advances and tools for predicting subsurface contaminant fate and transport. ASCEM facilitates efficient and integrated approaches to modeling and site characterization that provide robust assessments for cleanup and closure activities.

Subsurface simulation modeling can be complex and often involves multiple steps including data preparation, executing multiple simulations, visualization, and tracking input data and modeling results. Analyses such as sensitivity evaluations and uncertainty quantification often are required. The entire modeling process can occur over long time periods with significant iteration. To conduct modeling work flows, users typically make extensive use of batch files, scripts, and programs to link data and applications together. ASCEM has been developed to simplify this workflow. Two key elements are the Platform and Integrated Toolsets (accessed through the Akuna User Interface) and the High-Performance Computing (HPC) multi-process simulator (called Amanzi). The Platform manages all aspect of the modeling workflow, including conceptual model development, management of data and metadata for model input, sensitivity analysis, model calibration and uncertainty analysis, model execution, and processing of model output, including visualization. Development has focused on tight integration among the different toolsets and the Amanzi simulator and end user feedback. An example application to the Hanford Site deep vadose zone is described to illustrate the ASCEM workflow.

Using Piper Diagram Two-Component Mixing To Show a Sewage Lagoon Leaked

Phil Richerson, Oregon Department of Environmental Quality

Lehman Hot Springs is a resort located in the Blue Mountains east of Ukiah, Oregon. The resort had two evaporative sewage lagoons that held domestic wastewater. Oregon DEQ cited Lehman Hot Springs for illegal wastewater discharges seven times between 1995 and 2006.

In spring 2009, Oregon DEQ received a call that the sewage lagoons were nearly overtopping the berms. Over multiple site visits the next few months, DEQ staff identified water leaking from the base of the lagoon that ran to a nearby creek. The resort closed in mid-2009, when a judge ordered the owner to cease operations because of unsafe sewage lagoons.

In 2010, DEQ was preparing for a court case and wanted to evaluate if the "seeps" contained wastewater. The defendant claimed the seeps contained only groundwater. DEQ staff contended that, due to the location of the seep at the corner of the base of the lagoon, it likely contained wastewater. Other DEQ staff recommended sampling the wastewater for specific parameters and then analyzing them with the Stiff and Piper diagrams. The sampling occurred in July 2010 when DEQ sampled faucet water, spring water, seep water, hot springs, and lagoon water.

Three types of water were identified by the Stiff diagrams. These water types cluster together on the Piper Diagram. Two-component mixing can be readily apparent on a Piper diagram. If two waters mix, the composition of the mixture will lie on a straight line joining the two end members. The relative amount of each end member is inversely proportional to the distance of the mixture from that end member. The two-component mixing indicated the seep located at the base of the lower sewage lagoon likely contained between 15% and 22% water from the upper sewage lagoon and between 78% and 85% groundwater infiltrating into the sewage lagoons through a damaged liner and infiltration into the damaged collection system pipes. In other words, the chemistry of the samples was consistent with the idea that the lagoon was leaking.

During the investigation, the property ownership changed. The original owner plead guilty to criminal charges in 2012. The ownership also changed hands in 2012. DEQ went forward with civil penalty assessment for the 2009 violations.

An Administrative Law Judge ruled in DEQ's favor in 2012. The original owner appealed to the Environmental Quality Commission, which is a five-member citizen panel appointed by the governor of Oregon to serve as DEQ's policy and rulemaking board. In addition to adopting rules, the EQC also establishes policies, issues orders, judges appeals of fines or other Department actions, and appoints the DEQ director.

In September 2013, the EQC issued a Final Order assessing the original owner and the other respondents a $302,267 penalty for multiple violations of Oregon water quality law. The owner and his co-respondents have appealed the EQC's order and the matter is pending before the Oregon Court of Appeals.

After extensive renovations to the wastewater treatment system, Lehman Hot Springs is now operating as a limited use facility for private organizations.

Oral histories of Puget Lowland tribes: Do some myths provide a cultural memory of catastrophic laharic floods from Mount Rainier, Washington?

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Myths of Puget Lowland native peoples transcribed by Ballard (1929), Clark (1953), and others present allegories that appear to describe the profound affects of volcanic activity at Mount Rainier on downstream areas. In "How the whales reached the sea", whales burrow through a valley bottom to change the course of a river. The new stream course that resulted was the Stuck River, which is the historic name of a stream draining south from near Auburn into the Puyallup River. Today the White River, which heads on Mount Rainier's east and northeast flanks, roughly follows that course, although at times in the past the White River has drained north to Elliott Bay from near Auburn, where it debouches from Puget Lowland plateau into the Duwamish valley. Buried forests radiocarbon dated to about 1100 yr BP were exhumed in the in the mid-to-late 1990s at Auburn and Fife. The subfossil trees reveal that a great volcanic flood inundated these areas with a layer of andesitic sand and gravel ranging from about 0.5 to as much as 2 m in thickness. In the northern Duwamish River valley, this gravelly volcanic sand extends north to the Port of Seattle, where it is about 1. 5-m thick. A volcanic ash layer at Mount Rainier having a correlative age shows that the lahar that coursed down the White River was triggered by a moderate-size explosive eruption at the volcano. The lahar-derived sand and gravel in the lowland near Fife and the Port of Seattle likely was deposited within days or weeks of the eruption. The thickness and extent of the deposits indicates catastrophic aggradation in the valley bottoms of the Puget Lowland, and the scale of these landscape changes more than Millennia ago appears to have been captured in oral stories by the power of the burrowing whales changing the course of the river. Alternatively, the burrowing whales may also capture the power of the strong ground motion of the nearby Seattle and Tacoma Faults, both of which produced major earthquakes within a century of the eruption and lahar.

Other stories, such as "The young man's ascent of Mount Rainier" (Ballard, 1929) and "The lake on Mount Rainier" (Clark, 1953) describe a flood of water and debris that buried the Puyallup River valley near the present town of Orting. These stories likely are referring the Electron Mudflow, which buried the Orting area about CE 1500. We are using studies of tree-rings of the subfossil trees in an attempt to better constrain the ages of the events and to test the correlation of the Fife and Auburn buried forests.

