11th Washington Hydrogeology Symposium

WASHINGTON HYDROGEOLOGY SYMPOSIUM

PROGRAM AND ABSTRACTS

| Hotel Murano

| Tacoma, Washington

May 9-11, 2017

www.wahgs.org

11th Washington Hydrogeology Symposium

SCHEDULE OVERVIEW

DATE	ACTIVITY
MONDAY *May 8*	**Field Trip:** Stormwater Management Approaches *(half day - morning)* **Field Trip:** Nisqually National Wildlife Refuge *(half day - afternoon)*
TUESDAY *May 9*	**First Day of Symposium** **Opening Session / Keynote Talk** **Platform Presentations** **Exhibits** Lunch Provided **Poster Session and Reception** *(early evening)*
WEDNESDAY *May 10*	**Second Day of Symposium** **Keynote Talk** **Platform Presentations** Lunch Provided - Hirst Decision Panel **Exhibits and Posters**
THURSDAY *May 11*	**Workshop 1:** Training for Water Rights Analysis – Certified Water Rights Examiners *(8:30am-4:30pm)* **Workshop 3:** Unsaturated-Zone Water and Contaminant Transport: A Twenty-First Century Understanding *(8:30am-4:30pm)*

2017 WELCOME

11th Washington Hydrogeology Symposium

Welcome to the 11th Washington Hydrogeology Symposium! We are pleased to convene this year's Symposium at the Hotel Murano in Tacoma, Washington in the shadow of Mt. Rainier and on the shores of Puget Sound. We hope the Symposium offers you an opportunity to learn about recent developments in the field of hydrogeology and connect with colleagues from across the Pacific Northwest.

We are excited to present a comprehensive technical program that covers new developments in hydrogeology throughout Washington State and beyond. Fifty-seven platform and twenty-nine poster presentations cover a diverse suite of topics including stormwater management, groundwater contaminant fate and transport, water resource availability, and aquifer storage and recovery, to name a few. In addition to the technical program, three workshops are offered during the Symposium, including Training for Water Rights Analysis – Certified Water Rights Examiners, Unsaturated-Zone Water and Contaminant Transport, and Groundwater in Tidally Influenced Aquifers. On Monday, symposium participants had the opportunity to attend a stormwater field trip to The Washington State University Extension Campus in Puyallup, led by WSU Professors Ani Jayakaran and Jen McIntyre, and USFWS Toxicologist Jay Davis. Also on Monday was a trip to the Nisqually National Wildlife Refuge led by Dr. Eric Grossman, Research Hydrologist with the U.S. Geological Survey.

We are privileged to welcome as keynote speakers for the Symposium both Dr. Ty Ferré, professor in the Department of Hydrology and Water Resources at the University of Arizona, and Dr. Aaron Wolf, professor of geography in the College of Earth, Ocean, and Atmospheric Sciences at Oregon State University. Dr. Ferré was the 2016 Henry Darcy Distinguished Lecturer and will present a retrospective on his experience as a Darcy Lecturer, as well as his research on integrating decision science with hydrologic modeling and measurement interpretation. Dr. Wolf will be presenting on international transboundary water conflicts and methods for resolution, using his integrated expertise in environmental science and dispute resolution theory.

Please take time to visit our exhibitors who are showcasing state-of-the art data collection, analytical, and reporting solutions. We also encourage you to participate in our Passport Program with our exhibitors for the opportunity to win prizes. We would also like to thank our sponsors who, through their generosity, have ensured the continuity of the Symposium's success and allowed the registration fee to continue to be offered at a very affordable price. A full list of our sponsors and exhibitors are included on the website, www.wahgs.org.

On behalf of the 11th Washington Hydrogeology Symposium Steering Committee, I hope you spend several enjoyable and productive days at the Symposium and that you plan to join us again in 2019!

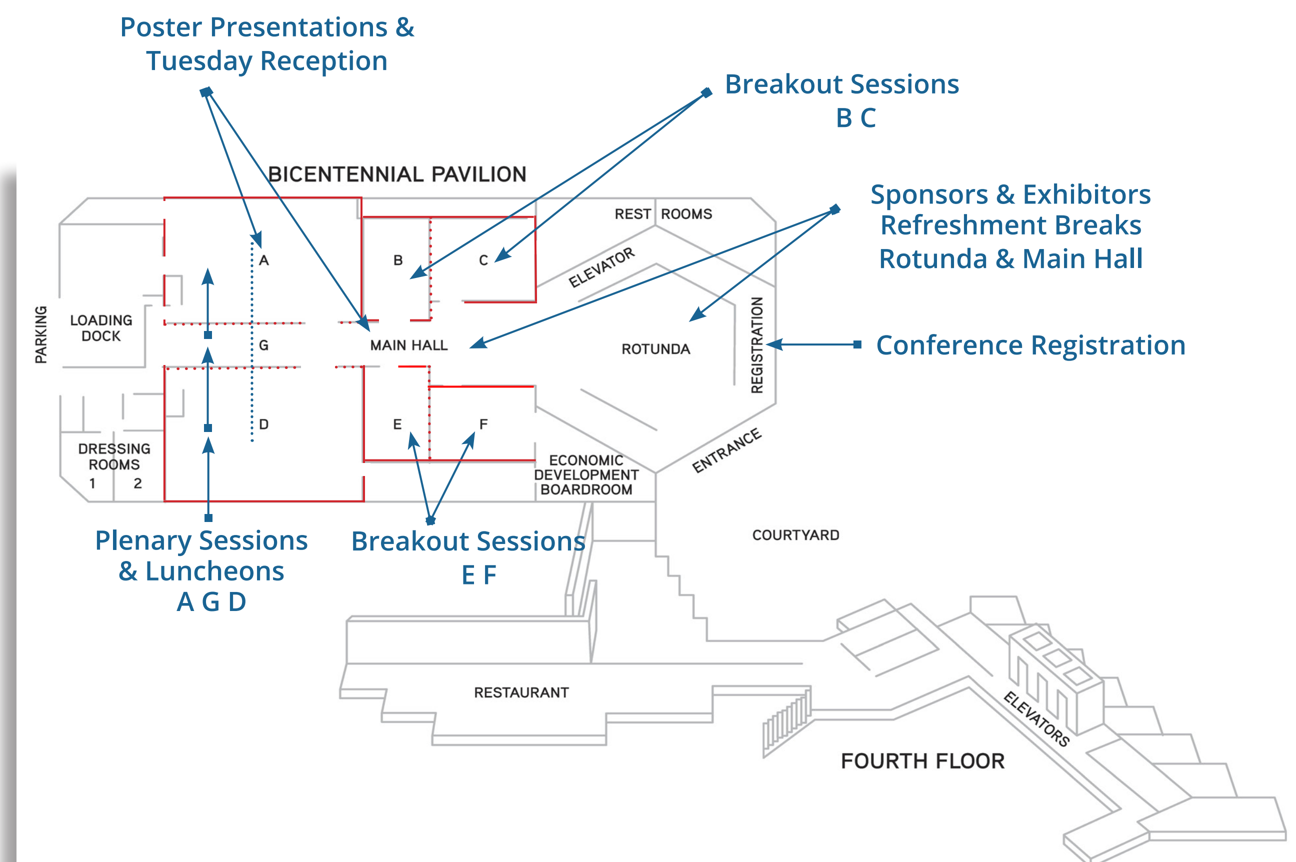
Sincerely,
Vicky Freedman
2017 Symposium Chair
Pacific Northwest National Laboratory

11th Washington Hydrogeology Symposium

KEY LOCATIONS

Hotel Murano, Tacoma

Bicentennial Pavilion



Main Hotel

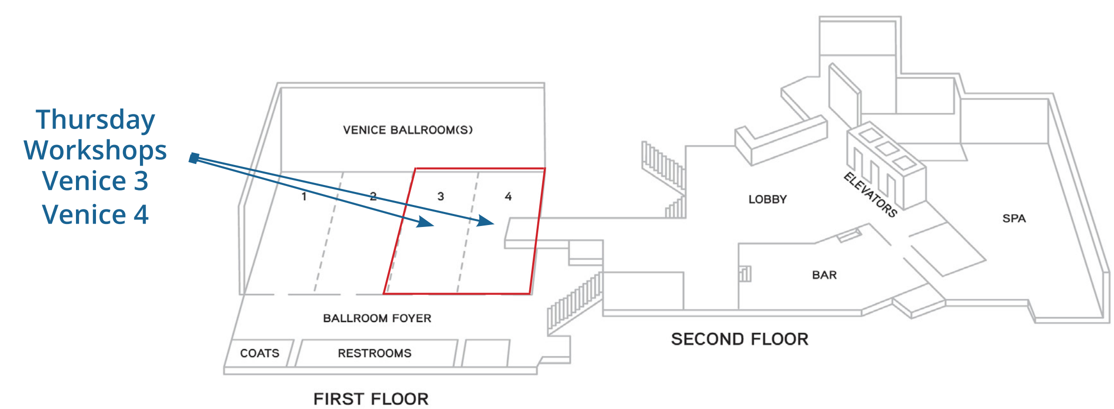


TABLE OF CONTENTS

11th Washington Hydrogeology Symposium

Nadine L. Romero Student Scholarship Recipients

We are pleased to announce the recipients of the first biannual Nadine L. Romero Student Scholarship, **Kara Kingen**, a BS geology major at Portland State University, and **Dallin Jensen** a MS graduate student in the Department of Geosciences at Central Washington University. Both students demonstrated exceptional academic achievements, are making valuable contributions to the hydrogeology and university communities, and have significant potential as future professional hydrogeologists. Congratulations Kara and Dallin!

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, May 9: 7:30 AM–5:30 PM | Wednesday, May 10: 8:00 AM–4:30 PM | Thursday, May 11: 8:00 AM– 1:30 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 5:15-7:00 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 5:15-7:00 PM. View the 2017 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.

New this year! Passport Book Contest

Your Passport book lists all our 2017 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. 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 when they check in for wifi access in their hotel room and in the meeting rooms. For those participants not staying in the hotel, please use the username: wahydrog and password: 2017. Questions can be answered by hotel front desk staff persons, and 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

11th Washington Hydrogeology Symposium Steering Committee

Vicky Freedman	Pacific Northwest National Laboratory, Chair
Danielle Squeochs	Washington Department of Ecology, Vice-Chair
Ken Nogeire	PBS Engineering and Environmental Inc., Treasurer
Bryony Stasney	Washington Department of Health, Secretary
Andy Gendaszek	U.S. Geological Survey, Officer
Angie Goodwin	Hart Crowser, Officer
Robert Mitchell	Western Washington University, Officer
Sophia Petro	Washington Department of Health, Officer
Joel Purdy	GeoEngineers, Officer
Christopher Brown	Pacific Northwest National Laboratory, Committee
Donna Buxton	City of Olympia, Committee
Ashley Cedzo	Regenesis, Committee
Karen Dinicola	Washington Department of Ecology, Committee
Jean Doesburg	Directed Technologies Drilling, Inc. , Committee
Mark Freshley	Pacific Northwest National Laboratory, Committee
Roy Jensen	Hart Crowser, Committee
Sue Kahle	U.S. Geological Survey, Committee
Andy Long	U.S. Geological Survey, Committee
Laurie Morgan	Washington Department of Ecology, Committee
Rose Riedel	Olympic Environmental Equipment LLC, Committee
Jason Shira	Washington Department of Ecology, Committee
Michelle Snyder	Pacific Northwest National Laboratory, Committee
Kurt Walker	Washington Department of Ecology, Committee
Gary Walvatne	Apex Companies, LLC, Committee
Fred Zhang	Pacific Northwest National Laboratory, Committee

Mary Jane Shirakawa Jan Kvammme	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 12th Washington Hydrogeology Symposium scheduled for April or May of 2019, please sign up at the Symposium Registration Desk. To kick things off, you will be invited to attend a free morning breakfast meeting on Wednesday, May 10, at 7:30 AM (RSVP required).

WIRELESS ACCESS

username: wahydrog
password: 2017

SCHEDULE AT A GLANCE

Tuesday, May 9, 2017		
7:30 AM	Check-in & Registration	
9:00 AM	**Opening Session** *(Room AGD)*	
9:00 AM	**Welcome and Opening Remarks** *Vicky Freedman* , 2017 Washington Hydrogeology Symposium Chair	
	Keynote Talk: A Retrospective – Lessons Learned and Data, Models and Decision Making … ***Ty Ferré,*** *Ph.D., Professor, Department of Hydrology and Water Resources, University of Arizona* *2016 Henry Darcy Distinguished Lecturer*	
10:15 AM	Refreshment Break | Exhibits | Posters	
10:40 AM	**1A–Remediation Technologies I** *(Room EF)*	**1B–Stormwater 1: Understanding the Problem** *(Room BC)*
SESSION 1	*Session Chair: Vicky Freedman*	*Session Chair: Karen Dinicola*
	Dissolved Heavy Metals in Groundwater: In-Situ Stabilization and Capture Technologies Utilizing Granular Reagent *Derek Pizarro, Premier Magnesia, LLC*	**The regulatory framework for addressing stormwater problems in Washington: what's covered, what's missing?** *Karen Dinicola, Washington Dept of Ecology*
	Maintaining a Problematic Groundwater Extraction System in Interior Alaska *Chris Allen, Shannon & Wilson, Inc.*	**Characterization of Western Washington Stormwater in Large Urban Areas: 2009-2013** *William Hobbs, WA State Department of Ecology*
	Evaluation of the mechanisms of arsenic sequestration in in-situ groundwater treatment systems implementing induced sulfate reduction via permeable reactive barriers with and without utilization of zero-valent iron *Lara Pracht, University of Washington*	**Ten Years of Clean Water. The Effects of Stormwater Source Controls on Sediment Quality in Thea Foss Waterway, Tacoma, Washington** *Dana de Leon, City of Tacoma*
	Ex Situ Treatments of Aqueous Film-Forming Foam Impacted Water *Gary Birk, Tersus Environmental*	**The Stormwater Action Monitoring Program's Mussel Monitoring Project: Using Transplanted Mussels to Assess Contaminants in the Puget Sound's Nearshore Habitats** *Jennifer Lanksbury, Washington Dept of Fish and Wildlife*
Noon	**Hosted Luncheon** *(Room AGD)*	
1:20 PM	**2A–Remediation Technologies II** *(Room EF)*	**2B–Stormwater 2: Management Approaches** *(Room BC)*
SESSION 2	*Session Chair: Mark Freshley*	*Session Chair: Donna Buxton*
	Surfactant Enhanced Push-Pull Method for In-situ Remediation of Petroleum Contaminated Soil and Groundwater *George A. Ivey, Ivey International*	**Western Washington State's Approach to Stormwater for New and Redevelopment Sites** *Dan Gariepy, Washington State Department of Ecology*
	Use of Multiple Treatment Technologies for TCE Source and Dissolved Plume Remedy *Christine Kimmel, Landau Associates*	**Catch basin cleaning and street sweeping effectiveness in Ellensburg, Washington** **Aimee** *Navickis-Brasch, HDR, Inc.*
	Sequential In Situ Bioremediation of a Former TCE Vapor Degreaser Source Zone *Clint Jacob, Landau Associates*	**Eastern Washington Stormwater Effectiveness Studies** *Art Jenkins, City of Spokane Valley*
	Vapor Intrusion - State of the Practice and Lessons Learned *Jennifer Wynkoop, Landau Associates*	**Western Washington's Regional Stormwater Monitoring Program** *Brandi Lubliner, Washington Dept of Ecology*
2:40 PM	Refreshment Break | Exhibits | Posters	

SCHEDULE AT A GLANCE

Tuesday, May 9, 2017		
3:00 PM	**3A–Site Characterization** *(Room EF)*	**3B–Stormwater 3: Hydrologic Approaches** *(Room BC)*
SESSION 3	*Session Chair: Ken Nogeire*	*Session Chair: Gary Walvatne*
	ITRC Case Study: Hanford 200 Area *John Price, State of Washington, Dept of Ecology Nuclear Waste Program*	**Hydrogeologic Parameters Evaluated as Part of Bioretention Cell Hydrologic Performance Monitoring** *Jennifer H. Saltonstall, Associated Earth Sciences, Inc.*
	Strontium Isotopes as Tracers of Hydraulic Fracturing Water in the Environment *Richard W. Hurst, Hurst & Associates, Inc/California Lutheran University*	**Estimating Hydraulic Conductivity in Unsaturated Soils and Predicting Performance of Stormwater Infiltration Facilities** *J. Scott Kindred, Kindred Hydro, Inc.*
	Non-intrusive geophysical methods to detect the soil conditions within and beneath an engineered surface barrier *Fred Zhang, Pacific Northwest National Laboratory*	**Outfall Mapping** *Abby Barnes, Washington State Department of Natural Resources*
	Elements of complexity in subsurface modeling *Mark Freshley, Pacific Northwest National Laboratory*	**City of Redmond Paired Watershed Stormwater Retrofit Effectiveness Study** *John Lenth, Herrera Environmental Consultants*
4:20 PM	Refreshment Break | Exhibits | Posters	
4:30 PM	**4A–Nitrate Fate and Transport** *(Room EF)*	**4B–A Focus on the Future of Stormwater Management** *(Room BC)*
SESSION 4	*Session Chair: Ken Nogeire*	*Session Chair: Karen Dinicola*
	Nitrate Concentrations in Groundwater beneath Whatcom County Pasture Fields Receiving Manure Applications *Steve Cox, USGS*	**Panel Members:** ***Abby Barnes**, WA Dept of Natural Resources* ***Dana de Leon**, City of Tacoma* ***Dan Gariepy**, WA Dept of Ecology* ***John Lenth**, Herrera Inc* ***Jana Ratcliff**, WA Dept of Transportation*
	Isotope investigation into soil nitrate accumulations in the lower Yakima Valley, Washington, and nitrate in agricultural drains *Dallin Jenson, Central Washington University*	
5:10 PM - 7:00 PM	**Poster Session & Reception** *(Posters in AGD; Reception throughout Bicenenial Pavilion)*	
	Session Chair: Bob Mitchell	
	Potential Impacts of Groundwater Discharge to the Pelton Round Butte Hydroelectric Project Waterbodies *Catherine Yonkofski, PNNL*	
	Evaluation of Computational Approaches for Delineating Boundaries of Aquifer Exemptions *Catherine Yonkofski, PNNL*	
	Estimating Global Groundwater Resources *Catherine Yonkofski, PNNL*	
	Understanding the Whatcom County vs. Hirst, Futurewise, et al. decision *Noel Philip, Department of Ecology*	
	Developing Conditional Points of Compliance at MTCA Sites Where Ground Water Discharges to Surface Water *Mark Adams, Washington State Department of Ecology*	
	The Role of Directional Drilling in Slope Failure Mitigation *Michael Lubrecht, Directed Technologies Drilling, Inc.*	
	Uranium occurrence in groundwater in northeastern Washington State *Sue Kahle, USGS Washington Water Science Center*	
	Snohomish Arsenic *Mike Young, Snohomish Health District*	

Poster Session list continued on next page

SCHEDULE AT A GLANCE

Tuesday, May 9, 2017	
5:10 PM	**Poster Presentations *(continued)***
	Applying Geospatial Tools during Conceptual Site Model Development at the Former Boise Cascade Mill, Yakima *Matthew Durkee, WA Dept. of Ecology*
	King County Groundwater Program - Vashon-Maury Island Volunteer Data: Assessment and Update *Eric Ferguson, King County DNRP*
	Comparison of the Chemical and Isotopic Composition of Groundwater and Surface Water in the South Sound Region, Washington *Andrew Oberhelman, University of Puget Sound*
	Groundwater Recharge Estimates Using the Soil-Water Balance Model; Chambers-Clover Creek Watershed and vicinity, Pierce County, Washington *Wendy Welch, USGS*
	Estimated Public Water Supply Withdrawals in Washington, 2015 *Ron Lane, USGS Washington Water Science Center*
	Characterizing Ground-Water Flow Velocity and Preferential Flow Zones *Jerome Gogue, Regional Manager at Geotech Environmental Equipment, Inc.*
	Calibration of a Hydrologic and Stream Temperature Model to the Nooksack River Basin for Climate Change Modeling *Stephanie Truitt, Western Washington University*
	Hydrogeologic Framework and Numerical Simulation of Groundwater Flow in Bellevue, Washington *James Bush, University of Washington*
	Hydrograph Baseflow Separation with 15 Minute Data, R, and Patience *Nathaniel Kale, Thurston County*
	Examining the Potential Effects of Forecasted Climate Change on Sedimentation in the Nooksack River Basin *Kevin Knapp, Western Washington University*
	Glacial melt and groundwater storage in Washington: Are the possibilities endless? *Maria Gibson, Oregon State University*
	Rethinking the Hydrogeologic Conceptual Model of Island County, WA, in order to Evaluate Seawater Intrusion Vulnerability *Chelsea Jefferson, Amec Foster Wheeler*
	Integrated Model Calibration - A Framework for Linking Model Calibration, Parameter Uncertainty Analysis, and Model Application *Miao Zhang, Anchor QEA, LLC*
	Analysis and Comparison of Puget Sound Lake Sediment *Mitchell Dodo, University of Puget Sound*
	The Role of Catchment Soil and Geologic Properties in Governing Mountain Recharge and Streamflow Response to Climate Change *Tung Nguyen, Washington State University*
	Community scale landslide susceptibility mapping for Washington state counties *Victoria Nelson, Washington State Department of Natural Resources*
	Geochemistry and Origins of Thermal Spring Waters of the Olympic Peninsula and Cascade Range, Washington *Jon Golla, University of Puget Sound*
	Loss via shallow groundwater of nutrients and major ions from a semi-arid dryland agricultural catchment *Michael Shaljian, Washington State University*
	Controls on the distribution of ASARCO heavy metals in Tacoma-area lakes *Angelica Calderon, University of Puget Sound*
	The Importance of Conducting Groundwater Tidal Influence Studies at Sites near Tidally Affected Surface Water *Eron Dodak, Integral Consulting Inc.*
	Lidar-based Landslide Inventory in the Puget Lowlands, Pierce County, Washington *Kara Jacobacci, Washington Geological Survey*

SCHEDULE AT A GLANCE

Wednesday, May 10, 2017		
8:00 AM	Registration Desk Opens	
8:30 AM	**Morning Keynote Session** *(Room AGD)*	
	Keynote Talk: Conflict and Cooperation over Shared Waters ***Aaron Wolf,*** Professor, Geography, College of Earth, Ocean, and Atmospheric Sciences, Oregon State University	
9:30 AM	Refreshment Break | Exhibits | Posters	
9:50 AM	**5A–Water Resource Availability** *(Room EF)*	**5B–Water Rights and Drinking Water Management** *(Room BC)*
SESSION 5	*Session Chair: Danielle Squeochs*	*Session Chair: Sofia Petro*
	Groundwater Availability for Summer Low Flows – Preliminary Assessment for a Near-Term Action in the 2016 Action Agenda for Puget Sound *Rick Dinicola, US Geological Survey*	**Three recent State Supreme Court Decisions and their impacts on Washington's Water Rights Permitting Future and on Permit Exempt Wells** *Michael Gallagher, WA State Department of Ecology*
	Groundwater Modeling in Support of Water Rights Changes for River Flow Restoration, Upper Clark Fork River, Montana *Gary Andres, NewFields*	**California's Leap into Groundwater Management** *Carl Hauge, California consultant*
	Expanding Groundwater Capacity for City Of Juneau *Jim Bailey, Shannon & Wilson*	**Assessing Public Water Supply Vulnerability to Climate Change** *Ginny Stern, WA Dept of Health*
	Modeling Groundwater Water Availability in the Post-Hirst Era Using a MODFLOW Simulation over Most of Thurston County, Washington *Kevin Hansen, Thurston County, Water Resources Department*	**The Growth Management Act's Voluntary Stewardship Program and Critical Aquifer Recharge Areas** *Laurie Morgan, Washington State Dept. of Ecology Water Quality Program*
	Structural control of recharge to aquifers within the Columbia River Basalt Group *Dale Ralston, Ralston Hydrologic Services*	**Using standard water quality parameters as predictors of future well performance** *Jim Bailey, Shannon & Wilson*
11:30 AM	**Hosted Luncheon and Panel** *(Room AGD)*	
	PANEL **Hirst Decision: Growth Management Act requirement to protect water resources** ***Carrie Sessions****, Washington State Department of Ecology* ***Rob Lindsay****, Spokane County Environmental Services, Spokane County Water Resources* ***Michael J. Gallagher****, Southwest Regional Water Resources, Washington State Department of Ecology.* ***Kevin Hansen****, Thurston County Water Resources*	

