WASHINGTON HYDROGEOLOGY SYMPOSIUM

April 22-25, 2024 | Muckleshoot Casino Resort

PROGRAM AND ABSTRACTS

WASHINGTON HYDROGEOLOGY SYMPOSIUM

| Muckleshoot Casino Resort | Auburn, Washington | April 22–25, 2024



SCHEDULE OVERVIEW

DATE	ACTIVITY
MONDAY April 22	Field Trip 1: Creek Restoration Projects in Pierce County, WA (8:00 AM - 5:00 PM) Field Trip 2: Lake Tapps and Flaming Geyser State Park (8:00 AM - 5:00 PM)
TUESDAY April 23	First Day of Symposium Opening Session / Keynote Talk Platform Presentations Exhibits Lunch Provided Poster Session and Reception (early evening)
WEDNESDAY April 24	Second Day of Symposium Keynote Talk Platform Presentations Lunch Provided Exhibits and Posters
THURSDAY April 25	Workshop 1: Water 101 – An Overview of Washington State Water Law, Water Rights, and Related Water Resources, Tools, and Challenges (8:00 AM - 5:00 PM) Workshop 2: Python in Hydrogeology (8:00 AM - 5:00 PM) Workshop 3: PFAS – Regulatory Context, Sampling Guidance, and Ex Situ/In Situ Treatment (8:00 AM - 5:00 PM) Workshop 4: Optimizing Water Wellfield Performance (8:00 AM - 5:00 PM)

2024 WELCOME



Welcome to the 14th Washington Hydrogeology Symposium, taking place in 2024 at the Muckleshoot Casino Resort near Auburn, Washington! We are excited to bring together professionals from industry, government, and Tribal Nations to discuss work in hydrogeology and related fields. The Symposium is an excellent venue for learning about the work of others and having meaningful discussions, as we look to advance the state of the practice.

Technical program – The technical program consists of sixteen technical sessions split across two tracks over two days. A poster session will be combined with a reception and refreshments on Tuesday evening for a great opportunity to engage poster presenters, sponsors/exhibitors, and colleagues. Sessions cover a wide variety of topics, including streamflow restoration, recharge estimation, groundwater usage, contaminant hydrology, remediation, emerging contaminants, tools/methods, climate trends, geologic carbon sequestration, and more. There is something for everyone!

Keynote speakers – We are pleased to hear from distinguished keynote speakers, Alicia Wilson and Phil Rigdon. Dr. Wilson comes to us as the 2023 Darcy Distinguished Lecturer in Groundwater Science and professor of hydrogeology in the School of the Earth, Ocean, and Environment at the University of South Carolina. She specializes in coastal hydrogeology, with a particular focus on coastal ecohydrology and submarine groundwater exchange. Phil Rigdon is the Department of Natural Resources Superintendent at the Yakama Nation, where he applies his background in forestry from the Yale School of Forestry Environmental Studies and the University of Washington to serve the needs of the Yakama Nation.

Field trips and workshops – We are excited to offer two field trips this year on Monday, April 22: *Lake Tapps and Flaming Geyser State Park* and *Creek Restoration Projects in Pierce County*. Field trips offer a chance to learn more about the hydrology and geology of Washington from the experts working on remarkable environmental restoration projects in the hydrogeological context of western Washington. On Thursday, April 25, we will offer four one-day workshops on the topics of water law/water resources, hydrogeologic modeling with Python/FloPy, optimizing wellfield performance, and approaches to addressing PFAS in the environment.

Exhibitors and Passport Program – Please spend some time visiting our exhibitors, who offer a variety of solutions for state-of-the-art field methods, sample analysis, data collection, water treatment, and more. We encourage you to visit each exhibitor and participate in our Passport Program for an opportunity to win prizes! We would especially like to thank our sponsors for their generosity, which helps ensure the long-term success of the Symposium.

Nadine Romero Scholarships – The Symposium is proud to award scholarships to undergraduate and graduate students as they continue their study and practice of hydrogeology, and to promote the development of new professionals in our field. We look forward to announcing this year's winners!

On behalf of the 14th Washington Hydrogeology Symposium Steering Committee, thank you for attending and taking advantage of the technical sessions, field trips, workshops, exhibitors, and networking opportunities. Our intent is that your time at the Symposium not only benefit you, but will serve to further advance and inspire the work in your organization and the hydrogeology community in the Northwest.



Sincerely,

Christian Johnson
Pacific Northwest National Laboratory
2024 Washington Hydrogeology Symposium Chair



KEY LOCATIONS

Muckleshoot Casino Resort

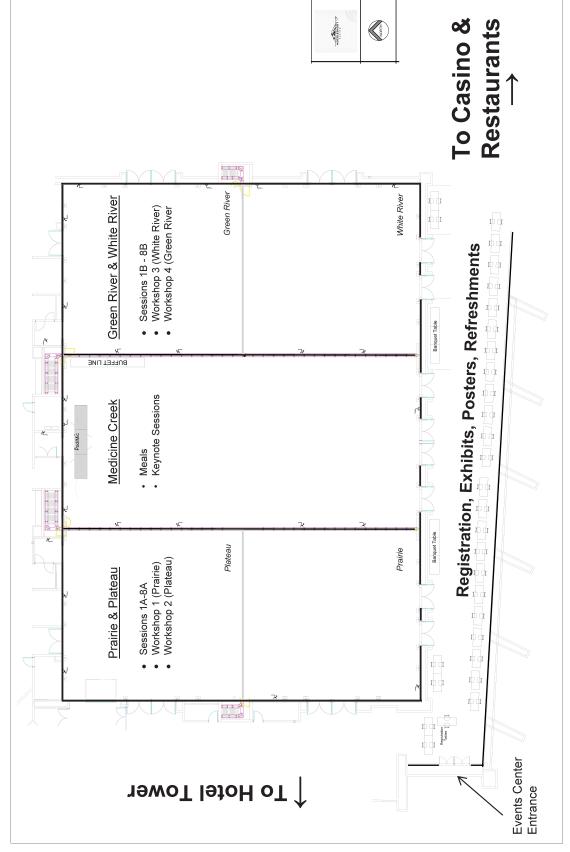




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Nadine L. Romero Student Scholarships

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

GENERAL INFORMATION

Symposium Registration Booth and Registration Hours

The Washington Hydrogeology Symposium Registration Booth is located in the hallway of the Events Center. Staff will be available there to provide assistance and information throughout the Symposium.

Tuesday, April 22: 7:30 AM-6:00 PM Wednesday, April 23: 8:00 AM-4:40 PM Thursday, April 24: 7:30 AM-5:00 PM

Name Badges

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

Symposium Sessions

Symposium sessions and Thursday workshops will be held in the Muckleshoot Events Center. 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 breaks at 9:45 and 11:15 AM. It is important that all posters be in place by the end of the afternoon break at 2:55 PM. Plan to be available at your poster during the Tuesday Poster Session and Reception from 4:30-6:30 PM. You may leave your poster up until the end of the afternoon break on Wednesday at 2:55 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 4:30-6:30 PM. View the 2024 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.