A Site-Specific Terrestrial Ecological Evaluation for Abandoned Mined Lands on a Watershed Scale

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This poster describes the ongoing work in the Monte Cristo Mining Area (MCMA) (Figure 1), a predominantly gold mining district in the Cascade Mountains, northeast of Seattle, Washington. The area was mined extensively in the 1890s and smaller scale mining continued into the twentieth century. Today there are more than 50 reported abandoned mines and prospects scattered across three watersheds (Weden Creek, Glacier Creek, and Seventysix Gulch) that together make up the headwaters of the South Fork Sauk River (SFSR).

Abandoned mine lands (AMLS) typically contain by-products of mining and milling operations that present potential risks to human health and ecological receptors. In the case of metal mine sites, risk assessment is often complicated by the presence of naturally elevated background concentrations and uncertainty of metal bioavailability in soils, sediment and surface water. Since it is not practical to cleanup to below background levels or when a contaminant of concern is not bioavailable, different approaches have been formulated to address these issues.

The MCMA is rugged, remote and currently has no road access. This dramatically increases the potential cleanup costs. Washington's Model Toxics Control Act (MTCA) regulations prescribe a means of rigorously calculating natural background concentrations. The U.S. EPA has developed technical guidance (rapid bioassessment protocols [RBPs]) for assessing aquatic biota to inform water quality monitoring and management. Also, Washington has recently developed sediment management guidance based on bioassays. Collectively these protocols serve as a cost-effective approach to identify cleanup requirements using biological indicators.

To date, we have completed a two-phase site-specific terrestrial ecological evaluation (TEE), and are conducting annual aquatic biological surveys to monitor water quality. For the terrestrial investigation, we collected soil and ecologically relevant plant and soil biota samples (from background areas and waste rock piles) to assess site-specific plant uptake and bioaccumulation factors. The uptake and bioaccumulation factors were used to develop a site-specific wildlife exposure model and the model was compared to published tissue concentration thresholds. This poster presents the results and conclusions from the terrestrial investigation and a few key preliminary findings from the aquatic surveys as well.

The Washington Nitrate Prioritization Project

Laurie Morgan, Washington State Dept. of Ecology

In 2013, the Washington State Dept. of Ecology Water Quality Program proposed the Washington Nitrate Prioritization Project (WNPP) because of growing concerns about contamination of groundwater by nitrates. The Safe Drinking Water Act limit for delivery of water from public water systems is 10 mg/L. This limit has been exceeded in well samples in various areas of the state going back decades. Not only is contaminated groundwater a public health issue, it also is very costly to public water supply systems and to individual households who must cope with contamination by treating water, buying bottled water or deepening or replacing their well on their own.

The goals of this project were to:

- Delineate areas where nitrates are high in groundwater
- Prioritize those areas by impact to people and resources
- Make information available to the public

The inputs for developing candidate Nitrate Priority Areas included:

- Database of nitrate sampling results for groundwater from state and federal databases
- US Geological Survey nitrate risk studies
- GIS resources, such as soils, surficial geology, agricultural land use and irrigated areas
- Assessment of drinking water use, at-risk populations and other prioritization factors

Monitoring data from the U.S. Geological Survey, the Washington State Dept. of Health and the Washington State Dept. of Ecology were collected and summarized and the well locations are mapped in ArcGIS. Clusters of wells where a sample has exceeded 10 mg/L is a strong indicator that groundwater at that location is at high risk of or currently is contaminated by nitrate. Other indicators include US Geological Survey nitrate risk analyses, NRCS soil drainage classes and travel time through the soil profile (Ksat), surficial geology, irrigated agriculture and well depths.

Using GIS tools and the above inputs candidate nitrate priority areas were delineated in GIS and tentatively ranked based on at risk populations and local drinking water source distribution. These draft delineations were further supported by geo-referenced nitrate concentration graphs for over 1200 wells with four or more sample results with at least one sample over 5 mg/L. Details of the study design and results are described in an accompanying report. Results of this study are intended to be used to prioritize actions to protect public drinking water supply and to prioritize actions to reduce sources of nitrate.

Approach to examine uranium occurrence in groundwater in northeastern Washington State

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Matt Schanz, NE Tri County Health

Recent groundwater monitoring in Northeastern Washington has shown elevated levels of uranium in several community water systems and in private wells. The U.S. Environmental Protection Agency (EPA) Final Rule for (Non-Radon) Radionuclides in Drinking Water took effect in 2003 and regulates uranium, with a maximum contaminant level (MCL) of 30 ug/L. In keeping with EPA's ruling, the Washington State Department of Health requires Group A public water systems to test and meet drinking water standards to reduce uranium exposure, protect from toxic kidney effects of uranium, and reduce the risk of cancer. However, a number of systems are not required to meet the MCLs, including Group A non-transient non-community systems (e.g., schools), Group A transient non-community systems (e.g., resorts, transient worker housing), and Group B systems, which serve fewer than 15 connections or fewer than 25 people per day. Furthermore, private wells, often for single-family use, are not regulated, and as such, generally are not sampled. Potential contamination in private wells and wells of unregulated systems could go unnoticed.

Naturally occurring uranium is associated with granitic and metasedimentary rocks, as well as younger sedimentary deposits, in northeastern Washington. Unfortunately, the occurrence and distribution of uranium in groundwater in this area are poorly understood. In 2012, the maximum uranium value measured by the Spokane Tribe of Indians was 203 ug/L. As of 2013, the maximum value measured in newly drilled private wells in Stevens County was 119 ug/L. Although much of the region is remote and sparsely populated, the bedrock aquifers in northeast Washington are increasingly being developed for drinking water supply. Within Ferry, Stevens, and Pend Oreille Counties, 54% of the population obtains water from supplies that do not monitor for uranium.

This poster presents a proposed investigation aimed at improving the understanding of the occurrence and distribution of uranium in groundwater in northeastern Washington. Specific objectives include compiling geologic, hydrogeologic, and radionuclide information for the region, assembling a data set of private wells and springs finished in bedrock units, obtaining uranium-concentration data for the wells and springs, and determining the ranges of concentrations of uranium in groundwater associated with each major geologic bedrock type. Completion of the study would aid homeowners, Tribes, health officials, and planners in evaluating the potential presence of uranium in groundwater and making informed decisions on further testing and treatment of drinking water supplies.

