12th Washington Hydrogeology Symposium

PROGRAM AND ABSTRACTS

WASHINGTON HYDROGEOLOGY SYMPOSIUM

| Hotel Murano

| Tacoma, Washington

April 9–11, 2019

www.wahgs.org

12th Washington Hydrogeology Symposium

SCHEDULE OVERVIEW

DATE	ACTIVITY
MONDAY *April 8*	**Field Trip:** SR530 Landslide Oso, Washington *(8:00 AM - 5:00 PM)*
TUESDAY *April 9*	First Day of Symposium **Opening Session / Keynote Talk** **Platform Presentations** **Exhibits** Lunch Provided **Poster Session and Reception** (*early evening*)
WEDNESDAY *April 10*	Second Day of Symposium **Keynote Talk** **Platform Presentations** Lunch Provided **Exhibits and Posters**
THURSDAY *April 11*	**Workshop 1:** Conceptual Site Model Development and Translation to Numerical Models *(8:00 AM - 12:00 PM)* **Workshop 2:** Understanding and Addressing Well Performance Issues *(8:00 AM - 5:00 PM)* **Workshop 3:** ITRC Guidance: Remediation Management of Complex Sites *(1:00 PM - 5:00 PM)*
FRIDAY *April 12*	**Field Trip:** Elwha River Restoration Port Angeles, Washington *(8:00 AM - 5:00 PM)*

2019 WELCOME

12th Washington Hydrogeology Symposium

Welcome to the 12th Washington Hydrogeology Symposium! We are pleased to convene this year's symposium at the Hotel Murano in Tacoma, Washington. The Hotel Murano is conveniently located in downtown Tacoma. We hope that this Symposium brings together our community of Hydrogeologists and offers you the opportunity to connect with colleagues and build new collaborations.

This year's technical program consists of 52 platform and 12 poster presentations. Specific topics include Hydrogeologic Characterization Methods and Approaches, Natural and Anthropogenic Impacts in River Corridors, and Innovative Remediation Technologies. These presentations will also include sessions and facilitated panels on streamflow restoration and climate change. The 2019 Steering Committee has also put together two informative field trips, giving symposium participants the opportunity to visit and learn about the Geology of the Oso Landslide or the Elwha River Restoration Site. In addition to the technical program, three workshops will be presented: Conceptual Site Model Development and Translation to Numerical Models, Understanding and Addressing Well Performance Issues, and ITRC Guidance on Remediation Management of Complex Sites.

We are excited to have two distinguished keynote speakers: Dr. Kamini Singha, Professor of Geology and Geological Engineering at Colorado School of Mines, and Dr. David Boutt, Associate Professor in the Department of Geosciences at University of Massachusetts-Amherst. Dr. Singha was the 2017 Darcy Lecturer, and her current research focuses on hydrogeology and environmental geophysics. Dr. Boutt was the 2018 Birdsall-Dreiss Distinguished Lecturer. His research focuses on the role of groundwater in catchment-scale hydrologic processes.

Please take time to visit our exhibitors. They offer a variety of solutions for state-of-the-art data collection, analysis, and reporting. We also encourage you to participate in our Passport Program with our exhibitors for the opportunity to win prizes. We would especially like to thank our sponsors. Through their generosity, they have ensured the continuity of the Symposium.

For the second year, the Symposium will be able to award the Nadine Romero Scholarship to an undergraduate and graduate student to support their continued study of Hydrogeology. The Symposium established the scholarship to support the development of new professionals in our field. We look forward to announcing this year's scholarship winners.

On behalf of the 12th Washington Hydrogeology Symposium Steering Committee, I hope you have several enjoyable and productive days at the Symposium, and that you plan to join us again in 2021!

Sincerely,

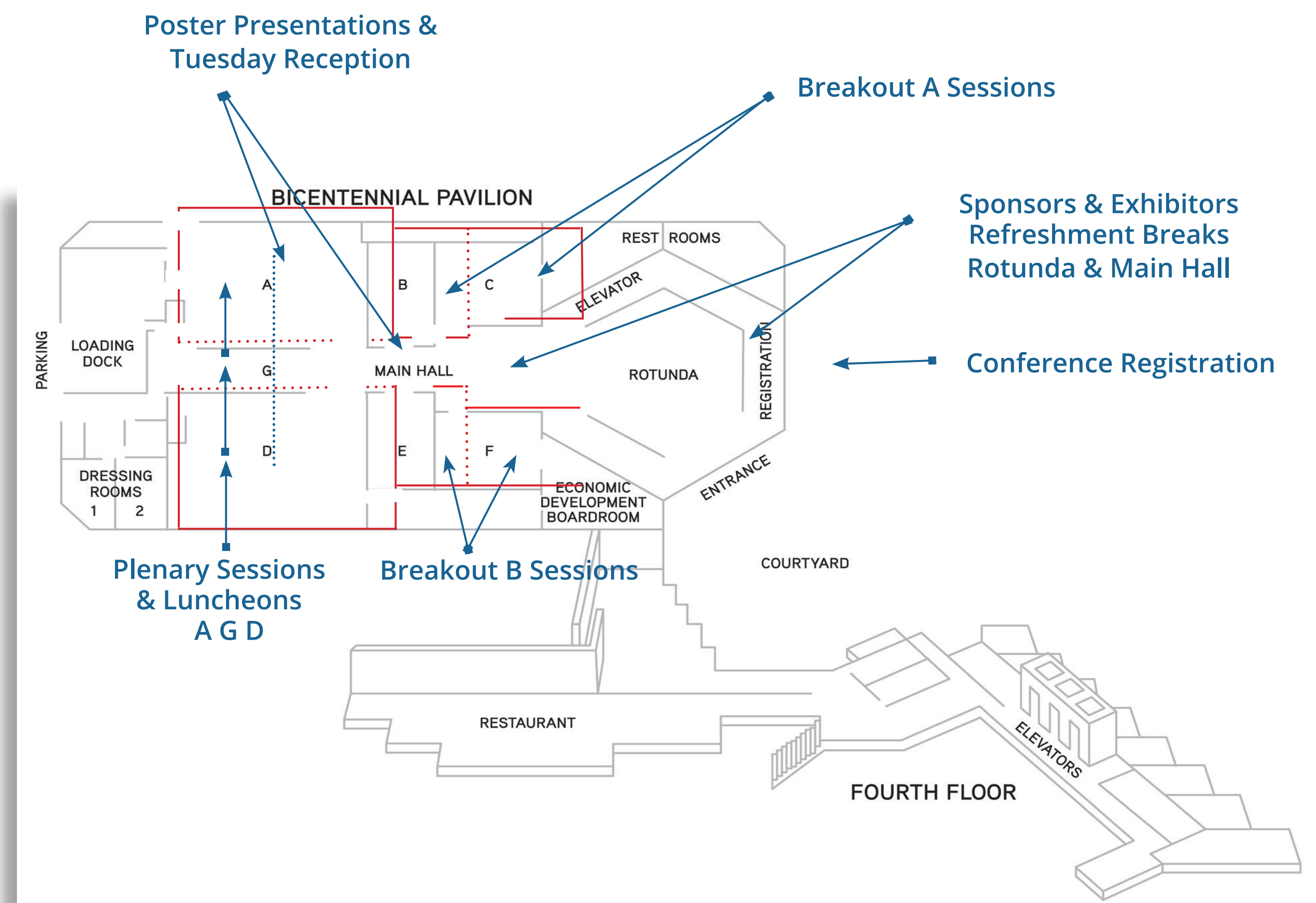
Danielle Squeochs
2019 Symposium Chair
Washington State Department of Ecology

12th Washington Hydrogeology Symposium

KEY LOCATIONS

Hotel Murano, Tacoma

Bicentennial Pavilion



Main Hotel

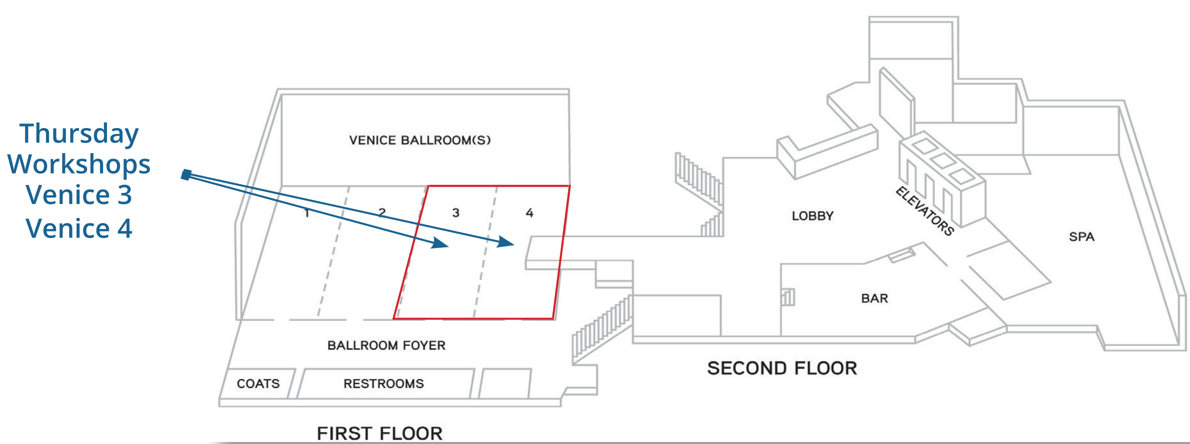


TABLE OF CONTENTS

12th Washington Hydrogeology Symposium

Nadine L. Romero Student Scholarships

The biannual Nadine L. Romero Student Scholarship recognizes students who have demonstrated exceptional academic achievements, are making valuable contributions to the hydrogeology and university communities, and have significant potential as future professional hydrogeologists.

Scholarship recipients will be announced at the Symposium and on the Symposium website.

GENERAL INFORMATION

Symposium Registration Booth and Registration Hours

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.
Tuesday, April 9: 7:30 AM–5:20 PM | Wednesday, April 10: 8:30 AM–4:20 PM | Thursday, April 11: 8:00 AM– 5:00 PM

Name Badges

Please wear your name badge. It 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 will be held in the Venice rooms located on 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 15 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 be in place by the end of the afternoon break at 3:00 PM. Plan to be available at your poster during the Tuesday Poster Session and Reception from 5:20–6:45 PM. You may leave your poster up until the end of the afternoon break on Wednesday at 2:40 PM.

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

Poster Session and Reception

We hope you will join us at the Symposium Poster Session and Reception on Tuesday from 5:20–6:45 PM. View the posters, visit our sponsors and exhibitors, and enjoy food and beverages while networking with colleagues.

Sponsors / Exhibits

Sponsors and exhibitors showcasing their latest products and services will be available throughout the day on Tuesday and on Wednesday through the afternoon break.

2019 Passport Book Contest

Your Passport book lists all our 2019 Sponsors and Exhibitors. Get your passport stamped as you visit each exhibitor table. Those who visit every table and turn in a completed passport are entered into our prize drawings, including a grand prize. Drawing takes place during the Wednesday afternoon break. *Must be present to win.*

Internet Access

Complimentary internet access is available in all meeting rooms, the Murano lobby, and the hotel restaurant. Overnight guests at the Murano will receive a user name and password for wifi access in their hotel room and in the meeting rooms. For those participants not staying in the hotel, please use:

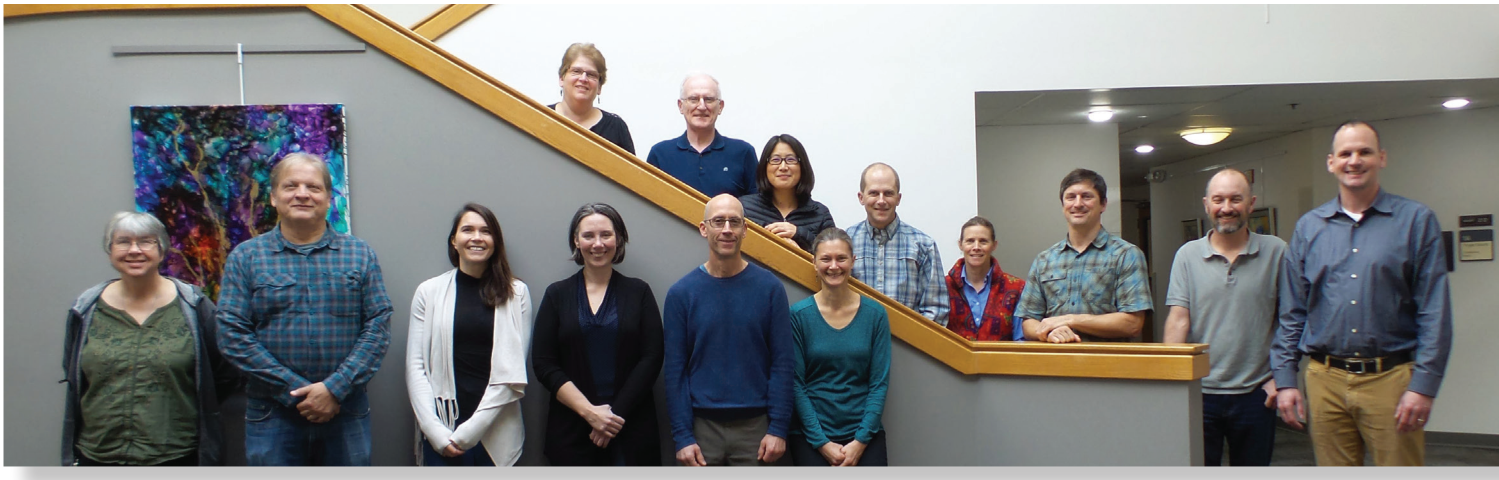
Username: WAHYDRO | Password: 2019

Please direct your questions to the hotel front desk staff persons or Symposium staff at the Registration Booth.

Important Phone Numbers

Hotel Murano: 253-238-8000 | Registration Booth: Hotel number plus extension 7125
Tacoma Visitors Bureau: 253-284-3254 | Emergencies: Dial 911

STEERING COMMITTEE



Top left to right: Vicky Freedman, Mike Gallagher , Xingyuan Chen, Mark Freshley, Sheryl Howe, Leland Fuhrig, Chris Allen, Ken Nogeire
Bottom left to right: Laurie Morgan, Roy Jensen, Catherine Yonkofski, Danielle Squeochs, Andy Long, Bryony Stasney

12th Washington Hydrogeology Symposium Steering Committee

Danielle Squeochs	Washington State Department of Ecology, Chair
Andy Long	U. S. Geological Survey, Vice-Chair
Ken Nogeire	PBS Environmental, Treasurer
Catherine Yonkofski	Pacific Northwest National Laboratory, Secretary
Bryony Stasney	Washington State Department of Health, Officer
Vicky Freedman	Pacific Northwest National Laboratory, Officer
Bob Mitchell	Western Washington University, Officer
Angie Goodwin	Hart Crowser, Officer
Jason Shira	Aspect Consulting, Officer
Chris Allen	Shannon & Wilson, Inc., Committee
Xingyuan Chen	Pacific Northwest National Laboratory, Committee
Mark Freshley	Pacific Northwest National Laboratory, Committee
Leland Fuhrig	U. S. Geological Survey, Committee
Mike Gallagher	Washington State Department of Ecology, Committee
Andy Gendaszek	U. S. Geological Survey, Committee
Dibakar Goswami	Washington State Department of Ecology (DPTEC) , Committee
Sheryl Howe	Washington State Department of Health, Committee
Roy Jensen	Hart Crowser, Committee
Sue Kahle	U. S. Geological Survey, Committee
Laurie Morgan	Washington State Department of Ecology, Committee
Sophia Petro	Washington State Department of Health, Committee
Rose Riedel	Olympic Environmental Equipment, Committee
Michelle Snyder	Pacific Northwest National Laboratory, Committee
Gary Walvatne	Apex Consulting, Committee
Fred Zhang	Pacific Northwest National Laboratory, Committee

Mary Jane Shirakawa	UW Conference Management University of Washington | www.uwconferences.org

Please note! Interested persons are welcome to join the Symposium Planning Committee. If you are interested in participating in the planning of the 2021 Symposium, please sign up at the Symposium Registration Desk. To kick things off, you will be invited to attend the committee breakfast meeting on Wednesday, April 10, at 7:30 AM (*Breakfast complimentary; RSVP required*).

Tuesday, April 9, 2019		
7:30 AM	Check-in & Registration	
9:00 AM	**Opening Session** *(Room AGD)*	
9:00 AM	**Welcome and Opening Remarks** *Danielle Squeochs, 2019 Washington Hydrogeology Symposium Chair*	
	Keynote Talk: Hydrogeophysics of the Critical Zone: Links Between Groundwater and Tree-Water Use ***Kamini Singha,*** *Professor, Geology and Geological Engineering, Colorado School of Mines, Golden, Colorado. 2017 Darcy Lecturer*	
10:15 AM	Refreshment Break | Exhibits | Posters	
10:40 AM	**1A–Contaminant Hydrogeology** *(Room BC)*	**1B–Hydrogeologic Characterization Methods and Approaches** *(Room EF)*
SESSION 1	*Session Chair: Catherine Yonkofski*	*Session Chair: Bryony Stasney*
	Identifying the Technical Basis for Technical Impracticability Waivers for Recalcitrant Radionuclides *Vicky Freedman, Pacific Northwest National Laboratory*	**Soil-Water Balance Model Estimates of Recharge and other Water Budget Components for the Upper Chehalis River Basin** *Andrew Gendaszek, U.S. Geological Survey*
	Uranium in Groundwater in Northeastern Washington State *Sue Kahl, U.S. Geological Survey*	**Estimating Aquifer Parameters from Large Sets of Pumping-Test Data Using Streamlined, Python-Based Analysis Software** *Benjamin Scandella, Oregon Water Resources Department*
	Pump-and-Treat Performance Assessment Using a Rebound Study *Christian Johnson, Pacific Northwest National Laboratory*	**Using the Borehole Permeameter Method to Estimate Hydraulic Conductivity in Glacially-Consolidated Soils** *J. Scott Kindred, Kindred Hydro, Inc.*
	Field Ready Electrochemical Detection of Arsenic *David Lloyd, FREDsense Technologies*	**Innovative Drilling for Emergency Characterization of Hydrostratigraphy** *Jim Bailey, Shannon & Wilson, Inc.*
Noon	Hosted Luncheon *(Room AGD)*	
1:00 PM	**2A–Climate Impacts** *(Room BC)*	**2B–Aquifer Storage and Recovery** *(Room EF)*
SESSION 2	*Session Chair: Xingyuan Chen*	*Session Chair: Angle Goodwin*
	The Effects of Forecasted Climate Change on Hydrology and Stream Temperature in the North Fork of the Stillaguamish River Basin *Robert Mitchell, Western Washington University* **Panel Discussion Topic: Surface Water and Groundwater Resources Under Changing Climate** ***Panel Members:*** *Dr. Xingyuan Chen, Pacific Northwest National Laboratory* *Jon Turk, Licensed Hydrologist* *Bart Nijssen, Professor, Civil and Environmental Engineering, UW* *Bob Mitchell, Professor, Engineering Geology, Western Washington University*	**Estimating Aquifer Recharge Potential Within a Multi-Decision Criteria Analysis to Locate Suitable Managed Aquifer Recharge Locations in the Yakima River Watershed, Washington USA.** *Maria Gibson, Oregon State University* **Use of Injection Wells for Disposal of Non-Contact Cooling Water** *Roy Jensen, Hart Crowser, Inc.* **Policy, Permitting and the Particulars of Aquifer Storage and Recovery in Washington State** *Danielle Squeochs, Washington State Department of Ecology* **Fresh Look at Design and Maintenance of UIC Wells** *Jim Bailey, Shannon & Wilson Inc.*
2:20 PM	Refreshment Break | Exhibits | Posters	

Tuesday, April 9, 2019		
2:40 PM	**3A–Analysis and Web-based Tools in Hydrology** *(Room BC)*	**3B–Water Quality Monitoring Approaches and Technologies** *(Room EF)*
SESSION 3	*Session Chair: Leland Fuhrig*	*Session Chair: Mark Freshley*
	A Framework to Deliver Real-time and Long-term Hydrologic Data: Web-Based Applications for Water Resource Analysis *Sachin Shah, U.S. Geological Survey*	**Deep Vadose Zone Monitoring for the Hanford Central Plateau** *Chris Strickland, Pacific Northwest National Laboratory*
	Building Web-Based 3D Hydrogeologic Models and Providing Groundwater-Monitoring Data: An Update from the Washington Geological Survey *Carrie Gillum, Washington Geological Survey*	**Well Flow Dynamics and Application of Passive Sampling Techniques for Long Term Monitoring at Remediation Sites** *Sanford (Sandy) Britt, PG, CHG, QED Environmental*
	Time-Series Analysis for Groundwater: Quick Methods to Assess Groundwater Response to Precipitation *Andrew Long, U.S. Geological Survey*	**Characterization of PFAS in Soil, Groundwater, Surface Water, Stormwater, and Sediment at Portland International Airport (PDX), Oregon** *Heather Gosack, Apex Companies, LLC*
	Cellular Telemetry for Water Monitoring *Nathaniel Kale, Thurston County*	**Analysis Tools for Remedy Performance Assessment** *Michael Truex, Pacific Northwest National Laboratory*
	Estimating Stage-Discharge Curves in R *Nathaniel Kale, Thurston County*	**A Performance Monitoring Approach for Pump-and-Treat Systems: Hanford Site Case Study** *Michael Truex, Pacific Northwest National Laboratory*
4:20 PM	Refreshment Break | Exhibits | Posters	
4:40 PM	**4A–Groundwater Management and Planning** *(Room BC)*	**4B–Groundwater Rights and Regulation** *(Room EF)*
SESSION 4	*Session Chair: Jason Shira*	*Session Chair: Vicky Freedman*
	Critical Aquifer Recharge Areas Guidance Update *Laurie Morgan, Washington State Deptartment of Ecology Water Quality Program*	**Issues Using the USGS Kitsap Model for Water Rights Investigations** *Joe Becker, Robinson Noble, Inc.*
	Sustaining Redmond's Shallow Alluvial Aquifer in an Expanding Urban Environment *Amanda Balzer, City of Redmond*	**Toolbox for Computational Evaluations of Impacts of Subsurface Operations** *Catherine Yonkofski, Pacific Northwest National*
5:20 PM - 6:45 PM	**Poster Session & Reception** *See poster listing on next page. Posters in AGD. Reception throughout Bicenenial Pavilion*	