2024 Passport Book Contest

Your Passport book lists all our 2024 Sponsors and Exhibitors. Get your passport stamped as you visit each exhibitor table. Those who visit every table and turn in a completed passport at the registration desk are entered into our prize drawings, including a grand prize. *Must be present to win.*

GENERAL INFORMATION

Internet Access

Complimentary internet access is available in all meeting rooms, the Muckleshoot Events Center, and the hotel restaurant without restriction. No username or password is required to connect.

Safety and Security

All guests must present identification (driver's license, state ID, passport, etc.) to enter the property. Guests under the age of 21 must enter the conference venue through the Muckleshoot Events Center entrance (see page ii) or be accompanied by an adult age 21+ at all times. Security staff are able to escort guests under 21 from the main entrance to the Events Center.

Smoking

The Muckleshoot Events Center and hotel tower are 100% smoke free. Smoking is allowed in certain areas of the casino. To avoid smoky areas, we recommend entering the Symposium through the Events Center Entrance (see page ii).

Questions can be answered by hotel front desk staff or Symposium staff at the Registration Booth.

Important Phone Numbers

Muckleshoot Casino Resort: 253.804.4444 | Explore Auburn, WA: 253.931.3090 | Emergencies: Dial 911

STEERING COMMITTEE

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Schedule At-a-Glance

Tuesday

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Wednesday

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Thursday

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	Tuesday, A	pril 23, 2024	
7:30 AM	Registration Check-In (Open Coffee Exhibits	
	Welcome/Opening Remarks and Keynote Speaker (Medicine Creek)		
8:30 AM	Keynote: Subseafloor Hydrogeology - Moving beyond watersheds to the seafloor		
	Alicia Wilson, University of South Carolina, 2023 Darcy Lecturer		
9:45 AM	Refres hment Break	Exhibits Posters	
10:00 AM	Session 1A: Remediation Approaches (Prairie & Plateau)	Session 1B: Streamflow and Nooksack River (Green River & White River)	
	Implementation of Carbon-based Injectates in a Permeable Reactive Barrier to Control Petroleum Hydrocarbon Contamination	Predicted Effects of forest management scenarios on Magnitude of Late Summer Streamflow in the South Fork Nooksack River Susan Dickerson-Lange, Natural Systems Design	
	Mike Mazzarese, AST Environmental	, , , , , , , , , , , , , , , , , , ,	
	Application of Combined Technologies for Remediation of Carbon Tetrachloride	Life Cycle Habitat Model Supporting Watershed Restoration and Instream Flow Protection for Fish Conservation and Recovery	
SESSION 1	John Sankey, True Blue Technologies	Eric Doyle, Confluence Environmental	
	Performance Assessment of Monitored Natural Attenuation for	Anticipating the Impacts of Management Alternatives on	
	Chlorinated Solvents at the Kent Highlands Landfill	Groundwater and Stream Depletion: Groundwater Model	
	Michael Brady, Parametrix	Development and Application Gilbert Barth, S.S. Papadopoulos & Associates	
	Chlorinated Solvent Remediation via Combined Activated	Approaches for Increasing Late Summer Streamflow in	
	Carbon, Reactive Iron, and Bioaugmentation	Tributaries to the Lower Nooksack River	
	Mike Mazzarese, AST Environmental	Jay Chennault, Associated Earth Sciences, Inc.	
11:15 AM	Refreshment Break	Exhibits Posters	
11:25 AM	Session 2A: Data Visualization and Management (Prairie & Plateau)	Session 2B: Surface Water/Groundwater and Septic/Treated Water Recharge (Green River & White River)	
	Building Resilient Datasets to Preserve Data Sovereignty for the	Overview of Recent USGS Washington Water Science Center	
	Yakama Nation Mary Weber, Yakama Nation Fisheries	Projects on Groundwater-Surface Water Interaction Rich Sheibley, U.S. Geological Survey	
	ORIGEN: Building a Tool for Insights Below the Surface	Assessing Water Quality Impacts from Septic Systems in the Tri	
	Jennifer Fanning, Pacific Northwest National Laboratory	Lakes Area	
		Kevin Hansen, Thurston County	
SESSION 2	Making Your Data Shine - Dashboards for Data Visualization and	Reinterpretation of the Stratigraphy of the Orting Lake Upland,	
	Interpretation in R Shiny Timothy Clark, Herrera Environmental Consultants	Deep UIC and Aquifer Testing Results, and Irrigation Reuse through Purple Pipe Infrastructure	
	innouty clark, herrera Environmental consultants	Gus Carlson, Associated Earth Sciences, Inc.	
	Data Catalogs for Management of Environmental Information	The Rise and Fall of a Nitrate Plume - From a LOSS to an MBR and	
	with Geospatial Context	Future Reclaimed Water Use	
	Christian Johnson, Pacific Northwest National Laboratory	Luke Mioduszewski, Associated Earth Sciences, Inc.	
12:30 PM	Hosted Luncheon	(Medicine Creek)	
1:40 PM	Session 3A: Field Methods and Sensors (Prairie & Plateau)	Session 3B: Climate Trends and Impacts (Green River & White River)	
	Potential Implications of Drilling Method on Well Performance Michael Piechowski, Terraphase Engineering, Inc.	Analysis of King County Monitoring of Stream Discharge and Precipitation Over Decadal Time Spans J. Michael Brown, University of Washington	
	Overview of Turbidity Sensor Technology for Water Quality	Groundwater Level and Climate Variable Trends and Implications	
	Assessment	for Groundwater Resources in Oregon	
CECCION 2	Bill Mann, In-Situ Inc.	C. Amanda Garcia, U.S. Geological Survey	
SESSION 3	Multi-well Testing Program in a Tidally Influenced Variable Density Aquifer	Evaluating Groundwater Elevation Trends in Wells Completed in Basalt and Basin-fill, Walla Walla River Basin, Washington-Oregon	
	Rebecca Dozier, Haley & Aldrich	Amy Yoder, U.S. Geological Survey	
	Applications of 4D Electrical Resistivity Tomography for	Climate Change Resilience and Adaptability for Water Supply	
	Monitoring Vadose Zone Water Migration at the Hanford Site	Daniel O'Neill, WA State Department of Ecology	
	Tim Johnson, Pacific Northwest National Laboratory		
2:55 PM	Refres hment Break	Exhibits Posters	