Wednesday schedule continued on next page

SCHEDULE AT A GLANCE

Wednesday, May 10, 2017		
1:00 PM	**6A–Aquifer Storage and Recovery** *(Room EF)*	**6B–Geospatial Data for Determining Soil and Groundwater Flow** *(Room BC)*
SESSION 6	*Session Chair: Danielle Squeochs*	*Session Chair: Fred Zhang*
	City of Othello Aquifer Storage and Recovery Program: Addressing Municipal Water Supply Needs in the Columbia Plateau *Andrew Austreng, Aspect Consulting, LLC*	**Estimates of Tailings Facility Evaporation and Area Using Landsat Imagery** *Jason Keller, GeoSystems Analysis, Inc*.
	Advances in Groundwater Science and Practice: Developing Groundwater Replenishment or Recharge Systems *Bill Mann, In-Situ Inc.*	**Characterizing Groundwater to Surface Water Discharge Zones Using Unmanned Aerial Vehicles and Thermal Infrared** *Howard Young, CDM Smith*
	Evaluation of Aquifer Storage and Recovery: Columbia River Off-Channel Aquifer Storage Project *John Covert, WA State Dept of Ecology*	**Characterizing groundwater flow in complex glacial stratigraphy near Puget Sound** *Andy Long, USGS, Washington Water Science Center*
	Groundwater Storage Element Projects in the Yakima Basin Integrated Plan *Dave Nazy, Department of Ecology*	**Whatcom County Groundwater Data Collection and Conceptual Model Development** *Katherine Beeler, Associated Earth Sciences, Inc.*
2:20 PM	Refreshment Break | Exhibits | Posters Passport Contest Prize Drawing	
2:40 PM	**7A–Groundwater, Surface Water, and Atmospheric Interactions** *(Room EF)*	**7B–Climate Change Impacts** *(Room BC)*
SESSION 7	*Session Chair: Andy Long*	*Session Chair: Bryony Stasney*
	Linking Surface Water and Groundwater Models for Improved Watershed Analyses and Management *Jonathan Turk, Brown and Caldwell*	**Climate Change and the Anticipated Impacts on Pacific Northwest Groundwater Supplies** *Matt Bachmann, USGS*
	Groundwater - surface water interaction between the Spokane Valley / Rathdrum Prairie Aquifer and the Spokane River: an examination of recent assessments of nutrient and contaminant loading to the Spokane River *Rob Lindsay, LHG, Spokane County Environmental Services*	**Groundwater discharge temperature under altered climate conditions: New analytical solutions to estimate the magnitude and timing of changes in temperature of groundwater discharge** *Erick Burns, U.S. Geological Survey*
	Long-term Impact of Dam Operation on Thermal and Biogeochemical Dynamics in the Hyporheic Zone *Xuehang Song, Pacific Northwest National Laboratory*	**Historical Trends in Spokane River Seasonal Low Flows: The Relative Influences of Changes in Water Demands, Water Sources, and Watershed Hydrology** *John Porcello, GSI Water Solutions*
	Hydrograph-analysis method for episodic aquifer recharge extended to episodic increases of soil-water storage *John Nimmo, U.S. Geological Survey*	**Planning for the unknown; a numerical modeling approach to developing water management strategies for a changing climate** *Jacob Scherberg, GeoSystems Analysis*
	Quantifying Evaporation and Transpiration Rates using Stable Isotopes *Carey Gazis, Central Washington University*	**Fires, Floods and Dams – Wildfire Hydrology Lessons from the Benson Creek Incident** *Martin Walther, Washington State Department of Ecology*

SCHEDULE AT A GLANCE

Wednesday, May 10, 2017		
4:30 PM	**8A–Engineering Geology** *(Room EF)*	**8B–Climate Change Panel** *(Room BC)*
SESSION 8	*Session Chair: Andy Gendaszek*	*Session Chair: Xingtuan Chen*
	Using a Groundwater Model to Assist in the Design of Howard A. Hansen Dam Drainage Tunnel Rehabilitation *Li Ma, PhD, LHG, Shannon & Wilson, Inc*	**Panel Members:** ***David Judi***, *Pacific Northwest National Laboratory* ***Charles Pitz*** *(retired), WA Department of Ecology* ***Sasha Richey***, *Washington State University* ***Nathalie Voisin***, *Pacific Northwest National Laboratory*
	Managing Unstable Slopes in a High Precipitation Environment *Marc Fish, WSDOT*	
	Geophysical characterization and monitoring of earthen dams *Nigel Crook, hydroGEOPHYSICS, Inc.*	
5:30 PM	2017 Symposium Presentations Adjourn	

Thursday, May 11, 2017	
8:30 AM - 4:30 PM	**Workshop 1: Training for Water Rights Analysis – Certified Water Rights Examiners** Room: Venice 4, Hotel Murano
	Workshop Presenters: ***Danielle Squeochs, Scott Turner, Buck Smith, John Rose, Tyler Roberts***
8:30 AM - 4:30 PM	**Workshop 3: Unsaturated-Zone Water and Contaminant Transport: A Twenty-First Century Understanding** Room: Venice 3, Hotel Murano
	Workshop Presenter: ***John R. Nimmo***, U.S. Geological Survey, Menlo Park, CA

KEYNOTE SPEAKER

Tuesday, 9:15 AM

Ty Ferré, Ph.D.

Professor, Department of Hydrology and Water Resources, University of Arizona
2016 Darcy Distinguished Lecturer

"A Retrospective – Lessons Learned and Data, Models and Decision Making … Or, how to gain 20 pounds and not regret an ounce of it!"

Practicing hydrogeologists construct detailed numerical models to predict the responses of hydrologic systems to natural and applied stresses. These predictions form the basis for decisions that must balance optimal use of resources and ecosystem support. These decisions typically involve multiple interested parties with strongly differing priorities for water allocation. Despite the importance that stakeholders place on water resources, budgets for hydrogeologic studies are often limited. As a result, the hydrologic models used for decision support are severely data limited. This requires improved methods to identify the optimal set of observations to collect and to use model-predictions to support robust decision-making under considerable uncertainty. Dr. Ferré will build from the basic concepts of decision science to present concepts and recent developments in optimal design of hydrogeologic monitoring networks. He will also discuss how hydrogeologic models can be used for decision support under uncertainty. Finally, he will show that focusing hydrologic analysis on the specific, practical problems of interest can guide optimal measurement selection, advance hydrologic science, and improve the integration of science into economic and policy decisions. Approaches developed by leading researchers in the field will be presented, including work within Dr. Ferré's research group on the Discrimination-Inference for Reduced Expected Cost Technique—a framework for integrating multi-model analysis and decision science to improve the efficiency and effectiveness of hydrogeologic investigations. Dr. Ferré will offer two recommendations. First, most attempts to produce quantitative predictions with uncertainty are fruitless. Second, rather than avoiding biased, advocacy models, we should embrace them ... as part of a model ensemble that can lead to better decisions.

Dr. Ferré gave this talk 123 times as the 2016 Darcy Lecturer. He traveled to 26 countries on six continents. When not giving the talk, visiting school, or giving a related short course, he was eating. Photo evidence of his excess can be found on his Darcy Lecture blog (https://darcylecture2016.wordpress.com/) along with questions and answers, references, and other general information. Now that he has had the chance to lose most of the weight that he gained, he would do it again in a heartbeat

Ty Ferré received his bachelor's degree in geophysical engineering from the Colorado School of Mines and his Ph.D. in Earth sciences from the University of Waterloo.

Research Areas of Interest: Primary focus on improving the selection of measurements to support hydrologic decision-making which involves the development of methods that use decision science to formulate hydrologic models and then use those hydrologic models to select and interpret measurements. Research and teaching interests bridge measurement and analysis in hydrology. He and his students address the following general questions: How can we identify the most important measurements to collect? How can we extract the most information from our measurements? What do instruments really measure? Dr. Ferré is particularly interested in these questions as they relate to water flow in the vadose zone.

KEYNOTE SPEAKER

Wednesday, 8:30 AM

Aaron Wolf, Ph.D.

Professor, Geography, College of Earth, Ocean, and Atmospheric Sciences, Oregon State University

"Conflict and Cooperation over Shared Waters"

Water management is, by definition, conflict management: Whether in the Western US or internationally, competing stakeholder interests include domestic users, agriculturalists, hydropower generators, recreators, and environmentalists – any two of which are regularly at odds, and the complexity of finding mutually acceptable solutions increases exponentially as more stakeholders are involved. Add international boundaries, and the difficulty grows substantially yet again.

While press reports of shared waters often focus on conflict, what has been more encouraging is that, throughout the world, water also induces cooperation, even in particularly hostile basins, and even as disputes rage over other issues. This has been true from the Jordan (Arabs and Israelis) to the Indus (Indians and Pakistanis) to the Kura-Araks (Georgians, Armenians, and Azeris), as well as here in the US where collaborators span political and economic spectrums. This presentation will discuss conflict and cooperation over shared water resources internationally and in the US West, and reflect on processes of conflict transformation, including lessons from both Western and spiritual models of dialog.

Aaron Wolf has an M.S. in water resources management (1988, emphasizing hydrogeology) and a Ph.D. in environmental policy analysis (1992, emphasizing dispute resolution) from the University of Wisconsin, Madison. His research focuses on issues relating transboundary water resources to political conflict and cooperation, where his training combining environmental science with dispute resolution theory and practice have been particularly appropriate. Dr. Wolf has acted as consultant to the US Department of State, the US Agency for International Development, and the World Bank, and several governments on various aspects of international water resources and dispute resolution. He has been involved in developing the strategies for resolving water aspects of the Arab-Israeli conflict, including co-authoring a State Department reference text, and participating in both official and "track II" meetings between co-riparians.

Dr. Wolf, a trained mediator/facilitator, directs the Program in Water Conflict Management and Transformation, through which he has offered workshops, facilitations, and mediation in basins throughout the world. He developed and coordinates the Transboundary Freshwater Dispute Database, which includes a computer compilation of 400 water-related treaties, negotiating notes and background material on fourteen case-studies of conflict resolution, news files on cases of acute water-related conflict, and assessments of indigenous/traditional methods of water conflict resolution (www.transboundarywaters.orst.edu). He was also a member of UNESCO's task force for the development of the Sixth Phase of the International Hydrology Program (2002-2007), the UNESCO/ADC Third Millennium Program on International Waters, and IWRA's Committee for International Collaboration, and is a co-director of the Universities Partnership on Transboundary Waters.

Panel 4B: A Focus on the Future of Stormwater Management

Tuesday, May 9, 2017 | 4:30-5:10

Panel Moderator: Karen Dinicola

Managing stormwater in Washington is an evolving field. Not long ago, managing stormwater meant getting the water off the pavement and into the receiving waters as quickly and efficiently as possible. Our state now fully embraces a collective responsibility to manage stormwater differently to reduce its environmental impacts.

Much of the credit for our progress is owed to the local governments and Washington State Department of Transportation (WSDOT) who are required to implement broadly scoped stormwater management programs. The Clean Water Act National Pollutant Discharge Elimination System (NPDES) municipal stormwater permitting program and Underground Injection Control (UIC) rules have driven a lot of the positive changes over the past two decades. But those regulatory programs are largely reactive to land use changes.

What should stormwater management be like in the future? In the Puget Sound region alone, the current population of about 4 million is expected to double by 2070. Despite the progress Washington has made toward better stormwater management practices and understanding of the impacts, we still are not on track to handle the water quality and habitat problems that will likely follow the land development needed to accommodate those projected population increases.

The panelists will be asked to share their thoughts on the following questions:

What are the biggest differences among stormwater management approaches around the state?

- How do we balance the need to manage stormwater on site, across systems, and within watersheds?
- Where should we focus our efforts: retrofits to fix impacted areas, or protection of good-quality habitat?
- What scientific information are we missing to manage stormwater effectively?
- What changes or emphasis in regulatory approaches would make the biggest impact?
- What kind of education should stormwater managers of the future be getting?

Panelists will underscore the successes and lessons learned in stormwater management over the past two decades and frame the challenges that remain. As time allows, the audience will have a chance to ask more questions about continuing to improve stormwater management.

Panel Members

Abby Barnes, WA Dept of Natural Resources: Abby Barnes has worked for the Washington State Department of Natural Resources Aquatic Lands Division since 2013 and oversees the Aquatics Sediment Quality Unit and Outfall Program. Abby has been actively involved in Washington State stormwater management issues for the last 10 years, particularly in both industrial and municipal NPDES permits. Abby is Vice Chair of the Puget Sound Ecosystem Monitoring Program (PSEMP) Stormwater Work Group.

Dana de Leon, City of Tacoma: Dana de Leon is a Professional Engineer at the City of Tacoma, Environmental Services, Science and Engineering. Dana has 28 years of experience in stormwater studies related to NPDES regulatory issues, source evaluations, treatment technologies, cleanup, capital improvement projects, and tracking publically-owned stormwater treatment facilities. Dana chairs the PSEMP Stormwater Work Group and is a member of the Stormwater Strategic Initiative Technical Team.

Dan Gariepy, WA Dept of Ecology: Dan Gariepy is a Professional Engineer in the Municipal Stormwater Unit of the Water Quality Program at the Washington State Department of Ecology, where he has worked since 2011. Dan has been in environmental and stormwater engineering for more than 20 years and previously worked as a consultant to NPDES permitted municipalities. Dan now leads the Stormwater Technical Team that oversees updates to the Stormwater Management Manuals for Eastern and Western Washington.

(panel members continued)

John Lenth, Herrera Inc: John Lenth has over 20 years of experience in water resource science, management, and planning. As the Water Practice Director for Herrera, John has designed and implemented numerous studies to characterize stormwater pollutant concentrations from various land uses and the effectiveness of related control measures including low impact development. John holds a B.A. in English from Seattle University and a M.S. in Environmental Science from Western Washington University.

Jana Ratcliff, WA Dept of Transportation: Jana Ratcliff is the NPDES Municipal Stormwater Permit Coordinator for WSDOT. Jana has worked for WSDOT since 2004, previously as the Statewide Erosion Control Coordinator and Total Maximum Daily Load (TMDL) Lead. Jana is a graduate of the Evergreen State College and has a bachelor's degree in environmental studies.

Wednesday Lunch Panel: Hirst Decision–Growth Management Act requirement to protect water resources

Wednesday, May 10, 2017 | 12:00-1:00 PM

In October 2016, the Washington State Supreme Court issued a decision in the Case of Whatcom County vs. Hirst, Futurewise, et al. The court ruled that the county had failed to comply with Growth Management Act requirements to protect water resources. The ruling requires counties to make an independent decision about legal water availability when making land use decisions.

This panel brings together experts who have been actively engaged and impacted by the Hirst Decision. Representatives from the Department of Ecology will summarize the implications of the Hirst Decision and the proposed legislative fixes. Representatives from Thurston and Spokane Counties will discuss physical groundwater availability in their respective counties.

Carrie Sessions, Policy and Legislative Coordinator, Washington State Department of Ecology (Ecology): Carrie joined Ecology in November 2015 and works as the Policy and Legislative lead for the Water Resources Program. Prior to working at Ecology, Carrie was a consultant on environmental economics and spent several years teaching applied leadership. She is a graduate of Colorado College and holds a MPA and MS from the University of Washington in environmental policy and economics, with an emphasis in water resource management.

Rob Lindsay, Water Programs Manager, Spokane County Environmental Services, Spokane County Water Resources: Rob Lindsay is the Water Programs Manager for Spokane County Environmental Services. He is a registered hydrogeologist in the State of Washington, and has a B.S. degree in Environmental Geology from Western Washington University. Rob's responsibilities include oversight of Spokane County's Water Resource planning activities, the Regional Water Reclamation Facility and the Water Resource Education Center. Prior to serving Spokane County, Rob spent over 20 years as an environmental engineering consultant.

Michael J. Gallagher, Section Manager, Southwest Regional Water Resources, Washington State Department of Ecology: Mike has been with Ecology for over 32 years. For the past nine 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 six years as the section manager for the SWRO Water Resources Section. Mike holds a BS in Geology from the University of Puget Sound, a MS in Geology from Western Michigan University, and a Masters in Public Administration from The Evergreen State College.

Kevin Hansen, County Hydrogeologist, Thurston County Water Resources: Kevin Hansen is County Hydrogeologist for Thurston County, Washington. He has 35 years' experience with hydrogeology, groundwater modeling, environmental remediation and water resource evaluations at hundreds of sites in the U.S., Taiwan, and Mexico. He holds a Master's Degree, multiple professional certificates, and one U.S. Patent. Mr. Hansen is licensed as a Hydrogeologist in Washington, and as a geologist in Pennsylvania and Delaware.

Panel 8B: Climate Change

Wednesday, May 10, 2017 | 4:30-5:30

Panel Moderator: Xingtuan Chen

This panel discussion will focus on the interactions between climate and surface and groundwater, as well as regional implications to the Pacific Northwest. Panelists will have open discussions on the emerging research and management needs in assessing and mitigating the impacts of climate change on water resources given the known uncertainty in long-term climate projections. Important debates about climate change require understanding the costs of mitigating and adapting to these changes, relative to the costs of not mitigating and adapting to the important changes expected to impact water resources at both local and regional scales.

List of questions:

1. What are the projected impacts of climate change to groundwater resources in Washington State in the coming decades or longer?
2. How shall our state prepare for, and adapt to, the climate-related changes predicted for groundwater? Is groundwater a sustainable source for mitigating drought, particularly for supplying water for irrigation?
3. What is the predicted climate impacts on infrastructure resiliency?
4. How much can we believe in climate model projections?

Dr. David Judi has been a senior research engineer at Pacific Northwest National Laboratory since January, 2015. His research focus at PNNL has been research and development of modeling and simulation tools to evaluate impacts from non-stationary extreme events, including natural (e.g., weather) and manmade (e.g., cyber) events. Prior to joining PNNL he was a technical staff member in the Energy and Infrastructure Analysis group at Los Alamos National Laboratory, starting in 2006. During this time, he developed capabilities for the National Infrastructure Simulation and Analysis Center (NISAC) in two primary areas: (1) high resolution modeling and simulation of coastal and fluvial flood hazards; and (2) modeling and simulation tools to quantify urban water and wastewater system resilience. These capabilities use high-performance computing techniques to alleviate big data challenges and meet event-based time constraints. These tools have been and continue to be used to support infrastructure resilience studies across multiple DHS programs. Dr. Judi completed a Ph.D. in Civil and Environmental Engineering at the University of Utah in 2009.

Charles Pitz recently retired from the Washington State Department of Ecology, where he was the lead groundwater hydrologist for the Environmental Assessment Program. The final year of Charles's career was focused largely on developing an improved understanding of the potential impacts of climate change on the groundwater resources of Washington State (a summary of this work was published in March 2016). Over the course of the past 38 years, Charles has worked in technical positions in industry, academia, private consulting, and government. Charles earned a Master's Degree from Washington State University in 1985, and is a licensed hydrogeologist.

Dr. Sasha Richey is an Assistant Research Professor at Washington State University. Her research focuses on integrating diverse datasets to assess large-scale hydrologic systems. Dr. Richey received her Ph.D. in Civil Engineering from the University of California, Irvine in 2014, where she used satellite remote sensing to quantify groundwater stress in the world's largest aquifer systems. Her overarching research goal is to understand where, how, and to what extent different sectors are using water and how the volumes of use compare to available supplies, with an emphasis on groundwater systems. She enjoys working at the interface of research and water resources management and has contributed to multiple "science diplomacy" efforts in the United States and internationally to advance the role of scientific research in decision making. Currently, Dr. Richey's research combines satellite and in situ observations of hydrologic systems into modeling and decision support frameworks over large regional scales, including in the Columbia Plateau Aquifer in the Pacific Northwest (USA) and in Central Asia.

Dr. Nathalie Voisin is a research engineer at the Pacific Northwest National Laboratory. Nathalie's expertise is hydro-meteorology modeling, in particular the implementation of water resources management into integrated climate change impact assessments and coupling with Earth Systems, socio-economic, land surface hydrology, estuary and electric grid models. Lately, she successfully led an interdisciplinary project focusing on transferring extreme climate events (droughts, heat waves) representation into an electricity grid model, and demonstrating the operational intricacies between water and grid managements. Dr. Voisin holds a B.S. in Civil Engineering, an M.Sc. in Atmospheric Sciences and a Ph.D. in Civil and Environmental Engineering.

Oral Abstracts

Poster Abstracts

Dissolved Heavy Metals in Groundwater: In-Situ Stabilization and Capture Technologies Utilizing Granular Reagent

Derek Pizarro, Premier Magnesia, LLC
Drew Baird, FRx, Inc.

Background/Objectives. Dissolved metals in groundwater remain a challenging remediation problem. Most remedial solutions focus on extractive options due to a paucity of proven in-situ technologies, which is partly a consequence of the geochemical complexities of in-situ stabilization. A few proven, commercially available products provide effective stabilization through complexation, adsorption, co-precipitation, and alkaline buffering of metal species. These products have been comprehensively evaluated in bench-scale testing and are highly proven in remedial construction. However, the form of these materials – typically granular or milled solids with low to moderate solubility and high densities – dictate they are normally used for stabilization of metals in soil or sediments, where mechanical blending methods are utilized to achieve distribution and homogenization.

Outside of engineered reactive barriers, these solid products are not commonly used for in-situ groundwater treatment of large dissolved plumes. Traditional injection techniques have generally resulted in poor subsurface distribution of these granular solids, even in groundwater zones with high permeability.

Approach. We present an effective method for delivering a granular, calcined magnesia solid for full-scale treatment of dissolved metals in groundwater while presenting the advance of this chemical technology from customary soil blending and injection, to contemporary reactive barriers, and emergent injection emplacement. Each evolution will illustrate important remedial constructions considerations – safe handling, efficient mixing or injection, and penetrative or mechanical distribution in the target treatment zone. These field programs depict a less intensive, less intrusive, and less expensive remedy in the place of long term capture or extensive site construction. Submitted as examples, these projects were a former fertilizer-manufacturing site with a dissolved lead and arsenic plume, an active production multi-fuel power plant with dissolved nickel reaching permitted discharge ponds, and a former agricultural chemicals facility with a dissolved lead plume.

Activities. Demonstrating this method as a progressive step in groundwater treatment of dissolved metals, especially for deeper overburden zones, the focus will be on the final case study – a 15-acre plume of dissolved lead with concentrations up to 350 mg/L in a low-pH aquifer with very slow seepage velocity. Product dosage was precisely determined in bench-scale laboratory testing, but the initial pilot scale utilizing traditional injection methods proved unsuccessful at delivering the required dose to the target zone. An alternate approach was selected and successfully piloted to deliver the required dosage, and the full-scale injection project involved conveyance of approximately 525,000 lbs of granular magnesia via 70 direct-push borings and 419 discrete injection intervals.

Maintaining a Problematic Groundwater Extraction System in Interior Alaska

Chris Allen, Shannon & Wilson, Inc.

An industrial facility in Alaska operates a 10 well, approximately 0.5 MGD groundwater extraction system to maintain hydraulic capture of an onsite contaminant plume. Each extraction well has a required minimum pumping rate, in order to achieve hydraulic capture, that was derived from numerical groundwater modeling. However, maintaining these target rates has been difficult due to declining well efficiency, notably from well screen clogging from formation of biological based encrustations, and pore space plugging from sediment migration. These clogging conditions typically result in declining well performance after as little as one month of operation.

Over the past five plus years, twice-yearly maintenance efforts have employed a variety of both traditional and innovative methods to determine the most effective ways to improve well performance while extending the operational time between rehabilitation events. These methods have included the use of mechanical, chemical and induced resonance technologies. More recently, an ongoing preventative clogging program of bi-weekly rehabilitation is being tested on four wells. This approach does not require any alteration or removal of well equipment and is accomplished in conjunction with routine site monitoring activities. In general, the preventative approach seeks to continuously disrupt the formation of biofouling material and enhance the removal of fines that are plugging the filter pack pore spaces.

The preventive maintenance efforts were started in February of 2016 and the efforts have has resulted in:

- A significant decrease or cessation in the decline of well performance;
- Reduction in the frequency of full well rehabilitation events;
- An estimated annual savings of more than $100,000 in maintenance/rehabilitation costs

This preventative approach is one that could be applied at many remediation sites with groundwater extraction systems that are struggling with well performance issues.

Evaluation Of The Mechanisms Of Arsenic Sequestration In In-Situ Groundwater Treatment Systems Implementing Induced Sulfate Reduction Via Permeable Reactive Barriers With And Without Utilization Of Zero-Valent Iron

Lara Pracht, University of Washington
Brett Beaulieu, Floyd Snider
Benjamin Kocar, MIT
Rebecca Neumann, University of Washington

Throughout Washington State, and worldwide, arsenic contamination of groundwater supplies threatens both human health and the environment. Given the prevalence and negative consequences of arsenic-contaminated groundwater, it is important to develop robust arsenic remediation strategies. In-situ arsenic removal from groundwater by induced microbial sulfate reduction, either with or without the addition of zero-valent iron (ZVI), is a promising remediation strategy. It works by injecting the appropriate microbial substrates into the subsurface as a permeable reactive barrier, creating biogeochemical conditions that favor the formation of minerals that incorporate arsenic during precipitation or create surfaces upon which arsenic adsorbs. Laboratory studies have demonstrated the effectiveness of this technique, but field-scale studies are limited. Furthermore, the exact mechanisms of arsenic immobilization have not been explicitly demonstrated, leaving uncertainty as to the long-term stability of arsenic sequestration in the remediation treatment.

Here we present the results of field and laboratory investigations of two different large-scale applications of this remediation strategy in a wetland area near Tacoma, WA, that contains elevated levels of arsenic and iron from a nearby slag-containing landfill. One treatment injection used ZVI while the other did not. The treatment with ZVI successfully removed arsenic from groundwater while the treatment without ZVI actually increased groundwater arsenic concentrations. X-ray absorption (µXAS) analyses conducted on sediment collected from the two treatment areas showed that the presence of ZVI facilitated the development of iron minerals (Fe(III) and mixed valence minerals) that sequestered arsenic, which was speciated as arsenate (As(V)). Sequential extractions performed on the sediment indicated a large portion of this sequestered arsenic was sorbed rather than co-precipitated. The same sediment analyses indicated that in the treatment without ZVI, conditions were more reducing; arsenic was predominately speciated as arsenite (As(II)) and was sequestered by co-precipitation in sulfide minerals.

Collectively, results suggest that the As-S stabilization mechanisms responsible for arsenic removal in the treatment without ZVI were not as effective as the As-F or As-Fe-S mechanisms responsible for arsenic removal in the treatment with ZVI. However, it remains unclear how stable the As-F and As-Fe-S associations are and if arsenic could be re-mobilized with changes in groundwater chemistry.