Tuesday, April 9, 2019	
5:20 PM - 6:45 PM	**Poster Session & Reception** *(Posters in AGD; Reception throughout Bicenenial Pavilion)*
	Using R for Analysis of Continuous Surface Water Temperature Data *Pat Hallinan, Washington State Deptartment of Ecology*
	Long-Term Analysis of Baseflow Trends in the Southeast Puget Sound Basin *Alexander Headman, U. S. Geological Survey*
	Long Term Volunteer Data Collection on Vashon-Maury Island *Eric Ferguson, King County DNRP*
	Modeling the Effects of Climate Change on Streamflow and Stream Temperature in the South Fork of the Stillaguamish River *Katherine Clarke, Western Washington University*
	Using Ensemble Data Assimilation to Estimate Long-term Hydrologic Exchange Fluxes under Highly Dynamic *Kewei Chen, Pacific Northwest National Laboratory*
	Sumas-Blaine Aquifer Nitrate Characterization, 2018 *Eric Daiber, Washington State Department of Ecology*
	Simulation of Groundwater Storage Changes in the Quincy Basin, Washington *Lonna Frans, U.S. Geological Survey*
	100 Years of Washington Hydrology *Valerie Bright, U.S. Geological Survey*
	Air Stripping Addresses Critical Drinking Water Treatment Needs *David Fischer, QED Environmental Systems*
	Estimating Ground and Surface Water Contributions to a Throughflow Lake Using Stable Isotope Hydrology *Ayman Alharbi, Washington State University*
	Hydrogeology of University Basin Area of Seattle, King County, Washington *Jennifer Hilden Saltonstall, Associated Earth Sciences, Inc.*
	What do Almost 30 Years of Data from a Countywide Database Tell Us about the Water Resources of Kitsap County, Washington? *Joel Purdy, Kitsap Public Utility District*

Wednesday, April 10, 2019		
8:00 AM	Registration Desk Opens	
8:30 AM	**Morning Keynote Session** *(Room AGD)*	
	Keynote Talk: Groundwater as a Buffer to Climatic Change: Dynamic Subsurface Storage of Glaciated Landscapes ***David Boutt,*** *Associate Professor, Department of Geosciences, University of Massachusetts-Amherst* *2018 Birdsall-Dreiss Distinguished Lecturer*	
9:30 AM	Refreshment Break | Exhibits | Posters	
9:50 AM	**5A–Streamflow Restoration I** *(Room BC)*	**5B–Groundwater and Surface Water Interactions** *(Room EF)*
SESSION 5	*Session Chair: Mike Gallagher*	*Session Chair: Andy Gendaszek*
	Restoration of Incised Stream Channels as a Means of Improving Water Storage, Stream Flow and Climate Resiliency *Tim Abbe, Natural Systems Design*	**Monitoring Groundwater and VOC Discharge to Surface Water in the Transitional Zone** *Tom Colligan, FloydSnider, SPC*
	Mission Creek Flow Improvement: An Example of First Steps to Solving Instream Flow and Water Supply Challenges *Jason Shira, Aspect Consulting*	**A Slough of Challenges: Permitting and Activated Carbon Placement on the Lower Columbia Slough** *Carmen Owens, Apex Companies, LLC*
	Assessing the Impacts of Stream Restoration on Groundwater Dynamics and Potential Storage at Indian Creek in the Teanaway Community Forest *Nora Boylan, Oregon State University*	**Dynamic River Stage Variations Lead to Multimodal Residence Time Distributions of Hydrological Exchange Flow** *Xuehang Song, Pacific Northwest National Laboratory*
	Estimating Future Domestic Home Water Needs Under RCW 90.94 in A Rural Northeastern County Watershed, Stevens County, Washington *Gene St. Godard, Water & Natural Resource Group, Inc.*	**Hydromorphic Classification of the Hanford Reach Through Machine Learning of Field Observations and Hydrodynamic Simulations** *Zhangshuan Hou, Pacific Northwest National Laboratory*
11:30 AM	Hosted Luncheon *(Room AGD)*	
1:00 PM	**6A–Streamflow Restoration II** *(Room BC)*	**6B–Case Studies in Hydrogeology** *(Room EF)*
SESSION 6	*Session Chair: Mike Gallagher*	*Session Chair: Danielle Squeochs*
	Washington's New Streamflow Restoration Law - A First Year Overview *Michael Gallagher, WA State Department of Ecology*	**What are we Learning about Widespread Application of Bioretention?** *Karen Dinicola, WA State Department of Ecology*
	Use of a Coupled Ground and Surface Water Model (GSFLOW) in the WRIA 55 RCW 90.94 Watershed Plan Update *Mike Hermanson, Spokane County Environmental Services*	**Site-Specific Investigation for a Salt Contaminated Organic Peat Soil** *Steve Graham, S Graham Engineering and Geology Inc.*
	Panel Discussion Members: *Lisa Dally Wilson, President, Dally Environmental* *Mike Gallagher, Washington State Department of Ecology* *Michael Hermanson, Spokane Co. Env. Services Dept.* *Stephanie Potts, Washington State Department of Ecology* *Gary Stoyka, Whatcom County Public Works Department*	**Analysis of Groundwater Response to Tidal Fluctuations at Near-shore Groundwater Monitoring Sites Along Coastlines in Puget Sound** *Chad Opatz, US Geological Survey, Washington Water Science Center*
		Geothermal Exploration in Washington State Using a Play-Fairway Approach *Alex Steely, Washington Geological Survey*
2:20 PM	Refreshment Break | Exhibits | Posters Passport Contest Prize Drawing	

Wednesday, April 10, 2019		
2:40 PM	**7A–Natural and Anthropogenic Impacts in River Corridors** *(Room BC)*	**7B–Innovative Remediation Technologies** *(Room EF)*
SESSION 7	*Session Chair: Gary Walvatne*	*Session Chair: Ken Nogeire*
	Dam Operations and Subsurface Hydrogeology Control Dynamics of Hydrologic Exchange Flows in a Large Regulated River Corridor within the Hanford Reach, Washington *Pin Shuai, Pacific Northwest National Laboratory*	**In Situ Remediation of Carbon Tetrachloride Using BOS 100(r)** *Mike Mazzarese, RPI Group*
	The Application of Non-Invasive Geophysical Techniques to Earthen Dam Investigations *Nigel Crook, hydroGEOPHYSICS, Inc.*	**Installing a Prototype Horizontal Reactive Media Treatment (HRX®) Well** *Michael Lubrecht, Directed Technologies Drilling, Inc.*
	Sediment Monitoring During Elwha River Dam Removal: Lessons Learned During the Nation's Largest Dam Removal Project *Christopher Curran, U.S. Geological Survey*	**Using Real-Time Monitoring to Rapidly Assess and Adjust Groundwater Remediation Strategies** *Bill Mann, In-Situ Inc.*
	Western Washington Applications of the Streamflow-Routing Package (SFR2) in MODFLOW *Leland Fuhrig, U.S. Geological Survey*	**Optimization and Performance of ZVI Amendments for In-Situ Chemical and Biological Reduction** *David Alden, Tersus Environmental*
	Water Temperature in the Lower Quinault River, Olympic Peninsula, Washington *Kristin Jaeger, U.S. Geological Survey*	**TPH-G, From 200,000 ug/L to 130 ug/L within 30 days of Treatment** *Glenn Hayman, Hayman Environmental*
4:20 PM	Symposium Presentations Adjourn	

Thursday, April 11, 2019	
8:00 AM - 12:00 PM	**Workshop 1: Conceptual Site Model Development and Translation to Numerical Models** Room: Venice 3, Hotel Murano
	Workshop Presenters: *Vicky Freedman, Pacific Northwest National Laboratory* *Mike Truex, Pacific Northwest National Laboratory*
8:00 AM - 5:00 PM	**Workshop 2: Understanding and Addressing Well Performance Issues** Room: Venice 4, Hotel Murano
	Workshop Presenter: *Jim Bailey, Shannon & Wilson, Inc.*
1:00 AM - 5:00 PM	**Workshop 3: ITRC Guidance: Remediation Management of Complex Sites** Room: Venice 3, Hotel Murano
	Workshop Presenters: *John Price, Washington State Department of Ecology* *Elisabeth Hawley, Geosyntec Consultants* *Mike Truex, Pacific Northwest National Laboratory*

KEYNOTE SPEAKER

Tuesday, 9:00 AM

Kamini Singha, Ph.D.

Professor, Geology and Geological Engineering
Colorado School of Mines, Golden, Colorado
2017 Darcy Distinguished Lecturer

"Hydrogeophysics of the Critical Zone:
Links Between Groundwater and Tree-Water Use"

Earth's "critical zone" – the zone of the planet from treetops to base of groundwater – is critical because it is a sensitive region and open to impacts from human activities while providing water necessary for human consumption and food production. Quantifying water movement in the subsurface is critical to predicting how water-driven critical zone processes respond to changes in climate and human perturbation of the natural system. While shallow soils and above-ground parts of the critical zone can be easy to instrument and explore, the deeper parts of the critical zone—through the soils and into rock—are harder to access, leaving many open questions about the role of water in this environment. Here, I open the black box in the subsurface and shed light on a few key subsurface processes that control water movement and availability: linkages between changes in evapotranspiration and subsurface water stores, water movement in 3-D over large areas, and potential control of slope aspect on subsurface permeability. Geophysical tools are central to the quantitative study of these problems in the deeper subsurface where we don't have easy access for observation. Specifically, I 1) study transpiration controls subsurface water stores of daily and seasonal timescales throughout growing seasons, 2) map subsurface water movement by measuring small, naturally occurring voltages measured with a simple voltmeter and 3) test hypotheses about subsurface weathering and the subsequent controls on hydrogeology using seismic methods.

Kamini Singha is the Ben Fryrear Endowed Professor for Innovation and Excellence at the Colorado School of Mines. She serves as the Associate Department Head of the Department of Geology and Geological Engineering and Interim Director of the Hydrologic Science and Engineering Program. She worked at the USGS Branch of Geophysics from 1997 to 2000 and served on the faculty of Pennsylvania State University as an assistant and associate professor from 2005 to 2012. Her research interests are focused in hydrogeology and environmental geophysics. Dr. Singha is the recipient of an NSF CAREER award, was awarded the Early Career Award from the Society of Environmental and Engineering Geophysics in 2009, and became the National Groundwater Association's Darcy Lecturer in 2017 and a GSA Fellow in 2018. She earned her B.S. in geophysics from the University of Connecticut in 1999 and her Ph.D. in hydrogeology from Stanford University in 2005.

KEYNOTE SPEAKER

Wednesday, 8:30 AM

David Boutt

Associate Professor, Department of Geosciences
University of Massachusetts-Amherst
2018 Birdsall-Dreiss Distinguished Lecturer

**"Groundwater as a Buffer to Climatic Change:
Dynamic Subsurface Storage of Glaciated Landscapes"**

The northeastern United States is experiencing rapid changes in its hydrology due to intense land-use change, urbanization, and climate change. It also possesses some of the highest density, longest term observations of hydrologic variables (e.g. streamflow and groundwater levels) in the US and world. The focus of this presentation is how small unconfined aquifer systems, and the streams to which they are connected, respond to hydroclimatic and land use changes. The research is data-driven. Physical and geochemical information is used to understand how different subsurface environments and surface-water groundwater interactions impact the sensitivity of groundwater storage to climate variability. Analysis of groundwater levels and streamflows reveal a heterogeneous response of aquifers to climate variability, highlighting the role of subsurface hydrologeologic heterogeneity to aquifer response. A long-term rise in water levels can be observed from analysis of water level trends. This is associated with an increase in precipitation and land-use change ultimately leading to an increase in nuisance flooding. Integrating isotopic tracers into this work has improved our understanding of the role of extreme precipitation events on groundwater storage. Isotope data have also shed light on the fundamental importance of groundwater discharge to streamflow in the region. This work highlights the importance of understanding groundwater processes in generating in streamflow – with implications for water supply, baseflow generation, climate refugia, and assessing flood risk in a changing world.

David Boutt is an Associate Professor in the Department of Geosciences at the University of Massachusetts-Amherst. He received B.S. and M.S. degrees from the Department of Geological Sciences at Michigan State University in 1997 and 1999. His MS work focused on understanding the impacts of land-use change on groundwater quantity and quality at the watershed-scale. He earned his Ph.D. from the New Mexico Institute of Mining and Technology (Socorro, New Mexico, USA) in 2004 and held a postdoctoral position at Sandia National Laboratories before joining the faculty at UMass-Amherst in 2005. During his Ph.D. research he was awarded an AGU Horton Research Grant. Dr. Boutt's dissertation work focused on the coupling of fluid flow and deformation in fractured and faulted media through the development of discretely-coupled fluid-solid models.

His current research program focuses on understanding the role of groundwater in catchment-scale hydrologic processes. This involves delineating the contribution of groundwater storage to stream flow generation, spring discharge, and hydrologic budgets. A list of his publications can be found at https://blogs.umass.edu/dboutt/

Panel 2A: Climate Impacts

Tuesday, April 9, 2019 | 1:00–2:20 PM
Panel Moderator: Xingyuan Chen

Surface Water and Groundwater Resources Under Changing Climate
Climate variability and change has profound impacts to our environment and society. This session will focus on the interactions between climate, surface water, and groundwater, as well as their regional implications to the Pacific Northwest. We invite contributions that represent emerging research and management practices in assessing and mitigating the impacts of climate change on water resources given the known uncertainty in long-term climate projections. Topics may include the projected impacts of climate change to water resources in the Pacific Northwest, adaptation and mitigation strategy to changing climate, infrastructure and ecosystem resiliency, sustainable watershed management, numerical modeling, and long-term monitoring to understand the environmental and societal impacts of climate induced water resources extreme events such as droughts and floods.

Panel Members

Dr. Xingyuan Chen is a senior research scientist at the Pacific Northwest National Laboratory. Her main research expertise is multiscale hydrobiogeochemical modeling and data-model integration. She received her PhD degree in Civil and Environmental Engineering and a Master's degree in Statistics from the University of California, Berkeley. She serves a co-Principal Investigator on a DOE science focus area project studying the influences of hydrologic exchange flows on river corridor and watershed biogeochemical function.

Jon Turk is a licensed hydrogeologist with 18 years of experience providing diverse water resources consulting services throughout the United States. His expertise includes detailed studies and analyses of integrated water resource systems, long range water supply planning, well field management, and aquifer storage and recovery systems. Within the last few years, Jon has contributed to the development of the climate change adaptive management strategy for the island of Oahu, long-range water supply and climate resilience planning in southeast Florida, and optimization of water rights to address capacity and watershed challenges for clients here in Washington State. Jon is currently working with WSU and the Ecology's OCR on the 2021 Long-Term Water Supply and Demand Forecast for the Columbia River Basin.

Bart Nijssen is the Allan & Inger Osberg Professor in the Department of Civil and Environmental Engineering at the University of Washington (UW), where he heads the UW Hydro | Computational Hydrology group. After he completed his PhD at the UW in 2000, he worked at the University of Arizona and in the private sector, before returning to the UW in 2011. His research group builds tools to simulate and investigate the terrestrial hydrological cycle and uses these tools for a wide range of hydrologic research projects. He and his group investigate the effects of climate change on the hydrologic cycle, perform near real-time monitoring and forecasting studies for drought and streamflow, simulate the interactions between the various components of the climate system in coupled regional climate models, develop and analyze large datasets, and along the way write a lot of code that they are happy to share with others. He and his research group recently completed a study of the hydrological impacts of climate change in the Columbia River Basin for which they received an Award from the Bonneville Power Administration for Exceptional Public Service to BPA.

Bob Mitchell currently serves as the Digges Distinguished Professor of Engineering Geology in the Geology Department at Western Washington University. He has degrees in geology, geophysics, physics, and a Ph.D. in Environmental Engineering. Bob has been a faculty member in the Geology Department at Western since 1996, where he teaches courses in engineering geology, surface-water hydrology, hydrogeology, ground-water contamination. Bob has supervised numerous graduate students on applied research problems in the Puget Sound region including modeling the effects of climate change on snowpack, glacial recession, streamflow, stream temperatures, and hillslope processes in mountainous watersheds. Bob currently serves on the Board of the Environmental and Engineering Division of the GSA, Board of the Washington State Hydrogeology Symposium, and served eight years on the Washington State Geologist Licensing Board.

Panel 6A: Streamflow Restoration II

Wednesday, April 10, 2019 | 1:00–2:20 PM
Panel Moderator: Michael Gallagher

In January 2018, the Washington State Legislature passed Engrossed Substitute Senate Bill (ESSB) 6091 in response to the Hirst decision. Hirst was a 2016 Washington State Supreme Court decision that changed how some counties issued building permits. The court ruled that the county had failed to comply with the Growth Management Act requirements to protect water resources. In general, this decision limited a landowner's ability to obtain a building permit for a new home when the proposed source of water was a permit-exempt well and put the burden on the County (and on the property owner) to "prove " water was "legally available" for the new well.

ESSB 6091 (now codified as RCW 90.94) addresses the court's decision by allowing landowners to obtain a building permit for a new home relying on a permit-exempt well. The law also directs local planning groups to develop streamflow restoration plans that address the potentially negative impacts from new development.

This panel brings together experts who have been actively engaged in implementing RCW 90.94 by leading watershed planning units with adopted watershed plans in their respective WRIAs and chairing Watershed Restoration and Enhancement Committees for those WRIAs without an adopted watershed plan to develop streamflow restoration plans that address the physical and legal availability of water needs from new development of exempt wells within the WRIA over the next 20 years. Representatives from the Department of Ecology, Nisqually Tribe, Whatcom County, and Spokane County will summarize the progress to date in implementing the watershed plan adoption focus of this new law, including providing an update on progress made to date in the following watersheds: WRIA 1 (Nooksack), WRIA 8 (Cedar-Sammamish), WRIA 9 (Green-Duwamish), WRIA 11 (Nisqually), and WRIA 55 (Little Spokane).

Panel Members

Lisa Dally Wilson is President of Dally Environmental, a licensed civil engineer, and a professional facilitator with over 25 years of diverse experience in water resources. She provides consulting services in the areas of water resource planning and engineering and water policy and often facilitates stakeholders addressing complex water and natural resource challenges at a watershed scale. She recently worked with the Nisqually Indian Tribe, serving as facilitator of the Nisqually (WRIA 11) Planning Unit, co-project manager, and author of Nisqually Watershed Plan Addendum to meet the requirements of RCW 90.94. The Nisqually 'Hirst Response' is the first plan to gain approval under Washington's new streamflow restoration law. Lisa holds a BS from Cornell University and a Master's degree in Environmental Engineering from the University of Washington.

Mike Gallagher is the Section Manager of the Southwest Regional Water Resources Section at the Washington State Department of Ecology. Mike has been with Ecology for over 34 years. For the past eleven years, Mike has worked for the Water Resources Program in the Southwest Regional Office in Olympia – first as a unit supervisor/hydrogeologist and for the past eight years as the section manager for the SWRO Water Resources Section. Mike holds a BS in Geology from the University of Puget Sound, an MS in Geology from Western Michigan University, and a Master's in Public Administration from The Evergreen State College.

Michael Hermanson is the Water Resources Manager in the Spokane County Environmental Services Department. He managed the development of the Little Spokane Water Bank and is leading the development of a watershed plan update in WRIA 55 to meet the requirements of RCW 90.94. Over the last 12 years at Spokane County, Michael has been involved in the development and implementation of watershed plans for WRIAs 54, 55, and 57. He has been involved in numerous water resource investigations, both as a project manager and scientist. He graduated from Western Washington University in 1994 with a degree in Environmental Science.

continued next page

Panel 6A: Streamflow Restoration II - *continued from previous page*

Stephanie Potts is an Environmental Planner in the Water Resources Program at Ecology's Northwest Regional Office in Bellevue. She is the Chair of the WRIA 8 and WRIA 9 Watershed Restoration and Enhancement Committees. Stephanie has a background in environmental and transportation policy and most recently worked as a grant manager for community planning and development programs at the Seattle office of the U.S. Department of Housing and Urban Development. She has also worked for Smart Growth America in Washington, DC. She holds a BA in Environmental Studies and Anthropology, a Master of Environmental Studies from the University of Pennsylvania, and a Master of Public Administration from the University of Washington. From 2013-2015 she served in the Peace Corps as an agriculture volunteer in Ghana.