	Tuesday, April 23, 2024		
3:10 PM	Session 4A: Contaminant Hydrology (Prairie & Plateau)	Session 4B: Streamflow, Recharge, and Groundwater Management (Green River & White River)	
	The Complex Hydrogeology of the West Plains, Spokane County Ben Lee, Landau Associates, Inc.	Using USGS MODFLOW Results to Improve Calibration of the VELMA Ecohydrology Model for Modeling Streamflow Philip Murphy, InfoHarvest, Inc.	
	Tidal Wave Attenuation in a Coastal Aquifer Steve Graham, S. Graham Engineering and Geology, Inc.	Using Water Budget Informed Model Design to Assess Rising Groundwater Conditions in the Golden Valley Subbasin, Nevada Don Malkemus, Terraphase Engineering, Inc.	
SESSION 4	Groundwater Surface Water Interactions at a Tidally Influenced Cleanup Site Courtney Savoie, Maul Foster Alongi	Tracer-constrained estimates of groundwater recharge to the Columbia River Basalt in the upper Umatilla River basin, Oregon Henry Johnson, U.S. Geological Survey	
	Evaluating Remedial Progress in the River Corridor: Contaminant Rebound in the Unconfined Aquifer Underlying Hanford's 100-H North Study Area Sylvana Bendaña, Central Plateau Cleanup Company	Prediction and Management of Perched Water at a Proposed Managed Aquifer Recharge Facility Jason Keller, GeoSystems Analysis, Inc.	
4:30 PM - 6:30 PM	Poster Session &	Reception (Foyer)	
	Data Collection Efforts for Water Resources on Vashon-Maury Island Eric Ferguson, King County Groundwater Program		
	Response of the Naches River to the Removal and Redesign of Nelson Dam Chandler Sabin, Central Washington University		
	Combination of Thermal Treatment and Microbial Reductive Dechlorination to Address Groundwater Contaminant Rebound John Sankey, True Blue Technologies		
	Using MODFLOW and a Mass Balance Approach to Assess Groundwater Storage Enhancement via a Floodplain Infiltration Basin Lindsay Henning, Central Washington University		
POSTER SESSION	PFAS Document Abstraction using Open Semantic Search Neil Powers, INTERA, Inc.		
POSTEN SESSION	Monitoring Concrete Recycling to Minimize Environmental Risks Eric Daiber, Washington State Department of Ecology		
	Evaluating Managed Aquifer Recharge in the Yakima River Basin Brook Bauer & Elif Myers, Central Washington University		
	Evaluating Connections between Glacial Outwash Terrace Aquifers and Skagit River Alluvial Valley Aquifers Henry Williams, Western Washington University		
	Implementation of Updated Approaches for Slug Testing at Willamette River Site Kristin Anderson, Floyd Snider		
	Adaptive groundwater management made easy: a web-based de Aaron Lewis, EKI Environment & Water	cision support tool for the Arvin-Edison Water Storage District	

	Wednesday,	April 24, 2024
7:30 AM	Registration Check-In (Open Coffee Exhibits
	Welcome and Keynote S	Speaker (Medicine Creek)
8:30 AM	Keynote: Indigenous Perspectives on Water, Fish, and Drought: Collaborative Approaches to Complex Water Resource Cha Phil Rigdon, Yakama Nation	
9:45 AM	Refreshment Break	Exhibits Posters
10:00 AM	Session 5A: Hydraulic Characterization for Groundwater Remediation (Prairie & Plateau)	Session 5B: Groundwater Monitoring in the Lower Yakima Valley (Green River & White River)
SESSION 5	Implementing Improved Pump and Treat Remediation and Performance Monitoring of Groundwater Contamination within Discrete High-Concentration Zones Rebecka Bence, Pacific Northwest National Laboratory	Lower Yakima Valley Groundwater Management Program Sheryl Howe, Washington State Department of Health
	An Analytical Modeling and Inversion Framework to Estimate Vertical Concentration Profiles Around Long-screened Wells Frederick Day-Lewis, Pacific Northwest National Laboratory	Improving Wellhead Protection Area Delineations for 20 Lowe Yakima Valley Group A Wells Ben Lee, Landau Associates, Inc.
	Numerical Model Results for Groundwater Sample Interpretation Amber Nguyen, Pacific Northwest National Laboratory	Lower Yakima Valley: Ambient Groundwater Monitoring Network Melanie Redding, Washington State Department of Ecology
	A Deep Learning Surrogate Model for Efficient Groundwater Pump-and-Treat Optimization Xuehang Song, Pacific Northwest National Laboratory	Updated Hydrogeologic Conceptual Model in the East-Moxee Black Rock area of the Yakima Basin Dawn Chapel, Aspect Consulting
11:15 AM	Refreshment Break	Exhibits Posters
11:25 AM	Session 6A: Groundwater Use and Water Rights (Prairie & Plateau)	Session 6B: Streamflow & Stream Restoration (Green River & White River)
SESSION 6	Simulating Groundwater Response to Two Future Groundwater Use Scenarios in the Harney Basin, Southeastern Oregon Stephen Gingerich, U.S. Geological Survey Oregon Water Science Center	Fall City Floodplain Restoration Influence on Groundwater- Surface Water Connections, Streamflow, and River Temperatures Scott Kindred, Kindred Hydro, Inc.
	A New, Un-Mitigated 1,600-Acre Irrigation Groundwater Right in Eastern Washington Eric Weber, Landau Associates, Inc.	Augmentation from Irrigation Canal System to Enhance Yakima Basin Tributary Flow and Improve Stream Habitat Urban Eberhart, Kittitas Reclamation District
	Oregon Groundwater Allocation Rules Update Travis Brown, Oregon Water Resources Department	Groundwater Replenishment and Water Management on the Yakama Reservation Danielle Squeochs, Confederated Tribes and Bands of the Yakama Nation
	Simulating Potential Impacts of Proposed Water Supply Wellfield	Evapotranspiration and Floodplain Aquifer Storage in Taneum
	Extraction from Deep Puget Sound Aquifer	Creek
	Nathan Cutler, EKI Environment & Water	Carey Gazis, Central Washington University
12:30 PM	Hosted Luncheon	(Medicine Creek)