Sediment and phosphorus inputs from perennial streams to Lake Whatcom, Northwestern Washington State

Robert Mitchell, Western Washington University
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Nutrient enrichment presents a common problem in Washington lakes and streams by promoting algae growth and the depletion of dissolved oxygen. For example, Lake Whatcom in northwestern Washington State is subject to a Total Maximum Daily Load (TMDL) to limit phosphorus input. The 20-sq-km lake is supported by runoff from numerous perennial streams in a steep, 125-sq-km, moderately developed, forested watershed. Much of the phosphorus load occurs adsorbed to suspended sediment in streams and is transported to the lake during storm events. Understanding sediment and phosphorus transport to the lake is important for managing the TMDL and water quality in general because the lake serves as the drinking water source for about 100,000 people.

Our objectives are to calculate sediment and phosphorus fluxes to Lake Whatcom and examine relationships among precipitation and stream discharge, sediment, and phosphorus. A series of water samples were collected near the mouth of Smith Creek in the watershed during 22 storm events between February 2013 and January 2014 and analyzed for total suspended solids and total phosphorus. We used data from Smith Creek and historical data from four other streams to examine the effects of varying basin features on loading and to develop sediment-discharge and phosphorus-discharge models to estimate loading to the lake during the 2013 water year.

Relationships among sediment, phosphorus, and discharge vary temporally and spatially in the watershed. During most storm events, the sediment peak leads the discharge peak, indicating that transport is limited by sediment availability. In Smith Creek, the magnitude of hydrograph rise is the best predictor of the maximum sediment concentration during the event. Of the five streams studied, the steep, forested Smith Creek basin yielded the most sediment per area, likely sourced by eroding mass wasting deposits. The highest phosphorus yield was from a smaller, lower relief basin containing 29 percent residential development indicating potential anthropogenic sources. Our sediment and phosphorous yields ranged from 11.5 to 143 tonnes/sq-km/year and 25.7 to 68.5 kg/sq-km/year, respectively, and are comparable to estimates from similar streams in the Puget Sound region. Total suspended solids and total phosphorus are significantly correlated to discharge in most streams in the watershed, but variability within and among storm events results in uncertainty when calculating fluxes based on discharge. Continuous turbidity monitoring could allow for improved models and flux estimates.

Calibration of a Hydrologic and Dynamic Glacier Model to the Nooksack River Basin Using Gridded Surface Climate Data

Ryan Murphy, Western Washington University
Robert Mitchell, Western Washington University

The Nooksack River drains an approximately 2000 square kilometer watershed in the North Cascades in Whatcom County, Washington and is a valuable freshwater resource for regional municipalities, industry, and agriculture, and provides critical habitat for endangered salmon species. Nooksack River streamflow is largely influenced by precipitation and snowmelt in the spring, and glacial melt throughout the warmer summer months when precipitation is minimal. Regional climate projections through the end of the 21st century indicate an increase in average annual air temperature, a decrease in summer precipitation, and an increase in winter precipitation. Glacier retreat, which has been prevalent in the Pacific Northwest throughout the latter parts of the 20th century, is expected to continue. Due to a lack of spatially distributed long-term historical weather observations in the basin for downscaling purposes, we apply publically available statistically derived gridded surface data along with the Distributed Hydrology Soil Vegetation Model (DHSVM) with newly developed coupled dynamic glacier module to predict the impacts of future climate scenarios on snowpack, glaciation, and streamflow in the Nooksack River basin.

We calibrate and validate the DHSVM and glacier model to observed glacial mass balance and aerial extent as well as streamflow and SNOTEL data in the Nooksack basin using observational data (1915-2011) gridded at a spatial resolution of 1/16 degree lat/long developed by Linveh et al. (2013). Temperature lapse rates are assumed to be constant throughout the basin while precipitation lapse rates are estimated from monthly 30 year normals (1980-2010) using 800 meter gridded observational data from the Parameter-elevation Relationships on Independent Slopes Model (PRISM). Grid points within the basin are used to predict the impacts of climate change and glacier recession on basin hydrology using publically available, future climate datasets trained with the Livneh data. The downscaled future climate data were developed by Abatzoglou and Brown (2011) using the multivariate adaptive constructed analogs method (MACA). The MACA downscaled data incorporates 20 global climate models of the CMIP5 using RCP4.5 and RCP8.5 forcing scenarios. Climate models suitable for the Pacific Northwest are selected from the available datasets and the MACA downscaled gridded datasets are used as climatological forcings for the DHSVM. Here, we address the methodology, set-up, calibration, and validation of streamflow and glacier mass-balance in the Nooksack basin using the DHSVM.

The Relationship Between Saturated Hydraulic Conductivity and Grain-Size Distribution of Glacial Outwash Deposits within the Puget Lowland, Washington.

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A relationship between field-determined saturated hydraulic conductivity and grain-size distribution was analyzed for over 100 sites underlain by glacial outwash deposits throughout the Puget Lowland region of Washington State. For similar grain-size distributions, the advance outwash has lower permeability than the recessional outwash. Glacial over consolidation in the advance outwash results in compaction of the soil framework, reducing permeability by a factor of 3. Therefore, when using a grain-size distribution approach to approximate the saturated hydraulic conductivity, a distinction should be made between the advance and recessional outwash deposits.

Reassessing dairy nutrient management plans to evaluate nitrate concentrations leached through agricultural soils in Whatcom County, Washington

Sarah Gregory, Western Washington University
Robert Mitchell, Western Washington University

The Abbotsford-Sumas Aquifer in Whatcom County, Washington and southern British Columbia, CA is a shallow unconfined aquifer that has a history of nitrate contamination due to agricultural nutrient loading practices. To reduce the impact of manure application on the aquifer, the Whatcom Conservation District (WCD) and US Geological Survey are conducting a joint study investigating an alternative manure application strategy for dairy farmers.