Gary Stoyka is the Natural Resources Program Manager with the Whatcom County Public Works Department. Gary has over 25 years of experience in the natural resources and environmental field. He has been managing Whatcom County's response to the ESSB 6091 (RCW 90.94 and has been with Whatcom County for over five years. Prior to coming to Whatcom County, Gary worked at the Skagit County Public Works Department for eleven years including as manager of Skagit County's Clean Water Program, where he oversaw salmon recovery, watershed planning, lake management, marine resources committee, the water quality program, and management of closed landfills. Before coming to Skagit County, he spent nearly ten years in the environmental consulting field in the Puget Sound region managing and conducting hydrogeological and environmental site investigations and remediation at sites throughout the Northwest. Gary has a BS and MS Degree in Geology, is a Licensed Hydrogeologist in Washington, and is a Registered Professional Geologist in Oregon.

Oral Abstracts

pages 14–64

Poster Abstracts

pages 65–76

Identifying the Technical Basis for Technical Impracticability Waivers for Recalcitrant Radionuclides

Vicky Freedman, Pacific Northwest National Laboratory
Mark Rockhold, Pacific Northwest National Laboratory
Catherine Yonkofski, Pacific Northwest National Laboratory
Janelle Downs, Pacific Northwest National Laboratory
Scott Waichler, Pacific Northwest National Laboratory
Yilin Fang, Pacific Northwest National Laboratory

Injection wells are currently used to hydraulically contain the leading edge of a radioactive iodine-129 (I-129) groundwater plume that underlies the Hanford Site's 200-UP-1 Operable Unit within the Central Plateau. Hydraulic containment has been implemented because to date no viable treatment technologies have been identified that can achieve the federal drinking water standard of 1 pCi/L. The large spatial extent of the I-129 plume limits the practical implementation of readily available remedy options, and the presence of large amounts of natural stable I-127 as well as multiple iodine species (iodate, iodide, and organic-iodine complexes) in the groundwater present challenges for remedy performance. As evaluations of potential remediation technologies proceed, risk-informed remediation endpoints and alternatives—such as Applicable or Relevant and Appropriate Requirements (ARAR) Technical Impracticability (TI) waivers—are being evaluated as specified in the interim Record of Decision. A TI waiver may be a necessary remedy for I-129 at 200-UP-1 to achieve a plume condition that is still protective of human health and the environment. Although nearly 100 TI waivers have been granted at sites across the U.S.; a TI waiver has not yet been granted for a radionuclide, nor has one been granted for a U.S. Department of Energy (DOE)-managed site. This underscores the importance of developing a methodology for risk-based decision-making for iodine and other contaminants of concern at DOE sites.

Uranium in Groundwater in Northeastern Washington State

Sue Kahle, U.S. Geological Survey

A reconnaissance study of uranium in groundwater in northeastern Washington was conducted to make a preliminary assessment of naturally occurring uranium in groundwater relying on existing information and limited sampling. Naturally occurring uranium is associated with granitic and metasedimentary rocks, as well as younger sedimentary deposits, that occur in this region. U.S. Environmental Protection Agency regulates uranium in Group A community water systems at a maximum contaminant level (MCL) of 30 µg/L to reduce uranium exposure, protect from toxic kidney effects of uranium, and reduce the risk of cancer. However, most existing private wells in the study area, generally for single family use, have not been sampled for uranium. This talk will present available uranium concentration data from throughout a multi-county region, identify data gaps, and suggest further study aimed at understanding the occurrence of uranium in groundwater.

The study encompasses about 13,000 square miles in the northeastern part of Washington with a 2010 population of about 563,000. The area has a history of uranium exploration and mining, with two inactive uranium mines on the Spokane Indian Reservation and one smaller inactive mine on the outskirts of Spokane. Historical (1977–2016) uranium in groundwater concentration data were used to describe and illustrate the general occurrence and distribution of uranium in groundwater, as well as to identify data deficiencies. Uranium concentrations were detected at greater than 1 µg/L in 60 percent of the 2,382 historical samples (from wells and springs). Uranium concentrations ranged from less than 1 to 88,600 µg/L, and the median concentration of uranium in groundwater for all sites was 1.4 µg/L.

New (2017) uranium in groundwater concentration data were obtained by sampling 13 private domestic wells for uranium in areas without recent (2000s) water-quality data. Uranium was detected in all 13 wells sampled for this study; concentrations ranged from 1.03 to 1,180 µg/L with a median of 22 µg/L. Uranium concentrations of groundwater samples from 6 of the 13 wells exceeded the MCL for uranium. Uranium concentrations in water samples from two wells were 1,130 and 1,180 µg/L, respectively; nearly 40 times the MCL.

Additional data collection and analysis are needed in rural areas where self-supplied groundwater withdrawals are the primary source of water for human consumption. Of the roughly 43,000 existing water wells in the study area, only about 1,800 wells have available uranium concentration data, and some of those data are decades old. Furthermore, analysis of area groundwater quality would benefit from a more extensive chemical analysis to better understand local geochemical conditions that largely govern the mobility of uranium. Although the focus of the present study is uranium, it also is important to recognize that there are other radionuclides of concern that may be present in area groundwater.

Pump-and-Treat Performance Assessment Using a Rebound Study

Christian Johnson, Pacific Northwest National Laboratory
Michael Truex, Pacific Northwest National Laboratory
Jason Hulstrom, CH2M HILL Plateau Remediation Company

Performance assessment of pump-and-treat (P&T) systems is an important aspect of a P&T remedy for groundwater. Over time, the amount of contaminant mass captured can decline and groundwater concentrations may approach or decline below remediation targets. Such changes will typically precipitate the need for a remedial decision regarding transition from P&T to site closure or to another approach that could be more effective at achieving complete remediation. For P&T assessment, a rebound test can provide information to evaluate predicted plume behavior and the potential presence of continuing contaminant sources in support of remedy decisions for shutdown or transition. A recent rebound study for the 100-K West Area (KW) P&T system on the U.S. Department of Energy's (DOE) Hanford Site illustrates how such a study provides useful performance information to support remedy decisions.

The KW P&T system has been operating since 2007 in the 100-KR-4 Operable Unit (OU) along the Columbia River Corridor of the Hanford Site to provide the interim remedial action for remediation of hexavalent chromium (Cr(VI)) contamination in the groundwater. By January 2016, groundwater Cr(VI) concentrations had reached levels less than the remediation target of 20 µg/L at all 100-K West Area groundwater monitoring locations. A "rebound study" was designed for the purpose of collecting groundwater hydraulic and chemical information while the P&T system was temporarily shut down for an 11-month period starting in the spring of 2016. During this rebound period, the injection and extraction pumps were turned off, groundwater conditions were allowed to recover toward natural conditions, and intensive groundwater monitoring was conducted. The key objectives of this rebound study were to evaluate whether contaminant concentrations would remain below the 20 µg/L remediation target and to assess the potential for presence of residual Cr(VI) sources of groundwater contamination.

During the rebound study, Cr(VI) groundwater concentrations for the portion of the site closest to the Columbia River remained below 20 µg/L, but increased concentrations were observed for portions of the aquifer beneath the vicinity of facilities where historical operations are known or suspected to have discharged Cr(VI)-containing solutions. Analysis of the groundwater data (including depth-discrete samples) suggested potential continuing sources near the water table and/or remnant plumes in localized aquifer zones. This information has been used to guide planning for subsequent efforts to confirm contaminant sources and to test soil flushing as a source treatment process.

Field Ready Electrochemical Detection of Arsenic

David Lloyd, FREDsense Technologies
Emily Hicks, FREDsense Technologies

Characterization of hydrogeological formations requires the timely and accurate collection of water quality information for assessment. Naturally occurring elements being tracked as contaminants, such as arsenic, are difficult to measure due to their low abundance within the aquifer and regulated contaminant limits often meaning that current field kit technologies lack the accuracy for assessment.

While analytical lab methodologies allow for accurate assessment of arsenic concentration, the sampling delay makes coordinating environmental characterization programs difficult. FREDsense Technologies has developed a novel analytical method for rapid arsenic identification within a field context. Utilizing a novel analytical method, combining a bioassay/electrochemical approach, rapid arsenic measurements can be determined on site. The method has been developed into a field-deployable kit system, whereby the system can be deployed to any environment. The field kit has been designed to only require a single-step for operation, where a disposable cartridge is filled with a sample at a site without complex preparation or sample calibration. To date, the system has been demonstrated within utility production wells and shown to be comparable in accuracy and precision to regulated compliance methods EPA standard 200.8 (ICP-MS method). The simplicity of the protocol, low limit of detection (1 ppb) and accuracy/repeatability of the system allows for the field unit to be deployed at sites for rapid assessment of arsenic concentrations with only a one hour delay between sampling and results.

The immediacy of these results allows decision making, including adaptive field investigations, to occur on-site. Additionally, wetlands and tidal discharge studies are possible because the measurements are stable over a range of salinities. This would allow for close to real-time information on changing dissolved arsenic concentrations under conditions of changing salinity, redox potential, and/or oxygen content due to daily fluctuations in wetlands and tidally influenced zones of groundwater.

Soil-Water Balance Model Estimates of Recharge and other Water Budget Components for the Upper Chehalis River Basin

Andrew Gendaszek, U.S. Geological Survey
Wendy Welch, U.S. Geological Survey

An accounting of water budget components (including precipitation, interception, groundwater recharge, surface runoff, and groundwater pumping) is important to sustainably manage groundwater and surface-water resources. Many components, especially groundwater recharge, are difficult to quantify and require numerical tools such as water-balance models or field-collected data to estimate. In the Chehalis River Basin upstream of Grand Mound, Washington, we constructed a Soil-Water-Balance (SWB) model to estimate water-budget components at a daily timestep for the period between October 2011 and September 2015. SWB was developed by the U.S. Geological Survey (USGS) to calculate water-budget components using widely available data about soil properties, meteorological conditions, and land cover. Water-budget components except for groundwater pumpage were estimated at a 500-foot resolution using this model. Groundwater pumpage was estimated from public water purveyor records, Washington State Department of Health records, census population data, and water-use estimates. Mean annual precipitation for the basin was estimated at 72.6 inches from daily time-step gridded meteorological data. The SWB model estimated 35 percent of precipitation was lost to evapotranspiration, 30 percent was recharged to groundwater, 30 percent was surface runoff, and 5 percent was lost to interception. SWB model estimates of groundwater recharge were about 17 percent less than an independent estimate of base flow estimated from separation of the Chehalis River hydrograph recorded by the USGS streamflow gaging station at the outlet of the basin over the same period. These estimates support management of water resources in the Chehalis Basin by providing a baseline to assess future changes to recharge, groundwater pumpage, and other water-budget components.

Estimating Aquifer Parameters from Large Sets of Pumping-Test Data Using Streamlined, Python-Based Analysis Software

Benjamin Scandella, Oregon Water Resources Department
Michael Thoma, Oregon Water Resources Department

Aquifer tests can support effective groundwater resource management by constraining aquifer properties, but the tests are typically expensive to conduct and analyze. In Oregon there are roughly 25,000 permitted wells, and groundwater permit holders are required to submit pump test results on each of these wells as part of permit conditions. The data from these tests offer the potential to estimate aquifer transmissivity with unprecedented spatial distribution. However, the large volume of test data, the subjectivity of determining quality of data and results, and the limited available staff resources, require streamlined tools and methods analyze tests effectively and consistently, and with objective treatment of uncertainty. Here, we present a method based on the Cooper-Jacob approximation to estimate transmissivity and hydraulic conductivity and their confidence intervals using any combination of pumping and recovery phase data. This method, and its implementation in Python software being developed for integration with the Oregon Water Resources Department's database, opens the door to rapid and effective characterization of the spatial variability in aquifer properties. This method may be applied in other settings where large volumes of pumping test data are available.

Using the Borehole Permeameter Method to Estimate Hydraulic Conductivity in Glacially-Consolidated Soils

J. Scott Kindred, Kindred Hydro, Inc.

This presentation demonstrates that the borehole permeameter (BP) method can be used to estimate saturated hydraulic conductivity above the water table for a range of glacially-consolidated soils commonly found in the Puget Sound region. Glacially-consolidated soils in the Puget Sound regions are frequently targeted for stormwater infiltration. Furthermore, the BP method, combined with calibrated fitting parameters, provides a single closed-form expression for evaluating infiltration tests in both shallow horizontal facilities (similar to the pilot infiltration test) and deep boreholes.

The BP method, which was developed by soil scientists starting in the 1950's and refined over the last 30 years, assumes unsaturated conditions, a circular test configuration, and isotropic, homogeneous soil. The closed-form expression includes terms for pressure flow, gravity flow, and capillary flow in the soil. The relative contribution of these three flow components is determined by the soil sorption factor (α^*) and the shape factor (C). α^* determines the relative contribution of capillary flow (typically a function of the soil texture) and C accounts for the relative contributions of pressure flow and gravity flow. C is a function of the hydraulic head/radius ratio (H/r) of the infiltration test configuration and the shape factor fitting parameters (Z1, Z2, and Z3).

The BP fitting parameters were calibrated by comparing BP results with numerical modeling results for a range of advance outwash and glacial till soils and 14 infiltration test configurations. The test configurations included H/r ratios ranging from 0.05 to 200. A unique soil sorption factor (α^*) was calibrated for each of the soil types. Four sets of shape factor parameters were developed for a range of soil textures and H/r ratios. These parameters provided BP results that were within 10 percent of the numerical modeling results, which was considered sufficiently accurate given the model limitations and parameter uncertainty and variability.

Sensitivity analyses were conducted to determine how the numerical modeling results would be affected by changes in the numerical model and parameter assumptions. The sensitivity analyses demonstrated that the results for coarse-grained soils were relatively consistent for a moderate range of input models and parameters. The finer-grained soils (glacial till and silty advance outwash) did show 10 to 40 percent variability in flow rate given changes to the hydraulic conductivity function and the initial pore pressure/water content. Based on the results of the sensitivity analysis, BP results for fine-grained soils should be considered less accurate and a larger factor of safety could be assumed when using these results for sizing infiltration facilities.

Innovative Drilling for Emergency Characterization of Hydrostratigraphy

Jim Bailey, Shannon & Wilson
Steve Story, Holt Drilling
Chris Allen, Shannon & Wilson

The Salton Sea located in Southern California south of Palm Springs is the southern terminus for the San Andreas fault and a locale for sediment hosted, low temperature geothermal features. Commonly known as Mud Pots, these features are believed to form in this area by decarbonation reactions involving sedimentary carbonate that generate carbon dioxide (CO2) gas. As the gas rises through various water bearing sediments, likely along existing fault lineaments, they pull sediment and water toward the surface. Once surface sediments are breached, they generally form small wet areas that may or may not continuously flow turbid water.

In early 2018 one of these Mud Pots began migrating toward a major rail line that runs on the east side of the Salton Sea. This was the first time a Mud Pot had been observed migrating. The Mud Pot was flowing at a rate of 40 to 70 gallons per minute, and eroding soils in the direction of the tracks. As the Mud Pot got closer to the tracks the railroad took actions to stop the migration. One of the steps taken was to drill three exploratory borings to dephts of 320 to 800 feet close to the Mud Pot. The purpose of these borings was to determine the feasibility of depressurizing one or more aquifers that might be contributing to the flow of the Mud Pot.

Because of the eminent risk to the rail line, Imperial County declared an emergency, and a drilling company was needed quickly that could advance three boreholes through several hundred feet of soft plastic clay into one or more highly pressurized water bearing zones. If possible, the driller must also be prepared to install a screened well. The difficult drilling conditions included high concentrations of CO2 gas necessitating use of self-contained air, continuous gas monitoring, daytime temperatures up to 115 degrees Fahrenheit, and occurrence of high pressure gas and water at depth. Three different drilling methods were used in sequence to prepare for encountering pressurized conditions, protect the rig and site from a potential blowout, and enable installation of a well screen.

The drilling process was initially a 24-hour operation due to the urgency of the situation. One of the boreholes encountered a pressurized water bearing zone and a screen was installed. The other two holes which were both within 75 feet of the active Mud Pot did not encounter any significant water but did find high pressure CO2. Although the results of the drilling efforts are still being assessed, and the Mud Pot continues to migrate, the innovative drilling program was successful in overcoming some extreme subsurface conditions in a short time frame. This has provided for a better understanding of the subsurface hydrostratigraphy at the site and helped in developing solutions to protect the rail line long term.

The Effects of Forecasted Climate Change on Hydrology and Stream Temperature in the North Fork of the Stillaguamish River Basin

Robert Mitchell, Western Washington University
Kyra Freeman, Western Washington University
John Yearsley, University of Washington

The North Fork of the Stillaguamish River in northwest Washington State is a valuable regional water resource and critical habitat for endangered salmon species. The basin is about 730 sq-km with relief ranging from 55 m to 2100 m. About 19% of the basin is above 1000 m elevation and is snow dominated in the winter months. Snowpack is highly sensitive to fluctuations in temperature during mild maritime winters and is the main contributor to spring and summer streamflow in the Stillaguamish River. Forecasted climate in the Pacific Northwest is projected to increase winter air temperatures, leading to an increase in precipitation falling as rain. To assess shifts in snowpack, streamflow, and stream temperature in the North Fork basin resulting from forecasted climate warming, we apply gridded meteorological surface data with a physically based hydrology model, the Distributed Hydrology Soil Vegetation Model (DHSVM), and a stream temperature model, the River Basin Model (RBM).

We established the spatial characteristics of the North Fork basin at a 50 m grid resolution and applied historical meteorological gridded surface data developed by Linveh et al. (2013) to calibrate the DHSVM to streamflow from a USGS stream gauge near the mouth of the North Fork of the Stillaguamish. Field work was conducted in the summer of 2017 to determine stream morphology, discharge, and stream temperatures at a number of stream segments for the RBM calibration to a Washington Department of Ecology temperature gauge. Riparian input parameters for individual stream segments were characterized using a combination of LiDAR data, NOAA landcover data, and estimations based on previous Stillaguamish modeling studies. We simulate forecasted hydrology and stream temperature using gridded downscaled data from ten global climate models of the CMIP5 with RCP4.5 and RCP8.5 forcing scenarios developed using the multivariate adaptive constructed analogs method (Abatzoglou and Brown, 2012). Simulation results project a trending increase in stream temperature into the 21st century as a result of higher air temperatures, deceasing snowpack, and lower spring and summer stream discharges. By examining relative temperature differences among the North Fork Stillaguamish tributaries, management can be directed to locations in the basin where restoration efforts are likely to be most beneficial.

Estimating Aquifer Recharge Potential Within a Multi-Decision Criteria Analysis to Locate Suitable Managed Aquifer Recharge Locations in the Yakima River Watershed, Washington USA

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

Water demand is increasing in many watersheds, while the potential for surface water storage capacity stagnates. To enhance water supply under existing physical and regulatory constraints, managed aquifer recharge (MAR) provides flexibility where options are limited. To understand the extent in which MAR can be utilized, a host of factors require evaluation, but with advances in remote sensing, geographical information systems, and speed of data processing, identification of suitable MAR locations is now possible prior to onsite-field surveys. This study developed a Multi-Criteria Decision Analysis (MCDA) utilizing an Analytical Hierarchy Process and weighted overlay method to qualify MAR prospects in the Yakima River watershed, Washington, USA. To estimate MAR potential on a regional watershed scale, the MCDA was coupled with analytical solutions to approximate possible recharge rates and injection capacities in relation to suitability and with respect to discrete locations. Additionally, sensitivity analyses were conducted to understand the most influential factors and its effect on suitability. The watershed was subdivided into 6 structural basins, and potential suitable locations ranged from 9 to 50%. This coupled with the analytical analysis suggests the Yakima River watershed can sustain recharge rates that exceed historical surface storage capacities.

Use of Injection Wells for Disposal of Non-Contact Cooling Water

Roy Jensen, Hart Crowser, Inc.
John Haney, Hart Crowser, Inc.
Ward McDonald, Hart Crowser, Inc,
Keylin Huddleston, Hart Crowser, Inc.

Noncontract cooling water up to 10 million gallons a day generated from an industrial facility is discharged directly into a river. A plan has been developed to reduce water use in the facility and eliminate direct discharge into the river by using injection wells for disposal of up to 5 million gallons per day. The design philosophy and testing program of the injection wells will be discussed.

The aquifer beneath the site is extremely permeable and consists primarily of gravel and sand with a hydraulic conductivity of up to 3,000 feet/day. Depth to groundwater is generally 60 to 70 feet and fluctuates seasonally by as much as 8 feet. A production well screened at depths of 200 to 300 feet is producing about 8 million gallons per day with about 5 feet of drawdown.

Groundwater is used for cooling and is generally about 70 degrees F prior to discharge. The cooling system is continuous and cannot be stopped without interfering with the industrial process. The temperature of the river varies seasonally from about 35 to 60 degrees F and is related to the ambient air temperature. Groundwater temperature average 50 degrees F and is remarkably stable seasonally. The goal of the injection system is dispose of the water, without discharging to the river and without increasing river water temperatures, at temperatures greater than 2 degrees F above background.

The ultimate plan is to have three separate injection sites at the facility. The first injection site has been installed and tested. The goal of the first system was to handle a minimum of 2 million gallons per day (1,400 gpm). This first injection system consists of two wells; one well will be used to inject water and the second well will serve as a backup. The injection wells also are screened at depths of 200 to 300 feet and were tested at rates ranging from 500 to 2,000 gpm. The maximum observed drawup in the injection well tested was 10 feet. Based on the success of the first system, the second injection system is in development.