	Wednesday,	April 24, 2024
1:40 PM	Session 7A: Emerging Contaminants (Pesticides, PFAS, 6PPD-q, etc.) (Prairie & Plateau)	Session 7B: Geologic Carbon Storage & Related (Green River & White River)
	Understanding the Impacts of Pesticides on Washington State's Groundwater Resources Jaclyn Hancock, Washington State Department of Agriculture	Virtual Learning Environment for Geologic Carbon Storage Applications: A Machine Learning Approach for Visualizing Large Datasets for Carbon Storage Ashton Kirol, Pacific Northwest National Laboratory
SESSION 7	Reconstructing PFAS History of the Santa Ana River from Groundwater Concentration Data Stephen Breen, U.S. Geological Survey Washington Water Science Center	Characterizing Groundwater Chemistry in the Columbia River Basalt Group of Central and Eastern Washington Ellen Svadlenak, Washington Geological Survey
	Geochemical Modeling of PFAS Fate and Transport during Aquifer Storage and Recovery in the Pacific Northwest Brad Bessinger, Summit Water Resources	Enhancing Geomechanical Risk Assessment in Geological Carbon Storage with NRAP-wSOSAT: A Web-based State of Stress Analysis Tool Wenjing Wang, Pacific Northwest National Laboratory
	Overview of Trends and Future Requirements in State Regulations for Emerging Contaminants Heather Gosack, WSP USA	Geologic Carbon Sequestration: What is the Status of Underground Injection Control Class VI? William Gallin, Washington Geological Survey
2:55 PM	Refreshment Break Exhibits Post	ers Passport Contest Prize Drawing
3:10 PM	Session 8A: PFAS Issues and Panel (Prairie & Plateau)	Session 8B: Tools and Methods (Green River & White River)
	PFAS Forensics: Fingerprinting PFAS Sources and AFFF Impacts to Fish in Columbia Slough Jennifer Field, Oregon State University	Methods for Predicting the Capacity of Stormwater Infiltration Drywells Scott Kindred, Kindred Hydro, Inc.
	PFAS Contamination of Drinking Water near the Yakima Training Center in Central Washington Greg Caron, Washington State Department of Ecology	A Graphical Interface to Quantify and Visualize Streamflow Depletion Jessica Rogers, S.S. Papadopulos & Associates, Inc.
SESSION 8	PFAS Panel Discussion: Cleanup under WA MTCA, Unsaturated Soil Leaching, and More Kim Wooten, Washington State Department of Ecology Bonnie Brooks, Washington State Department of Ecology Mike Means, Washington State Department of Ecology Charles Schaefer, CDM Smith	Ecology's New Well Report Application: My Driller Portal Malone Scott, Washington State Department of Ecology - Well Construction and Licensing Office
		Water table estimates for Underground Injection Control Analysis, Clover Creek watershed, Pierce County, Washington Elise Wright, U.S. Geological Survey Washington Water Science Center
4:30 PM	Symposium Presentations Adjo	ourn Workshops on Thursday

	Thursday, April 25, 2024	
8:00 AM - 5:00 PM	Workshop 1: Water 101 - An Overview of Washington State Water Law, Water Rights, and Related Water Resources, Tools, and Challenges Room: Prairie	
	Workshop Presenters: John Rose, Washington State Department of Ecology Andrea Lauden, Washington State Department of Ecology Rebecca Inman, Washington State Department of Ecology Ben Carr, Washington State Department of Ecology Noah Wentzel, Washington State Department of Ecology Matt Janz, Washington State Office of the Attorney General	
8:00 AM - 5:00 PM	Workshop 2: Python in Hydrogeology Room: Plateau	
	Workshop Presenter: Christian Langevin, U.S. Geological Survey	
8:00 AM - 5:00 PM	Workshop 3: PFAS - Regulatory Context, Sampling Guidance, and Ex Situ/In Situ Treatment Room: White River	
	Workshop Presenter: Tamzen Macbeth, CDM Smith	
8:00 AM - 5:00 PM	Workshop 4: Optimizing Water Well Performance Room: Green River	
	Workshop Presenters: Jim Bailey, Shannon & Wilson, Inc. Todd Kinkaid, Shannon & Wilson, Inc. Brian Peck, Shannon & Wilson, Inc.	

KEYNOTE SPEAKER



Alicia Wilson

Professor, School of the Earth, Ocean & Environment University of South Carolina, Columbia, SC. 2023 Darcy Lecturer

"Subseafloor Hydrogeology: Moving beyond watersheds"

The field of submarine groundwater discharge (SGD) was launched in the 1990s by the remarkable discovery, via naturally-occurring isotopic tracers, that saline groundwater was discharging to the South Atlantic Bight in very large volumes. Subsequent studies confirmed that saline groundwater discharges to the Atlantic Ocean in volumes that rival river discharge. All available evidence indicates that this saline groundwater is highly enriched in nutrients compared to river water, so the nutrient contributions of this submarine discharge exceed that of river discharge. These findings have been slow to find widespread acceptance, however, because it has been exceedingly difficult to confirm this flow by means other than the original isotropic tracers. This discharge does not occur near the shoreline, and no conceptual models for SGD far from shore existed.

This changed recently when new studies using heat as a tracer identified clear pulses of groundwater discharge 10-15 km offshore in the South Atlantic Bight. This talk investigates this 20-year mystery and the recent discoveries that suggest that it is time to rewrite chemical budgets for the coastal ocean.

A licia Wilson is a professor of hydrogeology in the School of the School of the Earth, Ocean, and Environment at the University of South Carolina. She specializes in coastal hydrogeology, with a particular focus on coastal ecohydrology and submarine groundwater exchange. Wilson holds a Ph.D. from the Johns Hopkins University, an MS from Stanford University, and a BA from Dartmouth College. A fellow of the Geological Society of America, Wilson has served as the chair the GSA Hydrogeology Division. She is a recipient of the University of South Carolina's Mungo Undergraduate Teaching Award and has served as the Director of the School of the Earth, Ocean, and Environment.

KEYNOTE SPEAKER



Phil Rigdon

Department of Natural Resources Superintendent, Yakama Nation, Toppenish, WA.

"Indigenous Perspectives on Water, Fish, and **Drought: Collaborative Approaches to Complex Water** Resource Challenges"

n most of the West, there will never be enough water for everyone's desires. Even in good water years, fish do not have enough water. In drought years, agriculture also suffers. In the Yakima Basin, for at least a century, there has not been enough water to fully satisfy fisheries, irrigation, and municipal needs at the same time.

For the last decade, irrigation districts, the Yakama Nation, nonprofit groups, and federal, state and local governments worked together to resolve water challenges in the Yakima River Basin.

Mr. Rigdon's presentation will discuss water resource challenges in the Yakima River Basin and how lessons learned are being implemented as part of the Six Sovereigns process – resulting in the Columbia Basin Restoration Initiative.

Drawing from experience, Mr. Rigdon will share insights into the unique ways in which indigenous perspectives intersect with water management. His focus will be on collaborative processes approaches that bridge traditional knowledge with scientific expertise while supporting tribal sovereignty.

hil Rigdon is an enrolled member of the Yakama Nation and grew up on the Yakama Reservation in Southcentral Washington State. Mr. Rigdon has been the Superintendent of Yakama Nation's Natural Resources Department since May 2005 and has worked for the Yakama Nation since June 1989.

In his career, Mr. Rigdon has overseen the Yakama Nation's participation in a regional water rights adjudication, droughts, and litigation over the impacts of groundwater extraction on surface water. After years of conflict, Mr. Rigdon helped find a pathway to cooperation and collaboration in the Yakima River Basin. He continues to participate in collaborative water resource management at a local, regional, and national level.

Mr. Rigdon represents the Yakama Nation on the Intertribal Timber Council, Yakima Basin Integrated Plan Executive Committee, the Washington State's Columbia River Policy Advisory Group, Tapash Sustainable Forest Collaborative, the University of Washington Ecolab and the Hanford Natural Resource Trustee Council.