Three dairy farmers are enrolled in the Applied Risk Management (ARM) study. The project began in 2010 and ends in late spring of 2015. Each participating farmer designated a four acre control and a four acre treatment plot for the study. On the control plots, manure is applied from early March to late September. Manure is applied on the treatment plots year-round. Before farmers can apply manure to their treatment plots during the high risk winter months, they must enter current soil, weather, and field conditions into an interactive ARM Excel spreadsheet model. Based on the conditions entered, the ARM model recommends either applying immediately or delaying to a later date.

We are working with the WCD to monitor and measure nitrate concentrations in the vadose zone directly beneath participating dairy farms to assess the impact of nutrient loading practices on the fate and transport of nitrate in soils overlying the aquifer. Along with the WCD, we have collected soil and soil pore water samples from all three farms enrolled in the ARM program on a monthly basis. The collected samples are analyzed for nitrate, total nitrogen, ammonia, and phosphorus. We analyzed the data using the statistical software package R to determine which environmental and anthropogenic factors correlate most strongly with nitrate concentrations; and to determine if a statistically significant difference exists between nitrate concentrations on the control and treatment plots.

Preliminary analysis of variance results indicate that a statistically significant relationship exists between the control and treatment plots on only one of the dairy farms. On this field, nitrate concentrations measured underneath the treatment plots are significantly higher than nitrate concentrations underneath the control plots. Seasonality is the only variable that has a statistically significant relationship with nitrate concentrations on each field. The highest nitrate concentrations typically occur in the fall.

In addition to statistical analysis, we are using the data from the soil and soil pore water samples to calibrate and validate the nitrate leaching model Nleap on Stella (NLOS). Preliminary model predictions are similar to nitrate concentrations measured in the field. If the model proves to be a valid tool, ARM may incorporate it into their program. Farmers and the WCD could use the free, online model to predict nitrate fate and transport from manure applied to fields.

Investigation of Phosphorus Loading and Cycling at Waughop Lake (Pierce County): The Most Toxic Lake in Western Washington

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Waughop Lake (WL) in Lakewood, WA, is a small (13.3 ha) shallow (Zmax ~3 m) kettle lake where elevated phosphorus levels contribute to eutrophic conditions and toxic algal blooms during summer months. A likely source of water column P is thought to be the bottom sediment, which experienced excessive nutrient-loading during the late 1800's and early 1900's when the lake was used as an agricultural waste disposal site. The goal of this study is to better quantify the main P inputs and outputs to the lake, both natural and anthropogenic. Specific objectives are to determine: (1) the total phosphorus load of the water column and how it varies seasonally, (2) the sources of phosphorus entering the lake, (3) the extent to which phosphorus is transferred from bottom sediment to the water column, and (4) how WL compares to adjacent non-eutrophic Lake Louise (LL). Data collection has included sediment coring (to obtain sediment and pore water samples), bathymetric mapping (to determine lake volume), and twice monthly measurements of water chemistry, thermal stratification, and sediment accumulation rate. In addition a core was taken from LL for comparison of sediment and pore water chemistry.

Between May 23rd and July 18th of 2014 the total amount of P in the WL water column increased from 49,000 g to 97,000 g despite biological removal averaging 1.1E2 g of P/day, suggesting ongoing input of P to the water column. In addition the lack of a well-developed hypolimnion (due to shallow depth of WL) allows P that might otherwise be sequestered in bottom waters to mix into the water column during summer months. Passive diffusion of P from bottom sediment into the water column (3x10-3 g of P/day) was found to be an insignificant source of P but advective transfer may be important. To further understand the behavior of P in bottom sediment we analyzed pore water and sediment from the top ~50 cm of the WL sediment column. Sediment P content is high (700 – 3000 ppm), decreases toward the surface, and closely mimics the profile for Mn (but not Fe). Pore water shows a similar upward decrease in P (0.4 – 0.15 ppm) and is saturated with MnHPO4 and hydroxyapatite at shallower depths, suggesting P solubility at WL is controlled in part by a Mn phase. At LL sediment P contents again correlate with Mn but are 2-3x lower (350 – 1450 ppm) and increase toward the surface. Pore water at LL has ~10x lower P (~0.03 ppm to ~0.09 ppm) than WL and decreases toward the surface (opposite trend of the sediment). These data suggest high P in the WL water column may result not only from higher P in bottom sediment but also from different controls on sediment-water P partitioning. Ongoing work will attempt to quantify the flux of P from bottom sediment by advection, assess the impact of shallow groundwater inputs, and further understand the causes of differing elemental behavior between these two lakes.

Hydrogeologic Framework for the Puyallup River Watershed and Vicinity, Pierce and King Counties, Washington

Wendy Welch, US Geological Survey
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In January 2011, the U.S. Geological Survey (US Geological Survey) Washington Water Science Center, in cooperation with State and local project partners, began a project to characterize the water resources and create a numerical groundwater-flow model of the Puyallup River Watershed (PRW) and vicinity. The characterization and groundwater model will contribute to an improved understanding of existing water resources and assist stakeholders in evaluating future groundwater sustainability.

The study area, which includes the PRW, covers about 1,220 square miles in northern Pierce and southern King Counties, Washington. The area is underlain by a northwest-thickening sequence of unconsolidated glacial and interglacial deposits which overlie sedimentary and volcanic bedrock units that crop out in the Cascade foothills along the southern and eastern margin of the study area. Defining extents and thicknesses of the aquifers and confining units within these unconsolidated deposits is essential to understanding ground-water flow and interactions with surface water features.

Four major elements were completed to construct the hydrogeologic framework:

(1) A digital surficial geology map was compiled by merging existing 1:100,000 digital data with several 1:24,000 geologic maps and geologic units were grouped into 13 hydrogeologic units consisting of aquifers, confining units, and an underlying bedrock unit; (2) A dataset of more than 1,000 wells was assembled from the US Geological Survey National Water Information System database and hydrogeologic unit assignments were made incorporating surficial geology, drillers' logs, and previous investigations; (3) Eight cross-sections were created to illustrate the likely correlations between hydrogeologic units across the entire study area; and (4) Maps were created to show the extents and thicknesses of the hydrogeologic units. These data and other information are being integrated into a numerical groundwater-flow model.