Ex Situ Treatments of Aqueous Film-Forming Foam Impacted Water

Gary Birk, Tersus Environmental
David Alden, Tersus Environmental

Background/Objectives. Per- and Polyfluoroalkyl Substances (PFASs) are surfactants and polymers that are widely distributed across the higher trophic levels and are found in air, soil and groundwater at sites across the U.S. Surfactant applications used heavily in the military include aqueous film–forming foams (AFFFs) used to extinguish fires involving highly flammable liquids. The toxicity, mobility and bioaccumulation potential of PFASs pose potential adverse effects for the environment and human health.

PFASs are fluorinated organic compounds in which the hydrogen atoms of the hydrocarbon skeleton are substituted fully by fluorine atoms. For this reason, they among the strongest organic compounds and thus considered non-degradable because they persist for a long time in the environment.

Practitioners have difficulty remediating these compounds at a reasonable cost because PFASs tend to be highly soluble, do not favorably partition into the vapor phase, and do not adsorb well to granular activated carbon (GAC). To date, adsorption on activated carbon was the only technically feasible method to treat PFAS-contaminated water. The presentation will provide updates on a novel treatment train approach to address ex situ treatment of AFFF impacted water.

Approach/Activities. In the pretreatment phase, PFASs are precipitated by metering the liquid surface active compound into a stirring tank. The amount of reagent can be adjusted to varying concentrations. The precipitation products are separated from the water as micro-flocks by simple processes such as sedimentation and filtration. The precipitants can be concentrated to a very high degree, which allows for very economical disposal as compared to GAC. Posttreatment of the remaining residual contaminants is performed by a downstream activated carbon and activated carbon / aluminum hydroxide / Kaolin filter. Due to the significant reduction in the PFAS-contaminated water in the initial precipitation stage (up to 90%), the PFAS contaminant load reaching the absorbent filter(s) is lowered, which leads to a significant extension of the adsorber's lifetime, again significantly lowering operating costs.

The presentation will also provide results of the effectiveness of an activated carbon / aluminum hydroxide / Kaolin mixture to treat PFASs. Studies have concluded that the adsorption capacity of the mixture for the smaller chain fluorinated substances PFBA and PFBS is vastly superior to that of GAC. This is likely due to the presence of the noncarbon components within the mixture creating unique physical chemical interactions with the smaller chain PFAS compounds.

The regulatory framework for addressing stormwater problems in Washington: what's covered,what's missing?

Karen Dinicola, Washington Dept of Ecology

Stormwater runoff in Washington is mostly regulated by local jurisdictions. The state also has a role in issuing stormwater permits that require preventive practices for construction sites and specific types of industries, and also for storm sewer system management. Most storm runoff in urban areas goes along curbs and into catch basins. From there it might go to a ditch or a stream, to Puget Sound, or to ground water. It might or might not pass through a treatment control facility. All of this depends on the setting: the hydrogeology, the climate, the age of the infrastructure, the location of the site and the discharge, and the type of requirements in place.

Stormwater is an expression of how we use the land. Our area's population is projected to double by about 2070, and that will put even more pressure on our capacity to protect receiving water bodies. As a region we are doing a much better job of managing stormwater than we were doing 20 years ago, and we continue to learn how to do it better. We are also getting better at prioritizing, and spending limited resources wisely and effectively. But there are parts of the problem that cannot (and should not) be addressed by our current regulatory framework.

This talk will walk through key regulatory tools and explain their intended uses as well as the gaps in their application. It is meant as a way to set context for the process of gathering information to improve our understanding of the stormwater problem and the best ways to address it.

Characterization of Western Washington Stormwater in Large Urban Areas: 2009-2013

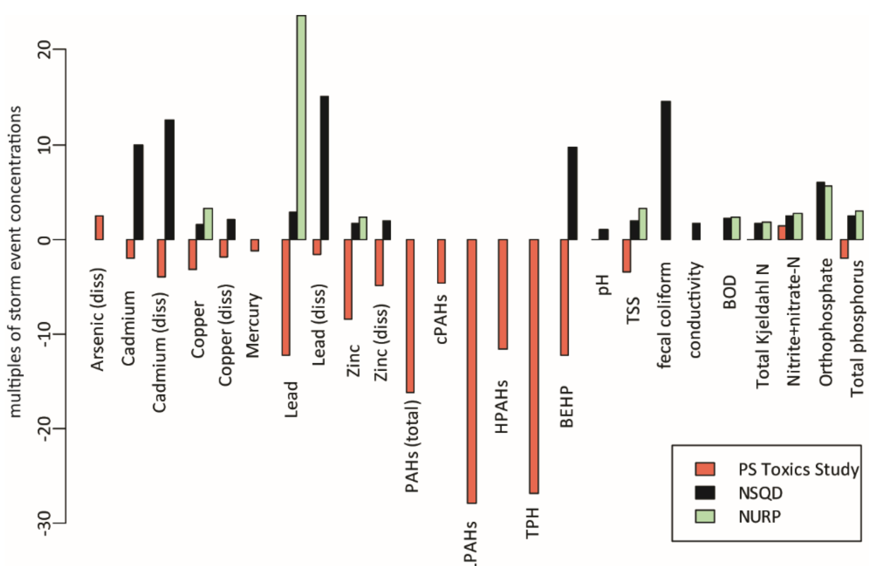
William Hobbs, Brandi Lubliner, Nathaniel Kale, Evan Newell, WA State Department of Ecology

Stormwater and storm sediment discharge data were collected by NPDES Phase I Municipal Stormwater permittees, under Special Condition S8.D, between 2007 and 2013. This study is a summary of the data. The Phase 1 permittees, all located in western Washington, collected highly representative storm-event data under a prescribed monitoring program that represented multiple land uses, storm characteristics, and seasons. The main goals of the study were to (1) compile and summarize the permittees' data using appropriate statistical techniques and (2) provide a western Washington regional baseline characterization of stormwater quality.

These findings are based on the analysis of 44,800 data records representing 597 storm events. Up to 85 parameters were analyzed in stormwater samples, and 67 parameters were analyzed in stormwater sediments. Metals, hydrocarbons, phthalates, total nitrogen and phosphorus, pentachlorophenol, and PCBs were detected more frequently and at higher concentrations from commercial and industrial areas than from residential areas. Residential areas exported stormwater with the highest dissolved nutrient concentrations.

For context, data were compared to previous stormwater studies and the Washington State water quality criteria. Stormwater pollutant concentrations were lower than those reported by EPA in the mid-1980s, but higher than stream and river concentrations draining to Puget Sound during storms (see Figure). Across all land uses, copper, zinc, and lead were found to not meet water quality criteria for the protection of aquatic life in 58%, 40%, and 28% of the samples, respectively. Mercury and total PCBs exceeded criteria in 17% and 41% of the samples, respectively. For most parameters measured in both stormwater and stormwater sediments, concentrations in stormwater sediments paralleled the trends found in water samples across all four land uses.

The statistical analyses used in this study have produced reliable statistical summaries and allowed for robust comparisons of the impacts of land use and seasons on contaminant concentrations and mass loads. The statistical summaries form a baseline for contaminant concentrations in stormwater that will allow for future comparisons.



Summary of S8.D median stormwater concentrations relative to median concentrations reported in other studies. The Y-axis displays the ratio (multiples) of the median concentrations reported elsewhere to the median concentrations in the S8.D study. Bars show the magnitude of difference as less than (negative) or more than (positive) the S8.D results. Many parameters were not measured in the previous studies. PS Toxics Study = Control of Toxic Chemicals in Puget Sound: Phase 3 Data and Load Estimates (Herrera, 2011); NSQD = National Stormwater Quality Database (Maestre and Pitt., 2005); NURP = Nationwide Urban Runoff Program (EPA, 1983). Note: PS Toxics Study sampled receiving waters and not stormwater directly.

Ten Years of Clean Water. The Effects of Stormwater Source Controls on Sediment Quality in Thea Foss Waterway, Tacoma, Washington

Dana de Leon, City of Tacoma
Mary Henley, City of Tacoma
Todd Thornburg, Anchor QEA

Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also referred to as Superfund, contaminated bottom sediments were remediated in the Thea Foss and Wheeler-Osgood Waterways in Tacoma, Washington under the oversight of the Environmental Protection Agency (EPA) at a cost of $105M. Sources of Contaminants of Concern (COCs) continue to exist in the drainage basins and are conveyed to the waterways via stormwater (municipal and private), aerial deposition, marinas, and groundwater discharges.

Since stormwater is one of the potential sources, the City of Tacoma is implementing a stormwater source control program (started in 2001) to protect the quality of waterway sediments and the integrity of the cleanup. The program is supported by post-construction sediment quality monitoring; stormwater, base flow, and storm sediment monitoring; and a validated contaminant transport model of the waterway (EPA WASP model). Contaminants of concern in waterway sediments include polycyclic aromatic hydrocarbons (PAHs) and bis(2-ethylhexyl)phthalate (DEHP). These contaminants are associated with various ongoing sources including municipal stormwater, marinas, atmospheric deposition, and groundwater discharges, many of which are common or ubiquitous in modern urban environments. The WASP model predictions in Thea Foss Waterway show excellent agreement with seven years of observed post-construction sediment quality data, validating the ability of the model to link pollutant loads to sediment concentrations, and predict the effects of source control actions on waterway sediment quality.

Our multi-pronged stormwater source control program consists of best management practices, business inspections, public education, source tracing investigations, and stormwater treatment. Over the 14 year period (August 2001-September 2015), these efforts have resulted in statistically significant reductions in suspended sediments, lead, zinc, PAHs, and DEHP, in spite of the inherently high variability of stormwater data. In recent years, the City performed basin-wide street sweeping and system-wide storm sewer cleaning in selected drainages to remove residual contaminated sediments that may continue to degrade stormwater quality. Street sweeping and system-wide sewer cleaning resulted in statistically significant reductions in PAHs and metals.

Finally, the City developed a GIS-based pollutant loading model of its urban drainages (HSPF model) to evaluate the cost-effectiveness of various treatment technologies and management practices for reducing pollutant loads in stormwater; including in-line treatment vaults, street sweeping, and low-impact development (LID). The model results identify areas and land uses that contribute disproportionately to stormwater pollution, where source control efforts are best focused, and recommendations for cost-effective source control investments.

The Stormwater Action Monitoring Program's Mussel Monitoring Project: Using Transplanted Mussels to Assess Contaminants in the Puget Sound's Nearshore Habitats

Jennifer Lanksbury, Washington Department of Fish and Wildlife (WDFW)
Laurie Niewolny, WDFW
Andrea Carey, WDFW
Mariko Langness, WDFW
Sandra O'Neill, WDFW
James West, WDFW

Stormwater runoff is a significant source of toxic chemicals into the Puget Sound. Although chemical contaminants in Puget Sound sediments and some organisms are monitored on a regular basis, the geographic distribution and magnitude of contaminants in biota living in nearshore habitats are not well known. In the winter of 2015/16 the Washington Department of Fish and Wildlife (WDFW) conducted a Puget Sound-wide assessment of toxic contaminants in blue mussels. Mussels were transplanted from a clean aquaculture source to 40 randomly assigned sites in urban growth areas of the greater Puget Sound, where they served as natural sampling devices, tracking chemical contamination over a three month period.

Long-term, biennial monitoring of nearshore mussels (and sediments) make up the "Status and Trends in Receiving Waters" element of the new Regional Stormwater Monitoring Program now called Stormwater Action Monitoring (SAM). SAM's broader role is using the results of monitoring and studies to inform policy decisions and identify the most effective management actions. The goals of this SAM project are to evaluate the degree to which nearshore habitats in the Puget Sound are exposed to pollutants from stormwater and other sources, to identify patterns in healthy and impaired Puget Sound urban shoreline areas, and to measure whether conditions are improving over time.

Mussel monitoring, combined with recent data on contaminants in juvenile Chinook salmon from Puget Sound river deltas, is helping to elucidate potential sources of contaminants to the nearshore. This presentation will provide an overview of how the SAM mussel monitoring project is measuring contaminant inputs into the Puget Sound; we will summarize results to date for several major classes of contaminants related to stormwater input and discuss how ongoing monitoring will inform future efforts to manage the stormwater problem in Washington State.

Surfactant Enhanced Push-Pull Method for In-situ Remediation of Petroleum Contaminated Soil and Groundwater

George A. Ivey, B.Sc., CES, CESA, P.Chem, EP, Ivey International

This study evaluates in-situ 'Push-Pull' method for surfactant enhanced remediation of petroleum hydrocarbon contaminated soil and groundwater at the Chester River Hospital Center (CRHC), Chestertown, Maryland. This site has been contaminated for over 20 years as a result of an on-site diesel spill from an underground storage tank.

The historical application of a conventional pump and treatment remediation approach at the site slowly recovered greater than 80% of the original spill mass over a 19 year period. However, the residual contamination currently presents a significant risk of impacting the nearby Chestertown municipal groundwater aquifer. Local stakeholder, legal and regulatory pressure required the site owner to evaluate innovative and cost-effective methods to enhance and expedite the site remediation to mitigate this risk in a sustainable manner.

A pilot-scale application was completed in 2014 at four impacted wells near the source zone using the 'push-pull' surfactant enhanced remediation process to target the contaminant smear zone within a silty medium to fine sand layer. A total of three 'push-pull' events were completed over a two week period, with on-going groundwater quality monitoring, and real-time field test measurements associated with each event, to evaluate the efficacy of this novel method for full-scale remediation.

The pilot-scale test results indicated that the in-situ 'push-pull' surfactant enhanced remediation method was very effective for the dissolution and recovery of sorbed petroleum hydrocarbon contaminant mass in the saturated and unsaturated smear zone. The calculated increase in contaminant mass recovery rates ranged between one thousand percent (1,000%) to over eighteen thousand percent (18,000%) compared to baseline levels at the subject wells associated with the existing pump and treatment remediation system.

The success of this pilot-scale 'push-pull' method received Maryland Department of the Environment (MDE) regulatory approval for proceeding to full scale application.

Use of Multiple Treatment Technologies for TCE Source and Dissolved Plume Remedy

Christine Kimmel, Landau Associates
Clint Jacob, Landau Associates

Remediation of source areas and an associated dissolved phase groundwater plume is being conducted at a large industrial manufacturing facility near Portland, Oregon. Groundwater contamination is primarily trichloroethene (TCE) with biodegradation breakdown products, cis-1,2-dichloroethene (cDCE), and vinyl chloride (VC). The treatment train consists of multiple components:

- A groundwater pump and treat system has been operated for over 25 years to contain and treat the site-wide dissolved phase plume.
- Phased source area investigations identified two separate, primary source areas through soil, groundwater, and soil vapor sampling.
- In situ anaerobic bioremediation has been used to treat the two aquifer source areas. Bioremediation was successfully applied to these areas using semi-active injection, passive injection, and injected permeable reactive barrier (PRB) approaches. Seven injection events totaling approximately 375,000 gallons of electron injection fluid have been performed beginning in 2008.
- Source zone soil vapor extraction is performed to mitigate accumulation of TCE vapor beneath the building slab. The SVE system has operated since 2012.
- Multiple purpose wells were installed in the source that allow for SVE operation, groundwater quality monitoring, and in-situ bioremediation injection using a single well.

This combined treatment train has mitigated exposure to contaminated groundwater and soil vapors through groundwater pump and treat and SVE, while reducing the overall remedial time frame through source zone bioremediation. Challenges have included difficult geology and biofouling of a groundwater extraction well near the bioremediation areas. Source bioremediation has resulted in substantial groundwater concentration reduction that precluded the need for a sub-grade vapor barrier beneath a constructed extension of the building, allowed shutdown of two extraction wells, and is expected to shorten the required period of pump and treat system operation.

Sequential In Situ Bioremediation of a Former TCE Vapor Degreaser Source Zone

Clint Jacob, Landau Associates
Christine Kimmel, Landau Associates

Source zone aquifer bioremediation is underway at a large industrial manufacturing facility near Portland, Oregon. The trichloroethene (TCE) source is beneath an active manufacturing building and within a larger dissolved phase plume. The plume is hydraulically contained by a 22-well groundwater extraction and treatment (GET) system operated since 1989. The bioremediation objective is source depletion to reduce the required period of operation for the GET system and for a soil vapor extraction (SVE) system preventing potential migration of soil vapors to indoor air.

The facility is above a complex, multi-aquifer groundwater system, used seasonally by the City of Portland as municipal water supply. The source zone (approximately 100 x 100 ft) is within an unconfined aquifer extending from the water table at 40 ft to a sloping aquitard at 65 to 85 ft. The results of depth-discrete groundwater sampling showed the highest TCE concentrations at the bottom of the aquifer, a contaminant profile that is consistent with historic release of dense non-aqueous phase liquid (DNAPL) and slow back diffusion of mass from the aquitard.

A sequential approach to bioremediation of source zone mass began in 2011. Bioremediation was stimulated through injection of electron donor substrates or “food” for native bacteria. Clear water injection testing and groundwater monitoring identified a preferential flow path with high contaminant flux at the downgradient edge of the source zone. An emulsion of water, lactate, and vegetable oil was injected to a well within this flow path, creating a permeable reactive barrier (PRB) for treatment of contaminant flux. Seven multipurpose wells designed for concurrent SVE, bioremediation injection, and groundwater monitoring were installed in the source. To minimize disruption of site activities, a dedicated mixing and injection station was installed with below grade injection lines to the 7 source wells. Periodic injections to the PRB well and source wells stimulated and sustain treatment. Based on monitoring results, the injection volumes and substrate concentrations were modified to optimize treatment effectiveness and longevity. Over the course of 5 injection events, 155,000 gallons of donor solution was injected to the wells. Electron donor solution was modified to utilize crude glycerin (a byproduct of bio-diesel production) and ferrous sulfate. Byproduct glycerin was a green and sustainable modification resulting in cost savings. Ferrous sulfate stimulated a complementary abiotic degradation pathway (beta-elimination).

Vapor Intrusion - State of the Practice and Lessons Learned

Jennifer Wynkoop, Landau Associates
Marv Coleman, Washington State Department of Ecology

Evaluation of vapor intrusion isn't new; however, it has been receiving additional attention in Washington since the Washington State Department of Ecology released their draft guidance in 2009. ASTM added language to the Phase I ESA Standard (ASTM E 1527-13) in 2013 to specifically address soil vapor and vapor migration risk during the property transaction due diligence process. EPA released comprehensive guidance on vapor intrusion in 2015 that further brought the issue to the forefront. EPA and Ecology have also issued recent guidance on short-term vapor exposure risk, specifically for TCE. With updates in state and federal guidance, we have seen increased emphasis placed on evaluation of the vapor intrusion pathway by the regulatory community at cleanup sites and increased attention from prospective purchasers at sites undergoing due diligence for property transactions. Increased emphasis has been placed on use of groundwater data for vapor intrusion screening purposes and collection of soil vapor and indoor air data rather than modeling alone to verify potential risks.

Evaluation of the vapor intrusion pathway is often more nuanced than soil or water testing and the state of the practice has evolved rapidly over the last ten years. The presentation will explore:

- The state of the practice in Washington and how paradigms from other guidance documents are being incorporated
- Adaptation of the tiered investigation approach to site specific conditions and needs
- Use of multiple lines of evidence when data is ambiguous, and
- Common pitfalls and lessons learned

Western Washington State's Approach to Stormwater for New and Redevelopment Sites

Dan Gariepy, Washington State Department of Ecology

The Washington State Department of Ecology is a leader in the development of criteria for management of stormwater in the municipal environment. Ecology implements many tools that will help improve hydrogeologic conditions in areas impacted by site development. Under Ecology's Municipal NPDES Permits for Western Washington, new and redeveloped sites need to incorporate infiltration wherever feasible. Ecology further ensures that infiltration occurs in a safe and sustainable manner by implementing source controls to prevent the mobilization of contaminants through to groundwater. In the permits issued in 2012, infiltration became more important with the implementation of Low Impact Development (LID). As part of the drive for attainment of Low Impact Development objectives, Ecology required municipalities to remove barriers and use Low Impact Development as the preferred and commonly used approach.

This talk will focus on Ecology's required management of stormwater at the site level for the protection of surface and groundwater resources.

Catch basin cleaning and street sweeping effectiveness in Ellensburg, Washington

Presenter: Aimee Navickis-Brasch, HDR, Inc.

Jon Morrow, City of Ellensburg

Ellensburg was issued an Eastern Washington phase II NPDES municipal stormwater permit in 2007. Among many stormwater system operation and maintenance practices, the City operates state-of-the-art Vactor trucks and street sweepers to prevent polluted solid materials carried by stormwater from entering our local streams. The permit is very prescriptive about when and how often permittees clean out catch basins, and the City is just beginning a project to study if street sweeping is more effective than catch basin cleaning at removing pollutants of concern. This talk will describe the City's road solids (grit) collection program and the reduction of copper and zinc through sweeping and catch basin cleaning. Copper and zinc are easily attached to sand grain particles and come from a variety of industrial and automotive sources. These metals are known to harm Coho and Chinook salmon. The City removes about 1,100 tons of road solids a year in both street cleaning programs.

Eastern Washington Stormwater Effectiveness Studies

Art Jenkins, City of Spokane Valley
Aimee Navickis-Brasch, HDR, Inc.

For the past several years, the Washington State Department of Ecology has funded grants to further collaboration between local jurisdictions in Eastern Washington (EWA) on determining the effectiveness of various stormwater best management practices (BMPs). This presentation will provide an overview of the considerations, approaches, and progress the joint effort has made to date as well as future work the various partners appear to be on track to completing. It will also discuss the development of templates for Quality Assurance Project Plans (QAPPs) for Stormwater Effectiveness Studies.

Eighteen cities and six counties in EWA currently have municipal stormwater permits allowing discharges of public storm drains to surface waters of the State. Pursuant to those permits, jurisdictions are required to "collaborate with other permittees to select, propose, develop, and conduct Ecology-approved studies to assess, on a regional or sub-regional basis, the effectiveness of permit-required stormwater management program activities and best management practices (BMPs)". In response to these requirements, a collaborative effort of staff from the EWA jurisdictions identified 24 study ideas (Phase 1) and then developed a ranked list of the top 14 studies (Phase 2), with the ranked list being submitted to Ecology on June 30, 2016. The current focus is Phase 3, developing the experimental design for the 14 "EWA Effectiveness Studies". Phase 3 will occur in two parts and focuses on preparing the following documents for each study: 3a) the Detailed Study Design Proposal (Proposal) and 3b) the Quality Assurance Project Plan (QAPP).

The proposed 14 EWA effectiveness studies include three classifications of BMPs and four primary objectives which are described. A distinction in the BMP classifications and primary objectives is made because these conditions will influence the experimental design particularly the QA/QC plan. In an effort to meet these goals in an efficient manner, the EWA Effectiveness Study QAPP Templates have been developed for each of the three BMP classifications: Structural BMPs, Operational BMPs, and Education and Outreach BMPs.

The objectives for this session include:

1. Provide an overview of the approach the EWA jurisdictions are taking to meet regulations along with an overview of the 14 EWA Effectiveness Studies,
2. Discuss the rationale for developing the QAPP Templates and provide an overview of the differences in the templates, and
3. Discuss how EWA jurisdictions plan to apply the study findings to refine various stormwater management programs and projects.

Western Washington's Regional Stormwater Monitoring Program: Stormwater Action Monitoring

Brandi Lubliner, Washington Dept of Ecology

Stormwater Action Monitoring (SAM) is a regional stormwater monitoring program. This collaborative monitoring program is funded by western Washington municipal stormwater permittees with additional contributions from state and federal agencies. Ecology is the service provider for administering the RSMP using permittees' funds and contracting out the studies. Ecology hired an SAM Coordinator in 2014 to launch and run the program.

SAM is founded on recommendations from an independent stakeholder committee, the Stormwater Work Group (SWG), that outlined in an overall strategy for a Stormwater Assessment and Monitoring Program for Puget Sound in 2010 with detailed technical appendices and specific recommendations for implementing the program through the permits issued by Ecology. SAM was designed to meet the permittees' stormwater monitoring requirements and to provide a structure, transparency, and accountability for other stakeholders to join. The SWG and a Pooled Resource Oversight Committee (PRO-C) oversee implementation of the RSMP.

There are three SAM components: status and trends in receiving waters (small lowland streams and marine nearshore areas of Puget Sound), effectiveness studies, and source identification. The studies began in 2015 and findings are coming in. All project deliverables are posted on the SAM webpage. The Association of Washington Cities is helping share study findings with permittees to improve their stormwater management practices and with Ecology's permit writers to improve the stormwater management actions and design details required by the permits.

SAM is a $10.5M program for the current 2013-2018 permit cycle. The SWG prioritizes and selects the SAM studies. The PRO-C oversees the budget and Ecology's contracting actions, ensuring that SWG recommendations are followed. In June 2016 the SWG recommended continuing the SAM in the next permit cycle with minor modifications.

ITRC Case Study: Hanford 200 Area

John Price, State of Washington, Dept of Ecology Nuclear Waste Program
Dib Goswami, Dept of Ecology, Nuclear Waste Program

The Interstate Technical & Regulatory Council (ITRC) authorized a team to prepare ITRC guidance on "Remediation Management of Complex Sites." Despite nearly 40 years of remediation efforts in the US and other industrialized countries, remediation of groundwater to a condition allowing for unlimited use/unrestricted exposure (UU/UE) remains a significant challenge. A substantial portion of the remaining challenges is owned by U.S. Department of Defense (DoD) and U.S. Department of Energy (DOE) which represent two of the largest soil and groundwater cleanup programs in the world. Conventional remedies and approaches are difficult to apply successfully at complex sites (from a hydrogeological and contaminant perspective). A 2012 National Research Council (NRC) committee recently examined cleanup efforts nationally and reported that at least 126,000 sites across the country have residual contamination at levels inhibiting site closure with an estimated "cost to complete" of $127 billion. Of these sites, roughly 10% are "complex".