KEYNOTE SPEAKER

Mr. Rigdon also served as President of the Intertribal Timber Council for five years and is currently serving on the Yale School of Environment Alumni Board. Mr. Rigdon obtained a BS in Forest Management from the University of Washington in 1996 and a Master of Forestry from Yale School of Forestry and Environmental Studies in 2002.

Oral Abstracts

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Poster Abstracts

pages 75-83

Implementation of Carbon-based Injectates in a Permeable Reactive Barrier to Control Petroleum **Hydrocarbon Contamination**

Mike Mazzarese, AST Environmental, Inc.

Background/Objectives: Managing dissolved contamination along property boundaries or adjacent to sensitive receptors has been an area of focus for the environmental industry as Risk Control Measures are often required in conjunction with risk assessment or remediation. In the 1990s the permeable reactive barrier (PRB) using zero valent iron (ZVI) was pioneered which has since been widely applied for the treatment of chlorinated volatile organic compounds (cVOCs). Unfortunately, this "Iron Wall" is ineffective for petroleum hydrocarbons (PHCs). For years attempts have been made at creating a passive PRB for the long term and sustained treatment of PHCs. Recently, the use of activated carbon-based injectates (CBI) has been increasing and evolving. The objective of this talk is to present a case study completed at the field-scale that presents how two different CBIs were used to create an injected PRB to effectively treat and control the migration of dissolved-phase PHCs across a property boundary. An interesting aspect of this work also included the requirement to treat the chlorinated solvent 1,2dichloroethane (1,2-DCA) which was historically used in gasolines as a lead scavenger. This talk will summarize the staged implementation of the CBI PRB including design considerations, injection techniques used, results of the remedial design characterization, and lessons learned. Focus will be placed on a performance assessment of the two CBIs used (colloidal and powdered activated carbon) in addition to the impact of using KB-1® to address residual 1,2 DCA impacts.

Approach/Activities: Field data will be presented from a case study where two types of CBI and modified KB-1® were used. The injection techniques will be discussed, one of which involved the injection of a slurry via a grid of interlocking, depth-targeted, temporary injection intervals to create the full-scale long-term PRB. A review of the geology, hydrogeology, injection program and the corresponding in-field and post-injection monitoring data will be presented, including the results of the robust remedial design characterization program.

Results/Lessons Learned: The presentation will ultimately review the persistence of the site owner, who's focus on the use of CBI lead to the successful PRB installation. The first stage of the CBI PRB installation resulted in increased petroleum hydrocarbon groundwater concentrations along some portions of the PRB. A robust site characterization program was completed which allowed for a more thorough PRB design. The petroleum hydrocarbon groundwater concentrations decreased to generic standards after the second stage of the CBI PRB installation; however, minor exceedances of 1,2-DCA remained. The third and final stage of the PRB installation was the introduction of 1,2-DCA cultured KB-1® which ultimately lead to the installation of the fully functioning and effective CBI PRB. All in all, the lessons learned from the above installation approach will be presented, along with how CBI can be used to successfully inject a PRB for petroleum hydrocarbons and additionally how creativity and KB-1® can be applied to effectively treat 1,2-DCA co-mingled with petroleum hydrocarbon plumes.

Application of Combined Technologies for Remediation of Carbon Tetrachloride

John Sankey, True Blue Technologies

Rod Baumann P.G., Trimedia, Omaha, NE, USA Daniel Bouchard, Ph.D., GHD, Montreal, QC, Canada Gary Birk, P.E., Tersus Environmental, Wake Forest, NC, USA

This presentation showcases a comprehensive remediation strategy tailored for a challenging case of groundwater contamination in the Midwest. The project targets a 900 ft x 600 ft plume contaminated with carbon tetrachloride (CT) and other chlorinated solvents, presenting concentrations ranging from 4 to over 4,000 µg/L. The contaminated zone, situated in the uppermost saturated sand unit at depths approximately 26 to 32 ft below ground surface (BGS), posed significant remediation complexities.

The remediation approach integrates direct push technology injections (DPT) to distribute amendments efficiently in the subsurface. Linear barriers, formed by injection points, are strategically placed, effectively creating barriers separated by the equivalent of 2 years of groundwater flow. Additionally, three permanent wells facilitate large batch amendment injections upgradient to the source zone, targeting areas inaccessible via DPT.

The remediation strategy combines a blend of zero-valent iron (ZVI), electron donors, pH buffers, micronutrients, and a chlorinated-methane degrading bioaugmentation culture. This sequential approach addresses CT through in situ chemical reduction and its breakdown products via anaerobic bioremediation.

Performance monitoring employs a suite of tools, including groundwater modeling coupled with tracer injections through the permanent wells. Geochemical groundwater parameters are monitored periodically to assess injectate impacts on aquifer conditions. Quantitative Polymerase Chain Reaction (qPCR) tests in groundwater gauge the evolution of microbial cultures capable of dechlorination, focusing on Dehalococcoides Mcartii, Dehalobacter, and key functional genes (i.e., cfrA, tceA, vcrA, and bvcA).

Compound-Specific Isotope Analysis (CSIA) tracks changes in carbon isotopic composition (δ13C) of chlorinated compounds (CT, PCE) and their respective breakdown products (chloroform, dichloromethane and TCE, c-DCE, and VC). This method enables the differentiation between biotic and abiotic processes involved in their transformation.

Moreover, CSIA serves as a valuable tool for assessing the effectiveness of remediation strategies by detecting inhibition in incomplete dechlorination processes. By examining the isotopic signatures of the compounds involved, CSIA provides crucial insights into the progress and efficiency of remediation efforts, guiding decisionmaking processes for environmental cleanup initiatives.

The presentation presents findings from baseline and post-injection groundwater sampling events, highlighting the project's effectiveness in addressing complex contaminant scenarios.

Performance Assessment of Monitored Natural Attenuation for Chlorinated Solvents at the Kent Highlands Landfill

Michael Brady, Parametrix

Lisa Gilbert, Parametrix

The Kent Highlands Landfill is located at 23076 Military Road South, Kent, Washington and is situated within a natural ravine on the eastern flank of the Des Moines upland where it adjoins the Green River Valley. The landfill operated from 1969 through 1986 as an unlined facility and the site was placed on the National Priorities List in 1990. Cleanup activities began in 1987 by a Consent Order. The Washington State Department of Ecology is the lead review agency for the landfill and performs periodic reviews related to the cleanup. Seattle Public Utilities (SPU) operates and maintains the closed landfill.

Contaminants from the landfill have migrated vertically into the underlying Sand Aquifer (SA) which discharges horizontally into the Recent Alluvium Aquifer (RAA) near the toe of the landfill in the Green River Valley. The RAA ultimately discharges to the Green River. Compliance monitoring at wells in the SA and RAA is conducted annually in September when water levels in the Green River are lowest.