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Sediment and Sediment-Bound Toxic Chemical Loads from the Green River to the Lower Duwamish Waterway, Washington

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The Lower Duwamish Waterway (LDW) Superfund Site is the final 8-km reach of the Green/Duwamish River as it enters Elliott Bay in Seattle, Washington, and is the site of intense current and historical anthropogenic influence that has resulted in contaminated sediments. The main contaminants of concern for human health include polychlorinated biphenyls (PCBs), dioxins/furans, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), and arsenic. To support the implementation of a cleanup plan of contaminated sediments in the LDW, a better understanding of the potential for sediment recontamination is needed. Approximately 99% of sediment entering the LDW originates from upstream sources in the watershed that are transported by the Green River to the LDW. However, limited field data are available regarding sediment and contaminant concentrations and transport and loading dynamics from the Green River to the LDW.

In 2013, the U.S. Geological Survey (USGS), in cooperation with Washington State Department of Ecology, began operating a new streamgaging station in a tidally influenced reach of the Duwamish River upstream of the LDW. The station provides real-time, continuous, publicly-available data on streamflow, turbidity, stream velocity, gage height, and temperature (http://waterdata.usgs.gov/usa/nwis/uv?12113390). Additionally, the USGS is collecting representative samples of whole water, suspended sediment, and bed sediment at the station during a range of flow conditions influenced by tides, storms, and operations at the Howard Hanson Dam. Suspended-sediment samples for chemical analysis are collected using a field-portable flow-through centrifugation technique refined for this project. Samples are analyzed by Washington-State-accredited laboratories for a large suite of compounds, including cPAHs and other semivolatile compounds, PCB Aroclors and the 209 congeners, metals, dioxins/furans, volatile organic compounds, pesticides, butyltins, hexavalent chromium, and total organic carbon. The chemical results, coupled with measurements of suspended-sediment concentration and continuous streamflow and turbidity data, will provide estimates of sediment and sediment-bound chemical loads associated with upstream sources in the Green River to the LDW. These results will improve our understanding of the potential for recontamination of recently remediated sediment within the LDW.

Preliminary results suggest that sediment and chemical concentrations and loadings vary over multiple orders of magnitude between sampling events. For example, a suspended sediment-associated loading of approximately 200 mg/hr of PCBs was estimated during a storm event, which was more than 50 times higher than low-flow loading estimates. This poster will provide additional project context and results from the first 2 years of data collection.

Hydrogeology of the Eastern Pasco Basin, Washington

Theresa Olsen, US Geological Survey
Sue Kahle, US Geological Survey

Since 1952 water diverted from the Columbia River has been used to irrigate parts of the Pasco Basin in eastern Washington. As a result of the surface-water irrigation, groundwater levels generally have risen in the area. The increases in groundwater fluxes and groundwater storage have created a need to better understand the flow system before and after the start of irrigation to assist in the management of the groundwater resources.

The objectives of the groundwater study have been defined by a joint effort of the Washington State Department of Ecology, U.S. Bureau of Reclamation and other parties. These objectives are to: (1) define the hydrogeology of the study area, (2) determine flow patterns of the groundwater system and quantities of movement so that the effect of stresses on the system in terms of artificial recharge and groundwater withdrawals can be documented, and (3) simulate the effects of management scenarios on groundwater availability.

An analysis of the hydrogeologic framework has been completed using well logs, geologic mapping, and field observations. Existing and new groundwater data were compiled and used to evaluate the flow system. A simplified geologic map will be presented with hydrogeologic cross sections constructed for the study area. This new framework data, including the refined stratigraphy, will be incorporated into the groundwater-flow model and changes in basin-fill groundwater storage due to existing anthropogenic stresses and potential management scenarios will be simulated.

Preparations of HAZUS Landslide Susceptibility Maps for Island, Skagit and San Juan Counties, Washington

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The Washington State Department of Natural Resources- Division of Geology and Earth Resources (WADNR-DGER) is preparing HAZUS landslide susceptibility data for Island and Skagit counties in Washington. This HAZUS landslide susceptibility data are being generated by using available LiDAR,

1:100,000 and/or 1:24,000 geology maps and early evaluations of the landslide maps such as Coastal Zone Atlas Map of Washington. Besides the use of the available data, the WADNR-DGER geologists make final evaluations of the geologic interpretations for HAZUS landslide susceptibility procedure based on wet and dry conditions which are described in HAZUS earthquake technical manual. Final products will be the first HAZUS landslide susceptibility map data in Island and Skagit counties, Washington.

The study will guide to prepare future HAZUS landslide susceptibility data for the entire landslide hazard prone areas in Washington.

Age of The Bonneville Landslide and the Drowned Forest of the Columbia River, Washington, USA —From Wiggle-Match Radiocarbon Dating and Tree Ring Analysis

Nathaniel Reynolds, Cowlitz Indian Tribe
JIm O'Connor, U.S. Geological Survey
Patrick Pringle, Centralia College
Robert Schuster, U.S. Geological Survey (retired)
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The Bonneville landslide, about 60 km east-northeast of Portland, Oregon, is the most well-known landslide within the Cascades landslide complex of the Columbia River Gorge, Oregon and Washington. The landslide blockage of the Columbia is recorded by indigenous oral histories describing the "Bridge of the Gods." In 1805, Lewis and Clark deduced that "stumps of pine trees" in the river were drowned by the blockage. Prior to completion of the first powerhouse at Bonneville Dam in 1937, Lawrence (1936) collected cross-section slabs of the "drowned forest of the Columbia". Although Lawrence later reported all samples were lost, in 2001 we recovered two slabs of drowned forest trees he had collected from about 15 km and 25 km upstream of the blockage. Tree-ring analysis of these two samples, as well as that of a tree recovered from deep within the landslide deposit in 1978 during excavations for the Bonneville Dam second powerhouse, shows that all three trees died the same year, confirming the Bonneville landslide dammed the entire Columbia River for tens of kilometers upstream. We employed two iterations of AMS radiocarbon dating (program Oxcal) on 9 samples from the three subfossil trees to obtain a summary "wiggle-match" age for emplacement of the landslide and the death of the three trees. The radiocarbon analysis shows the Bonneville landslide likely occurred between 1421–1447 CE (2σ confidence interval) and almost certainly occurred between 1416–1452 CE (3σ).