Policy, Permitting and the Particulars of Aquifer Storage and Recovery in Washington State

Danielle Squeochs, Washington State Department of Ecology
Melissa Downes, Washington State Deptartment of Ecology

Since its creation in 2006, the Office of Columbia River (OCR) has aggressively pursued water supply development for both instream and out-of-stream uses. Subsequently, OCR has developed over 410,000 acre-feet of water supplies in Eastern Washington, with more water under long-term development tied to future demand projections. To meet these competing water management objectives, OCR invests in a wide variety of water supply projects. Municipal, industrial and agricultural water suppliers are looking to implement cost effective on-site storage to meet peak water needs, especially during drier summer months. These may range from above ground municipal tanks to irrigation regulation reservoirs to underground aquifer storage and recovery.

OCR is investing and partnering with municipalities and others within the Columbia River Basin to explore aquifer storage and recovery (ASR). ASR is attractive because of its cost effectiveness, climate change resiliency, source reliability and locally, it's potential to relieve declining aquifer yield. Development of ASR projects, as with many water supply projects, can be lengthy from vision to operation. Typical project elements include hydrogeological investigation, water quality/treatment assessment, environmental review, feasibility and design, construction and pilot study, and final permitting. This talk provides an overview of the regulatory framework for ASR in Washington State, noting that compliance with groundwater quality standards and recovery efficiency remain high on the policy radar of potential ASR applicants.

Drilling, testing and analysis is ongoing to find suitable areas to locate new underground water storage. Preferred ASR sites will have minimal environmental impacts, low capital costs and do not impair existing water rights. Additionally, these projects offer a cost- effective method to mitigate the impacts of climate change by capturing and storing water, when it is available, for use during drier times of the year. OCR continues to lead the way in ASR project development, currently partnering and investing in ASR projects with the cities of Yakima, Kennewick, White Salmon and Othello.

Fresh Look at Design and Maintenance of UIC Wells

Jim Bailey, Shannon & Wilson
Paul Van Horne, Shannon & Wilson

Underground Injection control wells (UIC) are being looked at more frequently as a viable, cost effective solution to managing stormwater runoff in Western Washington's urbanized glacial environments . If subsurface receptor soils are favorable for infiltration, a properly designed and maintained UIC well can operate efficiently for many years. Review and testing of several UIC systems installed over the last 5 years has highlighted several issues that impact the performance of these systems. These issues include well design, initial development including baseline infiltration testing, monitoring parameters, and maintenance approaches.

Well design options for UIC wells can include gravel filled borehole, PVC, or stainless steel screens. Since most UIC wells will need an artificial filter pack, the borehole diameter must be considered when determining the screen slot size and length. Once constructed, the initial infiltration testing should include a screen development step prior to or part of the testing process. This data is key for successful long term monitoring of UIC performance.

At some point all UIC wells will require rehabilitation to improve hydraulic connection between the borehole and surrounding infiltration receptor soils. Monitoring water level changes during storm events was evaluated as a potential tool for determining maintenance frequency. Unfortunately, it was determined that water level data alone cannot be relied on as an indicator of UIC performance unless there is concurrent monitoring of injection flow rates.

Rehabilitation of UIC wells are more challenging than normal water wells due to lack of standing water. However the causes and solutions for declining UIC performance is identical to water supply wells. A proper rehabilitation program will need to include the use of several standard rehabilitation methods applied in a slightly modified approach.

A Framework to Deliver Real-time and Long-term Hydrologic Data: Web-Based Applications for Water Resource Analysis

Sachin Shah, U.S. Geological Survey
Tony Welborn, U.S. Geological Survey

Water-resource management requires appropriate and timely hydrologic data to understand and best respond to the challenges caused by changing hydrologic conditions and extreme events such as floods, droughts, and other natural hazards. By compiling and leveraging historical and newly collected data through digital solutions, mobile, and web-based applications, water resource managers can act swiftly and with confidence to address water issues. Most hydrologic analyses are either project-based, where data are collected periodically during defined time periods, or continuous, where data are collected in real-time. For each scenario, water managers and the public need access to data that facilitates the understanding of hydrologic conditions so that they can make informed decisions. The U.S. Geological Survey (USGS) collects long-term data and delivers these data in both real-time (current conditions) and historical contexts (long-term trend analysis) that allows users to make informed water-related decisions, including emergency response and other management needs. New technological solutions developed by the USGS in cooperation with its partners have helped resource managers anticipate regional environmental changes to address issues such as groundwater subsidence and water-quality effects related to dynamic hydrologic conditions. For example, interactive web mapping applications developed by the USGS present real-time current conditions of stream, water quality, lake, reservoir, precipitation, and well data in the context of current weather-related data collected by USGS or compiled from and other public sources. Another example is the use of interactive web applications to provide long-term groundwater monitoring data collected by the USGS and it cooperators and show present and historical connections between population growth, groundwater use, and subsidence. Delivering water data through innovative solutions has helped USGS provide timely data for everything from movement of floodwaters to preparations for water treatment processes to irrigation management. As applications are modernized and new data are included, the public's understanding of hydrology and how the data benefit their daily lives can grow, open and transparent data can increase confidence in water management institutions, and data-driven decisions can drive investment in water resource solutions to meet challenging and continually changing water issues.

Building Web-Based 3D Hydrogeologic Models and Providing Groundwater-Monitoring Data: An Update from the Washington Geological Survey

Carrie Gillum, Washington Geological Survey
Jessica Czajkowski, Washington Geological Survey
Ian Hubert, Washington Geological Survey
Ashley Cabibbo, Washington Geological Survey
Michael Tonkel, Washington Geological Survey

The geology of Washington State is complex and exerts a fundamental control on aquifer distribution, character, and connectedness. Part of the guiding mission at the Washington Geological Survey (WGS), a division of the Washington Department of Natural Resources (DNR), is to provide timely and understandable information to sustainably manage earth and water resources. In 2018 we began two water-related pilot projects that will provide better data and visualization tools for researchers, decision makers, and the public.

Understanding long-term trends in major aquifers requires high-quality groundwater data. To this end the WGS will begin to supply groundwater data to the National Ground-Water Monitoring Network. The first year of the project focuses on Thurston County at the southern end of the Puget Sound Aquifer System. The data from 40 wells were provided by the county and will be assessed for inclusion in the database and classified into subnetworks and monitoring categories. The program will expand in 2019 to include data from Kitsap County, Island County, and the Southeast Region of DNR. We hope to continue adding regions in future years.

Visualizing and applying the information from 3D hydro-geologic models is a critical step towards informing decisions about water availability, quality, and preservation or recovery of habitat for native or sensitive species such as salmon. The Water Science Center of the U.S. Geological Survey has produced and made available more than 100 hydro-geologic and water availability models. The WGS is undertaking a pilot study to determine the feasibility and value of converting these data into a standard, usable format, and making the models publicly available for viewing and download on the Washington Geologic Information Portal. The Pasco Basin groundwater model was selected for this initial phase. Ultimately a researcher will be able to identify hydro-geologic units at depth while visualizing the data in 3D, examine and identify the elevation of unit contacts at specific locations, and visualize well data and surface geology in 3D alongside the framework.

Time-Series Analysis for Groundwater: Quick Methods to Assess Groundwater Response to Precipitation

Andrew Long, U.S. Geological Survey

Understanding the characteristics of how groundwater levels and spring flow respond to precipitation is essential to good water management. Models that simulate this response range from simple to complex. Time-series analysis encompasses some of the simpler methods that include those useful for modeling and general analysis of groundwater response. Two such methods, spectral analysis and convolution, are useful for estimating the response time, or lag time, from precipitation events to groundwater responses. Spectral analysis also indicates which months of the year normally have the highest and lowest precipitation, groundwater level, or spring flow. Convolution provides an estimate of the changing response over time that theoretically would result from a single precipitation event, which is information that normally cannot be obtained directly from a groundwater record. This information includes an estimate of the system memory; that is, how long the effects of a precipitation event last in the aquifer. These two methods were applied to about 30 monitoring wells and springs in Washington, Oregon, Idaho, South Dakota, and Texas.

Cellular Telemetry for Water Monitoring

Nathaniel Kale, Thurston County

Thurston County Stormwater has installed six cellular telemetered monitoring devices from three different vendors over the past two years, and connected them to both an internal database and a public-facing dashboard (https://www.thurstoncountywa.gov/sw/Pages/monitoring-dashboard.aspx). We have learned a lot about what does and does not work, and have some principles in place for installing new systems.

As of December 2018, Thurston County has two Ott Ecologs, two In-Situ Tube 300Rs, and two Campbell Scientific CR 300s. They all report data on intervals ranging from one hour to one day, using FTP to send files over cellular connections.

Here are some lessons we have learned:

Everything is changing very quickly. At the beginning of 2017 when we started acquiring telemetry devices there were very few options for all-in-one or modem-embedded devices, all of the technology was 3G, and customers had to provision their own SIM cards. All that has changed in the last 18 months.

Managing your own SIM cards can be difficult, but may be worth it. Retail cellular outlets have no idea how to handle the needs of monitoring programs, and will often try to sell you the wrong plan. They also can't help much with troubleshooting SIMs for monitoring equipment. Equipment manufacturers have started to resell SIM cards with their own data plans, which are both better tailored for the needs of monitoring, and usually cheaper as well. Recently we've begun testing Internet of Things (IoT) specific SIM vendors like Soracom, which are much cheaper than both options.

Some programming knowledge and/or IT support is essential. Most vendors will offer you easily configurable access to their own proprietary cloud, but these solutions are usually limited. If you want to put data directly from the device into your own system you'll need someone who can program a server for you.

Telemetry saves you time – eventually. In our experience telemetry sites take significantly longer to set up than non-telemetry sites. Initially they also require more site visits to fix problems; more moving parts means more chance to break down. But, once they've been deployed for a few months and the kinks are worked out, they can reduce field visits. Especially sites with frequent visits, say twice a month or more, the savings in time can quickly surpass the additional setup time.

Radio and satellite are two other telemetry methods commonly deployed. We have not tested satellite telemetry packages to date due to cost of the RF transmitting hardware, which can be several thousand dollars per unit. Radio is cheaper, but relies on access to a good radio network in your area.

Telemetry can save time and increase public engagement in your monitoring program, if deployed correctly. It can also be a time-sink or a dead end if tackled in the wrong way or without the necessary skills. New developments are in the works and cellular telemetry is likely to get more efficient, better coverage, and cheaper in the near future as the industry demand increases.

Estimating Stage-Discharge Curves in R

Nathaniel Kale, Thurston County

Creating stage-discharge rating curves is usually done one of three ways: using paper graphs, Microsoft Excel, or expensive proprietary software. The R programming language provides a fourth alternative, leveraging modern computing power and statistical rigor without the need for pay for software.

Creating curves is combination of science and art. The gager starts by estimating the gage zero flow (G.Z.F.) from measurements taken in the field, which is the height on the staff gage where surface water flow becomes negligible. Then the gager uses a process of successive estimation, plotting the stage and discharge points on a log-log plot at various offsets from the originally estimated G.Z.F, by subtracting the offset from each of the stage values. The plot that results in the straightest line is selected as the relationship and used to estimate flows from measured stages.

This process is time-consuming and prone to human error, especially when performed manually on paper. It also necessarily results in an estimate of the true relationship, because gagers can only produce so many graphs. Time devoted to curve creation also increases exponentially when dealing with streams that change over time (all of them) or streams with multiple curves at different stages (many of them), because each new curve must be developed through the same process of estimating multiple offsets and plotting them all.

We made an R module that accepts stage and discharge data, and automatically calculates the best offset. It calculates offset stages for all of the possible G.Z.F. values between 0 and the minimum recorded stage value in 0.01 increments (corresponding to the North American convention of 0.01' increments on staff gages). It calculates the R2 value of a log-log relationship between the offset stage measurements and the discharge measurements for each offset, and returns the R2 value and offset value of the offset with the best fit. It also creates graphs of each of the offset log-log relationships, as well as a plot of the R2 values against their corresponding offsets.

Because the R module does the grunt work of creating graphs and calculating statistics, the gager has more time to apply the "art" side of curve creation, such as when and where to split datasets, which measurements to include and which to exclude, and when and how to apply shifts. It also provides a statistically robust, defensible, and precise estimate of the true stage-discharge relationship, which is increasingly valuable in a post-Hirst world.

Leveraging R to help create stage-discharge relationships has saved us time, reduced the potential for human error, and given us confidence that challenges to our calculated discharge values can be met and refuted.

Deep Vadose Zone Monitoring for the Hanford Central Plateau

Chris Strickland, Pacific Northwest National Laboratory
Rob Mackley, Pacific Northwest National Laboratory
Vince Vermeul, Pacific Northwest National Laboratory
Tim Johnson, Pacific Northwest National Laboratory
Vicky Freedman, Pacific Northwest National Laboratory
Mike Truex, Pacific Northwest National Laboratory

At several sites, such as the DOE Hanford Site, contaminant migration in the deep vadose zone (DVZ) is a slow process, occurring at scales from decades to hundreds of years. Monitoring to observe subsurface processes and driving forces related to contaminant transport or to directly observe contaminant movement in the DVZ is an important element of the overall remediation strategy.

Recent developments in subsurface characterization and monitoring have shown potential to provide substantial improvements in the ability to understand a range of site attributes. Data needs include fate and transport mechanisms, contaminant inventories, and the field monitoring necessary for determining the effectiveness of selected remedies. The development of robust, long-term characterization and monitoring strategies is needed.

A monitoring strategy is needed, not only to assure protection of human health and the environment, but to also potentially provide substantial cost savings for long-term stewardship. The strategy should include monitoring configurations that evolve in response to changing data requirements. It is anticipated that more intense methods and frequency of monitoring will be required at early stages, progressing to less intensive methods and frequency of monitoring over time. Monitoring approaches that integrate time-lapse geophysical imaging and borehole logging can be used to both provide critical information on system behavior and reduce long-term costs. The potential for using a combination of electrical, electromagnetic, and seismic methods within the context of a comprehensive monitoring strategy for the Hanford central plateau is presented.

Well Flow Dynamics and Application of Passive Sampling Techniques for Long Term Monitoring at Remediation Sites

Sanford (Sandy) Britt, PG, CHG, QED Environmental Systems
Rose Reidel, Olympic Environmental

Contaminated groundwater decision trees depend on accurate and reliable groundwater sampling data. Low flow purging and sampling techniques were introduced to improve sampling data, limit purge volumes, reduce turbidity and agitation during sampling, and to improve repeatability. Passive, no-purge, approaches have likewise been introduced to improve sampling by limiting waste generation, and improving cost structures. How do these methods reflect aquifer concentrations? Do they represent aquifer concentrations differently? How do the different approaches assure reliable groundwater data for remedial decision-making?

Strategic Environmental Research and Development Program (SERDP) project ER-1704 tested passive and dynamic sampling procedures in the lab, in the field, and in model domains to better understand flow dynamics in wells. Results describe a flow field where water flows largely horizontally from the formation to the well, then flows vertically in the well bore to the pump intake during pumping; and also vertically due to tiny density contrasts when not pumping. Sampling results rely on these downhole flow dynamics. Normally, these effects are not known.

Passive sampling approaches normally yield similar results without purging, but care is necessary to understand whether stratification in the aquifer is maintained or homogenized in the unpurged well, or if stratification is partially maintained. Determination of these effects requires substantial effort and is probably not warranted for standard monitoring. However, the study is informative in that it explains some of the dynamics associated with why passive and active samples often yield similar chemical results, and illustrates why practitioners still must always pay attention to seemingly unimportant details such as slow purge parameter drift.

Characterization of PFAS in Soil, Groundwater, Surface Water, Stormwater, and Sediment at Portland International Airport (PDX), Oregon

Heather Gosack, Apex Companies, LLC
Adam Reese, Apex Companies, LLC
Ashleigh Fines, Apex Companies, LLC

The Portland International Airport (PDX) historically used aqueous film forming foam (AFFF) in fire training areas, fire apparatus, and stationary systems within PDX. Working collaboratively with the Oregon Department of Environmental Quality (DEQ), the Port of Portland (Port; property owner) began an investigation in April 2017 to assess the potential environmental impacts of the historical use of AFFF, including certain per- and polyfluoroalkyl substances (PFAS) present in AFFF. This presentation will provide an overview of the environmental investigation activities conducted to date, and the challenges associated with PFAS characterization in multiple media at a large site.

PDX and its fire department are regulated under Federal Aviation Administration (FAA) and National Fire Protection Association (NFPA) regulations and guidance, which identify the type, testing, use, and training required for lawful use of AFFF. The requirements, codes, and regulations governing the type of AFFF, frequency of live-fire training, and equipment testing protocols at airports has changed during the four decades since AFFF was originally developed and in use. The former and current fire stations and the former fire training facilities at PDX are located within a large stormwater drainage basin. Storm sewer pipes near the stations and training areas direct stormwater towards drainage ditches and ultimately the Columbia Slough waterway. Typical of commercial aviation facilities, historical activities included fire training and AFFF storage over unpaved ground, potentially resulting in PFAS impacts to media.

Reconnaissance groundwater sampling conducted in April 2017 identified PFAS compounds above the U.S. Environmental Protection Agency (EPA) Health Advisory (HA) limit of 70 nanograms per liter (ng/L) for combined perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS). Based on the results from the April 2017 groundwater monitoring event, a preliminary assessment was conducted, and additional investigative activities were completed in August and September 2017 to further characterize PFAS groundwater impacts at PDX. Soil samples were collected and concentrations of PFAS compounds were detected above conservative protection of residential drinking water screening levels. Stormwater and surface water samples were also collected and concentrations of PFAS were detected exceeding conservative human health screening levels in the vicinity of PDX. Sediment samples were also collected; however, PFAS compounds were not detected in sediment.

Groundwater in the vicinity of the fire training facilities and the immediate vicinity of PDX is currently used for irrigation, landscaping, and golf courses. The City of Portland has developed the West Wellfield, in the eastern portion of PDX, as a supplemental and emergency supply of municipal water for the Portland Metro area. All water wells obtain groundwater from the Columbia River Sand Aquifer (CRSA), the Troutdale Gravel Aquifer, or deeper aquifers.

Additional investigation is on-going to determine the extent of soil and groundwater PFAS impacts and to develop a plan for remediation, if necessary. Since there are no current regulatory standards for PFAS compounds in Oregon, the Port is proactively utilizing the most conservative standards promulgated in various states within the USA to assess PFAS impacts at PDX.

Analysis Tools for Remedy Performance Assessment

Michael Truex, Pacific Northwest National Laboratory
Chris Johnson, Pacific Northwest National Laboratory
Patrick Royer, Pacific Northwest National Laboratory
Vicky Freedman, Pacific Northwest National Laboratory

The DOE-EM SOMERS (Scientific Opportunities for Monitoring at Environmental Remediation Sites) document provides guidance for groundwater monitoring using an objectives-driven, integrated systems-based monitoring approach. As described in the SOMERS document, remedy performance monitoring is critical for remedy management and for transitioning to long-term monitoring. Technically defensible assessments are needed to describe plume dynamics for remedy management and for transition of active remedies to passive remedies. Assessments often require analyzing large disparate data sets, the results of which then need to be communicated to both stakeholder and regulator communities. To this end, a web-based analysis tool set has been developed. The single-page web application includes a tool that uses monitoring well concentration data to quantitatively evaluate plume dynamics and a tool that uses water level data to quantitatively evaluate hydraulic gradients, which are needed to interpret plume dynamics. The tool set uses temporal and spatial filters, as well as statistical analyses, so that concentration data can be instantly plotted and analyzed for a user-defined set of wells and for a selected monitoring timeframe. The web-based platform offers effective access to data and analyses to support remedy management efforts.

A Performance Monitoring Approach for Pump-and-Treat Systems: Hanford Site Case Study

Michael Truex, Pacific Northwest National Laboratory
Mark Byrnes, CH2M Hill Plateau Remediation Company
Matt Tonkin, S.S. Papadopulos & Assoc.
Nathan Bowles, Gram Northwest
Art Lee, CH2M Hill Plateau Remediation Company
Kathy Leonard, CH2M Hill Plateau Remediation Company
Chris Johnson, Pacific Northwest National Laboratory

Pump-and-Treat (P&T) remediation can be an effective approach to diminish existing groundwater contaminant plumes. P&T is often applied as a first step in remediation, with a planned transition to Monitored Natural Attenuation (MNA) or other approaches to reach remedial action objectives. At the Department of Energy Hanford Site, this combined approach of P&T followed by MNA is a remediation strategy for existing contaminant plumes in the Central Plateau portion of the site. Management of this type of remedy requires evaluation of plume response to P&T and an approach for transitioning to the MNA portion of the remedy. Thus, monitoring of the remedy needs to include quantitative assessment of plume data with respect to progress toward performance objectives. A structured approach to plume monitoring and remedy performance assessment was developed and applied for the Hanford Site. Using this approach as a case study highlights important aspects of P&T performance monitoring and illustrates effective integration with remedy modeling and remedy performance documentation.

Critical Aquifer Recharge Areas Guidance Update

Laurie Morgan, Washington State Deptartment of Ecology Water Quality Program

The Dept. of Ecology is updating the Critical Aquifer Recharge Areas Guidance. This talk will be a report on where we are with the update and what we have found so far.