In the fourth periodic review Ecology requested SPU identify further engineering evaluations due to excessive restoration times related to vinyl chloride exceedances of the site-specific cleanup level of 0.025 μg/L . The cleanup level is based on a person being exposed over a lifetime of drinking the river water while at the same time consuming fish from the river. Ecology was seeking SPU identify active remediation measures to be completed.

In response, Parametrix reviewed remedial options and determined that monitored natural attenuation (MNA) would achieve desired restoration timeframes. BIOCHLOR and BIOSCREEN modelling were completed and degradation rate constants were evaluated (Newell et. al 2002) indicating that the site would achieve compliance at the Green River, point of discharge at the property boundary, by 2023 to 2025. In the fifth periodic review (2019), Ecology requested SPU complete pore water sampling to confirm the contaminant modelling.

Two shallow piezometers were installed adjacent to the Green River to evaluate contaminants discharging from groundwater to the river. Monitoring of the piezometers was completed in September 2022 and September 2023 concurrent with the annual groundwater monitoring program.

The 2022 piezometer results showed vinyl chloride at very low concentrations or absent near the Green River. The presence of parent chemicals of trichloroethene (TCE) and cis-1,2-dichloroethene (cis-1,2-DCE) below cleanup levels was further evidence that the sample was representative of contaminants that had migrated from the landfill. The 2023 results showed vinyl chloride was no longer present in either piezometer but again TCE and cis-1,2-DCE present below cleanup levels in one of the samples. This sampling effort confirmed the model predictions and ultimately that the use of MNA as the primary remediation mechanism remains appropriate. Trends at nearby compliance wells were also consistent with the degradation rate constant showing that these wells will similarly achieve compliance regarding vinyl chloride within appropriate restoration time frames without active remediation necessary.

Chlorinated Solvent Remediation via Combined Activated Carbon, Reactive Iron, and Bioaugmentation

Mike Mazzarese, AST Environmental, Inc.

Chlorinated solvent degradation products, also known as daughter products, are generated at most remediation sites where an electron donor is introduced or where sufficient natural organic carbon is present in the aquifer. For sites where either perchloroethylene (PCE) or trichloroethylene (TCE) is the parent compound, the degradation products are primarily cis-1,2-dichloroethylene (DCE) and/or vinyl chloride (VC). Where source areas exist (e.g., mg/L concentrations of parent compounds), significant daughter product concentrations can be generated and can persist for extended periods of time, even decades.

This presentation will review two project sites where activated carbon impregnated with metallic iron, a complex carbohydrate, a facultative microbial consortium designed to degrade chlorinated solvents, and a second microbial consortia designed to breakdown the polymeric carbohydrate to monomeric fragments were mixed and applied via in situ injection. This synergistic combination has been shown to generate significantly less daughter products and to degrade parent and daughter products completely to ethylene in an expedited timeframe compared to traditional enhanced reductive dechlorination (ERD) approaches.

Site 1. A combined remedial strategy was implemented to treat elevated levels of TCE in a shallow fine-grained aquifer at a former large industrial facility. This remediation effort was comprised of 1) in situ chemical oxidation to treat the shallow, mostly unsaturated soil mass, 2) a metallic iron-impregnated activated carbon PRB was installed downgradient of the source to manage the flux of dissolved mass offsite, and 3) the source area was treated with the above-mentioned combination of technologies and microbial consortia. Within the source area, total chlorinated ethylene (TCE+DCE+VC) concentrations in the source area have been reduced by 99.9% in less than three years. The initial TCE concentration was 47,800 ppb and is currently 2 ppb. DCE and VC concentrations peaked approximately six months post application and have since declined to 21 ppb and 9.4 ppb, respectively.

Site 2. A multi-year phased approach was utilized to remediate a comingled plume at a former chemical plant that stored, repackaged, and distributed a multitude of chemicals, including hydrogen peroxide, methylisobutyl carbinol (MIBC), PCE, acetone, ethanol, and diesel fuel. The first phase was a combination of ex situ and in situ remediation methods that were selected to achieve the site clean-up goals in specific plume areas of immediate concern. The initial total chlorinated ethylene (PCE+TCE+DCE+VC) concentrations were over 213,000 ppb with much of the mass as DCE (72%). After one-and-a-half years of source area treatment, the total concentration was 354 ppb with 25% being DCE and the balance as VC. After demonstrating over nine years of mass flux control with a PRB, and significant groundwater mass reductions in the source area, managed closure status has been requested by the consultant and is pending approval from the regulatory agency.

The innovative combination of activated carbon, impregnated reactive iron, an electron donor, nutrients and bacteria was shown to generate significantly less daughter products and to degrade parent and daughter products completely to ethylene in an expedited timeframe compared to traditional ERD approaches at each of the two subject sites.

Predicted Effects of forest management scenarios on Magnitude of Late Summer Streamflow in the South Fork **Nooksack River**

Susan Dickerson-Lange, Natural Systems Design

Julia Jay, Natural Systems Design Margaret Taylor, Nooksack Natural Resources Department Robert Mitchell, Geology Department, Western Washington University Bob McKane, U.S. Environmental Protection Agency - Office of Research and Development Jonathan Halama, U.S. Environmental Protection Agency - Office of Research and Development

Like many rivers that drain the western slopes of the Cascade Range in Washington, water quality and water quantity are currently impaired in the South Fork Nooksack River. Current conditions result in degraded habitat conditions for salmonids and limited water availability, and future summer streamflow is projected to be substantially lower and warmer by the end of the century. To test potential strategies to buffer future declines in summer streamflow, we modeled the effects of hypothetical forest management scenarios on the magnitude of late summer streamflow. We applied two hydrologic models, DHSVM and VELMA, to quantify the effects of forest gap creation on snow storage and the effects of forest thinning and harvest on transpiration rates and soil water storage. By implementing end-member scenarios to estimate the outer bounds of effects, we find that introducing 40 m forest gaps through the entire snow zone resulted in an average 25% increase in median August streamflow under historical climate conditions, and a 9% increase under end-of-century climate conditions. By implementing forest thinning rather than clear cut harvest rotations across harvestable lands, simulations indicate minimal effects on August streamflows in the next 25 years; however, results indicate a 20% increase in median August streamflow under end-of-century climate conditions in conjunction with a more mature forest mosaic. The effects estimated by each model represent semi-independent influences on the water budget, specifically snow storage in the forest gap scenarios and soil water storage in the forest thinning scenarios. Therefore, the effects may be additive and forest management strategies for climate resilience could consider both gap cuts and forest thinning for an enhanced summer streamflow effect.