A Hydrologic Assessment of Instream Flow Standards in Washington State

Roy Jensen, Hart Crowser, Inc.

The Washington State Department of Ecology (Ecology) is obligated by state law to establish minimum stream flows, commonly known as instream flows, in rivers and streams that protect and preserve stream resources. Instream flows can be established based on fish, wildlife, scenic, aesthetic, and other environmental values. As of 2014, instream flow regulations have been established in 26 of the 62 watersheds, or WRIAs, in Washington. In this paper, we will review the status of the instream flow program and compare established inflow standards to historical stream flow data.

Establishing instream flows is just one part of a comprehensive process of regulating water resources in a watershed. The first instream flow standards were established in 1976. The process of establishing instream flows varies with watershed-specific conditions and has evolved over time with changes in regulatory and technical policies.

The primary goal of establishing an instream flow standard is to establish minimum stream conditions that are protective of the resources established for the stream. Fish habitat is the principal resource considered in establishing instream flows. It is assumed that if fish habitat is protected, then other resources will also be protected. Fish habitat factors are translated to stream flow as recorded at a specific control station gage location. In theory, historical stream flows are not used as the basis for establishing instream flows. In practice, instream flows are set based on resource goals and then modified to reflect actual stream flow conditions.

Historical stream flows as recorded at control station gages were compared to the established instream flow standards. At all control station gages, recorded minimum stream flows drop below the established instream flow standard for periods of 1 to 4 months. Available stream flow data suggest that, with some exceptions, stream flows in Washington are generally stable. There may be continuing pressure on stream flows due to increasing water demand and climate changes.

There is a real threat to the existing stream flow monitoring network due to financial pressures on government resources. The stream gage system in Washington should not be reduced but expanded because of the importance of stream flow monitoring in assessing compliance with instream flow standards and evaluating the health of watersheds.

Database Population and Geospatial Modeling of the Hydrostratigraphy at an Active Landfill in King County, WA.

Sevin Bilir, King County Science & Technical Support

King County is conducting environmental characterization at an active landfill in King County, WA. A geospatial database is key in evaluating and communicating conditions at the landfill. Data from 1,000+ locations populates an EQuiS™ database and was used to build a geologic model (RockWorks15®) .This model can inform the regulators and educate the public on geologic concepts and environmental conditions.

Prior to awareness of regulations requiring bottom lining systems, waste had been placed in unlined areas. Since 1986, waste has been placed in lined areas. The landfill is located in an area that has been developed for both residential and nonresidential use. At one time, adjacent properties served as a disposal facility, accepting farm, industrial, and commercial wastes and as a former chemical and solvent repackaging facility.

The landfill is located on a drumlinized hill about 350 ft above the valley floor. Historically, sediments were deposited by rivers, lakes, and glaciers, over volcanic and sedimentary bedrock derived sediments. The sediments can be continuous with coarse sands and gravels, suggesting channel fill deposits. These sediments are overlain by a thick layer of advance outwash sands and gravels and further capped by a complex suite of till, ice-contact deposits, and recessional outwash sediments.

Groundwater at the landfill and vicinity occurs both as a regional aquifer and as perched zones. The regional aquifer is entirely recharged by precipitation, is made of advance outwash and older sediments and is separated from the refuse areas by more than 200 ft of unsaturated sands and gravels. The local recharge area for the perched zones is located immediately south of the landfill on the adjacent property.

Ongoing landfill operations will benefit from the database. Electronic data can be imported into the 3D model and site infrastructure can be visualized along with the refuse and geology. The 3D model will be refined and improved as more data is collected.

RRAWFLOW: Rainfall-Response Aquifer and Watershed Flow Model

Andrew Long, US Geological Survey

The Rainfall-Response Aquifer and Watershed Flow Model (RRAWFLOW) is a lumped-parameter model that simulates variable streamflow, springflow, groundwater level, solute transport, or cave drip for a measurement point in response to precipitation, recharge, or solute injection. The RRAWFLOW model includes a time-series process to estimate recharge from precipitation and simulates the response to recharge by convolution; i.e., the unit hydrograph approach. Lumped-parameter models have only a small number of parameters that represent the overall hydrologic characteristics of the model area, as opposed to distributed-parameter models that include many spatially distributed parameters. For many applications, lumped models simulate the system response with equal accuracy to that of distributed models, but moreover, the ease of model construction and calibration of lumped models makes them a good choice for many applications.

The RRAWFLOW open-source code is written in the R language and is available at http://sd.water.usgs.gov/projects/RRAWFLOW/RRAWFLOW.html, along with an example model of springflow that includes all input and output files, a user's manual, and a quick-start guide for the novice. The user need not know the R language. The RRAWFLOW model provides professional hydrologists and students with an accessible and versatile tool for lumped-parameter modeling.

Field Trip & Workshops

35th Anniversary of the Mount St. Helens Eruption

Monday, April 13, 2015, 8:00 AM to 7:30 PM

The May 18, 1980 eruption of Mount St. Helens drastically altered the surrounding landscape and greatly affected drainage-basin hydrology and sediment transport in the Toutle River. Impacts included the forest-destroying blast, the valley-filling debris avalanche, a massive lahar, and a blanket of volcanic ash. Join us on a field trip along the Toutle River to the Coldwater Lake area located northwest of Mount St. Helens. Our trip will begin with a stop at the Mount St. Helens Visitor Center at Silver Lake (near Castle Rock), and then we will proceed easterly along Hwy 504. Stops will be made along the way for presentations and discussions of the impacts of the eruption to sedimentation in and along the Toutle River, the impacts on water resources, and the natural recovery of the landscape. The field trip will include a longer stop near Coldwater Lake where we will have an opportunity for a 2-mile loop trail walk, hopefully with Mount St. Helens in view (walking/hiking shoes with good treads advised). (Note that the road is closed beyond Coldwater Lake until May; Johnston Ridge will not be open.) Transportation originates at the Hotel Murano.