The ITRC guidance includes a number of case studies. One of the case studies is DOE's Hanford Site 200 Area (vadose zone/groundwater) located in southeastern Washington state. The site was formerly used to produce plutonium for national defense Nuclear reactors irradiated uranium fuel elements, followed by chemical processing to separate the isotopes of interest. During these processes, some of the liquid processing waste was disposed to the subsurface. Portions of the vadose zone above the groundwater are contaminated all the way from the surface to the groundwater. The major contamination source is the carbon tetrachloride, It is estimated that liquid waste containing about 0.9 million kilogram of carbon tetrachloride was released to the soil column out of which about 120,000 kg is in the aquifer.

Extensive characterization effort through installation of wells, sampling were conducted from 2004 to 2006 as a part of a the remedial investigation and feasibility studies in the vadose zone above and the groundwater below to identify and locate carbon tetrachloride dense nonaqueous phase liquid (DNAPL) source term(s). In order to stop contaminant loading to groundwater through vapor phase transport especially from the vadose zone source of carbon tetrachloride, active soil vapor extraction (SVE) system was initiated in 1992. Passive soil vapor extraction systems were also installed at the end of FY 1999 at eight wells open near the vadose-groundwater interface. An interim remedial measure pump-and-treat (P&T) system was initiated in 1994 to prevent carbon tetrachloride from spreading. During the interim remedial measure, carbon tetrachloride concentrations decreased in the original target area and more than 10,900 kg (24,000 lb) of carbon tetrachloride were removed from groundwater and treated. A final remedy decision signed in 2008 specifies a 25-year period of pump & treat remediation to reduce the mass (by about 95%) and concentration of contaminants in the aquifer. The pumping rate exceeds 2000 gallons per minute (gpm), with a maximum treatment capacity of 3000 pgm. A series of treatment trains remove up to 12 different contaminants. The remedy then transitions to a period of natural attenuation expected to control plume migration, but require up to 100 years to reach remedial action objectives.

Strontium Isotopes as Tracers of Hydraulic Fracturing Water in the Environment

Richard W. Hurst, Hurst & Associates, Inc/Califonia Lutheran University

The use of hydraulic fracturing in oil and gas production has raised concerns about groundwater contamination proximal to oilfields. Developing methods whereby we can assess and quantify potential impacts from produced oilfield water is, therefore, extremely important. Strontium isotopes (87Sr/86Sr) have been used to trace and discriminate among various sources of water (e.g., seawater, oilfield brines, local groundwater, etc.) in the the environment. In this presentation, three case studies will be discussed that demonstrate the utility of this isotopic system as a means of assessing contributions, if any, of oilfield production water to local ecologic/hydrologic systems.

At a seawater intrusion barrier near Long Beach, CA, historic oil production from the Miocene Monterey Formation and the use of evaporation ponds to dispose of oilfield production water suggested the latter could be contributing to local salinity. If true, proposed extensions of the barrier systems would have to be redesigned; 87Sr/86Sr results indicated the source of salinity was seawater not brines. The barrier was extended as originally planned.

In Oklahoma, local groundwater was being impacted by saline waters suspected of originating from oilfield water evaporation/storage ponds. Local groundwater 87Sr/86Sr ratios, ~ 0.7087, were lower than the production water, 0.711. Analyses of 6 impacted groundwater samples were identical to those of the storage pond water; the client initiated remediation procedures on impacted groundwater.

Lastly, during production testing of a lower Miocene play southeast of Hong Kong (Pearl River Mouth Basin), the volume fraction of water produced with the oil increased over time. Prior to abandoning the well, samples of the produced water were analyzed to evaluate the source. Lower Miocene seawater is expected to have a 87Sr/86Sr ratio of ~ 0.7084; analyses of the produced water, however, were identical to those of modern seawater, 0.70923. As a result the well was not abandoned, the leak in the production piping was discovered and repaired. Subsequently investigations identified a reservoir with more than one billion barrels of oil.

Used in conjunction with other geochemical/isotopic tools, Sr isotopes afford an effective means of identifying and monitoring sources of production water.

Non-intrusive geophysical methods to detect the soil conditions within and beneath an engineered surface barrier

Fred Zhang, Pacific Northwest National Laboratory
Christopher Strickland, Pacific Northwest National Laboratory

The surface barrier is a commonly used technology for containment of waste sites such as landfill, mine tailings, and contaminated sites. Surface barriers can reduce or eliminate infiltration to immobilize contaminants and to control the production of hazardous drainage. Depending on the type of the wastes, the design life of a surface barrier varies from decades to millennia. The length of the monitoring period of barrier performance is often beyond the life of most monitoring instruments installed in the field. Hence, long-term monitoring technologies that can non-intrusively assess barrier impacts both in the near surface and to large depths are needed.

The innovative geophysical methods are now available and capable for non-intrusively detecting the distribution of soil wetness and/or contaminant plume in the soil. However, its application in monitoring a surface barrier system has to date been very limited. The challenge is that a surface barrier is often composed of multiple components that are made of natural (e.g., soil, rocks, asphalt) and man-made (e.g., plastic, metal) materials. These materials have drastically different electric properties and are either highly conductive, or moderately conductive, or non-conductive. Furthermore, surface barriers are typically much longer laterally relative to the depth and this geometry can also influence the practicality of some subsurface monitoring methods. As a result, geophysical loggings will not produce desired results without considering the properties of these materials particularly metallic infrastructure and the design of the surface barrier.

The presentation will talk about the methodologies for using the electrical resistivity tomography (ERT) and the electromagnetic induction (EMI) to detect soil wetness within and below a surface barrier and contaminant plume below a barrier.

Elements of complexity in subsurface modeling

Presenter: Mark Freshly, Pacific Northwest National Laboratory

Vicky Freedman, Pacific Northwest National Laboratory
Michael Truex, Pacific Northwest National Laboratory
Mark Rockhold, Pacific Northwest National Laboratory
Diana Bacon, Pacific Northwest National Laboratory

This presentation provides an overview of complexity elements that should be considered when applying subsurface flow and transport models to support environmental analyses. Commonly, modeling assessments reduce dimensionality, coarsen discretization and simplify process representation due to a combination of budgetary and temporal constraints. Application of more complex models is hindered by the perception that they are time-consuming to run, difficult for the public to understand, and may have unstable numerical behavior. Thus, many analysts presume they are better off using a simple model rather than building a more complex model that may cost more, but produces more technically, defensible results.

This presentation provides an analysis of complexity elements through a review of three modeling applications that contain the following elements of complexity: 1) process description, 2) heterogeneity description, and 3) simulation approach. Two of the applications presented use an approach that creates a simple empirical model that reproduces the behavior of a large number of simulations generated from a complex model. The first application is an approach designed to support cleanup levels protective of groundwater, and the cost-effective shutdown of soil vapor extraction systems. The second application investigates the importance of simulating different categories of geochemical reactions for carbon sequestration. In a third application, the modeling history for a uranium-contaminated site demonstrates that conservative parameter estimates were inadequate surrogate for complex, critical processes. All three applications highlight how complexity considerations are essential to create scientifically defensible models that achieve a balance between model simplification and complexity.

Hydrogeologic Parameters Evaluated as Part of Bioretention Cell Hydrologic Performance Monitoring

Jennifer H. Saltonstall, Associated Earth Sciences, Inc.
Doug Beyerlein, Clear Creek Solutions, Inc.
William Taylor, Taylor Aquatic Science

Hydrogeologic assessments were conducted on ten bioretention cells located throughout the Puget Lowland in support of a regional bioretention infiltration effectiveness study as part of the regional stormwater monitoring program funded by municipal permittees and administered by Ecology.

The bioretention cells are infiltration (artificial recharge) basins designed with a layer of compost-amended sand (bioretention soil) to provide water quality treatment. The design of these cells uses a hydrologic model to size the facility based on inflow data and hydrogeologic parameters for the bioretention soil and native subsurface geologic unit. This study collected field data on thickness, particle-size distribution and permeability of the bioretention soil mix and native subsurface geologic unit; evaluated the site hydrogeologic setting and installed shallow ground water level monitoring stations; and included field infiltration testing of each cell. The field-measured parameters were collected to document the current condition of the cell relative to the as-built drawings and available background geotechnical information.

The information will be used in WWHM2012 (Western Washington Hydrology Model, version 2012) modeling to compare the previously documented hydrologic design information with our field-collected information and will note where there are significant differences. The first phase of the project included site selection and development of a Quality Assurance Project Plan and was completed in January 2016. Ten cells were selected from a range of approximately 23 projects containing approximately seventy different cells from throughout the Puget Sound region. The second project phase included hydrogeologic and geotechnical analyses of bioretention soil mix and native subsurface geologic unit, ground water level monitoring, and field infiltration testing at the selected cells. The site conditions will be compared with inflow, ponding, and outflow hydrologic monitoring conducted during the 2016-2017 winter by the project team, and hydrologic design model predictions developed based on the design of the cell.

For these ten cells we present data collected from the hydrogeologic assessments and preliminary 2016-2017 wet season monitoring data for rainfall, inflow, ponding, and outflow hydrographs; and shallow ground water fluctuation. Initial conclusions on key hydrogeologic parameters and hydrologic performance will also be presented.

Estimating Hydraulic Conductivity in Unsaturated Soils and Predicting Performance of Stormwater Infiltration Facilities

J. Scott Kindred, Kindred Hydro, Inc.

Borehole permeameter (BP) methods have been developed to estimate bulk hydraulic conductivity in unsaturated soils. The BP approach has been used in shallow boreholes excavated using a vactor truck and deeper drilled boreholes completed within the unsaturated zone. Under ideal conditions, the BP procedure involves adding water to the borehole at a steady rate and monitoring the head rise until it achieves steady state. The test results provide estimates of bulk hydraulic conductivity (K) using analytical methods developed by others. These analytical methods assume uniform, isotropic soil conditions with no interference from the water table or perching horizons.

In recent years, the BP approach has been tested and refined over numerous stormwater infiltration assessments. Our experience in glacial soils shows that actual conditions in the field deviate significantly from the ideal conditions assumed by the analytical solutions for estimating K. Examples of these deviations include small-scale soil layering (anisotropy), changes in bulk soil texture within the tested soil interval, and interference from the water table beneath the bottom of the tested interval. For these reasons, the estimated K values obtained by the BP approach are referred to as bulk K. Bulk K can be used to estimate the performance of drilled wells or dug pits used in stormwater infiltration facilities.

Outfall Mapping

Abby Barnes, Washington State Department of Natural Resources
Aaron Copado, WSU SW Center

In order to have a better understanding of unclassified and prohibited harvesting areas closed due to unknown sources of pollution, Washington State Departments of Natural Resources, Health, Ecology, and Washington State Stormwater Center worked together to develop a collection of the stormwater outfall mapping performed by municipalities covered under the Clean Water Act Phase I and Phase II stormwater permits. It was proposed that having a statewide GIS file of stormwater outfalls will begin to help State agencies understand indiscreet local sources of input into geoduck tracts and shellfish harvest areas, ESA-listed species distributions, and critical (or important) habitats. Collection of stormwater systems and outfalls is a complicated process that municipalities have struggled with for many years. The attributes collected, methods and protocols, and outfall definitions vary greatly throughout Permittees. Results of the collection and assemblage of these data have led State agencies to work towards developing documents, tools, and definitions to better assist this mapping process in the future. This presentation will show the collected outfall data and associated problems with the data.

City of Redmond Paired Watershed Stormwater Retrofit Effectiveness Study

John Lenth, Herrera Environmental Consultants
Andy Rheaume, City of Redmond Public Works

The Washington State Department of Ecology (Ecology) issues Municipal Stormwater General Permits (municipal stormwater permit) to regulate discharges from separated storm sewers owned or operated by Phase I and Phase II cities and counties. The municipal stormwater permits establishes minimum requirements for permittees to address stormwater impacts from new development and redevelopment through the implementation of programmatic and structural best management practices (BMPs), including low impact development (LID) techniques. In theory, if these BMPs are applied to all the developed land in a watershed, the receiving water would be protected from stormwater related hydrologic and water quality impacts. While the effectiveness of stormwater BMPs has been well-documented on the site scale, limited data exists nationally on the effectiveness of these controls in aggregate for actually improving conditions in receiving waters.

In February 2014, Ecology approved a Citywide Watershed Management Plan (WMP) for the City of Redmond (City) that allows use of a watershed approach for implementing required stormwater BMPs pursuant to the municipal stormwater permit. Through the implementation of this WMP, the City will establish a fee-in-lieu program that will allow investments in stormwater BMPs to occur using private funding. The WMP also requires the City to make a sizeable investment of public funding towards watershed rehabilitation efforts. The City will focus these investments in a subset of priority watersheds that are moderately impacted by urbanization and therefore expected to respond more quickly to rehabilitation efforts. This provides a unique opportunity to study the effectiveness of stormwater BMPs for improving receiving water conditions on an accelerated time frame.

Recognizing this opportunity, the City is implementing a study to quantify improvements in receiving water conditions based on routine and continuous measurement of various hydrologic, chemical, physical, and biological indicators of stream health. This study is utilizing a “paired watershed” experimental design that involves the collection of these measurements in three “application” watersheds that are moderately impacted by urbanization and prioritized for rehabilitation efforts, in two “reference” watersheds that are relatively pristine and not subject to rehabilitation efforts, and two “control” watersheds that are impacted by urbanization and not targeted for rehabilitation efforts.

This study initiated in the fall of 2015 and will be implemented over an anticipated ten-year timeframe with funding from the Stormwater Action Monitoring Program, which is a regional municipal stormwater permittee funded program. Project partners include Ecology, King County, Kitsap County, City of Seattle, United States Environmental Protection Agency and the United States Geological Society. Over its implementation period, this study will provide valuable feedback to federal, state and local governments regarding the effectiveness of stormwater management practices at recovering an urban water bodies.

Nitrate Concentrations in Groundwater Beneath Whatcom County Pasture Fields Receiving Manure Applications

Steve Cox, USGS
Raegan Huffman, USGS
Bob Black, USGS
Matt Bachmann, USGS

The U.S. Geological Survey, working in cooperation with the U.S. Environmental Protection Agency and in conjunction with the Whatcom County Conservation District (WCCD), collected water quality data from December 2011 to March 2015 from shallow wells installed in pasture fields receiving regular manure applications in Whatcom County. This work was conducted for the purpose of evaluating WCCD's proposed Application Risk Management (ARM) tool. The ARM tool relies on a combination of field-specific hydrology, crop growth requirements, and near-term environmental conditions (precipitation amount, temperature, etc.) and allows farmers to apply manure outside of the currently utilized calendar-based application window. At each of three different sites, similar total manure loading rates were applied on adjacent paired fields, with one field following the existing calendar-based schedule and the other following the recommendations of the ARM tool. Water quality samples were collected and measurements were made from the top six inches of the aquifer using an inflatable well packer to isolate portions of the well screen open to the top six inches of the saturated zone.

Under both scheduling systems, high soil nitrate levels in the autumn were flushed through the unsaturated soil to underlying groundwater with the onset of seasonal rains. This pattern was consistent between sites, and suggests that while the ARM schedule of delaying the last autumn manure application until mid-winter may reduce the immediate impact to groundwater, manure application rates on all fields were too high to prevent excess nitrate accumulation in the soil column beyond what the crops could utilize. In approximately 85% of all samples under both management plans, nitrate groundwater concentrations beneath pasture fields receiving manure applications were above the drinking water standard of 10 mg/l-N, though the duration of exceedance and the amount of excess nitrate were influenced by the application schedule.

Nitrate mass balance modeling using soil nitrate concentrations collected by WCCD suggests that the recommended manure application rates in Whatcom County result in soil leachate arriving at the water table with 20-40 mg/l-N, consistent with observed shallow groundwater concentrations beneath these fields.

Isotope investigation into soil nitrate accumulations in the lower Yakima Valley, Washington, and nitrate in agricultural drains

Dallin Jenson, Central Washington University
Carey Gazis, Central Washington University

Nitrate in the groundwater of the lower Yakima Valley, Washington has long been known to frequently exceed the EPA maximum contaminant level standard for potable water (10 mg/L), adversely impacting communities with disadvantaged socio-economic status. In this research, nitrogen and oxygen isotopic signatures were determined for nitrate soil leachates and irrigation return flow collected in the lower Yakima Valley, Washington and compared to previous isotopic studies of nitrate in Central Washington. Isotope signatures for nitrate from soil leachate largely resembled those from nitrate in groundwater in a local EPA study which was largely attributed to a mixture of manure and fertilizer. However, they also resemble isotopic values attributed to naturally occurring soil nitrate from a study at the nearby Hanford Site, Washington. A mass balance calculation based on $\Delta^{17}O$ data suggests that there is a ~9% atmospheric contribution to nitrate in soil accumulations below caliche layers at several locations. This atmospheric input agreed with other research on the atmospheric contribution to naturally occurring soil nitrates in areas with similar Mean Annual Precipitation values, and was consistent across multiple sites. We argue a consistent atmospheric component concurrent with that expected for naturally occurring nitrate across multiple sites implies the nitrate in these soil samples at depth may have a largely predominately non-anthropogenic origin, as a significant anthropogenic input would dilute this atmospheric signature. We suggest the flushing of naturally occurring soil nitrate to groundwater during land use conversion to irrigated agriculture may represent a previously overlooked significant nitrate input to shallow alluvial aquifers in this region.

Groundwater Availability for Summer Low Flows – Preliminary Assessment for a Near-Term Action in the 2016 Action Agenda for Puget Sound

Rick Dinicola, USGS

Groundwater discharge to streams and rivers in the Puget Sound basin is the primary source of water for sustaining summer low flows, although a robust understanding of how anthropogenic and natural stressors affect summer low flows in Puget Sound is lacking. USGS has tools and data that can help understand the effects of current and future stressors on low flows throughout the basin, and has proposed to put that information to work through a regional-scale Near-term Action (NTA) for the 2016 Action Agenda for Puget Sound. The ultimate goal of the NTA is to provide hydrogeologic and water-use information to the Washington Department of Ecology and other water-resources stakeholders to help foster development of water management strategies that protect instream flows while ensuring water supplies for domestic, agricultural, and other out-of-stream uses. For subbasins in the Puget Sound lowlands, the information will include measures of the resilience of summer low flows to expected changes in groundwater recharge and use as affected by population growth, land-cover change, and climate change. The approach will include generating and compiling monthly groundwater budget data and related hydrogeologic information for all subbasins underlain by the 7,200 sq-mi Regional Aquifer System of the Puget Sound lowlands. Data will be compiled for approximately 36 subbasins (about two per Water Resource Inventory Area) that cover the lowlands, and will include groundwater recharge, discharge to streams and rivers, use (withdrawals and consumptive use), and discharge directly to Puget Sound. In addition, current surface-water withdrawals, streamflows, and groundwater storage will be compiled at a similar scale to allow a holistic comparison of water demands, summer low flows in streams and rivers, and groundwater availability in different hydrogeologic settings of Puget Sound. This proposed evaluation will go beyond those river systems identified in the Summer Stream Flows Vital Sign and will address all major systems in the Puget Sound basin, thus providing important feedback for assessing which systems are the most critical. For this presentation, the proposed approach will be described and preliminary results for selected subbasins with available water-budget data will be presented.

Groundwater Modeling in Support of Water Rights Changes for River Flow Restoration, Upper Clark Fork River, Montana

Gary Andres, NewFields
Tom Mostad, Montana Natural Resources Damage Program
Andy Fischer, Clark Fork Coalition
Karl Uhlig, WGM Group

Groundwater modeling was conducted to evaluate the potential for water rights change applications to improve streamflow conditions along the Upper Clark Fork River (CFR) in Montana. The applications will be designed to leave water in the river that was historically diverted for agricultural use. Previously diverted water would no longer be needed due to possible revisions to irrigation ditches which would eliminate seepage while still providing the necessary water for irrigators.

The instream flow augmentation activities are being developed by the Montana Natural Resources Damage Program (NRDP) in partnership with the Clark Fork Coalition (CFC) and technical support from The WGM Group and NewFields. Water Rights Change Applications are planned to be submitted to the Montana Department of Natural Resources and Conservation (DNRC).

Groundwater modeling was critical for identifying reaches of the CFR to be protected such that the non-diverted water left in the river would not then be used by irrigators. The modeling was also necessary to evaluate potential impacts to existing water rights holders that may utilize the ditch seepage water, though rights to using seepage water is an issue being evaluated by DNRC.

The modeling code MODFLOW was used to simulate groundwater-surface water interactions for current and post-ditch revision conditions. Monthly time steps simulate seasonal conditions by allowing changes in precipitation and irrigation recharge and variations in river and tributary stream water levels.

The model extends from Deer Lodge to Galen Montana and is roughly 8 by 13 miles. Two model layers were used to provide resolution for surface water impacts. River Package cells represent the CFR and streams, and Well Package cells simulate the two primary ditches identified for revisions, along with other irrigation ditches. Aquifer parameters were specified using mapped geology and an evaluation of aquifer performance tests.

The model was calibrated to observed water levels at wells throughout the model domain including single time measurements and monthly measurements to validate seasonal predictions of the model. Surface water gain/loss analyses from flow measurements at gages along the CFR and tributary streams also guided calibration.

The calibrated model was then used to evaluate changes in groundwater elevation and groundwater-surface water interactions resulting from completion of different phases of the ditch revisions. Ditch revisions were simulated by eliminating recharge at the ditch reaches that would be either lined or run through piping. Particle tracking was also employed to identify the timing and location along streams and reaches of the CFR where seepage water currently discharges to.

Results show that ditch revisions would result in over 12 cfs of additional flow in the CFR during late summer months when river flows tend to be low. Groundwater levels would decline at locations near the ditches during summer months by a few feet, but these changes are not expected to prevent use of the wells.

The project is being discussed with existing water rights holders to get landowner input and to assure that the project will both improve CFR streamflow and not adversely affect existing water rights holders.

Expanding Groundwater Capacity for City Of Juneau

Jim Bailey, Shannon & Wilson

The City and Borough of Juneau (CBJ) Alaska recently expanded both its groundwater and surface water capacities to ensure a reliable long term potable water source. The primary source of water was five wells located above the downtown area in Gold Basin which provided an average of 3.0 million gallons a day (MGD) of water. A secondary surface water source operates intermittently due to seasonal excess turbidity. Over the past several years, peak summer demands have exceeded the available supply resulting in the CBJ being unable to supply visiting cruise ships with water.

In 2009, CBJ completed an extensive rehabilitation program on five existing wells that successfully improved performance and yield. These wells were installed between 1975 and 1989. The observed capacity improvements lasted for several years but due to over pumping, yields began declining by 2012. In 2013 a comprehensive numerical groundwater model was developed for the well field to evaluate the potential capacity of the Gold Basin Aquifer. The numerical modeling results indicated the shallow aquifer could support two more wells without exceeding the natural groundwater recharge capacity or impacting flow to Gold Creek.

Based on the modeling results test well drilling was done in 2014 to delineate aquifer thickness and aquifer yields at several potential well sites. In 2015, CBJ replaced the five existing wells and installed two additional wells in locations identified from the numerical modeling and test drilling. These seven new wells now produce enough water to meet both peak summer demand for the City and the many cruise ships that come to Juneau daily between April and October.

Modeling Groundwater Water Availability in the Post-Hirst Era Using a MODFLOW Simulation over Most of Thurston County, Washington

Kevin Hansen, Thurston County, Water Resources Department

The Washington Supreme Court decision in Whatcom County v. Hirst et al (6-Oct-2016) placed new emphasis on larger groundwater models to assist assessments of the physical availability of groundwater. Thurston County is a GMA entity entirely covered by five (5) WRIA Rules, and developed a larger MODFLOW model as a general-purpose groundwater simulation tool. It has now been turned to use for calculating many factors associated with the physical availability of groundwater, including compliance with Minimum Instream Flows (MIFs). Currently in calibration and sensitivity analysis, the 5-layer MODFLOW simulation has approximately 2.1 million active cells at a uniform spacing of 200x200 feet, over about 77% of the County, plus watershed edges and some areas outside the County. The model incorporates five layers extended to higher-elevation watershed boundaries or major surface water. Bedrock contributions to aquifers are explicitly solved-for. The model utilizes larger and more dynamic machine memory, computational speed, multiple processor cores, fast solvers, and modeling interface capability (GMS 10.2) that were previously unavailable to other investigators (whose data and analyses formed the core startup datasets). A detailed terrain raster at a re-sampled 10-meter resolution was built using 1-meter LiDAR-based hydro-enforced DEM topography, DNR Salish Sea bathymetry, major lake bathymetry and a fringe of USGS DEM data. Groundwater seepage face elevations were determined at June-July (early dry season) elevations from LiDAR-resolved streams intersecting Hydro-Enforced DEM elevations. Two external databases and open source shapefiles are used for editable source data storage - outside the modeling software itself. Input includes spatial and tabular datasets provided by Thurston County, the USGS, Ecology EIM, DOH Sentry, Ecology PARIS, and Ecology's GWIS (for water rights-based withdrawal estimation). Rainfall is tracked at the sub-shed level using the County weather gage network. A two-year GIS department effort mined Thurston County's permit-tracking database to locate septic systems – helping to estimate consumptive use for permit-exempt wells outside Group A/B water service areas. Pumping wells from all data sources are currently loaded at more than 14,000 model cells (WEL-type Boundary conditions) and that number is growing. Stream boundary conditions are currently STR boundary conditions. Stream baseflow discharges are being calculated using validated curve separations, then calibrated to key STR model boundary cells using gage data from the County, Ecology and the USGS. At the 2017 Washington Hydrogeology Conference, the above approach will be presented in its then-current and publicly-disclosable form as it informs the assessment of the physical availability of water in the post-Hirst era.