Life Cycle Habitat Model Supporting Watershed Restoration and Instream Flow Protection for Fish **Conservation and Recovery**

Eric Doyle, Confluence Environmental Company

Tyson Carlson, Aspect Consulting

The conservation and recovery of Pacific salmon and steelhead is an enormous technical and social challenge. While many factors have contributed to species decline, freshwater habitat degradation is particularly complex because these habitats intersect with and are negatively impacted by many aspects of economic development. Species recovery will depend in part on our collective ability to protect and restore functional habitats, a challenge that only becomes more difficult in a rapidly changing climate. Amongst other needs, this will necessarily require continued investments in watershed restoration and instream flow protection and the effective management of overburdened natural resources. Ecosystem models are an essential tool for meeting this challenge. While models are never "right", in the sense that they cannot fully capture the complexity of natural systems and their predictions rarely conform to reality, they can nonetheless be accurate enough to guide pressing management decisions. The Okanogan Ecosystem Diagnosis and Treatment (EDT) model is a deterministic, life cycle-based habitat model that has been integrated with long-term habitat monitoring to support salmon and steelhead (Oncorhynchus spp.) recovery efforts in this important Columbia River subbasin. The Okanogan EDT model was recently used to help local governments in this watershed meet the requirements of the 2018 Washington State Streamflow Restoration Act. Here we describe how EDT was used to quantify impacts from projected future water demand and the offsetting benefits of proposed streamflow and habitat restoration projects. Our analysis showed convincingly that the proposed actions would achieve a "net ecological benefit", as required under law, with a large factor of safety. The Okanogan Watershed Plan Addendum was approved by the Washington Department of Ecology of EDT in 2021. This unique application of EDT demonstrates the value of quantitative models for management planning and decision support.

Anticipating the Impacts of Management Alternatives on Groundwater and Stream Depletion: Groundwater **Model Development and Application**

Gilbert Barth, S.S. Papadopulos and Associates, Inc.

Jessica Rogers, Ph.D., S.S. Papadopulos & Associates, Inc. Jay Chennault, L.Hg., P.E., CWRE, Associated Earth Sciences, Inc.

The Whatcom Groundwater Model (WGM) was developed for predicting impacts of surface water and groundwater management alternatives in the vicinity of the Lower Nooksack River. The WGM was constructed using the latest available data on geologic structure, monthly precipitation, flow, and pumping stresses (delineated by individual water rights), and calibrated using a combination of water level observations, stream flow observations and hydrogeologic constraints. The WGM reproduces typical monthly variability in groundwater levels and surface water flows. The model was used to evaluate a variety of water management alternatives and identify those with substantial potential for improving hydrologic conditions. Targeted improvements included groundwater levels, stream depletion timing, and maintaining or improving seasonal low flows. Seasonal low flows in the Lower Nooksack River area are sensitive to changes in stream depletion. This sensitivity is seen as an opportunity: modifying conditions contributing to late summer stream depletion produces significant estimates of improvements in seasonal low flows. Several different shallow pumping conversion scenarios were simulated, including converting direct surface water diversions to shallow aquifer pumping, converting both shallow Sumas aguifer pumping and direct surface water withdrawals to deep aquifer pumping, and moving shallow aquifer pumping and direct surface water withdrawals at least a half mile away from the stream. All the conversion scenarios resulted in predicted increases in seasonal low flows. Another type of scenario considered was Aquifer Storage Recovery (ASR), which assessed the potential for using wet season surface water supply to augment declining groundwater levels so that pumping wells could continue extracting through the dry season. Extensive processing demonstrated the spatial and temporal scenario impacts, providing the opportunity for users to review the offsets involved. Understanding offsets associated with alternatives is critical to help the community understand the redistribution in timing and space of a limited resource and to identify the most effective management alternatives.

Approaches for Increasing Late Summer Streamflow in Tributaries to the Lower Nooksack River

Jay Chennault, Associated Earth Sciences, Inc. (AESI)

The Ag Water Board of Whatcom County (AWB), Bertrand Watershed Improvement District (WID), and Whatcom County farmers have implemented a series of projects aimed at increasing late summer streamflow in tributaries to the Lower Nooksack River. Low streamflow during the late spring to early fall in the Nooksack basin (WRIA 1) have been repeatedly identified as a significant concern and limiting factor for ESA-listed aquatic species in the Nooksack basin. Summer low flows in small tributaries to the Nooksack River can be in the single digits. Surface to groundwater conversions projects were identified as a method to augment streamflow and improve habitat as described in Ecology's Draft Rule Supporting Document for the Nooksack Rule Amendment. Converting surface water diversions to groundwater sources improves streamflow during the low flow period by providing temporal buffering of depletion impacts from pumping. Between 2010 and 2016 seven senior surface water rights for direct diversions from Bertrand Creek were converted to groundwater wells resulting in over 2 cfs of additional flow in the creek during low flow periods. In 2017 the Bertrand WID implemented a streamflow augmentation project that resulted in a 1.1 cfs increase in streamflow in September. Implications from the 2015 Foster decision have made it more difficult to implement surface to groundwater right conversions and streamflow augmentation projects. As a Foster Pilot Project organization, the AWB and the Drayton WID are currently in the planning stages of an additional streamflow augmentation project and additional surface water to groundwater right changes. The streamflow augmentation project that could double the flow for the North Fork Dakota Creek which commonly experiences flow of less than 2 cfs in August.

Building Resilient Datasets to Preserve Data Sovereignty for the Yakama Nation

Mary Weber, Yakama Nation Fisheries

Danielle Squeochs, Yakama Nation Water Resources Program
Darren Olney, Yakama Nation Water Resources Program*
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As part of a regional groundwater management program, the Yakama Nation has initiated a comprehensive review of its data collection and management protocols. Building resilient datasets protects against catastrophic data loss and protects Tribal Water Management for generations to come.

Through this process, staff identified core components of what makes a dataset resilient. The core components include appropriate context for the data, a clear organizational system, durability, and ability to be updated as technology and staff change. Staff specifically identified system vulnerabilities that contribute risk to long term data management - one primary issue is data collection by third parties.

Moving forward, staff have built a process that includes considerations for third-party data collection and data uncertainties. All work is supporting the long term effort of the Yakama Nation's Groundwater Replenishment program.

ORIGEN: Building a Tool for Insights Below the Surface

Jennifer Fanning, Pacific Northwest National Laboratory

Joshua Wassing, Pacific Northwest National Laboratory Patrick Royer, Pacific Northwest National Laboratory Christian Johnson, Pacific Northwest National Laboratory Joseph Loftus, Pacific Northwest National Laboratory Tycko Franklin, Pacific Northwest National Laboratory

The visualization of geologic subsurface data requires the use of complex three-dimensional technologies, and the building of a modern application which allows for rapid visualization and enables the user to make informed decisions for environmental remediation. To facilitate a sleek and effective web-based visualization of subsurface geology, the ORIGEN (Online Retrieval Interface for GEologic information) application showcases the geologic framework models of Department of Energy sites and other associated data within the three-dimensional subsurface context. ORIGEN incorporates functionality to visualize and interrogate pertinent subsurface datasets, such as soil sample concentration data. The technology behind ORIGEN plays a crucial role in implementing a responsive web application. ORIGEN leverages the AWS Cloud Development Kit in conjunction with the Svelte and Three.js libraries to provide a browser-based application that is both scalable and robust. This cloud-based solution enables seamless user access via a web browser, while still maintaining efficient utilization of consumergrade user computational resources. This technology allows for the rapid visualization of two-dimensional geologic cross-sections at arbitrary user-defined locations, which may include specific wells. The visualizations provide contextual insight to the data and supports communication and decision-making regarding site cleanup and restoration.