Leaders and Contacts: Contact: Gary Walvatne, Hahn and Associates, Inc., garyw@hahnenv.com.
Leader: Tom Pierson, USGS Cascades Volcano Observatory, tpierson@usgs.gov

PLEASE NOTE that the Washington Hydrogeology Symposium holds no responsibility or liability for those participating in the Symposium field trip. All field trip registrants must complete and sign the liability waiver form.

Well Drilling Workshop

Monday, April 13, 2015, 8:00 AM – 4:00 PM

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 include an off-site drilling demonstration.

This workshop is authorized 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.

Workshop Presenters: Scott Malone, WA Dept. of Ecology; Kris Byrd and Ken Smith, OR Dept. of Environmental Quality

Contact: Angie Goodwin, angie.goodwin@hartcrowser.com, (206) 324-9530

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

Location: Presentation is located at Clover Park Technical College, 4500 Steilacoom Boulevard SW, Lakewood, WA. Drilling demonstration is next door to the college at the USGS Warehouse, 8914 Lakeview Avenue Southwest, Lakewood, WA 98499.

Bioremediation Fundamentals and Applications

Thursday, April 16, 2015, 8:00 AM – 12:00 PM
Room: Venice 3 - Hotel Murano

This four-hour classroom session will provide essential understanding of the complex processes involved in the bioremediation of environmental contamination. Major topics covered include microbial respiration, remedy design and implementation, on-going performance assessment, regulatory concerns, and cost. Discussion will primarily focus on the in situ and ex situ remediation of petroleum hydrocarbons, chlorinated solvents and heavy metals. This Workshop offers a hands-on opportunity to design bioremediation approaches for hypothetical case studies, as well as practice reviewing and assessing performance during real-world application examples.

Participants will leave with a working knowledge of how to design and implement remedies and assess performance for both oxidative and reductive bioremediation approaches. This course is designed to complement the Characteristics and Remediation Technologies for Petroleum Releases short course.

Workshop Leader and Contact:
Troy Fowler, Bioremediation Specialists L.L.C. (troy@bioremediation-specialists.com)

Characteristics and Remediation Technologies for Petroleum Releases

Thursday, April 16, 2015, 1:00 – 5:00 PM
Room: Venice 3 - Hotel Murano

This 4-hour classroom session explores how petroleum hydrocarbon releases into the environment evolve chemically, biologically, and toxicologically during the weathering process and how remediation strategies may be influenced. The course will discuss unique research exploring how environmental modification of diesel- and motor oil-range petroleum hydrocarbons creates polar organics, and how creation of polar organics impacts final analytical results that rely on molecular boiling point. Toxicological discussions will explore the subject of "silica gel cleanup" (SGC) and whether including this treatment to remove excess polar organics provides a more accurate assessment of risk. These environmental changes further influence the fate, transport, and degradability of residual organics. Concentration rebound is commonly encountered over the course of environmental cleanup, with the most substantial rebounds noted with more hydrophobic petroleum contaminants. The course will discuss how petroleum weathering should influence the final remedial approach, guide expectations during the cleanup, and give reasonable goals for cost and timeframe. Technology strengths and weaknesses will be discussed, including traditional dig-and-haul, ex situ treatments, and in situ physical, chemical, and biological remediation technologies. Participants will leave with a working knowledge of how to interpret analytical data at petroleum-impacted sites along with how to design and implement remedies and assess performance during the remediation process.

Workshop Leaders and Contacts:
Troy Fowler, Bioremediation Specialists L.L.C. (troy@bioremediation-specialists.com)
Kirk O'Reilly, Exponent, Inc. (koreilly@exponent.com)

Natural Stress Impacts on Well Water-Level Response: Analysis and Removal Applications

Thursday, April 16, 2015, 8:00 AM – 4:00 PM
Room: Venice 4 - Hotel Murano

Natural stresses, such as barometric pressure and river-stage fluctuations can produce significant temporal well water-level responses within confined and unconfined aquifer systems. These induced natural stress effects can significantly interfere with the analysis of well tests performed for hydraulic characterization, remediation performance monitoring (e.g. pump-and-treat), or general aquifer flow-characterization (flow-gradient, flow-direction) investigations. The physical basis and analysis of external natural stress responses within well water-level records for hydrologic characterization applications has been the subject of numerous scientific papers over the past 70 years. In this "hands-on" workshop, the attendee will be provided a number of test cases that demonstrate natural stress analysis and removal techniques from well water-level records. A free-copy of the software program MRCX (Multiple Regression Correction in Excel) will be provided to attendees and demonstrated as part of the workshop presentation for natural stress removal from well water-level records. MRCX is a user-friendly Microsoft Excel-based software program, which utilizes the time-domain based, multiple regression technique (i.e. convolution/deconvolution), for barometric and river-stage stress removal, as described in Mackley et al. (2009) and Spane and Mackley (2011). As a general outline for the workshop, a brief introductory background on the relevance and inter-relationship of physical field measurement parameters will be provided. Significant scientific papers that have advanced our understanding of the impacts of natural stress on well water-level records will be recognized. Following the background introduction, the workshop will provide instruction and test example presentations (utilizing the MRCX software) for the following topics:

- Development and use of Barometric Response Functions (BRF)
  - Time-domain multiple-regression method
  - Aquifer model identification
  - Well response prediction
  - Natural stress removal from well records
  - Aquifer property characterization applications
- Specific barometric test example applications
  - Removal of barometric stress from unconfined aquifer well response for
    - Groundwater-flow characterization within low-gradient areas
    - Support of large-scale pump-and-treat system, aquifer property characterization
  - Direct hydraulic property characterization
    - Reservoir/well zone property determination
    - Low-permeability, caprock permeability analysis
    - Vadose zone pneumatic diffusivity estimation
    - Deformation prediction associated with fluid extraction/injection within confined aquifer systems
- River-stage stresses within unconfined and confined aquifer systems
  - Time-domain multiple-regression method
  - Identifying river response functions
  - Well response prediction
  - Natural stress removal from well record
- Specific river-stage test example applications
  - Removing river-stage influences in support of
    - Remediation performance monitoring (e.g. pump-and-treat)
    - Hydraulic property characterization (constant-rate pumping test)

Workshop Instructors:

Dr. Frank Spane (frank.spane@pnnl.gov) has worked as a Staff Scientist at Pacific Northwest National Laboratory (Richland, WA) for over 25 years. He has over 40 years' experience in hydrogeologic investigations and specializes in well test analysis for projects ranging from hazardous waste sites, carbon sequestration investigation, energy storage studies, and nuclear repository characterization investigations.