Local government planners are required to update comprehensive plans and ordinances to protect Critical Areas using Best Available Science under the Growth Management Act (GMA). “Critical Aquifer Recharge Areas” are one of the Critical Areas. WAC 365-190-030 defines Critical Aquifer Recharge Areas: (b) Areas with a critical recharging effect on aquifers used for potable water, referred to in this chapter as critical aquifer recharge areas.

The current Critical Aquifer Recharge Area guidance is from 2005. A lot has changed since it was last revised. The current guidance is out-of-date in several respects including the following: The GMA laws and rules regarding Critical Areas have been amended since 2005. There have been many additional cases before the Growth Management Hearings Board and Superior Court since 2005. The outcomes of these cases need to be reflected in the guidance. Resources referred to within the document have changed. Some of the resources linked to no longer exist and some of these need to be replaced by an alternative or more updated resource. The USGS has completed many more groundwater studies that contribute to best available science for groundwater protection.

In addition, several groundwater issues have arisen and developed since 2005. One example is stormwater infiltration through Low Impact Development (LID) and Underground Injection Control Wells (UICs, such as dry wells). Stormwater infiltration plays a role both in recharging groundwater supplies and preventing groundwater contamination. Ecology has developed guidance for stormwater infiltration.

Another example is Agriculture and Critical Areas. In 2011, the legislature passed the Voluntary Stewardship Program to address impacts to critical areas from agricultural activities in unincorporated areas of Washington. GMA requirements for Critical Areas differ depending on the county’s participation in the Voluntary Stewardship Program.

Groundwater protection is fragmented under several Ecology Programs and other agencies. This guidance project will require working closely with others who administer these programs and those who provide groundwater science. The current Critical Aquifer Recharge Area Guidance is online at https://fortress.wa.gov/ecy/publications/SummaryPages/0510028.html.

Sustaining Redmond's Shallow Alluvial Aquifer in an Expanding Urban Environment

Amanda Balzer, City of Redmond
John Porcello, GSI Water Solutions
Aaron Moldver, City of Redmond

The City of Redmond operates five water supply wells, screened in a shallow unconfined alluvial aquifer located in the heart of Redmond's downtown core, providing approximately 40% of Redmond's drinking water. Increased urban density in Redmond's downtown is in conflict with the sensitive aquifer system. The development of a 3-dimensional transient groundwater model was critical in evaluating challenges of urbanization and informed a path forward to sustain our aquifer while embracing development. Modeling analyses have focused on evaluating the effects of urban redevelopment (increased impervious cover, changes in stormwater management, temporary construction dewatering, and construction of permanent subsurface structures) on aquifer recharge, groundwater levels, groundwater pumping sustainability, supply well capture zones and base flow to gaining streams.

Issues Using the USGS Kitsap Model for Water Rights Investigations

Joe Becker, Robinson Noble, Inc.
Jim Hay, Robinson Noble, Inc.

The USGS completed a hydrogeologic framework study and published a calibrated numerical model of the Kitsap Peninsula in 2016 with the goal of providing “a valuable tool for water managers coordinating regional-management plans” (Frans and Olsen, 2016). The Washington Department of Ecology has since distributed a number of preliminary permits to water right applicants requiring mitigation be proposed for assumed surface water impacts. The authors examined over 15 of these permits, issued to several different water purveyors, and all are extremely similar. One requirement in common is that an applicant’s new point of withdrawal “shall be integrated into the Kitsap Groundwater Model developed by the USGS” and the model used to estimate possible impacts from the proposed groundwater withdrawal on streams.

However, the USGS Kitsap Model has several issues that must be addressed when using it for water right investigations. The most significant issue is that well production rates in the model are not necessarily constant between model runs.

Typically, the effects of a new water right are examined by comparing a baseline simulation with the subject well producing the current water right allocation to a predictive simulation with the increased water right allocation, keeping all other model inputs equal. This standard procedure is not possible using the unmodified Kitsap Model due to the Newton solver selected by the USGS. With the Newton solver, when the hydraulic head in a well-containing cell falls below a specified threshold, the well’s production rate is automatically ramped downward. During the USGS steady-state simulation, this caused 1,432 wells to lower their production rates from assigned values, including 310 wells which turn completely off. In USGS transient simulations, the number of wells with variable production rates varies between stress periods. Compounding the issue is how the USGS simulates return flow. Septic and irrigation return flow is simulated by recharge wells (for corresponding production wells) in non-sewered areas. Yet when modeled production rates are reduced by the Newton solver, the corresponding return flow is not similarly reduced.

To solve the problem, the authors made several modifications to the model. All model layers in the published model are simulated as convertible between confined and unconfined conditions. We left the top two layers as convertible, but changed all other layers to confined. This resulted in a large decrease in the number of problem wells. However, when running transient conditions, 131 wells were still experiencing ramped down production. We turned off the production for both these wells and the corresponding return-flow injection wells; no further wells had variable production rates. With these changes, however, the degree of calibration, as defined by calibration statistics, was reduced.

Other model issues include how to handle return flow for new water rights, an inability to run the model in some other MODFLOW pre-/post-processor software (e.g., GMS), and long run times.

Toolbox for Computational Evaluations of Impacts of Subsurface Operations

Catherine Yonkofski, Pacific Northwest National Laboratory
Inci Demirkanli, Pacific Northwest National Laboratory
Delphine Appriou, Pacific Northwest National Laboratory

During the last two decades, EPA's Region 8 has experienced an exponential growth of subsurface operations. Like all EPA's regions dealing with similar activities, ensuring the protection of groundwater resources has become a high-priority need. Any decision making related to underground injection operations for waste disposal and/or energy and mineral development activities (e.g., considering boundaries of exempted aquifers, permitting/determining area of review) requires a quantitative understanding of the system characteristics. Proposed operational parameters must ensure the protection of groundwater in addition to supporting sustainable development of these projects. This quantitative understanding is developed on available project and site data and use of appropriate modeling techniques—in many cases, a range of modeling approaches applied for the purposes of estimating uncertain characteristics. While sophisticated numerical approaches provide detailed information, they also rely on expensive data and very specific high-level expertise. Analytical and semi-analytical solutions, verified to address certain aspects of system behavior, can provide additional and quick tools for decision makers. Therefore, a need exists to have reliable, tested, and verified set of analytical and semi-analytical solutions that are accessible to decision-makers in a consistent and user-friendly fashion and collectively address various system characteristics to support science-based decision making. We've developed a user-friendly software package of scientific, data-driven methodologies that can evaluate the subsurface area impacted by underground injection operations. The software contributes to ensure the protection of groundwater resources and public health. The Version 1 software toolbox includes methods specifically selected for plume delineation in brine disposal operations (based on previously selected methodologies) and evaluation of pressure effects (non-reactive, single-phase transport).

Restoration of Incised Stream Channels as a Means of Improving Water Storage, Stream Flow and Climate Resiliency

Tim Abbe, Natural Systems Design
Susan Dickerson-Lange, Natural Systems Design
Pete Cruickshank, Chelan County Natural Resource Department
Mike Kane, Kane Natural Resources
Mary Jo Sanborn, Chelan County Natural Resource Department
Erin McKay, Chelan County Natural Resource Department
Adrienne Roumasset, Chelan County Natural Resource Department
Mike (Rocky) Hrachovec, Natural Systems Design
Leif Embertson, Natural Systems Design
John Soden, Natural Systems Design
Mike Kaputa, Chelan County Natural Resource Department

The removal of wood from streams has resulted in widespread channel incision throughout the Pacific Northwest. Wood accumulations, whether formed by physical processes or beavers, create backwater ponds, raise water tables, and result in sedimentation that creates and maintains the alluvial valleys that function as shallow subsurface reservoirs. Thus, an underappreciated legacy of systematic wood removal and beaver trapping is the widespread loss of in-situ surface and subsurface water storage throughout stream networks. The net result is that some regions of Washington State have lost tens of thousands of acre-feet of in-situ water storage; however, widespread restoration of degraded channels has the potential to result in water storage comparable to building new reservoirs, but at a fraction of the economic and environmental cost. With low flows projected to decrease further in a warming climate, a restoration approach may buffer hydrologic impacts while also increasing water availability to riparian forests and improving aquatic habitat.

Quantitative analysis of channel incision, stream and valley morphology, and floodplain sediments in the tributary network of Mission Creek, which flows into the Wenatchee River in Chelan County, Washington, indicated the potential to restore 6-16 acre-feet per mile of stream restoration actions. Estimates suggest that scaling to 10 miles of restoration could result in a baseflow contribution of up to 0.3 cfs for 17 weeks. Thus, an alluvial water storage pilot restoration project was implemented in Poison Creek, in the Mission Creek watershed, in 2017 with the aim to retain sediment, re-aggrade the incised channel, and restore in-situ water storage. The project is currently being assessed as one of the alternatives to increase the domestic reserve in the Mission Basin.

The Poison Creek pilot project is testing three primary hypotheses: 1) wood obstructions raise water elevations that trigger aggradation of the channel bed; 2) raised water elevations increase ground and surface water storage throughout the treated length of the stream; and 3) increased water storage will lead to an increase in the duration and magnitude of recessional (base) flows. Topographic survey and time lapse photography demonstrate successful storage of sediment behind and within 19 wood structures, with substantial decreases in local stream gradient from 5-8% to 1-3%. Evidence of bank seepage downstream from wood structures, and the presence of numerous floodplain backwater areas during the August 2018 dry season suggest an increase in local water storage. Continuing data collection from a network of monitoring wells is expected to provide additional evidence for hydrologic effects.

Based on the successful implementation of this pilot project, we have additionally developed a GIS analysis framework to estimate water storage potential and restoration feasibility across the Mission, Peshastin, and Chumstick watersheds. The results from this analysis along with efforts to ground-truth results are being used to identify and prioritize reaches for additional pilot implementation and monitoring. Additional restoration projects will be used to assess effectiveness with a goal of ultimately implementing extensive restoration as a method to increase local water storage and augment baseflows.

Mission Creek Flow Improvement: An Example of First Steps to Solving Instream Flow and Water Supply Challenges

Jason Shira, Aspect Consulting
Dan Haller, Aspect Consulting
Pete Cruickshank, Chelan County Natural Resources Department
Tyson Carlson, Aspect Consulting
Mike Kaputa, Chelan County Natural Resources Department

Through the lens of the Streamflow Restoration Act we will present the hydrogeologic conceptual model of the Mission Creek Basin, limiting factors, and opportunities to improve late season streamflow and maintain rural domestic growth. Mission Creek Basin, a subbasin of the Wenatchee River Basin, suffers from low streamflow in the late summer and fall, and from a limited reserve of water for permit-exempt groundwater uses. CCNRD and Aspect, in collaboration with local landowners, developed and evaluated seven alternatives to increase instream flow and continued rural growth. An alluvial water storage pilot project conducted by CCNRD and Natural Systems Design was folded in as an eighth alternative. The four recommended alternatives to increase the domestic reserve in the Mission Basin are a combination of water banking, surface water right conversion to groundwater, construction of a small off-channel reservoir, alluvial water storage, and updating the basin boundaries based on hydrogeologic conditions.

Assessing the Impacts of Stream Restoration on Groundwater Dynamics and Potential Storage at Indian Creek in the Teanaway Community Forest

Nora Boylan, Oregon State University

With decreasing snowpacks and changing precipitation patterns, Washington State is constantly looking for ways to conserve, store, and protect its water supply. Parties throughout Washington have turned towards stream restoration as a means of utilizing alluvial aquifers for groundwater storage and augmented late season flows. However, the relationship between restoration and augmented storage potential are still under investigation due to unique aquifer characteristics hindering or enhancing groundwater storage. Indian Creek, a tributary of the Teanaway River in central Washington, provides an excellent opportunity to investigate groundwater dynamics as they react to stream restoration. Due to historic railroads, logging activities, and over-grazing, Indian Creek watershed has been degraded, resulting in an incised stream and disconnected floodplain. Starting in 2014, several parties including the Washington Department of Ecology (Ecology), Washington Department of Fish and Wildlife (WDFW), and the Yakama Nation (YN) began working on restoring Indian Creek. Since then, over 80 acres of floodplain have been treated with large wood. Currently, ongoing monitoring of the project at Indian Creek involves stage gages, piezometers, and surveyed cross-sections. Through this study we investigate if large wood placement in Indian Creek is having a measureable impact on groundwater dynamics throughout the system. We compound this with calculations of total potential storage of the alluvial aquifer surrounding Indian Creek and present our results through a comprehensive field-base groundwater model. Furthermore, we are able to develop an investigation template for other groundwater storage investigations connected to stream restoration in other montane meadows.

Estimating Future Domestic Home Water Needs Under RCW 90.94 in a Rural Northeastern County Watershed, Stevens County, Washington

Gene St.Godard, Water & Natural Resource Group, Inc.
Jessica Kuchan, Mentor Law Group, PLLC
Erik Johansen, Land Services Director, Stevens County
Adam Cares, Planner, Stevens County Land Services Deptartment

The Colville River Watershed, Water Resource Inventory Area (WRIA) 59, is located within Stevens County in northeastern Washington. In 1977, the Washington State Department of Ecology, adopted an instream flow rule regulating the surface waters of WRIA 59 (Chapter 173-559 WAC). Over the past twenty years, Stevens County, in conjunction with other local governments, conservation district, tribes and citizens (referred to generally as the "WRIA 59 Planning Unit") developed a Watershed Plan, conducted instream flow studies to determine if instream flow rule implemented in 1977 (WAC-173-559) should be modified, evaluated potential water storage projects, and developed a feasibility study for a water bank for promoting economic growth. Over the past year, in response to the adoption of RCW 90.94.020, Stevens County, in conjunction with the WRIA 59 Planning Unit is developing an Addendum to the Watershed Plan to evaluate the impact of future domestic permit-exempt wells within WRIA 59.

The Colville River Watershed is a 1,007-square mile area and lies in a generally north-south orientation. The Watershed is approximately 45 miles long and 23 miles wide and extends from near the towns of Springdale and Loon Lake at the southern (upstream) end of the basin to near the town of Kettle Falls at the northwestern (downstream) extent of the basin. The Colville River begins as Sheep Creek in the headwaters near Loon Lake, and flows in a generally northerly direction until the Colville River empties into the Columbia River at Lake Roosevelt, approximately 2 miles west of Kettle Falls.

The WRIA 59 Planning Unit, under the leadership of Stevens County, has been collecting data within the mainstem and subbasins for over a decade. This data was used as the foundation for developing future water consumptive use estimates for the next 20-years. The basin contains three major aquifer systems: 1) A deep confined aquifer in the main Colville River Valley; 2) A shallow unconfined aquifer present in various areas on the main valley floor and the lower tributaries; and 3) the bedrock fractured aquifers located throughout the basin and tributaries.

Stevens County used historical building permit data collected since 2001 for unincorporated areas in WRIA 59 to estimate future domestic consumptive use in homes by estimating building trends and locations. This study included the estimation of future domestic in-house consumptive use, and outdoor use from lawn watering. A lawn survey was conducted at a 95% confidence interval was also conducted to determine average lawn size at a basin and subbasin level.

The study included determining the potential subbasins which may have the highest impacts from the future building density. A key conclusion of the study suggests that the impacts of future development are more highly influenced by the primary aquifer source for future homes, rather than by the location of new homes within a certain subbasin.

Monitoring Groundwater and VOC Discharge to Surface Water in the Transitional Zone

Tom Colligan, FloydSnider, SPC
Brett Beaulieu, FloydSnider SPC

The nature of phreatic discharges to marine waters in the Puget Sound is of interest to a wide audience, because of the increasingly recognized role of the transitional zone in measuring compliance and in the challenges of monitoring. In this investigation at a Port Angeles shoreline, the water chemistry in the transitional zone beneath intertidal marine sediments is studied to understand whether discharging groundwater containing benzene and other contaminants emanating from behind a bulkhead can be effectively sampled, the degree of attenuation from uplands monitoring wells, and whether the results indicate preferential pathways. A series of hand driven piezometers were installed and sampled during a night time low tide event, in conjunction with monitoring well and surface water sampling. Benzene and gasoline- and diesel-range petroleum hydrocarbon concentrations, and sodium and chloride were compared between uplands, transitional zone, and marine waters. Transitional zone groundwater near the point of discharge was closer in sodium and chloride composition to upland groundwater than marine waters, indicating minor mixing with saline waters prior to discharge. Contaminant concentrations indicate substantial attenuation of benzene and gasoline- and diesel-range petroleum hydrocarbons occurred in groundwater between uplands monitoring wells and transitional zone sampling locations. Results from the investigation indicate that samples representative of the transitional zone discharging groundwater can be collected using hand tools from beneath intertidal sediments and that these samples provide a more accurate measure of contaminant attenuation prior to discharge than upland monitoring wells.

A Slough of Challenges: Permitting and Activated Carbon Placement on the Lower Columbia Slough

Carmen Owens, Apex Companies, LLC
Ashleigh Fines, Apex Companies, LLC
Adam Reese, Apex Companies, LLC
Jennifer Sutter, Oregon Department of Environmental Quality

Background/Objectives. The Columbia Slough, located in Portland, Oregon, comprises a 19-mile main channel that parallels the Columbia River, with approximately 12 additional miles of secondary waterways which drain over 32,700 acres. Much of the land use immediately adjacent to the Slough is industrial. Stormwater runoff and historical discharges have contaminated sediment and fish tissue throughout the waterway. PCBs have been found at elevated concentrations in sediments and fish tissue, and represent the primary risk driver in the Slough.

Sediment adjacent to the former Pacific Meats site is one of the polychlorinated biphenyl (PCB) hot spots targeted for remedial action in the Lower Columbia Slough. Significantly contaminated sediment extends over an approximately 60,000 square foot area adjacent to three stormwater outfalls. Because this hot spot area has relatively consistent PCB concentrations and sediment conditions over a large area, it provides a uniquely suitable location to compare approaches for reducing the bioavailability of PCBs to aquatic receptors. Apex implemented the pilot study/hot spot cleanup on behalf of the Oregon Department of Environmental Quality (DEQ). This pilot study consisted of placing two types of activated carbon (AC) in separate cells within the study area. This presentation summarizes the unique challenges of the permitting required for this project, as well as strategies used to overcome design and implementation changes.

Approach/Activities. The AC products were to be delivered to the Slough within the application area at the design-specified thickness, accounting for variable placement conditions and drift during delivery. Challenges associated with the AC placement were significant and included:

- Very thin design amendment layer thickness;
- Permit-limited in-water work window;
- Limited over-water access due to low water conditions during in-water work window;
- Daily tidal fluctuations;
- Limited upland access and bank use restrictions on both sides of the waterway; and
- Distributing two different AC products within the application area at the design-specified thickness, accounting for variable placement conditions and drift during delivery.

Results/Lessons Learned. Multiple design iterations were necessary prior to successful implementation. Hurdles encountered included limited contractor interest due to unpredictable conditions and financial risk associated with project access uncertainties, as well as challenges in finding an application method that ensured accurate layer thickness.

Apex and DEQ overcame these challenges by working with adjacent property owners to create temporary access areas; employing low water access techniques, including inflatables, kayaks, air boats, and floating docks; and applying innovative value-engineered solutions, modifying AC application techniques to include the use of landscape-product blowers and telebelt trucks to achieve quality assurance goals while avoiding disturbance of the bank.

The result of this project was the successful application of activated carbon to the sediment surface at this PCB contaminated site. The unique implementation challenges of applying activated carbon in the Columbia Slough were overcome, and lessons were learned that can be applied to other similar sites.

Post-carbon sampling showed an 86% and 95% reduction of total PCBs in porewater in the SedimiteTM and AuqaGate+PACTM cells. Visual mixing was evident in the AquaGate+PAC cell, but could not be seen in the Sedimite cell.

Dynamic River Stage Variations Lead to Multimodal Residence Time Distributions of Hydrological Exchange Flow

Xuehang Song, Pacific Northwest National Laboratory
Xingyuan Chen, Pacific Northwest National Laboratory
John Zachara, Pacific Northwest National Laboratory
Jesus Gomez-Velez, Vanderbilt University
Pin Shuai, Pacific Northwest National Laboratory
Huiying Ren, Pacific Northwest National Laboratory
Glenn Hammond, Sandia National Laboratories

Residence Time Distributions (RTDs) are an important variable to evaluate the potential for biogeochemical reactions in the hydrological exchange zone. Previous tracer studies showed that RTDs followed time-invariant single mode exponential, lognormal, or power-law distributions in headwaters or low-order streams. However, there has been a growing recognition that RTDs can be more complicated and time-variable in response to dynamic hydrological forcing. In this study, we use particle tracking to estimate the RTDs along the Hanford Reach of highly dynamic Columbia River and to quantify the relationship between river stage fluctuations and RTDs. The particle tracking is conducted by using velocity output from 3D groundwater flow simulations. The relative roles of hydrological forcing and hydrogeologic setting are evaluated by applying various degrees of subsurface heterogeneity and variable river flow conditions to the model. Our results showed that dynamic river fluctuations created rapidly changing losing-gaining conditions and led to multi-mode RTDs. The river dynamics has a more significant impact than subsurface heterogeneity in controlling RTDs within the aquifer. Statistical analysis revealed that multiple modes of RTDs are correlated to multiple frequencies of river flow variation. Furthermore, our results showed the dam-induced high-frequency flow variation altered the RTDs by increasing the short-time component. Our study indicates a strong correlation between the time-variable RTDs a and river fluctuation, which can be used to develop surrogate models for the RTDs with river stage as inputs.