Structural control of recharge to aquifers within the Columbia River Basalt Group

Dale Ralston, Ralston Hydrologic Services
Robin Nimmer, TerraGraphics Environmental Engineering
Ken Neely, Idaho Department of Water Resources

Recharge to the regional aquifer underlying the Lewiston Basin in northern Idaho and eastern Washington occurs because the northerly dip of the basalt flows is greater than the northerly gradient of the Snake River. This recharge opportunity is compared to the more complex geologic setting of the Grande Ronde Formation along the Clearwater River, also in the Lewiston Basin. The Palouse Basin, which is 30 miles to the north, has the same stratigraphic section of rocks but receives much less recharge because the rocks are nearly horizontal.

Three Recent State Supreme Court Decisions and Their Impacts on Washington's Water Rights Permitting Future and on Permit Exempt Wells

Michael Gallagher, Washington State Department of Ecology
David Christensen, Washington State Department of Ecology

The era of cheap and readily available water supply in Washington State is over! Over the past four years, the Washington State Supreme Court issued three landmark decisions that dramatically altered the legal availability of Washington's groundwater and surface water supplies. The first decision, known as Swinomish v. Ecology (October 2013) invalidated the reservation established in a 2006 rule in the Skagit watershed and ruled that Ecology could not use Overriding Consideration of Public Interest (OCPI) to justify water use that impairs existing instream flows. The second decision, known as Foster v. Yelm (October 2015) ruled that Ecology cannot use OCPI to justify water use that impairs previously-established instream flows. Ecology conditioned Yelm's permit on both in-kind and out-of-kind mitigation to offset modeled impairment to the Deschutes and Nisqually Rivers. The Court reaffirmed their ruling in Postema (2001) that no impairment of instream flows is permitted, regardless of magnitude or ecological impact. In line with this conclusion, the Court also ruled that "out-of-kind mitigation", such as habitat improvements, cannot remedy for "legal impairment" and therefore cannot be used to address impairment of instream flows. The final decision, known as Hirst v. Whatcom County (October 2016) ruled that Whatcom County failed to comply with the Growth Management Act's (GMA) requirements to protect water resources and that the county has an independent obligation to ensure that new permit-exempt groundwater uses do not impair instream flows and closures when making water availability determinations for issuing building permits. Washington's water supply future is very limited for permitting new beneficial uses at this time. Solutions for water supply options will require legislative engagement to achieve broad support for balancing competing demands for limited water supplies.

California's Leap into Groundwater Management

Carl Hauge, California consultant

In 1913 the California Water Commission submitted the Water Commission Act to the legislature. The Act included state permit jurisdiction for both surface water and groundwater. However, when the act was introduced in the legislature it included state jurisdiction over surface water but not groundwater.

As a result groundwater extraction became a "wild west" scene in California. Landowners could extract as much as they could use, or "legally," could put to beneficial use. Landowners pumped all they could to establish a record of pumping that could be used in court adjudications. For years groundwater management was touted by the locals to be a local responsibility. State government acquiesced. But the locals continued to treat groundwater as a commons with no management required.

Several times in the past the legislature considered amending the Water Code to require groundwater management but declined to do so. But the present drought that began in 2011 that resulted in radically declining groundwater levels and increased land subsidence convinced the legislature to adopt the Sustainable Groundwater Management Act (SGMA) in 2014. SGMA requires local agencies to develop and implement groundwater management plans.

Groundwater Sustainability Agencies (GSAs) must be established by 30 June 2017. Twenty one groundwater basins that are considered to be high and medium priority that are critically overdrafted must have a Groundwater Sustainability Plan (GSP) by 2020. The other 106 high and medium priority basins must have a GSP by 2022. All GSPs must provide for a sustainable groundwater resource by 2040.

The California Department of Water Resources has increased its groundwater staff to meet the requirements of SGMA. The staff has already met deadlines dictated by SGMA for prioritizing groundwater basins, defining critically overdrafted basins, changing groundwater basin boundaries and developing best management practices.

Several issues that must be considered include a) over 2000 existing local agencies that have a board of directors with tax raising authority that will not surrender their authority readily; b) Investment backed expectations to pay for equipment, taxes, labor, seeds; c) groundwater law established by several court decisions; d) the hyporheic zone; e) surface water depletion by pumping wells; f) a water budget for the basin; and g) overdraft.

SGMA defines 6 undesirable results that must be avoided by a sustainable groundwater management plan: 1) lowering groundwater levels, 2) reduction of groundwater in storage, 3) sea water intrusion, 4) degraded water quality, 5) land subsidence, 6) surface water depletion.

After more than 100 years of treating groundwater as a commons, the success of SGMA will depend on unprecedented constructive cooperation on the part of more than 2000 local agencies.

Assessing Public Water Supply Vulnerability to Climate Change

Ginny Stern, Washington State Department of Health
Corina Hayes, Washington State Department of Health

The Washington State Department of Health's Office of Drinking Water has been exploring ways to retool its existing susceptibility and vulnerability risk assessments to evaluate and assign climate vulnerability ratings to water systems. Specifically – water supply vulnerability as it relates to the threats of drought, flooding and changes in sea level.

Washington public water systems are diverse in their size, resources, and expertise. Systems can range from large complex municipal systems like Seattle Public Utilities to small community or homeowner associations with 25 residents. All fall under the state drinking water regulations administered by the Department of Health. Safe and Reliable Drinking Water is the mission and mandate, but ultimately the responsibility falls on the shoulders of thousands of public water systems operators across the state. How should a small or medium sized water system evaluate and integrate climate vulnerability into their operating plan? How can climate risks be tracked at this "micro" scale?

Susceptibility and Vulnerability ratings have been used by the Office of Drinking Water to evaluate water quality threats since 1994. Through the existing programs such as wellhead and source water protection, vulnerability ratings have been used to educate water system operators and to refine water quality monitoring and treatment requirements. New efforts are underway to expand the application of susceptibility, risk and vulnerability as it relates to the challenges of climate change. If the goal is a climate ready utility – then utilities at all levels must be able to identify and evaluate their likely risks and then developed appropriate adaptations and strategies. In order to help utilities prepare, the Department needs to be able to identify, track and support those systems most as risk. Not all utilities share the same level of risk or the capacity to respond to it.

This presentation describes the current efforts under development. Historical experience with 1) regional flooding and 2) the 2015 drought has provided the collective experience this work is based on. While flooding, drought, and changes in sea level are not the only expressions of climate vulnerability, they are relatively familiar threats utilities can face. Because of that, they provide a foundation that can be used to engage "at risk" utilities and their customers in the discussion, planning and response to a changing climate.

The Growth Management Act's Voluntary Stewardship Program and Critical Aquifer Recharge Areas

Laurie Morgan, Washington State Department of Ecology, Water Quality Program

In 2007, the Washington State Legislature tasked the William B. Ruckelshaus Center with examining and reporting on conflicts between agricultural activities and Critical Areas Ordinances adopted under the Growth Management Act. Critical Areas include wetlands, aquifer recharge areas, fish and wildlife habitat conservation areas, frequently flooded areas and geologically hazardous areas.

Although all Critical Areas were subject to this legislation, the focus of the legislative direction and Ruckelshaus reporting was principally on surface water and habitat concerns, and not aquifer recharge areas. Nonetheless, Critical Aquifer Recharge Areas ordinances are subject to the legislation.

The Legislature subsequently created the Voluntary Stewardship Program in 2011, to be administered by the Washington Conservation Commission. The mission of the Voluntary Stewardship Program is to create a voluntary stewardship plan which protects critical areas while maintaining and enhancing the viability of agriculture.

Twenty-seven counties opted into the Voluntary Stewardship Program and have received funding to proceed. All Eastern Washington counties, except for Klickitat, have opted into the Voluntary Stewardship Program. Western Washington counties that have opted in include San Juan, Skagit, Mason, Thurston, Lewis, Grays Harbor, Pacific, and Cowlitz.

This talk will be a report out on the current status of Voluntary Stewardship Programs as they relate to Critical Aquifer Recharge Areas.

Using standard water quality parameters as predictors of future well performance

Jim Bailey, Shannon & Wilson
Andreas Wicklein, Pigadi GmbH
Hella Schwarzmüller, Kompetenzzentrum Wasser Berlin

One of the primary reasons for declining well performance is the result of biological, chemical and/or physical processes that occur in and adjacent to the well screen. In addition well construction and operation can greatly influence how the natural water quality conditions will impact future well performance. The City of Berlin, Germany has developed a database program that is used to evaluate the likelihood that any of their 750 wells could lose significant pumping capacity based on the analysis of specific input parameters. For example, input data analyzed by the program, will generate a well condition report. The report indicates the potential for development of several common conditions such as carbonate scaling, corrosion, biofouling, sand migration or iron precipitates. The report also provides an explanation for the assigned risk and provides recommendations to mitigate it. This program has recently been used in the U.S. on several municipal wells including one in Lacey, Washington. The results have helped the engineering team develop a long term operation and maintenance plan for two existing City wells where iron fouling is a known concern.

City of Othello Aquifer Storage and Recovery Program: Addressing Municipal Water Supply Needs in the Columbia Plateau

Andrew Austreng, Aspect Consulting
Tim Flynn, Aspect Consulting

The City of Othello (City) currently relies solely on groundwater wells completed in the Wanapum Basalt aquifer of the Columbia Plateau for water supply. Due to declining water levels and well yields in this aquifer, the City may experience future shortfalls in water supply, limiting the City's ability to support residential and economic growth. Although significant state and federal effort has been expended to address declining aquifer yields for irrigation water supplies (e.g., the nearby Odessa Groundwater Replacement Project), similar efforts to sustain and improve municipal and industrial water supplies have been more limited.

With grant funding from the Washington State Department of Ecology, Office of Columbia River, the City is evaluating the feasibility of an aquifer storage and recovery (ASR) program. Because of a lack of local natural surface water sources, options for obtaining source water for ASR are limited, prompting the City to take a unique approach. Under the proposed ASR program, water would be diverted from nearby irrigation canals and treated to drinking water standards to provide direct municipal supply, with excess treated water used to recharge the Wanapum Basalt aquifer. Accordingly, ASR source water availability is limited to the irrigation season when water system demands are also highest, limiting aquifer recharge to periods of non-peak (e.g., nighttime) system demands. The City is also evaluating the treatment and reuse of industrial (food processing) wastewater as a viable future water supply and potential source water for ASR.

This presentation will briefly describe the historical decline in well yields of the local Wanapum Basalt aquifer and provide an overview of the City's proposed ASR program to stabilize aquifer water levels and support well yields. The findings and recommendations of the feasibility study will be presented, with an emphasis on challenges and characteristics that distinguish this ASR project from other projects under development in Washington state. These results will be presented in the context of the City's current and future water demands, with discussions provided to address regulatory requirements.

Advances in Groundwater Science and Practice: Developing Groundwater Replenishment or Recharge Systems

Bill Mann, In-Situ Inc.

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

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

To meet requirements of the California Water Code Section 60300, WRD hydrogeologists and engineers track groundwater levels from a network of specialized monitoring wells and from groundwater producer's production wells. Currently, the network consists of approximately 400 WRD and USGS-installed monitoring wells at 50 locations throughout the District, which supply water level and water quality data for the District. Currently, 100 wells are outfitted with In-Situ® Level TROLL® 500 instruments that accurately measure and log water level and temperature data every six hours. The primary purpose of water level monitoring is to meet statutory responsibility to maintain groundwater availability. The Level TROLL 500 instruments reduce trips to the field, and enhance the WRD's monitoring program and ability to better manage through severe drought conditions, by allowing for more measurements, which increases data resolution.

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

John Covert, Washington State Department of Ecology
Joel Purdy, GeoEngineers, Tacoma
Michael Kendrick, GeoEngineers, Redmond
Phil Brown, EA Engineering, Portland
Guy Gregory, Washington State Department of Ecology

The Washington State Department of Ecology has completed Phase 4 of a hydrogeologic evaluation focusing on the feasibility of aquifer storage and recovery (ASR) at a project site in Douglas County, Washington. If developed, water will be removed from the Columbia River during springtime high flow periods, stored temporarily in one or more aquifers of the Columbia River Basalt Group (CRBG), then discharged back to the river during periods of high water demand.

This presentation describes the overall project potential, summarizes the data collected to date, and discusses how this project could become the largest ASR project in the Pacific Northwest, providing much-needed water during dry periods and perhaps addressing the water-energy nexus.

The 50-square-mile project area is isolated, with limited local beneficial use of groundwater. Characterization of the CRBG and associated aquifer system included construction of test and monitoring wells, down-hole video surveys, borehole geophysical logging, analyses of formation samples by X-ray fluorescence, groundwater chemical analyses, and aquifer testing and hydraulic analysis. Subsurface exploration encountered a layered aquifer system consisting of four primary hydrostratigraphic units. They are, from youngest to oldest: (1) Wanapum unit, (2) Vantage Interbed unit, (3) Grande Ronde unit, and (4) pre- Miocene basement rocks. The Grande Ronde unit is the preferred target for ASR based on its relative hydraulic separation from the overlying Wanapum unit and the near absence of existing local groundwater exploitation. Ten test wells are completed within the Grande Ronde unit. Seven Grande Ronde monitoring wells were completed at varying distances from the test wells. In addition, five monitoring points (one well and four vibrating wire piezometers) were completed within the overlying Wanapum unit, and one monitoring well was completed within the Vantage Interbed unit. Aquifer testing consisted of step-rate pumping tests at each test well location. These were followed by constant-rate aquifer tests ranging from 24-hour to 11-day durations.

The resulting range of values for bulk effective transmissivity and storativity are generally consistent with those observed in the CRBG at other locations in the Columbia Basin. Estimated near-well transmissivities are relatively high at most of the current testing locations. However, the effect of flow-limiting boundary conditions and/or the limited lateral extent of the Grande Ronde unit increases the rate of drawdown during pumping at several of the test sites, resulting in specific capacities that decrease rapidly with time. In these areas, boundary conditions reduce overall storage volume but will also limit the potential for loss of stored water outside of the project boundaries. Based on results of the first four phases, the area has potential for regional scale water storage, which can be used to supplement regional water supplies.

Furthermore, this project can provide frequency and regulation capacity for renewable energy sources utilizing green technologies that do not increase fossil fuel use. It has gained the attention of private partners to team with Ecology to beneficially and profitably provide both new water supplies to Columbia River water users downstream of the project area and a more reliable electric grid.

Groundwater Storage Element Projects in the Yakima Basin Integrated Plan

Dave Nazy, Department of Ecology
Tom Ring, Yakama Nation
Danielle Squeochs, Washington State Department of Ecology
Johnson Jennifer, US Bureau of Reclamation
Jonathan Rocha, US Bureau of Reclamation

The Yakima Basin Integrated Plan (YBIP) was developed to address significant water resources challenges present in the basin and to offset some of the worsening of these challenges resulting from a warming climate. The YBIP is composed of a set of elements and projects that are designed to increase water supply for agriculture, domestic use and instream flow, as well as improve conditions for aquatic life in the basin. The Groundwater Storage Element of YBIP would benefit both goals by increasing water supply and partially moderating unnaturally low and high mainstem flows that occur annually due to Yakima Project operations. Storing groundwater in the basin helps to offset some of the anticipated loss of snowpack and can provide thermal benefits to stream flow.

Work under the Groundwater Storage Element includes groundwater modeling, monitoring and pilot tests. The Bureau of Reclamation used the USGS groundwater model of the Yakima River Basin (Ely, et al., 2012) to estimate changes in groundwater storage and the timing, quantity, and location of return flows at the Parker Gage on the Yakima River. Model results were used along with geologic maps and other site- specific knowledge to identify a subset of candidate locations for additional data collection and pilot studies.

Groundwater monitoring is ongoing in the Kittitas Basin within the Kittitas Reclamation District to assess depth to groundwater, seasonal fluctuations, and response of the aquifer system to irrigation practices. Water is being diverted and infiltrated into unused irrigation canals in the Toppenish Basin where groundwater levels are being monitored. The City of Yakima has conducted ASR pilot tests and has received a permit for development of their artificial groundwater storage and recovery project. Other activities include identifying potential recharge sites and assessing broader use of groundwater storage throughout the basin.

This talk will summarize the Groundwater Storage Element of the YBIP and present some of the results and details of on-going efforts.

Estimates of Tailings Facility Evaporation and Area Using Landsat Imagery

Jason Keller, GeoSystems Analysis, Inc.
Jan Hendrickx, SoilHydrology Assoc, LLC
Adrianne Grimm, GeoSystems Analysis, Inc.
Frederick Partey, Robinson Nevada Mining Company
Michael Geddis, KGHM International Ltd.

Evaporation from mine tailings storage facilities is often the largest unknown component flux needed to constrain a tailing storage facility (TSF) water budget. Potential evaporation (PE) can be estimated using weather station measurements and the Penman-Monteith equation; however, PE estimates assume continuous water availability and cannot take into account drier locations in the TSF. The actual evaporation (AE) rates of a TSF depend on a number of factors such as: climate; tailing moisture content, texture, and water storage capacity; and tailing and solution salinity. Most TSFs have a large surface area which lends itself to estimates of actual evaporation using Landsat imagery in combination with an energy balance model. Key for AE estimates is the calibrated thermal band of Landsat that sets Landsat apart from many other satellites. Furthermore, Landsat imagery can be applied to determine the growth of the TSF over time. Landsat data and a three-temperature energy balance model were applied at a large tailings facility in Nevada to estimate monthly AE distributed over the site at 30 m spatial resolution from 1996 through 2015. The three-temperature model calculates AE via a surface energy balance determined from Landsat images containing reflectance and thermal information. Additionally, Landsat reflectance data were used in a site specific processing algorithm for the estimation of the tailings facility area on six month time intervals. The three-temperature model and Landsat images provided an efficient and accurate method to calculate spatially distributed estimates of tailings facility AE, and also captured seasonal changes in monthly AE and surface ponding. Landsat based estimates of tailings facility area were in agreement with storage curve tailings area estimates, providing a high temporal resolution estimate of tailings area.

Characterizing Groundwater to Surface Water Discharge Zones Using Unmanned Aerial Vehicles and Thermal Infrared

Howard Young, CDM Smith
Coffey Scott, CDM Smith
Crippen John, CDM Smith

An unmanned aerial vehicle (UAV), combined with lightweight sensors, is a powerful tool for characterizing groundwater discharge zones to surface water bodies and surface water inputs. Groundwater discharge to surface water is a substantial component of flow in Washington state rivers, lakes, and marine waters. Characterizing groundwater discharge zones is important for a number of current issues, including: groundwater contaminant plume investigation and remediation; temperature total maximum daily load (TMDL) studies in rivers; and groundwater resource studies.

The difference in temperature between groundwater and surface water can result in a thermal signature where groundwater discharges to surface water. A thermal infrared (TIR) camera can detect these surface temperature differences and allow for identification of the groundwater discharge zones. Groundwater temperatures are fairly constant throughout the year, in Washington State this is typically around 50 degrees Fahrenheit. Surface water temperatures in Washington State rivers, lakes, and Puget Sound vary significantly throughout the year ranging from temperatures in the 40s, during the winter and spring, to river temperatures in the 60's during the summer and fall. Due to the temperature contrast because groundwater and surface water in the winter, conducting a TIR survey in the winter provides the best opportunity to identify groundwater discharge zones with TIR.

The use of TIR imaging to identify areas of groundwater discharge to surface water and surface water mixing zones is nothing new; however, combining the use of new commercially available UAVs with TIR opens up new opportunities for characterizing groundwater to surface water discharge zones. Traditional aerial TIR surveys, relying on manned helicopters or fixed wing aircraft, are expensive, restricted to flying at higher altitudes, and subject to weather related restrictions. UAVs have the advantage of low cost, are capable of flying at altitudes ranging from 10 feet to 400 feet, can fly below cloud cover, and require much less training to operate than full size aircraft. Advances in UAV technology has made available affordable commercial UAVs capable of carrying payloads of up to 15 pounds, more than enough for carrying TIR cameras, optical cameras, and water quality instrumentation.

Characterizing groundwater flow in complex glacial stratigraphy near Puget Sound

Andy Long, USGS, Washington Water Science Center
Wendy Welch, USGS, Washington Water Science Center

Hydrogeologic units in the Puget Sound Basin primarily were deposited by glaciers. Multiple periods of glacial advance and retreat resulted in numerous discontinuous stratigraphic layers, with a total thickness of as much as 3,000 feet. The complexity of these deposits makes construction of a three-dimensional (3D) hydrogeologic framework model especially challenging. In Pierce County alone, over 30 geologic units of glacial and interglacial origin have been identified. For the present framework, these units were simplified and grouped into 10 hydrogeologic units based on similar hydraulic characteristics. These 10 hydrogeologic units have variable horizontal continuity due to their depositional processes, but also are cross-cut by subsequently incised stream valleys filled with alluvial units and a mudflow deposit. The 3D hydrogeologic framework model was based on geologic maps of the land surface, geologic well logs, and the land-surface topography. This 3D framework model is represented numerically by the top and bottom altitudes of each hydrogeologic unit in the study area. Areas where observed data were absent were interpolated or extrapolated. The irregular 3D geometry of a unit must fit neatly within the structure of all other surrounding units, which is particularly challenging in the case of a horizontally discontinuous unit that must fit between an overlying and underlying unit. These discontinuous units are numerous and pose the largest computational challenge for building the 3D framework. While software is available to assist in constructing complex 3D frameworks, each software package has particular strengths and limitations; therefore, a combination of different software packages was used to construct the 3D hydrogeologic framework model for Pierce County.

Whatcom County Groundwater Data Collection and Conceptual Model Development

Katherine Beeler, Associated Earth Sciences, Inc.
Charles Lindsay, Associated Earth Sciences, Inc.
Gary Stoyka, Whatcom County Public Works Department

Population growth in Whatcom County over the past several decades has led to an increase in the use of surface and groundwater resources to meet the growing domestic, industrial, commercial and agricultural needs of the County. This increase in water use, along with social and political changes, has led to a heightened level of concern regarding surface water-groundwater interactions and the effect of groundwater withdrawals on stream flows, which are necessary to sustain critical habitat for salmonids and other threatened species.

In 2014, Whatcom County, Public Utility District No. 1 of Whatcom County, City of Bellingham, Lummi Nation, and the Nooksack Indian Tribe, in cooperation with the Bertrand Watershed Improvement District and the Washington State Department of Ecology retained Associated Earth Sciences, Inc., Papadopulos & Associates, Silver Tip Solutions, HydroLogic Services Co., and Dumas & Associates to complete a multi-phase project to characterize the groundwater flow system in northwestern Whatcom County. The ultimate objective of the project is to develop a numerical groundwater flow model that can provide quantitative insights into the behavior of the natural system and how changes in water management actions, surface water use, groundwater withdrawals, groundwater recharge, and drainage management may affect the surface water and groundwater systems.

This presentation will focus on the data development and preparation of a conceptual model for a 426-square-mile proposed numerical model domain located in Whatcom County and southern British Columbia. During this phase of the project, over 250 technical publications were reviewed and compiled into a searchable literature database. The available geologic/hydrogeologic information and data from over 600 well logs were compiled into a detailed database that included information regarding well location and construction, surface and subsurface lithology, individual water levels, water level time series data, aquifer parameters from short-term and long-term aquifer tests, streamflow measurements, and estimates of groundwater recharge. The hydrogeologic units defined for the project area, based on existing technical publications and the interpretation of lithologic information on well logs, will be discussed. Lithologic cross-sections and maps were prepared showing hydrogeologic unit elevations, groundwater elevations, transmissivity, and hydraulic conductivity for each hydrogeologic unit.

Linking Surface Water and Groundwater Models for Improved Watershed Analyses and Management

Jonathan Turk, Brown and Caldwell

Spanaway Lake is a 250-acre kettle lake that receives substantial groundwater inflow. The surrounding watershed contains numerous septic systems and stormwater drywells and presents dispersed source terms for contamination. The objective of Pierce County's Spanaway Lake watershed management plan is to identify the likely sources or causes for the observed problems and develop source control and/or in-lake measures to address them. Plan development included watershed and lake characterizations, focused monitoring, source identification, evaluation of source control and lake treatment measures, and stakeholder involvement. This is the first lake and watershed management plan completed under the Pierce County's lake management program that BC helped develop. Spanaway Lake experiences toxic algal blooms of cyanobacteria, which have been linked to multiple potential sources of nutrient and bacterial contamination in the watershed.

To provide tools for informing watershed management decisions and utility planning, existing models historically developed by the USGS were updated using information collected in recent decades from long term water system monitoring, and project specific field data collection to fill data gaps. These initial activities confirmed the quantification of groundwater throughput in Spanaway Lake as a data gap to be addressed through field studies. These estimates were used to better define the complex surface water groundwater interactions and include water balance elements overlooked in previous numerical modeling. Our ongoing work involves modifying the source codes to the surface water and groundwater models (HSPF and MODFLOW) to provide linkages between the simulation output. A critical element of this process has been evaluating system response times and establishing appropriate simulation time steps. By running each model at an appropriate time step and post-processing the results for data integration, the tools have the capability of answering complex management questions and provide details supporting future scenario planning activities.

Groundwater - surface water interaction between the Spokane Valley / Rathdrum Prairie Aquifer and the Spokane River: an examination of recent assessments of nutrient and contaminant loading to the Spokane River

Rob Lindsay, LHG, Spokane County Environmental Services

Studies conducted by the United States Geologic Survey, and state and local agencies, have documented the significant exchange of groundwater and surface water between the Spokane Valley / Rathdrum Prairie aquifer and the Spokane River. This presentation summarizes the geologic history and hydrogeologic characteristics of the Spokane River valley and examines surface water quality implications associated with groundwater loading to the Spokane River. Two recent studies are examined: an assessment of non-point sources of sources of phosphorus to the Spokane River (Spokane County, 2008), and an assessment of sources of PCBs to the Spokane River (Spokane River Regional Toxic Task Force, 2016).