Rob D. Mackley (rdm@pnnl.gov) is a groundwater geologist for the Pacific Northwest National Laboratory (Richland, WA). His research is focused on groundwater monitoring, characterization, remediation, and surface-groundwater interaction. Rob is the lead author and developer of the MRCX software.

Special Considerations: Attendees should bring their own Windows-based laptop computer with a copy of Microsoft Excel version 2000 or newer to the workshop in order to use the MRCX software during the hands-on exercises.

References:

Mackley RD, FA Spane, TC Pulsipher, and CH Allward, (September) 2009. "Guide to using Multiple Regression in Excel (MRCX v.1.1) for Removal of River Stage Effects from Well Water Levels". PNNL-19775, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington

Spane, FA and RD Mackley. 2011. "Removal of River-Stage Fluctuations from Well Response Using Multiple-Regression"; Ground Water 49(6):794-807. doi:10.1111/j.1745-6584.2010.00780.x

Solute Transport Modeling: Ideal and Otherwise

Friday, April 17, 2015, 8:00 AM– 4:00 PM

Location: USGS Water Science Center Office, 934 Broadway, Suite 300, Tacoma

Overview The course addresses the fundamental aspects of the migration of solutes in the subsurface. The course begins with a discussion of transport for ideal conditions and then proceeds to a discussion of more complex conceptual models. The course will include discussion of non-ideal transport from the perspective of two-site and dual-domain models and an introduction to the complexities associated with the transport of metals. Attendees will leave the course equipped with a complete toolkit for conducting screening-level analyses and an appreciation of the subtleties of solute transport.

Syllabus The treatment of ideal solute transport will present attendees with a library of analytical solutions for simulating advection-dominated transport and advective-dispersive transport. A comprehensive screening model that can simulate the transport of solutes from a vadose zone source to a groundwater receptor will be presented. Non-ideal transport will be introduced through the two-site and dual-domain conceptual models. The discussion will address two-site sorption and the dual-domain (two-region) conceptual models. Reactive transport considering geochemical attenuation processes such as mineral precipitation and surface complexation will be introduced as an important tool for developing conceptual site models (CSMs) and evaluating remedial alternatives (such as monitored natural attenuation (MNA)). Topics will include data requirements, modeling approaches, and uncertainty. The focus will be on the use of freely-available software and the development of simple models for achievement of most study objectives.

Workshop Instructors

Christopher Neville (cneville@sspa.com). Mr. Neville is a senior hydrogeologist with S.S. Papadopulos & Associates, Inc. in Waterloo, Ontario. Mr. Neville's areas of expertise are the interpretation of hydrogeologic data, formulation of conceptual models, and quantitative analysis of groundwater flow and solute transport. He has designed and evaluated programs for the assessment and protection of groundwater resources, developed regional groundwater flow models, and analyzed and designed remedial measures. Mr. Neville obtained his M.Sc. in hydrogeology in 1992 from the University of Waterloo and a B.Eng. in civil engineering from McGill University in 1985.

Brad Bessinger (bbessinger@sspa.com). Dr. Brad Bessinger is a geochemist with S.S. Papadopulos & Associates in Portland, Oregon. Dr. Bessinger specializes in environmental geochemistry and the processes affecting the fate and transport of metals and organic compounds in the environment. He has developed geochemical reactive transport models for ground water evaluations, treatability studies, and monitored natural attenuation (MNA) investigations at contaminated sites nationwide. Dr. Bessinger received a Ph.D. in geochemistry from the University of California at Berkeley in 2000, a M.S. in rock mechanics in 1997, and a B.S. in engineering geology from Stanford University in 1993.

Environmental Information Management (EIM) System Groundwater Tools Workshop

Wednesday, April 15, 2015, 2:00 PM – 2:40 PM

Room EF, Bicentennial Pavilion

Overview of new, groundwater (GW)-related tools in the Dept. of Ecology's Environmental Information Management (EIM) System. Learn more about searching, mapping, charting, and downloading GW info; using EIM tools to determine X, Y, and Z well coordinates; and using the EIM map to search for GW-related reports. EIM contains GW monitoring data for 17,000 plus wells across Washington, with 350,000 continuous and discrete water level measurements, and 3 million GW quality results.

Workshop Leader and Contact: Christine Neumiller, chris.neumiller@ecy.wa.gov

PANEL - Part of 6A Instream Flow II Session

Instream Flow Program in Washington

Wednesday, April 15, 2015, 1:40 PM – 2:40 PM
Room: Bicentennial Pavilion - Room BC

Panel Members:
Jim Pacheco, Water Resources Program, Washington Department of Ecology, Olympia, Washington
Mike Gallagher, Water Resources, Southwest Region, Washington Department of Ecology
F. Michael Krautkramer, Principal Hydrogeologist, Robinson Noble

Moderator:
Roy Jensen, Senior Hydrogeologist, Hart Crowser

The instream flow program in Washington is designed to protect and preserve stream resources based on fish, wildlife, scenic, aesthetic, and other environmental values. Instream flow regulations have been established in 27 of the 62 watersheds. The process of establishing instream flows varies with watershed-specific conditions and has evolved over time with changes in political considerations, as well as regulatory and technical policies. Currently, fish habitat is the principal resource considered in establishing instream flows. In practice, instream flows are set based on resource goals and then are modified to reflect actual stream flow conditions. Groundwater is considered to be in hydraulic continuity with surface water, so instream flow regulations on surface water can control the use of groundwater. The panel will discuss such topics as the status of instream flow regulations, the importance of stream flow monitoring, and implications of established instream flow standards on groundwater.

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