Hydromorphic Classification of the Hanford Reach Through Machine Learning of Field Observations and Hydrodynamic Simulations

Zhangshuan Hou, Pacific Northwest National Laboratory
Ren Huiying, Pacific Northwest National Laboratory
Murray Christopher, Pacific Northwest National Laboratory
Arntzen Evan, Pacific Northwest National Laboratory
Chen Xingyuan, Pacific Northwest National Laboratory
Stegen James, Pacific Northwest National Laboratory
Huang Maoyi, Pacific Northwest National Laboratory
Gomez-Velez Jesus, Vanderbilt University
Duan Zhuoran, Pacific Northwest National Laboratory
Perkins William, Pacific Northwest National Laboratory

A new approach has been developed for classifying and mapping hydromorphic features in large, dynamic river systems, based on field observations of river bathymetry and two-dimensional (2D) river flow simulations. This approach extends and combines several methods recently published in the geomorphology literature. Several attributes of river bathymetry and flow were extracted on a highly-resolved 2D grid of the Hanford Reach of the Columbia River. Measures of riverbed bathymetry include elevation and its local variability, slope, aspect, and concavity/convexity. Flow simulations were from the 2D Modular Aquatic Simulation System (MASS2) model applied to a historical time period, which has been previously calibrated and validated for the Hanford Reach. Machine learning methods including principal components analysis, K-means and expectation-maximization clustering, were combined to identify four controlling variables that defined seven classes of hydromorphic features, with both information criteria and physical interpretability taken into account. When applied to the Hanford Reach, this classification scheme resulted in the identification of well-defined spatially coherent features that are physically interpretable and consistent over the entire reach, as well as in sub-domains within the reach. Field ground-truthing and observations of feature geometry and riverbed textural properties were used to verify this classification scheme, and to compare the results to existing hydromorphic classification schemes. The resulting feature maps are being used to guide selection of sub-domains of the Columbia River for mechanistic modeling of hydrologic exchange and novel biogeochemical reaction processes, to guide the selection of locations for field studies, and to support development and parameterization of reach- and watershed-scale reduced-order models.

Washington's New Streamflow Restoration Law - A First Year Overview

Michael Gallagher, Washington State Department of Ecology

In January 2018, the Washington State Legislature passed a new law in response to the 2016 Hirst Supreme Court decision. The Hirst decision changed how some counties issued building permits by limiting a landowner's ability to get a building permit for a new home when the proposed source of water was a permit-exempt well.

The new law, now codified as Chapter 90.94 RCW – The Streamflow Restoration Act, addresses the court's decision by allowing landowners to obtain a building permit for a new home relying on a permit-exempt well. The Act directs local planning groups in 15 of our state's watersheds to develop streamflow restoration plans that address the potentially negative impacts from new development over the next 20 years. The Act creates interim standards for new users of household permit-exempt wells in certain watersheds and establishes a one-time $500 fee for new building permits associated with new household permit-exempt wells. The interim standards (950 gallons per day or 3,000 gallons per day, depending on the watershed), will apply until Ecology updates existing instream flow rules based on locally developed recommendations.

The Streamflow Restoration Act also retains the current maximum limit of 5,000 gallons per day for permit-exempt domestic water use in watersheds that do not have existing instream flow rules. Finally, the Act invests $300 million over the next 15 years in projects that will help fish and streamflows.

This presentation will provide a summary of what has been accomplished in the first year of this new law.

Use of a Coupled Ground and Surface Water Model (GSFLOW) in the WRIA 55 RCW 90.94 Watershed Plan Update

Mike Hermanson, Spokane County Environmental Services
E.J. Wexler, EarthFX
Dirk Kassenaar, EarthFX

The process to develop a watershed plan update in the Little Spokane River Basin (WRIA 55) as required by the new Stream Restoration law, RCW 90.94, is currently underway. Beginning in 2011 Spokane County has been completing studies and developing tools to forecast water demand and assess impacts from new demands on instream resources in WRIA 55; tools well suited to implement the new Stream Flow Restoration law. A transient integrated groundwater and surface water model (GSFLOW) was developed to represent the complex geology underlying the watershed and the three-dimensional groundwater flow system. All components of the water budget in the Little Spokane River Basin were simulated and the model was calibrated to match observed groundwater heads, streamflow, and lake levels over a five-year period. This presentation will focus on the use of a sophisticated water demand model in conjunction with the GSFLOW model to assess impacts from future permit exempt wells on low flows in the Little Spokane River and its tributaries, evaluate the use of managed aquifer recharge to offset projected impacts, and assess stream flow benefits from the retirement of existing water rights.

What are we Learning about Widespread Application of Bioretention?

Karen Dinicola, Washington State Department of Ecology
Brandi Lubliner, Washington State Deptartment of Ecology

Stormwater management approaches will need to adapt to the pressures of land use and changing climate conditions. Ecology's municipal stormwater permits have required local jurisdictions to make Low Impact Development (LID) "the preferred and common approach to stormwater management." Bioretention is one of the most commonly applied LID management practices. We are concerned about the leaching of nutrients and copper from the bioretention soil medium and impacts to sensitive waters. Stormwater managers need to know that these facilities perform as intended so that they can confidently require their installation in new and redevelopment projects across their jurisdictions.

Stormwater Action Monitoring (SAM) has conducted bioretention studies focused on bioretention sizing, the soil medium, toxicity removal, specific pollutant removal, and maintenance requirements. The studies confirm that properly designed bioretention facilities generally do perform well and provide measurable water quality benefits:

- Hydrologic performance: Ten facilities designed according to different versions of Ecology's Stormwater Management Manual for Western Washington (SWMMWW) and located all around Puget Sound effectively accommodate all of the surface runoff directed to them, without bypass.
- Maintenance of function: Plant die-off, often due to lack of water in summer, does not appear to affect bioretention facility function, but it might be important for community acceptance. Plantings should be for hardy plants that can survive without frequent water during the dry PNW summers. Proper inlet design is necessary to ensure that stormwater enters bioretention facilities.
- Toxicity removal: Coho salmon, mayfly nymphs, and daphnia survived in highway stormwater runoff that was filtered through the bioretention soil medium (60:40 mix) that is required in the SWMMWW. The unfiltered runoff produced 100% mortality.

Contaminant treatment: Metals and nutrients are confirmed to leach from the 60:40 mix in new facility installations and continue to leach at diminished concentrations for the first several years. Fortunately the carbon levels are also increased which acts to bind the metals reducing bioavailability below the toxic thresholds. We are still concerned about sensitive waterbodies such as lakes. The age at which the bioretention facility flushing of nutrients and copper diminishes is an area of active work. Several studies have shown that fecal coliform bacteria and organic contaminants such as PAHs are treated well by bioretention. A Filterra planter box tested in a highway retrofit performed better at phosphorus removal than bioretention planter boxes but not as well in removal of other common stormwater pollutants including metals and PAHs.

Recommendations: Stormwater managers should continue updating their codes and conducting development plan reviews that support making LID "the preferred and common approach to stormwater management." Stormwater managers can be confident that facilities sized according to the SWMMWW will perform well for flow control and water quality treatment (except copper and nutrients) over time, even if the facilities are not ideally maintained. An active SAM project is developing a bioretention soil medium that will not export nutrients and still maintain flow control and other water quality treatment goals. Jurisdictions with sensitive receiving waters should add treatment trains or consider other alternatives that reduce phosphorus concentrations.

Ecology will continue to require permittees to remove barriers to LID in their codes and local ordinances. The SWMMWW will continue to use the 60:40 soil mix as the default bioretention soil medium, but other soil media may be approved as additional studies are completed.

Stormwater managers should continue to install bioretention systems as opportunities arise, and particularly along roadways. Use the 60:40 mix as long as you don't have a phosphorus-sensitive receiving water. Use on-site data to determine a facility infiltration rate. Select appropriate species to plant; maintain vegetation and replace dying plants with more hardy species as needed.

Site-Specific Investigation for a Salt Contaminated Organic Peat Soil

Steve Graham, S Graham Engineering and Geology Inc.

A large contaminated site in NE BC along a pipeline alignment was determined to be high risk for salt (Na and Cl ion) contamination on the basis of typical data collection procedures and lab analyses. Once the tree cover was removed, auger samples revealed that the soil at this site has peat or muskeg-like conditions for the first 5 feet, underlain by a silty clay till with low permeability. Despite having elevated levels of salt, there are no self-evident adverse impacts to most vegetation at the site.

Recent investigations have found that lab analyses of salt and hydrocarbon concentrations in peat soils can vary considerably according to the field collection and lab analysis methods used. In particular salt concentration is affected by choice of the wet and dry analysis techniques. However if the salt is not in the soil when conducting a wet analysis, then it must be present in the groundwater. Background hydrocarbon analytical results can also vary due to natural organic material in the soil. The latter can be removed by silica gel cleanup.

A structured sampling and analysis program was undertaken at the site to determine the physical characteristics of the peat medium and appropriate local values for adjusting salt concentrations by wet vs. dry analyses. Sequential flushing episodes of the peat soil indicated the potential for remediation by natural attenuation. Most salt was not bound to the organic medium, but could be removed in time by solution.

While this study is site-specific, the results may provide generic insight into the best field and lab methods to obtain meaningful data for investigation and remediation of contaminated oil and gas sites in peat and other organic soils.

Analysis of Groundwater Response to Tidal Fluctuations at Near-shore Groundwater Monitoring Sites Along Coastlines in Puget Sound

Chad Opatz, US geological Survey, Washington Water Science Center
Richard Dinicola, U.S. Geological Survey

The U.S. Geological Survey measured tidally influenced lag times in monitoring wells at three historically contaminated nearshore sites in Puget Sound.

Groundwater levels and specific conductance in monitoring wells, along with marine water levels (tidal levels) in adjacent marine water bodies, were monitored every 15 minutes during 2-week periods to better understand nearshore groundwater-seawater interactions at each site. Time-series data were collected over a complete neap and spring tide cycle. Vertical profiles of specific conductance were measured within the screened interval of each well prior to instrument deployment to determine if a freshwater/saltwater interface was present in a well prior to instrument deployment. A sharp freshwater-saltwater interface was measured in the screened interval at one site in two wells nearest the coastline. Other coastline wells exhibited either a uniform freshwater, brackish or saltwater profile.

Lag times between minimum spring-tide levels and minimum groundwater levels in wells ranged from about 0 to 8 hours. In addition to distance from shoreline, the variation in lag times at each site largely reflected the degree of groundwater flow heterogeneities present within the unconfined aquifer given the +13 foot tidal fluctuation.

The specific-conductance time-series data indicated a variety of possible hydrogeologic flow conditions, as indicated by changes observed in the screened interval of each well in concert with tidal fluctuations. Specific conductance fluctuations ranged from negligible to high depending on site specific conditions such as in-situ seawalls.

The results of these studies show how tidal levels might influence nearshore wells based on the unique conditions at each site.

Geothermal Exploration in Washington State Using a Play-Fairway Approach

Alex Steely, Washington Geological Survey
Corina Forson, Washington Geological Survey
Trenton Cladouhos, Cyrq Energy
Nicholas Davatzes, Temple University
Phillip Spake, Temple University

High-temperature geothermal resources are regions of the Earth where groundwater flows convectively through a volume of rock with elevated temperature and permeability. Where these resources are accessible, heat can be extracted and used for a variety of applications, from powering turbines to generate baseload carbon-free electricity to heating buildings or performing industrial work. Most geothermal resources, however, have no physical manifestation at the surface and are therefore challenging to locate. If such resources could be identified more easily, then they could be used to increase our production of carbon-free energy and decrease our reliance on carbon-based heating sources.

A "Play-Fairway" is a term from the oil-and-gas industry that describes using a broad and holistic set of data to define regions where a resource is likely to be found. As applied to geothermal exploration, the goal is to use all relevant data to effectively identify regions that are most likely to have enhanced permeability and a viable source of heat. Three areas were selected for detailed analyses based on the results of a statewide geothermal assessment: Mount Baker, Mount St. Helens shear zone, and Wind River Valley. A geothermal favorability model was developed using geology (faults, fractures, volcanic vents, intrusives, seismicity), geophysics (gravity, magnetotelluric, ground-based magnetic, passive seismic, and electrical resistivity), temperature at depth (temperature-gradient measurements and geothermometry), and surface features (hot springs and fumaroles) in each play area. Each layer was weighted using a consensus-based Analytical Hierarchy Process. Confidence in the model was assessed by assigning certainty values to input data based on observation density and quality. In general, confidence is high where observations are close and model errors are low; confidence is low where model errors are high or where observations are sparse. Exploration risk was calculated by scaling the favorability model by the confidence model to highlight areas with high favorability and high confidence in data. An infrastructure favorability model was also developed and reflects an array of factors that affect the feasibility of building a geothermal power plant.

These new favorability maps provide testable hypotheses regarding the heat source, permeability, and presence of fluid-filled fractures that together constitute a viable geothermal system. Favorable locations were chosen for drilling temperature-gradient (TG) holes to validate the model predictions. TG drilling commenced in summer 2018 and the results from a new ~470-ft hole will help to revise the favorability model.

Dam Operations and Subsurface Hydrogeology Control Dynamics of Hydrologic Exchange Flows in a Large Regulated River Corridor within the Hanford Reach, Washington

Pin Shuai, Pacific Northwest National Laboratory
Xingyuan Chen, Pacific Northwest National Laboratory
Xuehang Song, Pacific Northwest National Laboratory
Glenn Hammond, Sandia National Laboratories
John Zachara, Pacific Northwest National Laboratory
Patrick Royer, Pacific Northwest National Laboratory
Huiying Ren, Pacific Northwest National Laboratory
William Perkins, Pacific Northwest National Laboratory
Marshall Richmond, Pacific Northwest National Laboratory
Maoyi Huang, Pacific Northwest National Laboratory

Hydrologic exchange flows (HEFs) across the river-aquifer interface have important implications for biogeochemical processes and contaminant plume migration in the river corridor, yet little is known about the hydrogeomorphic factors that control HEFs dynamics under dynamic flow conditions. Here, we developed a 3-D groundwater model for a large regulated river corridor along the Hanford Reach (Washington, USA) to study how HEFs are controlled by the interplays between dam-regulated flow conditions and hydrogeomorphic features of such river corridor system. Our results revealed highly variable intra-annual spatiotemporal patterns in HEFs along the 75-km river reach, as well as strong interannual variability with larger exchange volumes in wet years than dry years. In general, the river was losing during late spring to early summer when the river stage was high, and river was gaining in fall and winter when river stage was low. The magnitude and timing of river stage fluctuations controlled the timing of high exchange rates. Both river channel geomorphology and the thickness of a highly permeable river bank geologic layer controlled the locations of exchange hot spots, while the latter played a dominant role. Dam-induced, sub-daily to weekly river stage fluctuations drove high-frequency variations in HEFs across the river-aquifer interfaces, resulting in greater overall exchange volumes as compared to the case without high-frequency flows. Our results demonstrated that upstream dam operations enhanced the exchange between river water and groundwater with strong potential influence on the associated biogeochemical processes and on the fate and transport of groundwater contaminant plumes in such river corridors.

The Application of Non-Invasive Geophysical Techniques to Earthen Dam Investigations

Nigel Crook, hydroGEOPHYSICS, Inc.
Jeremy Strohmeyer, hydroGEOPHYSICS, Inc.
Marc Levitt, hydroGEOPHYSICS, Inc.
Michael McNeill, hydroGEOPHYSICS, Inc.

The monitoring and maintenance of earthen dams is an ongoing and critical process to ensure the integrity of these structures, and prevent failure and the potential consequences. Typically, the majority of investigation techniques are invasive, such as drilling borings and cores or installing piezometers. This can present a conundrum to stakeholders and consultants in terms of poking holes in a structure designed to contain water or other materials. Geophysical methods present non-invasive, high resolution, spatially continuous survey and monitoring tools. These tools can be applied over the various stages of an earthen dam's lifetime; from preconstruction surveys for depth to bedrock, providing geotechnical parameters for seismic hazard analysis to charactering and monitoring seepage and assessing concrete structures such as spillways. These techniques provide a cost-efficient and rapid evaluation of many issues, reducing the need for drilling or providing a more focused target area. We present several case studies involving the use of a suite of geophysical methods, including seepage investigations and structural assessment as applied to earthen dams.

Sediment Monitoring During Elwha River Dam Removal: Lessons Learned During the Nation's Largest Dam Removal Project

Christopher Curran, U.S. Geological Survey
Christopher Magirl, U.S. Geological Survey
Jeffrey Duda, U.S. Geological Survey
Robert Hilldale, United States Bureau of Reclamation

The gradual, staged removal of two large dams on the Elwha River located on the Olympic Peninsula, Washington, USA, was the largest dam removal project in U.S. history when it began in September 2011. For almost 100 years, the 32-m tall Elwha Dam, located on the Elwha River 8 km upstream from the river mouth at the Strait of Juan de Fuca, blocked access of anadromous salmonids to the upper watershed. The construction in 1927 of the upper dam (64-m tall Glines Canyon Dam located 22 km upstream from the river mouth) further restricted the river and trapped fluvial sediment sourced from the upper watershed. The removal of both dams resulted in the release of large volumes of sediment that had profound effects on the downstream geomorphology of the river and posed challenges for scientists tasked with monitoring the transport of sediment. While some changes such as large-scale aggradation of the river bed and the subsequent incision of channel deposits were expected and planned for, other factors such as the timing and magnitude of sediment transport were largely unknown. Before dam removals and throughout the duration of the project, a network of USGS streamgages located upstream and downstream of both dams on the Elwha River provided invaluable hydrologic information to managers, engineers and scientists planning for and studying the effects of dam removal. During the 2-year deconstruction process, USGS streamgages provided real-time flood warning for the safe removal of dam structures and the protection of the human population in the downstream floodplain. The record of river stage provided by permanent and temporary streamgages during deconstruction was subsequently used as a proxy for monitoring the aggradation/incision of the channel bed and the detection and tracking of a large-scale dispersive sand wave initiated following the breach of the upstream Glines Canyon Dam. Turbidity sensors, installed prior to deconstruction at existing USGS streamgages and at a downstream sediment monitoring site, informed fisheries managers with real-time water-quality conditions for the successful reintroduction of salmonids, and provided scientists with a robust surrogate for suspended-sediment concentration and more accurate estimates of suspended-sediment load than could be provided by discharge alone. Two different types of hydroacoustic instruments provided additional suspended sediment - surrogate measurements with varying success. A bedload impact plate system was installed at the municipal water diversion downstream from both dams and instrumented with geophones and accelerometers for monitoring coarse bedload (≥ 16mm) transport rates. Physical sediment samples, both suspended and bedload, were collected sporadically and opportunistically during the project and were the basis for sediment-surrogate regression relationships used to calculate daily sediment loads.

Western Washington Applications of the Streamflow-Routing Package (SFR2) in MODFLOW

Leland Fuhrig, U.S. Geological Survey
Andy Long, U.S. Geological Survey

To simulate dynamic exchange of groundwater and surface water, the use of stream routing is an essential component of groundwater flow modeling, especially in regions where surface water flow and use are significant portions of the groundwater budget. The MODFLOW Streamflow-Routing (SFR2) Package has been incorporated into the Southeast Sound groundwater flow model currently being developed by the USGS Washington Water Science Center. Construction of the SFR2 package for this model primarily involved determining the respective paths and altitudes of each stream segment using a combination of existing National Hydrography Dataset (NHD) flow lines and Light Detection and Ranging (LiDAR)-derived altitudes.

Until 1989, rivers and streams primarily were simulated in MODFLOW with the River Package (RIV) and, in some cases, the Drain Package (DRN) for small tributaries. SFR2 improves on the earlier River (RIV) Package by its ability to route surface water throughout the watershed, to allow stream stage to vary with changing flows, and to allow a stream to stop flowing. Therefore, SFR2 allows for more complex and dynamic flow modeling scenarios that lead to better quantification of groundwater and surface water interaction. However, SFR2 requires considerably more effort than RIV in model construction and calibration. For example, inaccuracies in NHD cause difficulty in correctly routing streamflow in SFR2, and simulation with SFR2 adds nonlinearity to MODFLOW's numerical solution. Utilizing SFR2 has allowed for the construction of a groundwater flow model for the Southeast Sound project that will have the potential for use in a wide range of modeling scenarios in upcoming years.