Long-term Impact of Dam Operation on Thermal and Biogeochemical Dynamics in the Hyporheic Zone

Xuehang Song, Pacific Northwest National Laboratory
Xingyuan Chen, Pacific Northwest National Laboratory
James Stegen, Pacific Northwest National Laboratory
Glenn Hammond, Sandia National Laboratories
Hyun-Seob Song, Pacific Northwest National Laboratory

The hyporheic zone is an active region for biogeochemical processes such as carbon and nitrogen cycling, where the groundwater and surface water mix and interact with each other with distinct thermal and chemical properties. In a regulated river, human activities like the dam operation often induce significantly larger stage fluctuation (hydropeaking) than in a natural river system, which changes the hydrological, thermal and biogeochemical dynamics in the hypothetic zone. The impact of dam operation on the hyporheric exchange has not been extensively studied, especially for the thermal and biogeochemical processes in long time scale. For a better understanding of these long-term hydropeaking effects, we built a two-dimensional thermo-hydro-biogeochemical model along a transect perpendicular to the Columbia River (Hanford site, WA) with a six-year monitoring dataset of water table elevation and temperature. The model solves the fully coupled variably saturated flow and heat transport equations and also integrates denitrification and aerobic respiration with temperature dependent reaction rates for reactive transport simulation. The real water table elevation data was progressively smoothed with a low-pass filter to create six groups of hydraulic boundaries with decreasing time frequency. The simulated temperature profiles were compared with in-situ thermistor data to identify the impact of hydropeaking on thermal dynamics. The mass flux across the river boundary and the cumulative consumed organic carbon and nitrate of six hydropeaking scenarios were calculated, which indicated the hydropeaking induced by dam operation creates larger mass flux and brings more biogeochemical activities in the hyporheic zone.

Hydrograph-analysis method for episodic aquifer recharge extended to episodic increases of soil-water storage

John Nimmo, USGS
Kim Perkins, USGS

We have generalized the Episodic Master Recession (EMR) method to apply to increases of soil water storage due to precipitation events in addition to the original aim of quantifying episodic aquifer recharge. The method, based on a systematized version of the water-table fluctuation method, partitions a time series of water levels into discrete recharge episodes and intervals of no episodic recharge (see Nimmo et al., 2015, Discrete-storm water-table fluctuation method to estimate episodic recharge: Groundwater, v. 53, no. 2, p. 282-292). The systematic nature of this method is designed such that the values of essential parameters that require hydrologic judgment (lag time, fluctuation tolerance, and master recession) are established once for a given well and applied consistently for that well's data, thereby avoiding subjective influences on episode-to-episode comparisons. The extension to quantify augmentation of soil water storage due to particular infiltration events is possible by direct analogies of soil water content to water-table level, capacity of soil depth interval to specific yield, and added water per soil depth interval to recharge. By correlating each episode of increase in soil-water content to a specific interval of rainfall, one can investigate variations not only in the proportion of infiltrating water that contributes to aquifer recharge, but also in the proportion that contributes to soil water storage. This proportion varies with factors such as antecedent soil-water conditions, water table, and storm magnitude, intensity, and duration. If applied to a period of data long enough to include episodes with broadly diverse characteristics, the method has value for predicting how changes in soil or storm conditions, as may result from climatic change, affect the availability of water in the aquifer or soil.

Quantifying Evaporation and Transpiration Rates using Stable Isotopes

Carey Gazis, Central Washington University

Evaporation and transpiration rates in soils are difficult to measure because they both remove water from soil and they act simultaneously. Therefore, it is difficult to determine how much water is removed by evaporation versus transpiration. However, the two processes have different effects on the hydrogen and oxygen isotopic composition of the water that remains in the soil. Evaporation leads to an enrichment in deuterium and oxygen-18 in the remaining soil water while transpiration has no net effect on the isotopic composition of soil water. A process like this that does not change isotopic composition is called non-fractionating. Downward percolation of water is also a non-fractionating process. Because evaporation and non-fractionating losses (transpiration and downward percolation) have different effect on isotopes in soil water, equations that conserve mass and isotopes can be used to quantify these fluxes. In this study, this type of mass balance calculation was used estimate fluxes from the soil at a dry and a wet site in the rainshadow of the Cascade Mountains during three hydrologic seasons: 1) In late Summer to Fall, evaporative losses at both sites are similar while non-fractionating losses are approximately four times higher at the wetter site than at the drier site (near zero). 2) During Spring snowmelt, non-fractionating losses at both sites are dominated by downward percolation of recharge water. Evaporation at the drier site is near zero, while at the wetter site, the evaporation rate is comparable to the rate of non-fractionating loss. 3) In mid to late Spring, soils begin to dry, largely through high rates of transpiration. At both sites, the rates of non-fractionating loss are similar to that during recharge. Evaporation rates at the drier site are higher than during the recharge period, although still considerably lower than the evaporation rate at the wetter site.

The usefulness of this isotope mass balance approach is that it provides an estimate of the relative contribution of evaporation and transpiration in the soil water budget during the different hydrologic seasons. In this case, we have found that during the spring, evaporation rates are higher and evaporation is a larger proportion of the total output of water from soils at the wetter of two sites along a climate gradient, contrary to what one might expect based on regional free water evaporation estimates. However, in the fall, evaporation at the two sites is similar and it appears that plants at the drier site draw very little moisture from the soil. These results are compared to those at more sites along a climate gradient to determine the extent to which these trends in seasonal partitioning between evaporation and transpiration are controlled by climate.

Climate Change and the Anticipated Impacts on Pacific Northwest Groundwater Supplies

Matt Bachmann, USGS

Climate change projections for the Pacific Northwest suggest that the current trend towards warmer temperatures will continue to alter long-term and seasonal streamflow rates in ways that have been well documented, but the impact on groundwater supplies has been less well studied. Synthesized results from several USGS groundwater models for the region suggest that aquifers are vulnerable to different stressors than rivers and streams, and that the consequent exchange of water between surface and subsurface water supplies negatively impacts both, at different time scales. USGS groundwater models that simulate integrated groundwater response scenarios accounting for changes in precipitation patterns, air temperature, and water-use rates, demonstrate the combined impact of these stressors on regional groundwater aquifers.

The models indicate that a warming climate increases evapotranspiration rates to a degree that alters groundwater recharge more significantly than the forecasted changes in precipitation rates and patterns. Shallow aquifers are most vulnerable to this effect in the short term. Increased crop water demand resulting from a warmer climate is likely to increase groundwater extraction rates, and groundwater models demonstrate that seasonal pumping of irrigation water has a long-term cumulative effect on water levels in deep aquifer units. Basins draining into Puget Sound are expected to see minimal changes in groundwater levels in nearshore environments where groundwater outflow is dominated by submarine groundwater discharge. High altitude basins, which currently are expected to see reduced streamflow due to diminishing snowpack, will also see additional streamflow losses due to stream leakage into groundwater induced by declining shallow groundwater levels.

Groundwater discharge temperature under altered climate conditions: New analytical solutions to estimate the magnitude and timing of changes in temperature of groundwater discharge

Erick Burns, USGS
Yonghui Zhu, China University of Geosciences, Wuhan, PR China
Hongbin Zhan, Texas A&M University
Michael Manga, University of California-Berkeley
Colin Williams, USGS
Steven Ingebritsen, USGS
Jason Dunham, USGS

Changes in groundwater temperature resulting from climate-driven boundary conditions (recharge and land surface temperature) can be evaluated using new analytical solutions of the groundwater heat transport equation. These steady-state solutions account for land-surface boundary conditions, hydrology, and geothermal and viscous heating, and can be used to identify the key physical processes that control thermal responses of groundwater-fed ecosystems to climate change, in particular (1) groundwater recharge rate and temperature and (2) land-surface temperature transmitted through the vadose zone. Also, existing transient solutions of conduction are compared with a new solution for advective transport of heat to estimate the timing of groundwater-discharge response to changes in recharge and land surface temperature. As an example, the new solutions are applied to the volcanic Medicine Lake highlands, California, USA, and associated Fall River Springs complexes that host groundwater-dependent ecosystems. In this system, high-elevation groundwater temperatures are strongly affected only by recharge conditions, but as the vadose zone thins away from the highlands, changes to the average annual land surface temperature will also influence groundwater temperatures. Transient response to temperature change depends on both the conductive timescale and the rate at which recharge delivers heat. Most of the thermal response of groundwater at high elevations will occur within 20 years of a shift in recharge temperatures, but the lower-elevation Fall River Springs will respond more slowly, with about half of the conductive response occurring within the first 20 years and about half of the advective response to higher recharge temperatures occurring in approximately 60 years.

Historical Trends in Spokane River Seasonal Low Flows: The Relative Influences of Changes in Water Demands, Water Sources, and Watershed Hydrology

John Porcello, GSI Water Solutions
Jacob Gorski, GSI Water Solutions
Walter Burt, GSI Water Solutions

In recent years, much attention and discussion has occurred in the Spokane Valley of eastern Washington and the Rathdrum Prairie of northern Idaho regarding continued declines in the seasonal low flows of the Spokane River. A consortium of local water providers (the Spokane Aquifer Joint Board) funded a phased study in 2015 and 2016 that examined four factors controlling the river's seasonal low flows: 1) the timing and amount of seasonal and long-term changes in regional groundwater pumping and groundwater levels; 2) the rates and timing of releases from Post Falls Dam at the river's headwaters; 3) the timing of recharge events in the river reach below Post Falls Dam; and 4) inflows from the river's contributing watershed. Using data as far back as the early 1900s, signal-processing and statistical techniques were applied to the body of data that exists on past and present water demands, water uses, and the natural hydrologic processes occurring in groundwater and surface water. In the first phase of the data analysis process, the study identified four types of changes during the past six decades that should be benefitting the river's flows: (1) the lack of appreciable declines in precipitation, groundwater levels, and releases from Post Falls Dam; (2) a shift from direct surface water diversions to solely groundwater use; (3) a decrease in total water use as some agricultural lands have been retired and converted to municipal use; and (4) an accordant and substantial reduction in per-capita water use since the mid-1980s. Because the first phase of the study found that declines in seasonal low flows were continuing in spite of these positive changes, a second phase of the study was initiated to examine conditions in the Spokane River's contributing watershed. This phase of the study examined snowpack and temperature data from SNOTEL snow monitoring stations within the watershed. The SNOTEL data show increases in air temperatures and decreases in snow-water equivalent values in the middle and upper elevations of the contributing watershed, particularly during this century. While it is generally known that reduced snowpack results in lower summer flows in some river systems, this study empirically demonstrates that the continued decline in the Spokane River's seasonal low flows is directly (and most strongly) related to a decreasing snowpack within the upstream watershed (arising from climate change and/or decadal oscillations in climate) rather than the small (if any) concurrent changes that have occurred in annual precipitation volumes and surface and groundwater management activities within the Spokane Valley and the Rathdrum Prairie.

Planning for the unknown; a numerical modeling approach to developing water management strategies for a changing climate

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

The Walla Walla Basin, located in Eastern Oregon and Eastern Washington, USA, faces challenges in sustaining an agricultural water supply while maintaining sufficient flow in the Walla Walla River (WWR) to sustain endangered fisheries. Climate change is likely to affect the available water supply in the Walla Walla Basin, bringing changes in the quantity, timing, and distribution of available water. Management practices such as managed aquifer recharge and canal piping have been implemented with the goal of maximizing in stream flow while maintaining the water supply needed for productive agriculture. These goals require a combination of groundwater and surface water for agricultural water supply to allow for minimum flow requirements in the Walla Walla River to be achieved. The numerical groundwater-surface water model, Integrated Water Flow Model (IWFM), was calibrated to hydrological conditions in the Walla Walla Basin and was applied to evaluate the impact of potential water management scenarios on stream flow and groundwater storage under current climate conditions and potential future climate conditions. The model results are being used to develop water management strategies within the Walla Walla Basin for short term and long term climate conditions with regard to the question: What water management changes are necessary within the basin to support viable fisheries and remain agriculturally productive with decreased snow pack?

Fires, Floods and Dams – Wildfire Hydrology Lessons from the Benson Creek Incident

Martin Walther, Washington State Department of Ecology

In late August 2014, a thunderstorm over the burn scar from the Carlton Complex Fire caused a flash flood in Benson Creek and extensive mudslides throughout the watershed. By the next day, State Highway 153 was closed 6 miles south of Twisp, three of the five Wenner Lakes in Finley Canyon were empty, and dams at the other two lakes had been overtopped. Computer modeling found that this 5-year rainfall event on the burned watershed produced peak discharge flows that would exceed those from a 1,000-year event on the pre-fire watershed.

Forest fires can affect burned-area soils by reducing the effective ground cover, reducing the amount of soil structure, and forming water repellent layers that reduce infiltration. These changes result in both increased runoff volumes and faster runoff response, such that the post-fire peak discharges can be an order of magnitude or more larger than pre-fire runoff flows, especially in the first couple years after the fire.

Part of Dam Safety's investigation of the Benson Creek flood examined calculation procedures from the U.S. Forest Service Burned Area Emergency Response protocols. From this, we developed guidance and calculation procedures that hydrologists may use to perform hydrology calculations for burned watersheds. Increasing this capability among the state's hydrologists and engineers should improve our state's resiliency in responding to wildfires.

Using a Groundwater Model to Assist in the Design of Howard A. Hansen Dam Drainage Tunnel Rehabilitation

Li Ma, PhD, LHG, Shannon &Wilson
Sharon Gelinas , USACE, Seattle, WA

Howard A. Hansen Dam (HAHD) is located on the Green River, approximately 16 miles northeast of Enumclaw, Washington. It was built between 1958 and 1962 as a flood control project with a secondary purpose of water storage for the City of Tacoma. The US Army Corps of Engineers recognized seepage through the right abutment shortly after the original dam design studies were completed. In 1969, a drainage tunnel and a series of horizontal drains within the right abutment were installed to control seepage and stabilize the downstream side of the right abutment.

Following the record flood pool in January 2009, conditions were observed that could be indicative of the initiation of internal erosion/piping in the right abutment. Rehabilitation of the drainage tunnel was selected as an interim risk reduction measure for HAHD. Flow to the drainage tunnel is influenced by the pool elevation, preferential pathways in the landslide material, and precipitation. A 3-D MODFLOW model was developed to assist in the design of a more efficient drainage system to reduce the potential for soils piping while maintaining groundwater pressure relief in the right abutment. The model simulated a complex hydrogeologic system, including landslide deposits with highly variable permeability and preferential flow pathways, groundwater and surface water interaction, and multiple drainage systems. The calibrated model was used to estimate groundwater flows to the drainage system (tunnel and wells) that might occur at different pool levels. Maximum predicted tunnel flows were then used to design the new tunnel drain alternatives. Drainage tunnel rehabilitation was designed to accommodate the model predicted potential maximum flows of 2,500 gpm. Several design alternatives were evaluated using the calibrated groundwater model. The selected design included 23 6-inch horizontal drains drilled from the upstream side of the tunnel and 26 18-inch-diameter vertical boreholes drilled from ground surface through the existing tunnel to the top of the aquitard.

Managing Unstable Slopes in a High Precipitation Environment

Marc Fish, WSDOT
Samuel Johnston, WSDOT
Jaime Delano, WSDOT
Tracy Trople, WSDOT

A 25-mile-long stretch of US101 between the cities of Raymond and Aberdeen was constructed over weak marine sedimentary rocks during the early 20th century utilizing techniques that are no longer considered standard practice. The average precipitation along this section of highway is about 83 inches per year and precipitation through the winter months is approximately 5 times higher (45 inches versus 9 inches) than through the summer months. Every winter, this high level of precipitation leads to elevated ground water levels beneath and adjacent to US101; contributing to the numerous unstable slope issues that the Washington State Department of Transportation (WSDOT) manages along this section of highway. Recently installed geotechnical instrumentation has revealed that high winter precipitation, in conjunction with elevated groundwater levels, has led to ground movement and reduced slope stability at a large deep seated landslide near mile post (MP) 79. Also, a recently deployed array of single frequency global positioning systems (GPS) was deployed on a deep seated landslide near MP 73 to measure ground surface movement in near real-time. The array was successful in detecting vertical and horizontal displacements at thresholds of less than ½ inch in magnitude and transmitting the data back to the office. WSDOT anticipates being able to utilize similar GPS arrays as an inexpensive early warning system for unstable slopes that exhibit the potential for sudden movement (i.e. MP 73 and 79 landslides). This presentation explains how high precipitation and elevated groundwater levels contribute to slope instabilities along this 25-mile-long section of US101. It describes how WSDOT manages these known unstable slopes and the challenges they face while working inside the confines of an established highway maintenance and preservation program. Although unstable slope remediation can be expensive along this section of highway, WSDOT has both successfully and unsuccessfully created new highway alignments, constructed dewatering systems, and has built shear key-buttresses for several known unstable slopes. Other less permanent options that WSDOT routinely employs to maintain this section of highway include debris clean-up, crack sealing, highway leveling and paving, and instrumentation monitoring.

Geophysical characterization and monitoring of earthen dams

Nigel Crook, hydroGEOPHYSICS, Inc.
Shawn Calendine, hydroGEOPHYSICS, Inc.
Marc Levitt, hydroGEOPHYSICS, Inc.
Chris Baldyga, hydroGEOPHYSICS, Inc.

The monitoring and maintenance of earthen dams is an ongoing and critical process to ensure the integrity of these structures, especially with the aging nature of many of these structures. Nearly 20% of U.S. dam failures have been attributed to piping and seepage. All earthen dams have some degree of seepage, resulting from water percolating slowly through the dam and its foundation. If this becomes uncontrolled it can lead to rapid failures in dam integrity, with seepage typically occurring around dam infrastructure, through animal burrows, and cracks in the dams. Many monitoring procedures rely on visual cues, or from point source monitoring wells or drains, or invasive drilling or trenching procedures. Geophysical methods present non-invasive, high resolution, spatially continuous survey and monitoring tools enabling a cost-efficient and rapid evaluation of seeps or monitoring structures over time. The electrical resistivity method is well suited to such applications, with the resistivity of materials being highly dependent on soil moisture. We present several case studies involving the use of the electrical resistivity method to track and source seepage through earthen dam structures in WA.

Potential Impacts of Groundwater Discharge to the Pelton Round Butte Hydroelectric Project Waterbodies

Catherine Yonkofski, PNNL
Wenwei Xu, PNNL
Tarang Khangaonkar, PNNL

Pacific Northwest National Laboratory is working with Portland General Electric Company to improve temperature control of discharge through the surface water withdrawal operation at Lake Billy Chinook. The Pelton Round Butte (PRB) Hydroelectric Project on the Deschutes River consists of three hydropower generating dams that impound three reservoirs: 1) Lake Billy Chinook (Round Butte Dam), 2) Lake Simtustus (Pelton Dam), and 3) Reregulating Reservoir (Reregulating Dam). To independently validate conclusions recently reported by Xu and Khangaonkar, (2015) that groundwater discharge is acting as a source of heat to the PRB waterbodies, estimates of key heat flow parameters were made through a thorough literature review of the groundwater flows in the region. The objective of this study was to consolidate existing literature and recorded groundwater data to complete a preliminary quantification of groundwater heat flows into PRB waterbodies. To support this work, we reviewed the hydrologic setting, geologic and hydrogeologic properties, and local and regional subsurface thermal behavior about the study area. Following the hydrologic review, a simple conceptual model was built to perform a heat balance over the system. This poster presents findings from literature organized into relevant scopes to understand the groundwater flow system and solve for key components of groundwater discharge and subsequent heat flow equations.

Evaluation of Computational Approaches for Delineating Boundaries of Aquifer Exemptions

Catherine Yonkofski, PNNL
Inci Demirkanli, PNNL

We demonstrate a scientific and data-driven methodology for delineating boundaries of portions of drinking water aquifers to be exempted from protection under the Safe Drinking Water Act (SDWA) for operations, such as oil or gas development, waste injection, or subsurface mining. Operations that directly utilize underground sources of drinking water (USDW) as the operating reservoir differ significantly from other subsurface operations where there is typically a physical boundary or separation between the operating reservoir and drinking water resources. Therefore, it is important that the boundaries of the exempted portions of the aquifers are determined based on scientific analyses to ensure ground water protection. The purpose of this research is to develop a product that could be used by decision-makers to support planning and/or overseeing of such operations, and, simultaneously, ensuring the protection of ground water resources. Furthermore, this research raises awareness on the various uses of drinking water aquifers for competing needs. Resultant methodologies have the potential to become the basis of a user-friendly analysis tool.

Estimating Global Groundwater Resources

Catherine Yonkofski, PNNL
DJ Watson, PNNL
Mohamad Hejazi, PNNL/JGCRI

We present a methodology for global groundwater assessment and valuation to facilitate the discussion around what circumstances permit deep, potable groundwater to serve as a feasible alternative resource for drinking water or agriculture. This was ultimately achieved by incorporating non-renewable groundwater extraction cost-curves into the Global Climate Assessment Model (GCAM). Preceding that, aquifer properties from previous studies were combined to estimate the volume of groundwater available on a global scale. Results fell within range of previously reported values between 1 and 60 million km^3. Then a framework was created defining a cost function based on an analytical GW flow solution. Unit costs reflected the cost of electricity and well drilling/installation. Results showed agreement to groundwater unit cost estimates from other methods on a smaller scale, at which point, the analysis was applied on a global scale. Variations of constraints on well placements and yields allow for some uncertainty analyses of resultant unit costs. Overall this study provides spatial and temporal estimates of unit costs and volumes producible at a river basin scale across the world for the first time.

Understanding the Whatcom County vs. Hirst, Futurewise, et al. decision

Noel Philip, Department of Ecology

A recent State Supreme Court ruling affects counties' responsibilities under the Growth Management Act (GMA) to review permit-exempt (e.g. household) wells for building permits. The decision changed how counties decide to approve or deny building permits that use wells for a water source. The Department of Ecology is providing technical assistance to counties as they determine their next steps. Ecology is also answering questions from the well drilling community and connecting people to their local county government.

In 1985, Ecology adopted an instream flow rule for the Nooksack River (WAC 173-501). This rule closed most streams in the watershed to new, permitted water uses in order to protect stream flows needed for fish. Ecology's longstanding interpretation of the rule has been to allow for permit-exempt wells in most of the watershed. Whatcom County had aligned local regulations of permit-exempt wells to this interpretation of the instream flow rule. Ecology filed an amicus brief in support of Whatcom County to accompany the legal challenge of the county's land-use plan.

In Whatcom County vs. Hirst, Futurewise, et al., the Supreme Court ruled the county failed to comply with the Growth Management Act (GMA) requirements to protect water resources. It asks the county to go beyond Ecology's instream flow rule for the Nooksack River when proving legal availability of water for rural development.

Key findings from the case include ruling Whatcom County's comprehensive plan and zoning code fail to comply with the GMA requirements by allowing approval of subdivisions and building permits relying on permit-exempt wells in areas closed to new water uses under the Nooksack rule. Additionally, the court held GMA provisions requiring protection of water resources in land-use planning and permitting by counties necessitates protection of instream flows from impacts of permit-exempt wells.

The case directly relates to Whatcom County but appears to set legal precedent that applies in other counties where there are instream flow rules that were not intended to regulate permit-exempt water uses. It is unclear how the decision affects areas of the state where there are no instream flow rules.

With counties interpreting and applying the court case differently, there are many questions regarding the ruling's effect on property owners, other counties, and the drilling industry. This outreach is an attempt at providing clarity around Ecology's role in this complex issue.

Developing Conditional Points of Compliance at MTCA Sites Where Ground Water Discharges to Surface Water

Mark Adams, Department of Ecology
Jerome Cruz, Department of Ecology
Hideo Fujita, Department of Ecology

Establishing a location for measuring compliance with ground water cleanup levels under the Model Toxics Control Act (MTCA) can be confusing from a regulatory standpoint and challenging from a hydrogeologic standpoint, especially in a shoreline setting. The location for measuring compliance in MTCA is termed the Point of Compliance (POC), and two kinds of POCs are provided - standard and conditional. Conditional POCs are often needed for shoreline settings where ground water is discharging to surface water. The Washington State Department of Ecology (Ecology) has prepared draft regulatory guidance on when conditional POCs can be set and where they can be located in this setting.

The Role of Directional Drilling in Slope Failure Mitigation

Michael Lubrecht, Directed Technologies Drilling, Inc.

Natural slope failures precipitated by excess groundwater pore pressure are common in the Pacific Northwest, and the potential for catastrophic failures of engineered slopes associated with mine tailings, coal ash retention ponds, and other infrastructure has been recognized at the national level. Dewatering of these slopes is an important mitigation tool, however maintaining the safety of workers, downstream inhabitants, and adjacent properties while installing drains or wells can be problematic using conventional means.

Recent advances in the design and implementation of drainage systems using directional drilling provides another solution to these dewatering efforts. Recent dewatering projects using horizontal wells in Maine and Wisconsin have direct application to Northwest situations; with significant local expertise in this field, directional drilling for slope stabilization should be considered for non-routine drainage projects.