Water Temperature in the Lower Quinault River, Olympic Peninsula, Washington

Kristin Jaeger, U.S. Geological Survey
Christopher Curran, U.S. Geological Survey
Elyse Clifford, QIN-DNR
Chad Opatz, U.S. Geological Survey

The availability of cold-water refugia during summertime river-water temperature maximums is important for cold-water fish species including Endangered Species Act listed salmonids since water temperature influences metabolism, growth, and phenology. The U.S. Geological Survey monitored water temperature at 10 sites approximately evenly-spaced along the lower Quinault River on the Olympic Peninsula, Washington, from June 2016 to August 2017 to assess thermal conditions in the lower river. During this 15-month period, there was a near-continuous, 15-minute record at 7 of the sites; complications with thermistors at 3 of the 10 sites limited the temperature dataset to include only summer 2016. In addition, near-streambed and water-surface temperatures were measured along the lower river during a longitudinal survey from August 9 to 12, 2016, during summer baseflow conditions to potentially identify cold or cooler water regions. Measured August water temperatures were warmer than model-predicted August temperatures for the period, 1993–2011. Summertime (July–September) daily minimum temperatures exceeded established salmon habitat threshold temperatures of 16 °C (core summer season) and 17.5 °C (spawning, rearing, and migration periods) for 122 and 65 days, respectively, on average at all monitoring sites with a complete 15-month record that included two summer baseflow periods. Summertime water temperatures at those sites were generally cooler in the downstream direction along the lower Quinault River but became warmer in the downstream direction during the rest of the year, suggesting the river was influenced by diffuse discharge of groundwater with a relatively constant annual temperature. The August longitudinal temperature survey did not detect cold-water refugia (features more than 3 °C cooler than ambient stream water), although it did identify 11 cooler water features (CWF) approximately 100–800 m in length that were 0.1 °C cooler than adjacent upstream or downstream water. The CWFs appeared to correspond to local geomorphic conditions. In August 2017, 10 of the 11 CWFs were field surveyed, and 5 appeared to be influenced by shading from solar radiation by riparian vegetation or steep cliff banks. In addition, field observations suggest that finer scale (that is, less than 10 m) CWFs, specifically individual side pools associated with large, in-channel wood, increased in frequency in the downstream direction along the lower Quinault River. However, this study did not quantify the density or water temperatures associated with these fine-scale features that may serve as cool- or cold-water pockets or patches.

In Situ Remediation of Carbon Tetrachloride Using BOS 100(r)

Mike Mazzarese, RPI Group
Randall Boese, BB&A Environmental

The subject property in Oregon formerly operated as a retail and commercial farm facility. The facility stored and sold feed, farm equipment, and various farming chemicals (fertilizers, herbicides, and pesticides, etc.). In 2015, prior to potential sale of the property, a Phase I Environmental Site Assessment (ESA) and subsequent Phase II ESA were undertaken. The Phase II ESA identified elevated concentrations of carbon tetrachloride, ethylene dichloride , and chloroform in the area of the former grain elevator structure on-site. Carbon tetrachloride was historically used at this site as a grain fumigant. The project objective was to reduce groundwater concentrations below the risk-based concentrations (RBCs): carbon tetrachloride = 1,800 ppb, ethylene dichloride = 630 ppb, and chloroform = 720 ppb.

During the initial site investigation, shallow groundwater was first encountered at depths between 10 and 13 feet (ft) below ground surface (bgs) within a sandy gravel unit just above a competent shale unit at 16 to 18 ft bgs. In each of the push-probe borings at the site, refusal was met in the competent shale unit. Additional characterization to refine the conceptual site model was performed with the installation of 11 soil profiling locations (four were completed as permanent monitoring wells). A total of 90 soil and 11 groundwater samples were collected. In February 2016, a slurry of water and activated carbon impregnated with reactive iron (BOS 100®) was injected between 10 and 18 ft bgs into the area of source contamination identified by the RDC. The dosing of BOS 100® was based on the analytical soil and groundwater data obtained from the RDC investigation. Treatment at the site consisted of three target areas of varying BOS 100® dosage and a total of 87 injection points (7.5 ft triangular grid). Based on calculations of residual mass and adsorption isotherms, 10-17.5 pounds of BOS 100® were injected per injection horizon.

Contaminants of concern have shown significant decreases in concentration (89.0-99.9%) since in-situ treatment. There is evidence of continued contaminant degradation, based on dissolved methane detected in groundwater. A risk-based comparison of detected contaminant concentrations in groundwater to applicable RBCs do not identify any contaminants in groundwater currently exceeding applicable RBCs. A No Further Action determination is pending.

Installing a Prototype Horizontal Reactive Media Treatment (HRX®) Well

Michael Lubrecht, Directed Technologies Drilling, Inc.
Craig Divine, Arcadis
Daniel Ombalski, Directed Technologies Drilling, Inc.

Historically, horizontal directional wells have been used in an active sense, either to extract contaminated soil vapor or groundwater, or to inject treatment chemicals in gaseous or liquid form, either in discrete events or continuously. Each of these major activities requires ongoing site activities, system maintenance and energy consumption. Although horizontal treatment wells have been established as a form of Green and Sustainable Remediation, authors sought to improve sustainability by engineering a passive system that required no ongoing operating cost or labor expenditures.

In this presentation, an innovative new concept for treatment is described, which utilizes a large-diameter horizontal well oriented along the flow direction of a contaminant plume. The well, packed with reactive media, captures contaminated groundwater at the inlet end, funneling it through the media for treatment. The treated water then exits the media at the outlet end. Contrasting permeability between the media and the surrounding formation enhance this flow-focusing effect, creating a capture zone of a significantly larger diameter than the well itself.

This presentation briefly describes the patented Horizontal Reactive Media Treatment (HRX®) well, the installation of the prototype well at Vandenburg Air Force Base in California and reports early data from the first few months of well operation.

Using Real-Time Monitoring to Rapidly Assess and Adjust Groundwater Remediation Strategies

Bill Mann, In-Situ Inc.

The Aqua TROLL 600 Multiparameter Sonde with telemetry and HydroVu cloud data services enables remote management of remediation sites in near-real time. The system provides immediate feedback on geochemical parameters in 2” diameter wells during treatment pilots and tracer studies. Sensors include an EPA-approved method for optical dissolved oxygen, ORP, pH, temperature, conductivity, rhodamine and level. Rugged DO provides drift-free, accurate readings even in anaerobic environments. A complete antifouling system wipes the sensor faces before every reading making sure they remain representative, even in highly fouling environments. A large pH reference junction means calibrations last months as opposed to weeks, and batteries last 3-6 months, reducing trips to the site for maintenance. The instrument integrates with a telemetry system that fits securely in a sub 2” well and easily connects with HydroVu cloud-based visual graphic interface, allowing site managers to readily see break-through events, optimize sampling programs, and communicate with on-site personnel to optimize injections, saving chemical costs and improving outcomes. An Application Programming Interface (API) allows users to create a quick and reusable connection to their data within HydroVu from Earthsoft EQuIS and other popular data management systems for deeper analysis of large volumes of data.

Optimization and Performance of ZVI Amendments for In-Situ Chemical and Biological Reduction

Sangho Bang, Tersus Environmental
Gary Birk, Tersus Environmental
David Alden, Tersus Environmental

In Situ Chemical Reduction (ISCR) is an innovative environmental technique used for soil and groundwater remediation that involves the placement of a reductant or reductant generating material in the subsurface to decrease the concentrations of targeted environmental contaminants to acceptable concentrations. Zero-Valent Iron (ZVI) is most commonly used to remediate toxic organohalides such as chlorinated ethenes and ethanes, pesticides, energetic compounds and some metals and metalloids into harmless end products. [ITRC 2011]. The process combines both biological processes and ZVI-driven abiotic pathways to chemically reduce the contaminants. An advantage of incorporating ZVI is that it enables various chemical reduction pathways for chlorinated ethenes and limits the formation of undesirable breakdown products such as Cis-DCE and vinyl chloride.

Recent studies were undertaken to evaluate the reactivity, surface passivation, and pH fluctuation of various commercially available ZVI powders and an engineered ZVI media with a greater surface area. The ZVI samples were under identical conditions for 103 days with a solid to liquid ratio of 1:20 by weight. Particle size of all ZVI was under 100 mm. The lab-scale kinetic experiment demonstrated accelerated abiotic reactivity of the engineered ZVI media towards a synthetic mixture of chlorinated volatile organic compounds (cVOCs). Namely, tetrachloroethylene (PCE), trichloroethylene (TCE), cis-dichloroethylene (c-DCE), and 1,1,1-trichloroethane (111TCA) in a groundwater solution (each cVOC added at 5 mg/L).

The study concluded that the major difference between engineered ZVI media and off-the-shelf ZVI powders is the increased reactivity of the engineered ZVI media. The engineered ZVI media was also able to maintain circumneutral pH, generate higher rates of hydrogen and sustain the production of hydrogen for a longer duration.

TPH-G, From 200,000 ug/L to 130 ug/L within 30 days of Treatment

Glenn Hayman, Hayman Environmental
Alex Koch, Blue Sage Environmental

In 1986 at a car dealership in Auburn, WA, it was discovered that a 1,000-gallon gasoline UST had lost its integrity and had released gasoline into the surrounding soil and groundwater. It was reported that the UST was filled on Friday and empty on Monday more than once. In March 1988 the UST and contaminated soil around it was removed. Gasoline floating on the water table was intermittently pumped from a temporary well until August 1988. In 2007 the dealership was remodeled and a limited quantity of contaminated soil was excavated. When the automobile dealership business was sold in December 2015, cleanup of the gasoline contamination was required within 5 years of closing. However; the cleanup could not excavate or trench in the active new car lot that effectively covered the entire contaminated area. A number of remedial technologies were evaluated and the Boss 200® Trap and Treat® injectable treatment was selected. It was injected over an area of 5,455 square feet on a 5-foot triangular grid at 234 locations at depths up to 16 feet below ground surface (bgs). At each injection location, Boss 200® was injected at 2-foot intervals. To provide more uniform distribution of the treatment, half the locations were injected on even foot intervals and the other half were injected on odd foot intervals. A total of 1,248 individual injections were made. Prior to treatment the TPH-G concentration in groundwater was as high as 200,000 ug/L. Following the treatment, the TPH-G concentration at this location was 130 ug/L. Quarterly groundwater monitoring identified a small new treatment area and an area that required retreatment. Following treatment, site contaminants have not been detected in the groundwater.

It is anticipated that the confirmation soil sampling will be completed and presented at the symposium.

Using R for Analysis of Continuous Surface Water Temperature Data

Pat Hallinan, Washington State Deptartment of Ecology

R (https://www.r-project.org) is a free, open source, software environment for statistical computing and graphics. Using R provided a reliable and fast means to analyze a large data set of continuous monitoring data.

Two large data sets of continuous (15 minute interval), multiyear surface water temperature data were analyzed using R. Seven day averages of the daily maximum temperatures were needed to compare to applicable surface water quality criteria.

This presentation will demonstrate coding basics of reading data, ensuring consistent time and date values, identifying gaps in data, calculating seven day averages of the daily maximums, and making interactive plots. Using interactive plots allowed a quick means of checking data for inconsistencies.

Long-Term Analysis of Baseflow Trends in the Southeast Puget Sound Basin

Alexander Headman, U. S. Geological Survey
Valerie Bright, U. S. Geological Survey

Baseflow is the component of streamflow attributed to groundwater discharge. Understanding the characteristics of baseflow in rivers and streams informs management of both groundwater and surface-water resources and characterizes hydrologic response to changes in climate and land use. Estimates of baseflow also provide calibration targets for numerical models used to inform groundwater and surface-water management. Baseflow was estimated at 115 U.S. Geological Survey stream gages in the southeast Puget Sound Basin using continuous streamflow records and discrete measurements between 1914 and 2018. For streamgages with continuous records, the USGS program, HYSEP (HYdrograph SEParation), was used to separate the hydrograph into its baseflow and surface runoff components. For stations with continuous monitoring for the 1980-2010 timeframe this HYSEP derived baseflow provides a normalized dataset for comparison between time periods. Applying hydrograph separation over the stream network over the period from 1914 to 2018 allows for a long-term view of downstream discharge gains and/or losses within the stream network. This poster presents changes in baseflow for the Puyallup, Duwamish, and Nisqually basins as well as various other small streams that drain into Puget Sound. It also shows the variation in discharge gains and losses between gages and measurements throughout time. Where water-use data is available, possible causes are examined to attribute the discharge gain/loss between gages over the period from 1980-2010.

Long Term Volunteer Data Collection on Vashon-Maury Island

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 2019, four volunteers will be starting their 19th year of self-monitoring water levels and their 12th year for monitoring usage. These records are some of the longest water level data for Vashon-Maury Island that add and support findings from existing monitoring wells.

The volunteers monitor three different aquifer zones of Vashon-Maury Island. Two 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.

This poster shows that volunteer data can be a valuable asset when compared to existing monitoring well data. These datasets from dedicated (self-motivated) participants provide additional quality data. The number of volunteers who collect data has 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.

Modeling the Effects of Climate Change on Streamflow and Stream Temperature in the South Fork of the Stillaguamish River

Katherine Clarke, Western Washington University
Robert Mitchell, Western Washington University
John Yearsley, University of Washington

The South Fork of the Stillaguamish River in Northwest Washington State is an important regional water resource and habitat for several threatened salmonid species. The river is currently subject to a temperature total maximum daily load, so it is important to understand how forecasted climate change will affect future stream temperatures and thus salmon populations and migrations (WSDOE, 2015). The South Fork basin is approximately 660 square kilometers with elevations reaching just over 2000 meters. Snowpack is the main contributor to spring and summer streamflow and currently serves as a stream temperature buffer. Previous modeling studies of mountainous Puget Sound river basins predict that forecasted climate warming will result in less precipitation falling as snow in the winter, resulting in a reduced snowpack and a lower spring runoff. Forecasted lower spring and summer flows have been shown to increase stream temperatures (e.g., Cao et al., 2015). To predict changes in streamflow and stream temperature in the South Fork Stillaguamish River, we used projected, gridded meteorological data in a physically-based streamflow model, the Distributed Hydrology Soil Vegetation Model (DHSVM), and a spatially-distributed stream temperature model, the River Basin Model (RBM).

We established digital spatial characteristics of the South Fork basin at a 50-meter grid resolution, including soils, landcover, and elevation. We calibrated the DHSVM to measured stream discharge from a Washington State Department of Ecology (Ecology) stream gauge using historical gridded meteorological data processed by the Climate Impacts Group at the University of Washington. Field work was conducted in the summer and fall of 2018 to determine stream morphology, discharge, and temperature at ten stream sites throughout the basin. Data collected from field work were used in the calibration of the RBM to stream temperature data from the Ecology stream gauge. We used the calibrated models to simulate the effects of climate warming into the 21st century at 3-hour time steps using gridded downscaled data from ten global climate models of the Coupled Model Intercomparison Project Phase 5 with representative concentration pathways scenarios 4.5 and 8.5. Simulation results were processed at 30-year intervals surrounding the years 2025, 2050, and 2075. Similar to modeling results in the North Fork of the Stillaguamish River our results project a trending increase in winter streamflows, a reduced snowpack, lower spring and summer streamflows, and an increase in stream temperatures into the 21st century.

Using Ensemble Data Assimilation to Estimate Long-term Hydrologic Exchange Fluxes under Highly Dynamic Condition

Kewei Chen, Pacific Northwest National Laboratory
Xingyuan Chen, Pacific Northwest National Laboratory
Xuehang Song, Pacific Northwest National Laboratory
Glenn Hammond, Sandia National Laboratory
Hongbin Zhan, Texas A&M University
Pin Shuai, Pacific Northwest National Laboratory

Long-term monitoring of the vertical hydrologic exchange fluxes (HEFs) across the riverbed is important for understanding the impact of river water-groundwater interaction on the river corridor biogeochemical processes. While heat tracer methods, using analytical or numerical solutions based on heat dissipation and transport theory, are widely used to estimate the HEFs, their performance suffers during groundwater upwelling periods due to the damping of diurnal heat signal coming from river. Moreover, most heat tracer methods assume idealized boundary conditions such as constant flux, which limits their applicability in highly dynamic river corridor system. In this study, we developed a dynamic HEFs estimation approach that incorporated ensemble data assimilation technique with 1-D groundwater flow and thermal model. Given river stage and hydraulic head measurement below the riverbed, effective permeability of riverbed sediments was estimated by assimilating the riverbed temperature at multiple depths. Hydraulic conductivity was then calculated using the estimated permeability and temperature-correlated viscosity. HEFs were calculated from the hydraulic gradient and hydraulic conductivity based on Darcy's law. If hydraulic heads were not recorded, HEFs were estimated directly by assimilating the subsurface temperature at small time window assuming that HEF was constant during that window. This new approach was evaluated with synthetic data generated from 1-D and 3-D numerical hydro-thermal models. Our results showed that dynamic river fluctuations can lead to rapid reversal in HEFs directions, which could be captured by the proposed method. Hydraulic conductivity in the riverbed can vary up to 50% in annual cycle due to the viscosity change, thus using a single point-of-time measurement of hydraulic conductivity in different seasons might lead to inaccurate estimation of HEF. Direct estimation of HEF requires the assimilation time window to be small (< 15 minutes) and the observation point to be close to the top boundary to capture the sub-daily flux. This approach has been proven to be efficient for the long-term monitoring of HEF under highly dynamic flow condition, and can be extended to long-term spatial-monitoring of HEF in the future.

Sumas-Blaine Aquifer Nitrate Characterization, 2018

Eric Daiber, Washington State Department of Ecology
Gene Freeman, Washington State Department of Ecology
Pam Marti, Washington State Department of Ecology
Kirk Sinclair, Washington State Department of Ecology
Barbara Carey, Washington State Department of Ecology-Retired

The Sumas-Blaine aquifer (SBA) is virtually the sole source of drinking water for 25,000-35,000 rural residents of northern Whatcom County. The aquifer is vulnerable to contamination due to its shallow depth, high winter rainfall, as well as overlying agricultural and residential land uses.

The purpose of this 2018 study is to resample for nitrate and other parameters at approximately 200 of the 248 wells sampled by Ecology in 1997.

Nitrate concentrations detected from monitoring across the aquifer during the 1990s indicated that more than 20% of wells had nitrate-N concentrations higher than 10 mg/L. Subsequent monitoring at a subset (25) of these wells during 2003-2016 suggests there have been statistically significant decreasing nitrate trends in 9 wells and in the average nitrate concentration for the 25 wells. During 2016, one in four sampled wells still exceeded 10 mg/L nitrate-N.

Results of the 2018 resampling will be used to assess changes in the locations and concentrations of nitrate across the aquifer since 1997. Samples will be collected for nitrate, ammonia, chloride, and field parameters during March-April to correspond with the 1997 sampling period. We will attempt to substitute equivalent wells in locations where we are unable to access previously sampled wells.

Simulation of Groundwater Storage Changes in the Quincy Basin, Washington

Lonna Frans, U.S. Geological Survey
Lonna Frans, U.S. Geological Survey
Sue Kahle, U.S. Geological Survey

The Miocene Columbia River Basalt Group and younger sedimentary deposits of lacustrine, fluvial, eolian, and cataclysmic-flood origins compose the aquifer system of the Quincy Basin in eastern Washington. Irrigation return flow and canal leakage from the Columbia Basin Project have caused groundwater levels to rise substantially in some areas. Water resource managers are considering extraction of additional stored groundwater to supply increasing demand. To help address these concerns, the transient groundwater model of the Quincy Basin documented in this report was developed to quantify the changes in groundwater flow and storage.

The model based on the U.S. Geological Survey finite-difference numerical code MODFLOW, uses a 1-kilometer finite-difference grid and is constrained by logs and water levels from 698 wells in the study area. Five model layers represent two sedimentary hydrogeologic units and underlying basalt formations. Head-dependent flux boundaries represent the Columbia River and other streams, lakes and reservoirs, underflow to and (or) from adjacent areas, and discharge to agricultural drains and springs. Specified flux boundaries represent recharge from precipitation and anthropogenic sources, including irrigation return flow and leakage from water-distribution canals and discharge through groundwater withdrawal wells. Transient conditions were simulated from 1920 to 2013 using annual stress periods. The model was calibrated with the parameter-estimation code PEST to a total of 4,064 water levels measured in 710 wells. Increased recharge since pre-development resulted in an 11.5 million acre-feet increase in storage in the Quincy Subarea of the Quincy Basin.

Four groundwater-management scenarios were formulated with input from project stakeholders and were simulated using the calibrated model to provide representative examples of how the model could be used to evaluate the effect on groundwater levels as a result of potential changes in recharge, groundwater withdrawals, or increased flow in Crab Creek. Decreased recharge and increased groundwater withdrawals both resulted in declines in groundwater levels over 2013 conditions while increasing the flow in Crab Creek resulted in increased groundwater levels over 2013 conditions.

100 Years of Washington Hydrology

Valerie Bright, U.S. Geological Survey
Wendy Welch, U.S. Geological Survey
Sue Kahle, U.S. Geological Survey

Hydrogeologic assessments detailing the occurrence and movement of groundwater are an integral tool in the development, management, and protection of Washington State's groundwater resources. The U.S. Geological Survey (USGS) has completed many of these assessments over the past century, in some cases revisiting study areas at multidecadal and even centenary intervals. For example, in 1916, USGS scientists made field observations of geology, topography, soils, and stream discharge in the Quincy basin of central Washington and collected ~250 groundwater-level measurements in its principle aquifers. Interpretive products from the 1916 report include a hydrogeologic cross section, a description of formations, and a map of water-table contours. Numerous investigators worked in this area in subsequent decades, notably during the development of the Columbia Basin Project in the 1940s and 50s. In 2016, USGS used these historic datasets alongside new data to update the hydrogeologic framework of the Quincy basin and complete a groundwater-flow model to assist the Bureau of Reclamation and the Washington State Department of Ecology in managing groundwater resources within the basin. This example is just one of many across the state that may be of use to professionals interested in water resource management and water quality.

This poster presents an easily-accessible map of the boundaries and references of selected USGS hydrogeologic investigations completed in Washington State since 1900. Included are example studies from coastal areas, the densely populated Puget Sound region, central and eastern Washington, and cross-boundary areas shared with Canada, Oregon, and Idaho. Although methods of investigation and reporting change through time, these studies provide historical understanding and helpful insights into hydrogeologic conditions to support continuing investigations across the state.