Uranium occurrence in groundwater in northeastern Washington State

Sue Kahle, USGS
Theresa Olsen, USGS

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

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

This poster presents an investigation aimed at improving the understanding of the occurrence and distribution of uranium in groundwater in northeastern Washington. Specific objectives of the investigation include: (1) compiling existing geologic, hydrogeologic, and radionuclide information for northeastern Washington State, (2) converting available data sets to GIS format, (3) preparing maps of available data sets in order to identify areas of known MCL exceedances of uranium in groundwater and to evaluate data gaps, (4) obtaining reconnaissance uranium-concentration data for selected wells (~20 wells) in areas without data, and (5) preparing and publishing a USGS Scientific Investigations Map summarizing available data, data gaps, and suggestions for further study in order to understand the occurrence and distribution of uranium and in groundwater in northeastern Washington State.

Snohomish Arsenic

Mike Young, Snohomish Health District

Arsenic has had a long notorious history in Snohomish County. Arsenic was originally found in the gold mineral deposits of the Cascade Mountains and later rediscovered in contaminated soil at the former smelter site. At the end of the 19th century the Everett Smelter was becoming the largest commercial producer of arsenic in the world, now in the 21st century, work is still ongoing with this legacy contamination. A study of arsenic in groundwater was done in the 1990's after a well with extremely high arsenic was discovered in the foothills between the historic smelter and the mining area. However, arsenic can be found occasionally in wells throughout the county and testing is required for all new wells. This talk will summarize the history and provide a summary of new information from the USGS about the fate of arsenic in glacial aquifers, which will show the need for continued surveillance of groundwater.

Applying Geospatial Tools during Conceptual Site Model Development at the Former Boise Cascade Mill, Yakima, Washington, USA

Matthew Durkee, WA Dept. of Ecology

Geospatial tools such as GIS and surface modeling software provide a relatively quick method to model contamination concentrations and to develop user friendly site maps displaying this data. Other useful information such as plume footprint volumes can also be estimated. ESRI ArcGIS Geostatistical Analyst and Goldensoftware's Surfer were employed to develop these types of products using existing groundwater monitoring data for the Boise Cascade Mill cleanup sites. The data was previously submitted to the Washington State Department of Ecology following a number of studies by different environmental consultants and is available to the public.

The former Boise Cascade Mill site is located in northeast Yakima, Washington and covers an area of over 200 acres. A lumber mill operated from 1903 to 2006 and the facility is currently considered a brownfields site. A log pond located on the southern portion of the facility was drained in ~1963 and was filled with municipal solid waste for ~10 years. This unregulated landfill has been designated as a separate cleanup site by the Washington State Department of Ecology. Future cleanup of these sites will both protect human health and the environment, including receptors such as the Yakima River, and provide an economic boost to the community as the area is redeveloped into a mix of new land uses including eventual construction of a new major transportation corridor bisecting the sites.

Decomposition of large amounts of wood waste and municipal solid waste has led to a reduction of dissolved oxygen in the groundwater. The reducing conditions allow for metals, including arsenic, manganese, and iron, to precipitate into the groundwater over a wide area covering much of the 200 acres and beyond. Low pH in groundwater and elevated levels of sodium were also mapped for a portion of the area. Of the nine methods available in the ArcGIS Geostatistical Analyst, Kernel Smoothing, Inverse Distance Weighting, and Kriging/CoKriging provided the most representative groundwater elevation and contamination concentration contours. Data gaps in the well network for future investigation were also identified.

King County Groundwater Program - Vashon-Maury Island Volunteer Data: Assessment and Update

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 2017, four of these volunteers will be starting their 17th year of self-monitoring. These records are some of the longest water level data for Vashon-Maury Island.

Data from these volunteers monitor three different aquifer zones of Vashon-Maury Island. Three of the sites show seasonal variability of water level data up to 10 feet, while the other two sites have little to no annually change. Decreasing and increasing water level trends are present for a few sites. Water usage, to date, ranges from less than 30 gallons per day (GPD) to over 1,000 GPD per connection. As expected, more water is consumed during dry periods and less water during wet periods.

This poster is an update from previous work and shows that volunteer data can be a valuable asset with dedicated (self-motivated) participants. 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.

Comparison of the Chemical and Isotopic Composition of Groundwater and Surface Water in the South Sound Region, Washington

Andrew Oberhelman, University of Puget Sound
Jeffrey Tepper, University of Puget Sound

Water analyses of lakes in the South Puget Sound region (SPSR) collected by University of Puget Sound students over the past ten years reveal that each of the dozen lakes studied is chemically distinct, and that these data define linear arrays on element-element variation plots suggesting these lakes are mixtures of chemically distinct water sources. The primary goals of this project are to: (1) determine if observed chemical variations in the lakes can be explained by mixing and if so whether variations reflect different proportions of groundwater inflows, different compositions of groundwater inflows, or both, (2) explore the influence of shallow aquifer mineralogy on SPSR groundwater chemistry, and (3) identify regional patterns in groundwater chemistry.

Between May – August, 2016, a total of 54 samples of surface water (S) (streams and lake surfaces), groundwater (GW), precipitation (P), and shallow interflow (SI) were collected and analyzed for major and trace element concentrations plus δ18O and δD isotopic compositions. Variation diagrams for conservative elements (Ca, Na, Mg, Cl, and SO4) display linear trends analogous to those previously observed for lake water samples. These linear trends can be modeled as mixtures of a dilute component (e.g. rain), and a high concentration component (e.g. groundwater). A simple mass balance model utilizing Ca, Mg, Na, Cl, and SO4 concentrations was used to obtain semi-quantitative estimates of the proportions of water sources in four lakes: Gravelly (GW 63-88%, P 8-11%, SI 5-24%), Steilacoom (GW 10-14%, P 10-12%, SI 9-11%, S 60-80%), Spanaway (GW 25-56%, P 12-20%, SI 20-30%, S 15-20%), and Waughop (GW 47-61%, P 43-47%). These results are consistent with the proportions of lake inputs inferred from variation diagrams and with qualitative estimates of lake water sources from the literature. At Gravelly and Steilacoom lakes, where sufficient isotope data were available, similar proportions of sources are also obtained using O and H data.

Water samples from aquifers A1 (0-50ft), A3 (90-225ft), and C (300-500ft) overlap significantly in major ion and O/H isotopic compositions. Isotopically, samples from the three aquifers cluster along the regional meteoric water line (Sánches-Murillo et al., 2015) indicating that each aquifer contains modern meteoric water. For most parameters intra-aquifer chemical variations obscure any inter-aquifer chemical differences. However, samples from the A3 aquifer have the highest average alkalinity and the highest average major ion concentrations. The only exception is silica, which is most concentrated in the C aquifer with an average concentration of 15.1±1.7 ppm, while the aquifers A3 and A1 have average silica concentrations of 13.7±4.5 and 7.89±3.2 ppm respectively.

Groundwater Recharge Estimates Using the Soil-Water Balance Model ; Chambers-Clover Creek Watershed and vicinity, Pierce County, Washington

Wendy Welch, USGS

In 2014, the U.S. Geological Survey (USGS) Washington Water Science Center began a project to update the numerical groundwater-flow model of the Chambers-Clover Creek Watershed (CCCW) and vicinity. The project area is located in the southern Puget Sound Lowland of Pierce County and is approximately 500 square-miles and underlain by a thick sequence of unconsolidated glacial and interglacial deposits. Among other model refinements, the groundwater-flow model will be updated to include the following recently available data: monthly groundwater levels (2010 – 2015), streamflow, water use and recharge estimates.

Groundwater recharge is an important but difficult-to-estimate boundary condition for calibrating groundwater models, and several methods can be used to calculate it. For this project, the spatial and temporal distribution of recharge from precipitation was calculated using the Soil-Water-Balance (SWB) model (developed by the USGS). The SWB computer code calculates recharge at a daily timestep by using gridded and tabular inputs including: climate (precipitation and air temperature), land use, hydrologic soil group, flow direction and soil-water capacity. Calculations are made for each cell of a rectangular grid which can be imported directly into the groundwater-flow model. Results of the CCCW SWB model will be compared to recharge for the project area previously estimated by applying precipitation-recharge relations developed for Washington State.

Estimated Public Water Supply Withdrawals in Washington, 2015

Ron Lane, USGS Washington Water Science Center

Water use in the State of Washington has evolved in the past century-and-a-half from meager domestic and stock needs to the current complex demands for public-water supplies, domestic use, large irrigation projects, industrial plants and numerous other uses. This poster provides estimates of water withdrawn or diverted by Group A Public Water Supply systems in Washington State in calendar year 2015, presented by Water Resource Inventory Area (WRIA).

Characterizing Ground-Water Flow Velocity and Preferential Flow Zones

Jerome Gogue, Regional Manager at Geotech Environmental Equipment, Inc.
Rob Gingell, Geotech Environmental Equipment, Inc.

Accidental spills and leaks associated with normal operations have resulted in significant sub-surface contamination at many facilities. Assessment of contaminant transport potential is critical for site characterization. Data acquired may be used to quantify heterogeneities and dispersion – parameters necessary to estimate the extent and magnitude of underlying contaminants, define exposure routes and assess risks.

Accurately measuring groundwater flow velocity has been a goal of researchers for a number of years, particularly with the increased emphasis on subsurface transport processes at hazardous waste sites. Conventional methods have relied on estimates of hydraulic conductivity and calculations to estimate seepage velocity in the aquifer. Methods that stress the aquifer such as bail, slug, or pumping tests have been used for years to estimate aquifer hydraulic conductivity. Borehole flow meters can be used to evaluate the hydraulic conductivity of individual zones in test wells. Unlike previous attempts to determine ground-water velocity in a well, the colloidal borescope provides a direct field measurement of the water velocity in a well. By directly observing naturally occurring particles that are advected by ground-water movement, it is possible to relate flow in a well bore to the surrounding porous media.

Naturally occurring colloids exist in groundwater and by definition are neutrally buoyant. Therefore, colloids being carried by the natural groundwater can be observed/measured and a groundwater velocity and direction obtained. By plotting the trajectory and speed of a colloidal particle relative flow direction can be determined. The equipment for doing this type of characterization will be discussed. Equipment will be demonstrated and available for hands-on viewing.

Calibration of a Hydrologic and Stream Temperature Model to the Nooksack River Basin for Climate Change Modeling

Stephanie Truitt, Western Washington University
Robert Mitchell, Western Washington University
John Yearsley, University of Washington
Oliver Grah, Nooksack Indian Tribe

The Nooksack River in northwest Washington State provides valuable habitat for endangered salmon species, as such it is critical to understand how stream temperatures will be affected by forecasted climate change. Several factors affect stream temperature, including climate, topography, channel morphology, and vegetation. Stream temperature is also strongly influenced by hydrologic conditions which are sensitive to climate change in the Nooksack basin. In the Pacific Northwest, average annual air temperature is expected to increase along with winter precipitation, while summer precipitation is projected to decrease over the next century. Modeling studies in the upper Nooksack basin indicate a reduction in snowpack and spring runoff, and a recession of glaciers into the 21st century. How stream temperatures will respond to these changes is unknown. We use the Distributed Hydrology Soil Vegetation Model (DHSVM) coupled with a glacier dynamics model and the stream temperature model, RBM, to simulate hydrology and stream temperature from present to the year 2100.

We calibrate the DHSVM-RBM to the upper 1550 km^2 of the Nooksack basin, which contains an estimated 3400 hectares of glacial ice. We employ observed stream-temperature data collected over the past decade and hydrologic data from the four USGS streamflow monitoring sites within the basin and statistically downscaled observed climate data developed by Linveh et al. (2013). We conducted field work during the summer of 2016 on a subset of tributaries, measuring channel morphology and streamflow to estimate the Leopold parameters, the parameters that describe the relationship between channel depth and velocity. Air temperatures from both the Linveh and PRISM climate datasets were used along with observed stream temperature data collected by the Nooksack Indian Tribe to estimate the relationships between water temperature and air temperature. These relationships are used to specify the initial stream temperatures of the headwaters. We will present our methodology and calibration results, and the framework for futuristic modeling using downscaled data from global climate models.

Hydrogeologic Framework and Numerical Simulation of Groundwater Flow in Bellevue, Washington

James Bush, University of Washington

Though the city of Bellevue, Washington is the fifth-most populous and fourth-fastest growing community in Washington, groundwater studies encompassing the city are noticeably few. Population growth, urban development, and recent drought have highlighted the need for a more detailed and comprehensive understanding of Bellevue's groundwater system. In response, this study developed a conceptual hydrogeologic model and numerical groundwater flow model of Bellevue and its immediate vicinity.

The numerical model was implemented in MODFLOW 2005, and focuses on the unconsolidated sediments present in the study area. The model domain covers the Bellevue city limits and adjacent areas between Lake Sammamish and Lake Washington.

Hydrograph Baseflow Separation with 15 Minute Data, R, and Patience

Nathaniel Kale, Thurston County

To estimate baseflow at a gage in the Chehalis River, we used the R Statistical Computing language (R) to clean up and homogenize 15-minute and hourly discharge data, then simulate hundreds of possible baseflow separation scenarios and pick the best fit with the help of a simple goodness-of-fit function.

Separating baseflow from surface runoff, quickflow, or interflow with only mixed 15-minute and hourly discharge data is difficult. Several methods have been proposed, including recession curve, straight-line, and digital signal filter. We chose to use the digital signal filter, which has support in the scientific literature and is widely used.

Filter analysis requires daily discharge data over at least a year, but our data was mixed 15-minute and hourly data, with multiple missing days. We wrote a function in R to calculate daily total discharge, and to fill in missing data via linear interpolation.

The equation for digital filtering includes two user-specified constants – a 'filter parameter', and a number of passes (1-3). We generated hundreds of combinations of these two values, and created baseflow separations for every combination. Because we did not have the data to test our baseflow separation empirically, these hundreds of scenarios allowed us to do the next-best thing – use best professional judgment to pick among many options.

We needed a way to compare many baseflow scenarios that was more efficient than visually comparing hundreds of hydrographs. We came up with a way to generate a single number to compare scenarios. We wrote a goodness-of-fit function that split the hydrograph in half by total volume of water, then compared volumes of baseflow between the two halves. Baseflow scenarios with similar total volumes between the two halves of the hydrograph were considered better scenarios than those with dissimilar values.

Using R made this approach possible. It enabled us to leverage up to date scientific research through predefined software packages, clean and reformat data, quickly generate hundreds of scenarios, create a custom (and customizable) function for evaluating goodness-of-fit, graph the many possible scenarios, and quickly identify problems with the analysis and fix them.

Hydrologists need all the tools they can get to support hydrograph separation, particularly in the absence of empirical data. Generating many scenarios and evaluating them by splitting the hydrograph can provide additional valuable insight for applying best professional judgment.

Examining the Potential Effects of Forecasted Climate Change on Sedimentation in the Nooksack River Basin

Kevin Knapp, Western Washington University
Robert Mitchell, Western Washington University
Oliver Grah, Nooksack Indian Tribe

The Nooksack River originates on the north and western sides of Mt. Baker in the North Cascades of Washington State and discharges into Bellingham Bay in the Salish Sea. Because the Nooksack River is a critical water resource and provides valuable habitat for endangered Pacific salmon species, it is important to understand how the basin responds to future climate change. Due to the regional maritime climate, the Nooksack basin is highly sensitive to increasing temperatures. Climate change modeling studies in the basin indicate that as forecasted temperatures increase near the end of the century, the winter snowpack will decrease and be largely restricted to regions above 1100-1300 meters, about 500 m above historical averages. With more basin area snow-free and exposed to rainfall in the winter, runoff will increase and consequently raise the mass-wasting risk during the winter months and sediment delivery to streams. Our goals are to assess the increased risk by examining these high relief portions of the basin where steep slopes, young geology, and exposed glacial moraines contribute to high sediment yields.

As a first order assessment, we identify areas at risk of slope failure using an ArcGIS based non-probabilistic infinite slope model along with digital soil and vegetation grids and a newly developed LIDAR coverage for the upper Nooksack basin. Regions at risk are further analyzed with the Distributed-Hydrology-Soil-Vegetation Model (DSHVM), coupled with an infinite-slope failure model to determine the probability of shallow mass-wasting events for a variety of hypothetical storm events. The infinite-slope model is dependent on the DHSVM-simulated hydrology and soil moistures and uses a stochastic approach to predict the probability of slope failure on a cell-by-cell basis. We also compare historical turbidity and discharge relationships at USGS stream gauges, specifically during the warm 2015 water year when snowpack was restricted to higher elevations exposing more area for runoff. Using turbidity as a surrogate along with paired measurements of suspended sediment concentrations that are correlated to turbidity values, we are constructing sediment transport rating curves to estimate fluvial sediment loads based on futuristic discharges produced by previous climate-change modeling in the basin. We will present methodologies and preliminary results.

Glacial melt and groundwater storage in Washington: Are the possibilities endless?

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

Washington is the most glaciated state in the contiguous US. During the 1950s many glaciers in the Olympic and Cascade Mountains were advancing at accelerating rates. Today, glacier retreat is considered "ubiquitous, rapid, and increasing." Although the state relies heavily on glacial runoff to meet basic water demands, a statewide decrease in glacial volume is expected while climate warms. As areas become ice-free, can some of the meltwater be salvaged and stored in the subsurface? Such groundwater storage would not be a permanent solution to changes in freshwater flows, but might provide a buffer to permit the development of alternative, sustainable solutions. The presentation will explore some of the advantages and disadvantages of subsurface storage to salvage glacial meltwater runoff and speculate where such schemes throughout Washington might work.

Rethinking the Hydrogeologic Conceptual Model of Island County, WA, in order to Evaluate Seawater Intrusion Vulnerability

Chelsea Jefferson, Amec Foster Wheeler

Coastal groundwater aquifers used for water supply are subject to stress from increasing demand as well as the threat of seawater intrusion. Island County, WA, has elevated chloride concentrations in groundwater across central Whidbey Island where most residents rely on private water supply wells. The objective of this study is to rethink Island County's hydrogeologic conceptual model for the purpose of evaluating seawater intrusion vulnerability. The current model favors multiple semi-confined groundwater aquifers. The complexity of this model does not easily lend itself to straightforward assessments of vulnerability to seawater intrusion. Indeed, the method in use for assessing vulnerability uses an empirical correlation of chloride concentrations and water-level elevations. This study simplifies the conceptual model with water-level elevation and pump test data from water well reports. These data are input into ArcGIS in order to perform groundwater basin analysis and to make predictions of groundwater flow and its interaction with seawater. Analytical calculations are then used to evaluate the revised conceptual model.

Integrated Model Calibration - A Framework for Linking Model Calibration, Parameter Uncertainty Analysis, and Model Application

Miao Zhang, Anchor QEA, LLC

A general framework for groundwater model calibration and application is presented, as an alternative to traditional practice. Traditionally, model calibration, parameter uncertainty analysis, and model application are three distinct processes, with no explicit links between them. The so-called "calibrated" model is usually one of many models that can match the calibration targets equally well as a result of inherent non-uniqueness in inverse problems. Parameter uncertainty analysis typically involves adjusting one parameter at a time and comparing the mismatch error against the calibrated model. However, parameter uncertainty is seldom accounted for during model application, which is frequently based on a single deterministic model.

Under the integrated model calibration framework, instead of a single "calibrated" model, multiple models are used in predictive simulation. Although some models match the calibration targets less well than others, they are all used to make predictions. The predictions by these models are weighted by their goodness of fit. Parameter uncertainty is represented by the statistical distribution of parameter values that constitute the majority of the weight. As a result, model predictions are probabilistic, instead of deterministic, which allows the evaluation of risk/cost tradeoff. Examples will be used to demonstrate this framework in practice.

Analysis and Comparison of Puget Sound Lake Sediment

Mitchell Dodo, University of Puget Sound
Jeff Tepper, University of Puget Sound

The Puget Lowlands contain hundreds of small lakes that once originated as kettles. Recent sediment core studies by geochemistry classes at the University of Puget Sound show the composition in these lakes has changed over time, but no studies have compared the chemistry of recent sediment between lakes. This study focused on nine lakes that were sampled between May – August 2016. At each lake, three to five grab samples of surface sediment (~ top 10 cm) were collected from various depths and locations. The samples were fused and dissolved for ICP-ES analysis of major elements and leached with 20% nitric acid to measure labile heavy metals (Pb, Cu, Zn, and As). Loss of Ignition (LOI) and C/N analysis were also conducted to determine the abundance and characteristics of organic matter.

Elemental data for insoluble elements (Ti, Al, Zr, Sr, and Ca) define linear trends on element-element plots that suggest mixing between a clastic and organic component. The proportion of the clastic component appears very homogenous in some lakes, such as Gravelly (ranges from .77-1.07 wt. % Al2O3), but more heterogeneous in others lakes like Waughop (1.55-9.31 wt. % Al2O3) and Killarney (2.7-7.3 wt. % Al2O3). Sediment homogeneity can vary between lakes of similar size, such as Waughop (33 acres, extremely heterogeneous) and Wapato (28 acres, very homogenous), and there appears to be no correlation with depth. C/N data indicate the organic matter in lakes examined is dominated by algal matter (C/N<10) rather than terrestrial plant debris. Much of the heavy metal contamination in these lakes probably came from the former ASARCO Tacoma smelter: lakes farthest upwind from the site (Horseshoe, Crescent) have Pb contents <80ppm, whereas lakes closer and downwind from the site have Pb contents >300ppm. However, the data is indicative of the involvement of more than one source of metal contamination. Six of the lakes have lower Cu/Pb ratios (.08-.41) and lower Cu contents (<150ppm) that can be attributed to the smelter fallout. The other three lakes (Gravelly, Killarney, and Louise) have both higher Cu contents (>150ppm) and significantly higher Cu/Pb ratios (.847-9.348). We attribute these higher Cu contents to past application of CuSO4 as an algaecide.

Overall, this study reveals that even lakes located close to one another and of similar size and origin can display significant differences in surface sediment chemistry. While lake usage history certainly account for some of the differences, the trends observed from sample analysis suggest factors including water sources and watershed urbanization appear to be more important.

The Role of Catchment Soil and Geologic Properties in Governing Mountain Recharge and Streamflow Response to Climate Change

Tung Nguyen, Washington State University
Christina Tague, University of California at Santa Barbara
Jennifer Adam, Washington State University

Mountainous catchments are important sources of water supply for downstream areas, but this water is particularly vulnerable to projected climate change as many of these catchments are snowmelt dominant. Recent regional studies projected climate change to cause decline in snowpack and earlier snowmelt resulting in low summer flow in streams. However, average large scale hydrologic changes to future climate might not be the same at smaller catchment scales, when considering the differences in physical characteristics, such as soil and geology. The aim of this study is to explore how soil and geology-related parameters affect different metrics of climate elasticity of streamflow and recharge across three catchments in the Yakima River Basin in central Washington using a physically based hydro-ecological model, the Regional Hydro-Ecologic Simulation System (RHESSys). Optimal constrained model parameters for each catchment were first determined using a global optimization tool, Hybrid Covariance Matrix Adaptation Evolution Strategy (HCMA) based on published soil, geologic and streamflow data. Using the mean and covariance matrix of parameters obtained from HCMA, a number of parameter sets were randomly generated and subsequently used within the Distributed Evaluation of Local Sensitivity Analysis (DELSA) framework to explore their importance in governing streamflow response to climate perturbation. Our results show that soil and geologic parameters have distinct levels of sensitivities in each catchment. Moreover, the sensitivities of these parameters vary not only with changing temperature and precipitation but also with different metrics of climate elasticity of streamflow and recharge. Importantly, results reveal that dominant parameters also change over time thus choosing the most relevant parameter set for a particular catchment is of great importance for climate change studies. This research could be useful for predicting the responses of ungauged catchment to future changes and provide valuable insights for land and water managers in adapting to climate change at sub-basin scales.

Community scale landslide susceptibility mapping for Washington state counties

Victoria Nelson, Washington State Department of Natural Resources
Yuyang Zou, Washington State Department of Natural Resources
Recep Cakir, Washington State Department of Natural Resources
Ronda Strauch, University of Washington
Christina Bandaragoda, University of Washington
Erkan Istanbulluoglu, University of Washington

Landslide susceptibility maps for the state of Washington are nonexistent on the community scale or largely derived from simplistic methods, such as using slope angles alone. While slope angle is a strong predictor of slope failure, additional factors, including aspect, soil type, land cover and land use, geology, and hydrology, are commonly observed as significant predictors of stability and often used in more precise modeling schemes. A comprehensive approach is needed to more accurately assess risk and improve county mitigation plans on the community scale. As part of FEMA's Risk MAP program, the Washington State Department of Natural Resources (WADNR) identified regions susceptible to deep-seated and shallow landslides. The WADNR employed an analytical hierarchy process (AHP) to derive susceptibility maps for coastal communities from a survey of subject matter experts. A quantitative approach is needed to compare to the results of the qualitative, AHP methodology. Shallow and deep-seated landslide susceptibilities will be presented for Island County, WA using Landlab, an actively maintained, open-source modeling scheme uniquely adapted to the needs of high-resolution Earth surface dynamics investigations. The quantitative and qualitative products derived here will be combined to provide a comprehensive risk assessment for emergency planning and community resilience in Washington state.

Geochemistry and Origins of Thermal Spring Waters of the Olympic Peninsula and Cascade Range, Washington

Jon Golla, University of Puget Sound
Jeffrey Tepper, University of Puget Sound

Across Washington there are 98 low-temperature (~20-50 deg. C) geothermal springs that vary widely in chemical composition. This study focuses on seven sites: two in the Olympics (Olympic complex, Sol Duc) and five in the Cascades (Goldmyer, Carson, Baker, Bonneville, Ohanapecosh), which reflects a broader sampling area. The former are hosted in forearc marine-sediments and the latter in arc volcanics. Major goals of this study are to: 1) compare water compositions of springs hosted in different rock types, 2) estimate reservoir temperatures, 3) determine water sources and extent of water-rock reaction, and 4) develop conceptual models of the geothermal systems.