Air Stripping Addresses Critical Drinking Water Treatment Needs

David Fischer, QED Environmental Systems

While well established in groundwater remediation and chemical processing applications, air stripping is less widely known as a solution for some of municipal drinking water's most challenging issues. The widest historical use for air stripping is in the removal of volatile organic chemicals (VOCs). Typical VOCs include chlorinated solvents and hydrocarbons, often found in contaminated recovery water at remediation sites. For drinking water plants experiencing disinfection by product problems, the main contaminants of concern are the trihalomethanes (THMs), such as chloroform. THMs are VOCs efficiently removed by the air stripping process. Dissolved gases are another category of water contaminant that air stripping address. Dissolved gases of interest in the drinking water context include CO2, CH4, H2S and radon, all of which are easily removed by air stripping. Of the dissolved gases, waters high in CO2 concentration also tend to have lower pH and be prone to mobilization of lead and copper from distribution piping. Stripping off CO2 can lower the propensity for metals solubilization in some impacted drinking waters. The theoretical application of air stripping to the above drinking water treatment applications will be discussed. Additionally, pilot and operating plant data will be presented to illustrate process effectiveness and provide some guidance on expected costs.

Estimating Ground and Surface Water Contributions to a Throughflow Lake Using Stable Isotope Hydrology

Ayman Alharbi, Washington State University
Kent Keller, Washington State University
Barry Moore, Washington State University

Whether the ultimate goal be water use for potable supplies, restoration and ecological function, downstream flows, or other beneficial use, an accurate hydrologic budget is essential to lake management. Hydrologists have many tools to quantify surface inflows and outflows, but groundwater monitoring may require networks of wells or piezometers that are expensive to implement. Therefore, groundwater is often treated as the residual term in water balance equations; this yields only a net estimation and pushes all accumulated uncertainties into the groundwater term. We test the utility of stable isotope analysis (SIA) to provide a more accurate and economically viable approach to a lake water mass balance. Our study area is Liberty Lake, a throughflow lake with a large catchment area in eastern Washington, and for which we have substantial hydrologic data to test the efficacy of this approach. We used stable isotope δD and δ18O in lake water, inflow streams, springs, and precipitation in combination with meteorological data to infer the lake water balance. Preliminary results show that the local precipitation line is δ2H = 9.35 δ18O+1.12 which differs from the regional meteoric water line δ2H = 7.4 δ18O+0.67. The seasonal evaporation line for the lake is δ2H = 4.2 δ18O-52, and the mean isotope ratio of δ2H and δ18O in Liberty Lake are -9.7 ‰ and -91.5 ‰, respectively. The result shows that the lake water budget is susceptible to a change in snowmelt and precipitation, especially during late winter and spring. Additionally, the groundwater contribution is fairly fluctuated and has a significant effect in the lake budget. This study is the first effort using mass balance stable isotope approach in a lake in this region. SIA highlights the prominence of ground and surface water contribution for making responsible decisions regarding the environmental management of the lake.

Hydrogeology of University Basin Area of Seattle, King County, Washington

Jennifer Hilden Saltonstall, Associated Earth Sciences, Inc.
Curtis J. Koger, Associated Earth Sciences, Inc.

An assessment of existing hydrogeologic conditions in the University Basin area of Seattle, King County, Washington was completed to evaluate potential stormwater infiltration opportunities and constraints as part of study to reduce combined sewer overflow events. The study area was about 4,000-acres. Surface geology and native soil characteristics have a significant influence on the practical application of stormwater management strategies. Very low permeability lodgement till mantles much of the upland portion of the basin. In some locations a thin veneer of permeable recessional outwash deposits are present on top of the low permeability till unit, providing opportunities for dispersed stormwater infiltration. In other locations, exposures of thick sequences of advance outwash and pre-Vashon-age sand are present provide opportunities for concentrated stormwater infiltration. In areas of shallow groundwater or highly stratified sediments, larger infiltration systems are generally not feasible without built-in mitigation such as Class V Underground Injection Control (UIC) wells. UIC systems can be designed as part of a bioretention cell or can be designed as the sole method of stormwater infiltration, where storage is contained within the UIC well. UIC wells, either dug or drilled, create preferential flow paths for clean treated water to infiltrate vertically. UIC systems have been used to mitigate for groundwater mounding caused by stratified (layered) sediments and have been installed to access permeable sediments present beneath surficial till deposits where infiltration would not have otherwise been feasible.

The hydrogeology of the basin was illustrated in a project surface geology map and a series of hydrogeologic cross sections. The information will be used to guide potential stormwater infiltration projects throughout the University Basin area. Key hydrogeologic findings include: Pleistocene glacial and nonglacial deposits are present for several hundred feet below the basin. Groundwater conditions are complex. Differential erosion of paleotopography has created significant groundwater variability; in the eastern portion of the study area, groundwater elevations drop rapidly across a few hundred lateral feet, reflecting abrupt changes in the subsurface from the perched Vashon advance aquifer to the deeper regional aquifer. In the western area of the site, the Vashon advance outwash aquifer and pre-Vashon sand deposits contain a relatively continuous unconfined aquifer. Green Lake, historic Licton Springs, Ravenna 'swamp' and Ravenna Creek directly interact with groundwater in the aquifer system.

What do Almost 30 Years of Data from a Countywide Database Tell Us about the Water Resources of Kitsap County, Washington?

Joel Purdy, Kitsap Public Utility District

To monitor the well-being of Kitsap's water cycle and to have a scientific basis for management efforts, Kitsap PUD built and maintains a comprehensive hydrological monitoring network across Kitsap County. This network has been continuously operated since 1991. It currently consists of 29 precipitation monitoring sites, 30 streamflow monitoring sites and over 125 groundwater monitoring wells. In addition to tracking trends within Kitsap's water cycle, data from this network contributes to scientific studies, such as the 2014 USGS groundwater flow model, and resource management decisions, such as regional infrastructure build-out.

Water level, streamflow, precipitation and water quality data is keyed in and uploaded using an Access database interface developed in cooperation with King County. Data is openly displayed, accessed and shared on KPUD's public website. Some weather stations and stream gages transmit real-time data that can be plotted or downloaded using the website.

We will present examples how the data is used for: comparisons of long-term precipitation and groundwater level trends, production-well performance evaluations, aquifer responses to production rates, and mapping.

Field Trips

page 78

Workshops

pages 79–80

SR530 Landslide Oso, Washington

Monday, April 8, 2019, 8:00 AM – 5:00 PM

The SR530 Landslide near Oso Washington was a tragic debris flow that claimed the lives of 43 people on March 22, 2014. The landslide triggered local, state, and federal agencies to increase the assessment of geologic hazards across the State of Washington and evaluate local land use decision making in geologically hazardous areas. Joe Wartman (UW H.R. Berg Professor of Civil and Environmental Engineering) and students who have lead trips to the landslide area near Oso, Washington will lead the field trip and discussion surrounding research on the mechanisms leading to and during the debris flow and the ongoing studies to assess, understand, and prepare for the risks associated with debris flows.

7:50 AM: Meet in Hotel Murano lobby.
8:00 AM: Vans will depart from in front of the Hotel Murano.
5:00 PM: Arrive back at hotel.

Note: Please plan to dress for the weather.

Elwha River Restoration Port Angeles, Washington

Friday, April 12, 2019, 8:00 AM – 5:00 PM

Elwha River Restoration project includes the removal of two large dams on the Elwha River, restoration of the Elwha watershed, its native anadromous fish, and the natural downstream transport of sediment and woody debris. The Elwha project, including dam removal, restoration efforts, and protection measures, is serving as a "living laboratory" for monitoring large-scale ecosystem recovery and investigating particular ecosystem processes and components. Mike McHenry (Fisheries Biologist Lower Elwha Klallam Tribe), George Pess (Watershed Program Manager NOAA Fisheries), and Tim Abbe (Principal Geomorphologist Natural System Designs) will lead the field trip and discussion of their findings and observations concerning the watershed response to restoration efforts and ecosystem recovery.

7:50 AM: Meet in Hotel Murano lobby.
8:00 AM: Vans will depart from in front of the Hotel Murano.
5:00 PM: Arrive back at hotel.

Note: Please plan to dress for the weather.

Questions: Check at the Symposium Registration Desk

W1: Conceptual Site Model Development and Translation to Numerical Models

Thursday, April 11 | 8:00 AM – 12:00 PM | Venice Room 3

Groundwater management requires understanding the full system so impacts of potential actions can be identified. A first step in gaining this system-level understanding is integrating multiple physical, geochemical, and microbiological factors into a conceptual site model (CSM). A CSM is a tool that identifies and organizes factors important to a site, describes the site-specific environmental setting, contaminant properties, and risks; and provides a basis to select an appropriate remedy or management action. As such, the CSM is a core tool for environmental management, beginning at the onset of site characterization and continuing in usefulness until the site action is completed. In many cases, to apply the CSM for remedy decision-making and design, the CSM must be translated into a quantitative description of the site as a numerical flow and transport model. This workshop will present how site data are mapped into numerical models and how CSMs are used to build numerical models describing saturated and unsaturated flow and transport. The first half of the workshop will include a presentation of CSM approaches and supporting tools with interactive elements to allow discussion of participants' specific concerns. In the second half of the workshop, the course will demonstrate how the CSM site-specific information is integrated into numerical models using a freely available graphical user interface that allows the user to visualize the model domain (e.g., boundary conditions and geologic materials). The focus will be on identifying the level of modeling complexity needed to adequately represent the CSM; decisions on simulator selection, numerical considerations (e.g. grids), heterogeneity, and numerical approaches will be evaluated with respect to the CSM and data requirements. Hands-on demonstrations of different modeling approaches will be an integral part of understanding the CSM translation to the numerical modeling framework. Laptops will maximize the workshop experience but are not required.

Instructors:

- Vicky Freedman, Pacific Northwest National Laboratory
- Mike Truex, Pacific Northwest National Laboratory
- Matt Tonkin, S.S. Papadopulos & Associates, Inc.

Cost: $75.00 for conference attendees, $100.00 for workshop only *(lunch on your own)*

Note: Early morning and mid-morning break provided, lunch is on your own

---

W2: Understanding and Addressing Well Performance Issues

Thursday, April 11 | 8:00 AM – 5:00 PM | Venice Room 4

Water flow in the unsaturated zone is central to critical issues in many fields, for example agriculture, geophysics, hyProblems with well performance are usually preventable, often start with well construction and development, and are then exacerbated by water quality conditions, well operation, and rehabilitation efforts. This class will discuss the key factors affecting well performance including new well design, initial screen development, biological and mechanical plugging, well operation, and rehabilitation methods. An asset management-based approach is described that helps prioritize maintenance decisions and long term well field operation.

Over the past several years there has been significant research done worldwide related to optimizing well performance. This research has included looking at the mechanisms involved with biological and mechanical plugging of aquifers and the effectiveness of various rehabilitation technologies. The class will discuss several studies in Europe that looked at the mechanisms associated with poor well performance and innovative approaches being used to prevent or correct poor well performance.

Instructors:

- Jim Bailey, Shannon & Wilson, Inc.
- Others TBA

Cost: $125.00 for conference attendees, $150 for workshop only *(lunch on your own or order box lunch for $25)*

Note: Early morning, mid-morning, and afternoon refreshment break provided.

W3: ITRC Guidance: Remediation Management of Complex Sites

Thursday, April 11 | 1:00 PM – 5:00 PM | Venice Room 3

This course will provide a framework based on adaptive site management principles for remediation management of complex sites. It will also identify and integrate technical and nontechnical challenges into site objectives and remediation approaches, as well as develop a performance based action plan to guide long-term management. This training will interest state and federal regulators at complex sites, environmental professionals, and public and tribal stakeholders.

At some sites, complex site-specific conditions make it difficult to fully remediate environmental contamination. Both technical and nontechnical challenges can impede remediation and may prevent a site from achieving federal- and state-mandated regulatory cleanup goals within a reasonable time-frame. For example, technical challenges may include geologic, hydrogeologic, geochemical, and contaminant-related conditions as well as large-scale or surface conditions. In addition, nontechnical challenges may also play a role such as managing changes that occur over long time frames, overlapping regulatory and financial responsibilities between agencies, setting achievable site objectives, maintaining effective institutional controls, managing redevelopment and changes in land use, and funding considerations. This short course and associated ITRC guidance, Remediation Management of Complex Sites, provide a recommended process for remediation management at complex sites – termed "adaptive site management". Adaptive site management is a comprehensive, flexible, and iterative process of remediation management that is well-suited for complex sites where there is significant uncertainty in remedy performance predictions. Adaptive site management includes periodically evaluating and adjusting the remedial approach, which may involve multiple technologies at any one time and changes in technologies over time. Comprehensive planning and scheduled periodic evaluations of remedy performance help decision makers track remedy progress and improve the timeliness of remedy optimization, reevaluations, or transition to other technologies/contingency actions. Participants will learn how to apply the guidance to improve decision making and remediation management at complex sites. The guidance is intended to benefit a variety of site decision makers, including regulators, responsible parties and their consultants, and public and tribal stakeholders. Case studies will be used to describe real-world applications of remediation and remediation management at complex sites.

Instructors:

- John Price, Washington State Department of Ecology
- Elisabeth Hawley, Geosyntec Consultants
- Mike Truex, Pacific Northwest National Laboratory

Cost: $75.00 for conference attendees, $100.00 for workshop only *(lunch on your own)*

Note: Afternoon refreshment break provided.

Presenter Index

pages 82–85

PRESENTER INDEX

PRESENTER INDEX

Name	Email	Title	Session	Page
Freedman, Vicky	vicky.freedman@pnnl.gov	Identifying the Technical Basis for Technical Impracticability Waivers for Recalcitrant Radionuclides	1A	14
Fuhrig, Leland	lfuhrig@usgs.gov	Western Washington Applications of the Streamflow-Routing Package (SFR2) in MODFLOW	7A	58
Gallagher, Michael	mike.gallagher@ecy.wa.gov	Washington's New Streamflow Restoration Law - A First Year Overview	6A	49
Gendaszek, Andrew	agendasz@usgs.gov	Soil-Water Balance Model Estimates of Recharge and other Water Budget Components for the Upper Chehalis River Basin	1B	18
Gibson, Maria	howiemurphy@gmail.com	Estimating Aquifer Recharge Potential Within a Multi-Decision Criteria Analysis to Locate Suitable Managed Aquifer Recharge Locations in the Yakima River Watershed, Washington USA.	2B	23
Gillum, Carrie	carrie.gillum@dnr.wa.gov	Building Web-Based 3D Hydrogeologic Models and Providing Groundwater-Monitoring Data: An Update from the Washington Geological Survey	3A	28
Gosack, Heather	heather.gosack@apexcos.com	Characterization of PFAS in Soil, Groundwater, Surface Water, Stormwater, and Sediment at Portland International Airport (PDX), Oregon	3B	34
Graham, Steve	stevegraham@dccnet.com	Site-Specific Investigation for a Salt Contaminated Organic Peat Soil	6B	52
Hallinan, Pat	phal461@ecy.wa.gov	Using R for Analysis of Continuous Surface Water Temperature Data	Poster	65
Hayman, Glenn	glenn@HaymanEnvironmental.com	TPH-G, From 200,000 ug/L to 130 ug/L within 30 days of Treatment	7B	64
Headman, Alexander	AHeadman@usgs.gov	Long-Term Analysis of Baseflow Trends in the	Poster	66
Hermanson, Mike	mhermanson@spokanecounty.org	Use of a Coupled Ground and Surface Water Model (GSFLOW) in the WRIA 55 RCW 90.94 Watershed Plan Update	6A	50
Hou, Zhangshuan	zhangshuan.hou@pnnl.gov	Hydromorphic Classification of the Hanford Reach Through Machine Learning of Field Observations and Hydrodynamic Simulations	5B	48
Jaeger, Kristen	kjaeger@usgs.gov	Water Temperature in the Lower Quinault River,	7A	59
Jensen, Roy	roy.jensen@hartcrowser.com	Use of Injection Wells for Disposal of Non-Contact Cooling Water	2B	24
Johnson, Christian	cd_johnson@pnnl.gov	Pump-and-Treat Performance Assessment Using a Rebound Study	1A	16
Kahle, Sue	sckahle@usgs.gov	Uranium in Groundwater in Northeastern Washington State	1A	15
Kale, Nathaniel	kalen@co.thurston.wa.us	Cellular Telemetry for Water Monitoring	3A	30
Kale, Nathaniel	kalen@co.thurston.wa.us	Estimating Stage-Discharge Curves in R	3A	31
Kindred, J. Scott	scottk@kindredhydro.com	Using the Borehole Permeameter Method to Estimate Hydraulic Conductivity in Glacially-Consolidated Soils	1B	20

PRESENTER INDEX

Name	Email	Title	Session	Page
Lloyd, David	david@fredsense.com	Field Ready Electrochemical Detection of Arsenic	1A	17
Long, Andrew	ajlong@usgs.gov	Time-Series Analysis for Groundwater: Quick Methods to Assess Groundwater Response to Precipitation	3A	29
Lubrecht, Michael	mike@horizontaldrill.com	Installing a Prototype Horizontal Reactive Media Treatment (HRX®) Well	7B	61
Mann, Bill	bmann@in-situ.com	Using Real-Time Monitoring to Rapidly Assess and Adjust Groundwater Remediation Strategies	7B	62
Mazzarese, Mike	mmazzarese@astenv.com	In Situ Remediation of Carbon Tetrachloride Using BOS 100(r)	7B	60
Mitchell, Robert	robert.mitchell@wwu.edu	The Effects of Forecasted Climate Change on Hydrology and Stream Temperature in the North Fork of the Stillaguamish River Basin	2A	22
Moldver, Aaron	amoldver@redmond.gov	Sustaining Redmond's Shallow Alluvial Aquifer in an Expanding Urban Environment	4A	38
Morgan, Laurie	Laurie.Morgan@ecy.wa.gov	Critical Aquifer Recharge Areas Guidance Update	4A	37
Opatz, Chad	copatz@usgs.gov	Analysis of Groundwater Response to Tidal Fluctuations at Near-shore Groundwater Monitoring Sites Along Coastlines in Puget Sound	6B	53
Owens, Carmen	cowens@apexcos.com	A Slough of Challenges: Permitting and Activated Carbon Placement on the Lower Columbia Slough	5B	46
Purdy, Joel	jpurdy@kpud.org	What do Almost 30 Years of Data from a Countywide Database Tell Us about the Water Resources of Kitsap County, Washington?	Poster	76
Saltonstall, Jennifer Hilden	jsaltonstall@aesgeo.com	Hydrogeology of University Basin Area of Seattle, King County, Washington	Poster	75
Scandella, Benjamin	Benjamin.P.Scandella@oregon.gov	Estimating Aquifer Parameters from Large Sets of Pumping-Test Data Using Streamlined, Python-Based Analysis Software	1B	19
Shah, Sachin	sdshah@usgs.gov	A Framework to Deliver Real-time and Long-term Hydrologic Data: Web-Based Applications for Water Resource Analysis	3A	27
Shira, Jason	jshira@aspectconsulting.com	Mission Creek Flow Improvement: An Example of First Steps to Solving Instream Flow and Water Supply Challenges	5A	42
Shuai, Pin	pin.shuai@pnnl.gov	Dam Operations and Subsurface Hydrogeology Control Dynamics of Hydrologic Exchange Flows in a Large Regulated River Corridor within the Hanford Reach, Washington	7A	55
Song, Xuehang	xuehang.song@pnnl.gov	Dynamic River Stage Variations Lead to Multimodal Residence Time Distributions of Hydrological Exchange Flow	5B	47
Squeochs, Danielle	daja461@ecy.wa.gov	Policy, Permitting and the Particulars of Aquifer Storage and Recovery in Washington State	2B	25

PRESENTER INDEX

EXHIBITORS

Seametrics
Precision Environmental Sensors
An ONICON Brand
www.seametrics.com

Anderson Environmental Contracting LLC
AEC
www.aecllc.net

Washington State Dept of Natural Resources
Washington Geological Survey
www.dnr.wa.gov

Department of Ecology
State of Washington
ecology.wa.gov

In-Situ®
www.in-situ.com

USGS
science for a changing world
www.usgs.gov

HGI
hydroGEOPHYSICS
www.hgiworld.com

DTD
Directed Technologies Drilling Incorporated™
www.horizontaldrill.com
www.horizontaldrill.com

VISTACLARA INC.
NMR GEOPHYSICS
www.vista-clara.com

OTT HydroMet
www.ott.com

Olympic
Environmental Equipment, llc.
www.olympicenvironmentalequipment.com

Earthfx Incorporated
www.earthfx.com

Pacific Northwest National Laboratory
Proudly Operated by Battelle Since 1965
www.pnnl.gov

SYMPOSIUM SPONSORS

Silver Sponsors

SCHNEIDER WATER SERVICES

www.schneiderwater.com

HOLOCENE DRILLING

www.holocenedrillinginc.com

APEX

www.apexcos.com

geotech

www.geotechenv.com

SHANNON & WILSON

www.shannonwilson.com

Bronze Sponsors

PBS

www.pbsenv.com

HARTCROWSER

www.hartcrowser.com

GSI Water Solutions, Inc.

www.gsiwatersolutions.com

ROBINSON NOBLE

www.robinson-noble.com

SYMPOSIUM SPONSORS

Platinum Sponsors

Aspect CONSULTING

www.aspectconsulting.com

HOLT SERVICES INC

www.holtservicesinc.com