Water samples were analyzed for major cations (Na, K, Mg, Ca, Si), anions (Cl, SO4, HCO3), trace elements (Li, B, Sr, Fe, Mn, Al), and isotopic composition (18O/16O and D/H). Isotopic data suggest the dominant source of all springs is meteoric water. Cascade waters are consistently more enriched in chemical species and also more heterogeneous compared to Olympic waters. Based on anion abundances, the springs can be tentatively classified into three groups: Cl-dominant mature waters (Carson), Cl-HCO3-SO4-containing intermediate waters (Bonneville, Baker, Ohanapecosh, Goldmyer), and HCO3 waters (Olympic complex, Sol Duc). Three geothermometers were used to estimate subsurface temperatures: empirical silica (chalcedony) and cation (K-Mg) geothermometers yielded temperatures of 50-125 deg. C for Cascade waters and 50-100 deg. C for Olympic waters, similar to results obtained from multiple-minera-equilibration calculations (Cascade springs =50-150 deg. C; Olympic springs =50-70 deg. C) generated by SOLVEQ, a geothermal water speciation program. Mainly, these calculations indicate the spring waters were saturated at depth with a suite of common hydrothermal minerals (albite, chalcedony, kaolinite, muscovite, montmorillonites). Variations of projected geothermometer temperatures from discharge temperatures respectively ranged from +10-100 deg. C and +10-40 deg. C for the Cascade springs and the Olympic springs.

Differences in spring chemistry can be related to two main factors: 1) the presence of a magmatic contribution and 2) the amount of lateral subsurface flow, which influences the anion proportions amongst Cascade spring waters. Cascade thermal springs are most likely situated along outflow zones of volcanic geothermal systems, some with high topographic relief (Bonneville, Baker, Goldmyer, Ohanapecosh) and other with low relief (Carson). In lower relief systems, runoff and lateral flow are diminished, effectively eliminating opportunities to charge the water with SO4 and HCO3, and leading to Cl-dominated waters. Olympic thermal springs are probably part of a fault-controlled geothermal system, whose heat is supplied by a deep, convective circulation. These waters are more dilute because there is no magmatic contribution.

Loss via shallow groundwater of nutrients and major ions from a semi-arid dryland agricultural catchment

Michael Shaljian, Washington State University
C. Kent Keller, Washington State University
Kayla Jones, Washington State University
Erin Brooks, University of Idaho
David Huggins, USDA-ARS, Washington State University

Mineral-derived nutrient cations are essential to fertility, and acidification of soils due to chemical fertilization may result in unsustainable chemical denudation of the soil exchangeable cation pool. Nutrient cations may be leached from soils by the pathways of mineral weathering and losses from the soil exchanger. This study investigated nutrient cation, anion and silica losses for one year in drainage from a semi-arid, rain-fed catchment at the Cook Agronomy Farm (CAF) Long-Term Agroecosystem Research (LTAR) site in southeastern Washington. We measured flows, analyzed drainage samples and estimated hydrologic effluxes of nutrient cations, anions and silica from the catchment. The total dissolved nutrient cation denudation rate at CAF-LTAR is about 40 kg ha^{1} yr^{1}, which is comparable to other catchments on silicate terranes. The 2.1 keq ha^{1} yr^{1} of denuded cationic charge is dominated by Ca2+ (61%) and Mg2+ (35%). Principal counter-ions are HCO3- (43%), NO3- (38%) and SO42- (16%), suggesting that both H2CO3 and HNO3 are important drivers of acidification. A concurrent study compared measured changes to the pool of nutrient cations in the upper 30 cm of the soil exchanger from 2008-2015 and found annualized losses to be approximately equivalent to the 2016 hydrologic efflux. This may suggest that the source of exported nutrient cations in drainage is primarily cation exchange driven by fertilization. The LTAR Observatory Network will support continued long-term hydrologic monitoring in agricultural catchments to better understand the interaction of agroecological practices and nutrient cation depletion on a decadal timescale.

Controls on the distribution of ASARCO heavy metals in Tacoma-area lakes

Angelica Calderon, University of Puget Sound
Jeffrey Tepper, University of Puget Sound

Lake sediments and soils within the South Puget Sound region contain elevated levels of Pb, Cu, As, Zn, and other metals as a result of ASARCO smelting operations in North Tacoma from 1890-1986. While the geographic distribution has been well studied through soil surveys, there has been minimal research seeking evidence regarding the distribution of heavy metals within individual sediment columns. Moreover, previous data collected by Puget Sound students and faculty indicates that sediment profiles within the lakes do not correspond to smelter production history. Analysis of soils found higher levels of Pb and Cu content than expected in sediment deposited in the last 40 years, when it would be expected that these peaks in heavy metals would show up in sediment from around a 100 years ago. Research suggests that this phenomenon occurs due to increases in Fe/Mn ratios indicating some unknown geological mechanism delaying or moving heavy metals up the sediment column. Delayed rises in heavy metals like Pb indicates that there is a change in lake chemistry that could have an impact on heavy metal toxicity in lake sediments.

The Importance of Conducting Groundwater Tidal Influence Studies at Sites near Tidally Affected Surface Water Bodies

Eron Dodak, Integral Consulting Inc.
David Livermore, Integral Consulting Inc.

Many investigation and remediation sites are located near tidally affected surface water bodies, including freshwater, estuarine, and marine environments. Understanding the interaction of surface water body tidal fluctuations on nearshore groundwater zones is necessary to accurately assess the groundwater flow direction and hydraulic gradient, and to develop a robust conceptual site model. Tidal influence studies can be conducted to estimate the mean hydraulic head and vertical and horizontal gradients in wells screened in nearshore tidally influenced aquifers. In addition to calculating the mean hydraulic head over a period of time (typically 2 or 3 days), potentiometric surface trends can be evaluated with longer-term hydraulic head monitoring. This poster presents an overview of a commonly used filtering method (Serfes 1991) to remove diurnal and semidiurnal lunar and solar harmonics from a series of hydraulic head measurements. A case study for a site located at Commencement Bay in Tacoma, Washington, is also presented to illustrate the pitfalls of using the "snapshot-in-time" method to assess groundwater flow directions and hydraulic gradients at sites near tidally affected surface water bodies.

Lidar-based Landslide Inventory in the Puget Lowlands, Pierce County, Washington

Kara Jacobacci, Washington Geological Survey
Kate Mickelson, Washington Geological Survey
Trevor Contreras, Washington Geological Survey
Stephen Slaughter, Washington Geological Survey
Alyssa Biel, Washington Geological Survey

Much of Pierce County is underlain by packages of glacial sediment that are prone to failure. The Washington Geological Survey mapped landslides across Pierce County using high-resolution lidar data. From the landslide inventory, susceptibility and exposure analyses determine areas where the county may want to focus planning efforts. The Washington Geological Survey's inventory reduces the landslide-susceptible area by 51 percent in comparison with Pierce County's existing data.

Stormwater Management Approaches

Monday, May 8, 2017, 9:00 AM – Noon

Urban and suburban land development have caused significant changes in surface runoff patterns and increased concentrations of pollutants. For the past two decades, Washington has been a leader in identifying and requiring new stormwater flow control approaches and treatment techniques. The Washington State University Extension Campus in Puyallup features a variety of stormwater field and bench experiments including permeable pavements, "rain gardens," and toxicity studies. WSU Professors Ani Jayakaran and Jen McIntyre, and USFWS Toxicologist Jay Davis, will demonstrate the stormwater management approaches under study and engage participants regarding appropriate techniques for different hydrogeologic settings.

8:50 AM: Meet in Hotel Murano lobby.
9:00 AM: Vans will depart from in front of the Hotel Murano.
Noon: Arrive back at hotel.

Note: Please dress appropriately for the outdoors.

Contact: Karen Dinicola, kdin461@ecy.wa.gov

Nisqually National Wildlife Refuge

Monday, May 8, 2017, Noon – 5:00 PM

The Nisqually River estuary is located in southern Puget Sound just north of Olympia, Washington. In the early 1900's an earthen dike was built converting a thousand acres of the estuary to agricultural land. In 2009, the dike that had separated the 762 acres of the Nisqually Estuary from the tidal waters of Puget Sound was removed. Since the tidal waters have been restored, the site has been transitioning from fresh water to salt water habitat. This field trip will provide a tour of the wildlife area, and present an overview of the dynamic hydrology and geomorphology shaping this delta restoration project.

Dr. Eric Grossman, Research Hydrologist with the U.S. Geological Survey, will lead the tour and discuss relevant research.

11:50 AM: Meet in Hotel Murano lobby.
Noon: Vans will depart from in front of the Hotel Murano.
5:00 PM: Arrive back at hotel.

Note: Plan on a four mile walk on gravel or muddy trails. Bring rain wear as needed.

Contact: Andy Long, ajlong@usgs.gov, 253-552-1660

W1: Training for Water Rights Analysis – Certified Water Rights Examiners

Thursday, May 11, 2017. 8:30 AM – 4:30 PM, Venice Room 4

This workshop will provide an opportunity to learn more about the application of Water Law in Washington State and a refresher for Certified Water Rights Examiners. In 2010, the Washington State Legislature created the Certified Water Right Examiner Program. Ecology was directed to certify qualified individuals as water right examiners to conduct proof examinations of perfected (fully developed) water right permits and change authorizations.Proof examinations involve review of the associated water right record and performing a field examination of the water withdrawal or diversion works, distribution or transfer system, and the actual water use or uses. The certified water right examiner then prepares a Proof Report of Examination and Recommendations to submit to Ecology for their review and decision-making.This training will cover basic Water Rights Analysis, including:

- Water law in Washington State.
- Measurement of the flow of water through open channels and enclosed pipes.
- Water use and water level reporting.
- Irrigation crop water requirements.
- Aerial photo interpretation.
- Location of land and water infrastructure through the use of maps and global positioning.

Other topics related to the preparation and certification of water rights in Washington State

Instructors:

- Danielle Squeochs, Washington State Department of Ecology, Office of Columbia River, Union Gap, WA
- Scott Turner, Washington State Department of Ecology, Central Regional Office, Union Gap, WA
- Buck Smith, Washington State Department of Ecology, Northwest Regional Office, Bellevue, WA
- John Rose, Washington State Department of Ecology, Northwest Regional Office, Bellevue, WA
- Tyler Roberts, Washington State Department of Ecology, Office of Columbia River, Union Gap, WA

Note: Bring a Wi-Fi ready laptop

Cost: $125.00 *(lunch on your own)*

W3: Unsaturated-Zone Water and Contaminant Transport: A Twenty-First Century Understanding

Thursday, May 11, 2017. 8:30 AM – 4:30 PM, Venice Room 3

Water flow in the unsaturated zone is central to critical issues in many fields, for example agriculture, geophysics, hydrology, soil mechanics, waste disposal, and ecology. Major hydrologic problems such as aquifer recharge and subsurface contaminant transport rely on predictions of how much and how fast water goes through the unsaturated zone. This course examines unsaturated flow and associated contaminant transport from the standpoint of observational evidence, basic theory, and recently developed concepts and models. Diverse cases of unsaturated flow will be considered: diffuse and preferential, explainable and problematic, in soil and in rock. Certain questions will be explored throughout the course: what does the actual evidence support, what can we do with that, and what new techniques and models might be beneficial. Case studies and examples representing diverse climates and settings will be examined and topics will be treated in terms of both practical value and importance to earth science. Quantitative tools will be presented for common hydrologic problems such as estimation of contaminant travel times based on empirical evidence, and aquifer recharge based on water table fluctuations. In-class exercises will provide experience with selected methods of data evaluation for hydrogeologic applications.Water law in Washington State.

Instructor:

- John R. Nimmo, U.S. Geological Survey, Menlo Park, CA

Note: Bring a Wi-Fi ready laptop; a software download will be required for class.

Cost: $125 *(lunch on your own)*

PRESENTER INDEX

PRESENTER INDEX

Name	Email	Title	Session	Page
Dodak, Eron	edodak@integral-corp.com	The Importance of Conducting Groundwater Tidal Influence Studies at Sites near Tidally Affected Surface Water Bodies	Poster	98
Dodo, Mitchell	mdodo@pugetsound.edu	Analysis and Comparison of Puget Sound Lake Sediment	Poster	92
Durkee, Matthew	matthew.durkee@ecy.wa.gov	Applying Geospatial Tools during Conceptual Site Model Development at the Former Boise Cascade Mill, Yakima, Washington, USA	Poster	79
Ferguson, Eric	eric.ferguson@kingcounty.gov	King County Groundwater Program - Vashon-Maury Island Volunteer Data: Assessment and Update	Poster	80
Fish, Marc	fishm@wsdot.wa.gov	Managing Unstable Slopes in a High Precipitation Environment	8A	69
Freshley, Mark	mark.freshley@pnnl.gov	Elements of complexity in subsurface modeling	3A	33
Gallagher, Michael	mike.gallagher@ecy.wa.gov	Lunch Panel: Hirst Decision–Growth Management Act requirement to protect water resources	Lunch Panel	11
Gallagher, Michael	mike.gallagher@ecy.wa.gov	Three recent State Supreme Court Decisions and their impacts on Washington's Water Rights Permitting Future and on Permit Exempt Wells	5B	45
Gariepy, Dan	daga461@ecy.wa.gov	Panel: a focus on the future of stormwater management	4B	10
Gariepy, Dan	daga461@ecy.wa.gov	Western Washington State's Approach to Stormwater for New and Redevelopment Sites	2B	26
Gazis, Carey	cgazis@geology.cwu.edu	Quantifying Evaporation and Transpiration Rates using Stable Isotopes	7A	62
Gibson, Maria	gibsonma@geo.oregonstate.edu	Glacial melt and groundwater storage in Washington: Are the possibilities endless?	Poster	89
Gogue, Jerome	jeromeG@geotechenv.com	Characterizing Ground-Water Flow Velocity and Preferential Flow Zones	Poster	84
Golla, Jon	jkgolla@pugetsound.edu	Geochemistry and Origins of Thermal Spring Waters of the Olympic Peninsula and Cascade Range, Washington	Poster	95
Hansen, Kevin	hansenk@co.thurston.wa.us	Lunch Panel: Hirst Decision–Growth Management Act requirement to protect water resources	Lunch Panel	11
Hansen, Kevin	hansenk@co.thurston.wa.us	Modeling Groundwater Water Availability in the Post-Hirst Era Using a MODFLOW Simulation over Most of Thurston County, Washington	5A	43
Hauge, Carl	tuleluke@hcc.net	California's Leap into Groundwater Management	5B	46
Hobbs, William	whob461@ecy.wa.gov	Characterization of Western Washington Stormwater in Large Urban Areas: 2009-2013	1B	19
Hurst, Richard W.	hurstgchem@gmail.com	Strontium Isotopes as Tracers of Hydraulic Fracturing Water in the Environment	3A	31
Ivey, George A.	budivey@iveyinternational.com	Surfactant Enhanced Push-Pull Method for In-situ Remediation of Petroleum Contaminated Soil and Groundwater	2A	22
Jacob, Clint	cjacob@landauinc.com	Sequential In Situ Bioremediation of a Former TCE Vapor Degreaser Source Zone	2A	24
Jacobacci, Kara	kara.jacobacci@dnr.wa.gov	Lidar-based Landslide Inventory in the Puget Lowlands, Pierce County, Washington	Poster	99

PRESENTER INDEX

Name	Email	Title	Session	Page
Jefferson, Chelsea	chelsea.jefferson@amecfw.com	Rethinking the Hydrogeologic Conceptual Model of Island County, WA, in order to Evaluate Seawater Intrusion Vulnerability	Poster	90
Jenkins, Art	ajenkins@spokanevalley.org	Eastern Washington Stormwater Effectiveness Studies	2B	28
Jenson, Dallin	jensenda@cwu.edu	Isotope investigation into soil nitrate accumulations in the lower Yakima Valley, Washington, and nitrate in agricultural drains	4A	39
Judi, David	david.judi@pnnl.gov	Panel 8B: Climate Change	8B	12
Kahle, Sue	sckahle@usgs.gov	Uranium occurrence in groundwater in northeastern Washington State	Poster	77
Kale, Nathaniel	kalen@co.thurston.wa.us	Hydrograph Baseflow Separation with 15 Minute Data, R, and Patience	Poster	87
Keller, Jason	jason@gsanalysis.com	Estimates of Tailings Facility Evaporation and Area Using Landsat Imagery	6B	54
Kimmel, Christine	ckimmel@landauinc.com	Use of Multiple Treatment Technologies for TCE Source and Dissolved Plume Remedy	2A	23
Kindred, J. Scott	scottk@kindredhydro.com	Estimating Hydraulic Conductivity in Unsaturated Soils and Predicting Performance of Stormwater Infiltration Facilities	3B	35
Knapp, Kevin	knappk6@wwu.edu	Examining the Potential Effects of Forecasted Climate Change on Sedimentation in the Nooksack River Basin	Poster	88
Lane, Ron	rclane@usgs.gov	Estimated Public Water Supply Withdrawals in Washington, 2015	Poster	83
Lanksbury, Jennifer	jennifer.lanksbury@dfw.wa.gov	The Stormwater Action Monitoring Program's Mussel Monitoring Project: Using Transplanted Mussels to Assess Contaminants in the Puget Sound's Nearshore Habitats	1B	21
Lenth, John	jlenth@herrerainc.com	Panel: a focus on the future of stormwater management	4B	11
Lenth, John	jlenth@herrerainc.com	City of Redmond Paired Watershed Stormwater Retrofit Effectiveness Study	3B	37
Lindsay, Rob	rlindsay@spokanecounty.org	Lunch Panel: Hirst Decision–Growth Management Act requirement to protect water resources	Lunch Panel	11
Lindsay, Rob	rlindsay@spokanecounty.org	Groundwater - surface water interaction between the Spokane Valley / Rathdrum Prairie Aquifer and the Spokane River	7A	59
Long, Andy	ajlong@usgs.gov	Characterizing groundwater flow in complex glacial stratigraphy near Puget Sound	6B	56
Lubliner, Brandi	brandi.lubliner@ecy.wa.gov	Western Washington's Regional Stormwater Monitoring Program	2B	29
Lubrecht, Michael	mike@horizontaldrill.com	The Role of Directional Drilling in Slope Failure Mitigation	Poster	76
Ma, Li	lim@shanwil.com	Using a Groundwater Model to Assist in the Design of Howard A. Hansen Dam Drainage Tunnel Rehabilitation	8A	68
Mann, Bill	bmann@in-situ.com	Advances in Groundwater Science and Practice: Developing Groundwater Replenishment or Recharge Systems	6A	51

PRESENTER INDEX

Name	Email	Title	Session	Page
Morgan, Laurie	Laurie.Morgan@ecy.wa.gov	The Growth Management Act's Voluntary Stewardship Program and Critical Aquifer Recharge Areas	5B	48
Navickis-Brasch, Aimee	aimee.navickis-brasch@hdrinc.com	Catch basin cleaning and street sweeping effectiveness in Ellensburg, Washington	2B	27
Nazy, Dave	dave.nazy@ecy.wa.gov	Groundwater Storage Element Projects in the Yakima Basin Integrated Plan	6A	53
Nelson, Victoria	victoria.nelson@dnr.wa.gov	Community scale landslide susceptibility mapping for Washington state counties	Poster	94
Nguyen, Tung	tung.nguyen@wsu.edu	The Role of Catchment Soil and Geologic Properties in Governing Mountain Recharge and Streamflow Response to Climate Change	Poster	93
Nimmo, John	jrnimmo@usgs.gov	Hydrograph-analysis method for episodic aquifer recharge extended to episodic increases of soil-water storage	7A	61
Oberhelman, Andrew	aoberhelman@pugetsound.edu	Comparison of the Chemical and Isotopic Composition of Groundwater and Surface Water in the South Sound Region, Washington	Poster	81
Philip, Noel	nphi461@ecy.wa.gov	Understanding the Whatcom County vs. Hirst, Futurewise, et al. decision	Poster	74
Pitz, Charles	czarfishpelt@gmail.com	Panel 8B: Climate Change	8B	12
Pizarro, Derek	dpizarro@premiermagnesia.com	Dissolved Heavy Metals in Groundwater: In-Situ Stabilization and Capture Technologies Utilizing Granular Reagent	1A	14
Porcello, John	jporcello@gsiws.com	Historical Trends in Spokane River Seasonal Low Flows: The Relative Influences of Changes in Water Demands, Water Sources, and Watershed Hydrology	7B	65
Pracht, Lara	lara06@gmail.com	Evaluation of the mechanisms of arsenic sequestration in in-situ groundwater treatment systems implementing induced sulfate reduction via permeable reactive barriers with and without utilization of zero-valent iron	1A	16
Price, John	john.price@ecy.wa.gov	ITRC Case Study: Hanford 200 Area	3A	30
Ralston, Dale	ralston@moscow.com	Structural control of recharge to aquifers within the Columbia River Basalt Group	5A	44
Ratcliff, Jana	ratcij@wsdot.wa.gov	Panel: a focus on the future of stormwater management	4B	11
Richey, Sasha	sasha.richey@wsu.edu	Panel 8B: Climate Change	8B	12
Saltonstall, Jennifer	jsaltonstall@aesgeo.com	Hydrogeologic Parameters Evaluated as Part of Bioretention Cell Hydrologic Performance Monitoring	3B	34
Scherberg, Jacob	jacob@gsanalysis.com	Planning for the unknown; a numerical modeling approach to developing water management	7B	66
Sessions, Carrie	carrie.sessions@ecy.wa.gov	Lunch Panel: Hirst Decision–Growth Management Act requirement to protect water resources	Lunch Panel	11
Shaljian, Michael	mikeshaljian@gmail.com	Loss via shallow groundwater of nutrients and major ions from a semi-arid dryland agricultural catchment	Poster	96
Song, Xuehang	xuehang.song@pnnl.gov	Long-term Impact of Dam Operation on Thermal and Biogeochemical Dynamics in the Hyporheic Zone	7A	60

Name	Email	Title	Session	Page
Stern, Ginny	ginny.stern@doh.wa.gov	Assessing Public Water Supply Vulnerability to Climate Change	5B	47
Truitt, Stephanie	stephetruitt@gmail.com	Calibration of a Hydrologic and Stream Temperature Model to the Nooksack River Basin for Climate Change Modeling	Poster	85
Turk, Jonathan	jturk@brwncald.com	Linking Surface Water and Groundwater Models for Improved Watershed Analyses and Management	7A	58
Voisin, Nathalie	Nathalie.voisin@pnnl.gov	Panel 8B: Climate Change	8B	12
Walther, Martin	martin.walther@ecy.wa.gov	Fires, Floods and Dams – Wildfire Hydrology Lessons from the Benson Creek Incident	7B	67
Welch, Wendy	wwelch@usgs.gov	Groundwater Recharge Estimates Using the Soil-Water Balance Model ; Chambers-Clover Creek Watershed and vicinity, Pierce County, Washington	Poster	82
Wynkoop, Jennifer	jwynkoop@landauinc.com	Vapor Intrusion - State of the Practice and Lessons Learned	2A	25
Yonkofski, Catherine	catherine.yonkofski@pnnl.gov	Potential Impacts of Groundwater Discharge to the Pelton Round Butte Hydroelectric Project Waterbodies	Poster	71
Yonkofski, Catherine	catherine.yonkofski@pnnl.gov	Evaluation of Computational Approaches for Delineating Boundaries of Aquifer Exemptions	Poster	72
Yonkofski, Catherine	catherine.yonkofski@pnnl.gov	Estimating Global Groundwater Resources	Poster	73
Young, Howard	younghs@cdmsmith.com	Characterizing Groundwater to Surface Water Discharge Zones Using Unmanned Aerial Vehicles and Thermal Infrared	6B	55
Young, Mike	myoung@snohd.org	Snohomish Arsenic	Poster	78
Zhang, Fred	fred.zhang@pnnl.gov	Non-intrusive geophysical methods to detect the soil conditions within and beneath an engineered surface barrier	3A	32
Zhang, Miao	mzhang@anchorqea.com	Integrated Model Calibration - A Framework for Linking Model Calibration, Parameter Uncertainty Analysis, and Model Application	Poster	91

EXHIBITORS

CASCADE
DRILLING | TECHNICAL SERVICES
www.cascade-env.com

In-Situ
www.in-situ.com

Pace Analytical
www.pacelabs.com

YELLOW JACKET
DRILLING SERVICES
www.yjdrilling.com

geotech
www.geotechenv.com

JRW
BIOREMEDIATION
www.jrwbioremediation.com

USGS
science for a changing world
wa.water.usgs.gov

BLAINE
TECH SERVICES
www.blainetech.com

OLYMPIC
ENVIRONMENTAL EQUIPMENT
www.olympicenv.com

WASHINGTON STATE GEOLOGIST LICENSING BOARD
www.dol.wa.gov/business/geologist/geoboardinfo.html

DEPARTMENT OF
ECOLOGY
State of Washington
www.ecy.wa.gov

WASHINGTON DEPARTMENT OF NATURAL RESOURCES
NATURAL RESOURCES
www.dnr.wa.gov/geology

‖ SYMPOSIUM SPONSORS ‖

Gold Sponsor

Golder Associates
www.golder.com

HOLT SERVICES INC
www.holtservicesinc.com

Seametrics
www.seametrics.com

Silver Sponsors

HGI hydroGEOPHYSICS
www.hgiworld.com

HOLOCENE DRILLING
Licensed To Drill
www.holocenedrillinginc.com

SCHNEIDER WATER SERVICES
www.schneiderwater.com

Bronze Sponsors

GeoEngineers
www.geoengineers.com

HartCrowser
www.hartcrowser.com

Landau Associates
www.landauinc.com

PBS
www.pbsenv.com

Platinum Sponsor

Aspect CONSULTING

www.aspectconsulting.com