Making Your Data Shine - Dashboards for Data Visualization and Interpretation in R Shiny

Timothy Clark, Herrera Environmental Consultants

Stuart Whitford, Thurston County Environmental Health Kevin Hansen, Thurston County

Water quality monitoring generates vast and varied datasets vital for informed decision-making. However, these data can often be inaccessible and overwhelming for planners and decision makers. Thurston County Environmental Health maintains routine monitoring programs for 32 streams and 11 lakes, and in the past, County staff were tasked with writing annual reports each year, updating graphics, and uploading static PDFs to the web. This was a cumbersome effort and did not leave resources to interpret the findings, merely to present them.

Thurston County contracted Herrera to update their reporting structure, and we developed dynamic dashboards to visualize new and historic data with just a few clicks. R Shiny can be used to develop interactive dashboards that can be specifically tailored for lake data visualization. The Shiny dashboards can empower stakeholders to analyze data in real-time alongside experts, enhancing understanding and decision-making.

This presentation will discuss the benefits of accessible and interactive data, data dashboard options, and tips for development.

Data Catalogs for Management of Environmental Information with Geospatial Context

Christian Johnson, Pacific Northwest National Laboratory

Rebecka Bence, Pacific Northwest National Laboratory Kenneth Ham, Pacific Northwest National Laboratory

Environmental remediation projects often generate large quantities of data and can entail work spanning decades, which makes data management a key need. Regardless of whether the site is small (e.g., gas station) or large (e.g., Hanford), a wide range of information with a geospatial context (e.g., borehole/geology, bio/geo/chemistry, geophysics, and remote sensing) may be relevant to subsurface remediation. The time frame for a remedy could be decades (e.g., for pump-and-treat or monitored natural attenuation), which further underscores the need for data management. The key principle for good data management is that data must be findable, accessible, interoperable, and reusable (FAIR). This presentation will discuss elements for evaluating and selecting an approach to data management. Metadata standards, data catalog requirements, and current options for data catalog tools will be reviewed. Examples of data catalog implementation will be used to illustrate data catalog features.

Overview of Recent USGS Washington Water Science Center Projects on Groundwater-Surface Water Interaction

Rich Sheibley, U.S. Geological Survey

Kathy Conn, U.S. Geological Survey Andrew Spanjer, U.S. Geological Survey Reid Brown, U.S. Geological Survey James Foreman, U.S. Geological Survey Chad Opatz, U.S. Geological Survey

Understanding groundwater-surface water (GW-SW) exchange and hyporheic processes is critical for numerous hydrologic investigations such as habitat restoration, hydraulic modeling, source tracking, and chemical flux estimation. Methods and tools for hydraulic characterization, chemical assessment, temperature measurements, geophysical characterization, and remote sensing are valuable approaches to GW-SW evaluations. The United States Geological Survey (USGS) conducts GW-SW interaction studies throughout the Nation including in Washington State in collaboration with tribal, local, State, and Federal partners. A GW-SW Method Selection Tool assists with method selection based on project- and site-specific characteristics (https://water.usgs.gov/water-resources/software/GW-SW-MST/).

This talk showcases recent USGS Washington Water Science Center GW-SW projects (https://www.usgs.gov/centers/washington-water-science-center). Projects include utilizing fiber-optic distributed temperature sensing cables (FO-DTS) and/or forward-looking infrared (FLIR) thermal imaging to identify temperature differentials that may indicate groundwater discharge locations in a receiving surface water. For example, these locations may be important as cold-water refuges to support fish in river habitat. Other projects use vertical sediment temperature rods to measure and then model groundwater discharge and recharge fluxes. This can be used to, for example, quantify the percent of river flow from groundwater during summer low-flow conditions. Physical measurements with manometers and seepage meters are used to calculate instantaneous and spatially and temporally averaged discharge and recharge fluxes between groundwater and surface water. The discharge fluxes can be combined with piezometer-based pore water chemical sampling to calculate chemical fluxes. These tools have been used in Washington lakes to support nutrient source control programs. They are also being used in the dynamic tidal Puget Sound nearshore and river mouth estuaries to better characterize the shape and extent of the GW-SW mixing zone in contaminated shorelines. The results can be used to risk-rank shoreline areas based on the types and levels of contamination, hydrogeology, and bathymetry to assess the vulnerability of natural and built infrastructure to future climate change inundation scenarios. The experimental use of passive samplers installed in the hyporheic zones of rivers and the marine nearshore are being assessed to determine their effectiveness of identifying GW and SW sources of anthropogenic chemicals like PFAS and 6ppd-Q.

Assessing Water Quality Impacts from Septic Systems in the Tri Lakes Area

Kevin Hansen, Thurston County

Stuart Whitford, Thurston County Public Health, stuart.whitford@co.thurston.wa.us Nikki Guillot, Washington State Department of Health, <a href="https://nikki.gov/Nik

Thurston County is finalizing the results of a recent study of water quality impacts from septic systems in the Tri Lakes area using grant funding from the Washington State Department of Health and the U.S. EPA. The so-called 'Tri Lakes' area, comprising the region near Long, Pattison, and Hicks Lakes in Northern Thurston County, saw rapid post-World-War II growth peaking in the 1980s. Most of the growth was dependent on septic systems: inground sewage treatment systems that now have a median age above 40 years. More than 50,000 septic systems were installed county-wide, with over 5,000 installed in the Tri Lakes area alone.

The study made use of two long-term efforts to advance understanding of groundwater quality impacts from densely clustered septic systems. First, cataloging these septic systems has been ongoing since the 2000's (many systems were installed before modern regulations). Second, groundwater flow and transport modeling (MODFLOW-NWT and MT3D-USGS) have recently produced the capacity to predict some aspects of the potential extent of septic-related wastewater impacts.

To assess the impacts of these systems, between March and October 2022, fifty-eight water wells were sampled in the Tri-Lakes area for total coliform, E. coli bacteria and nitrate-nitrogen - as well as a screening for additional 'Chemicals of Emerging Concern' (CECs). The groundwater flow and transport predictive modeling was used to assist in the selection of sampling locations.

Results from the study indicate that septic-related wastewater has affected groundwater quality, and that new consumer products in CEC are frequently detectable in groundwater samples. The presentation will highlight the ongoing efforts to understand these impacts.

Reinterpretation of the Stratigraphy of the Orting Lake Upland, Deep UIC and Aquifer Testing Results, and Irrigation Reuse through Purple Pipe Infrastructure

Gus Carlson, Associated Earth Sciences, Inc. (AESI)

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The Orting Lake upland located in Pierce County, Washington is mantled by glacial deposits consisting primarily of lodgement till and outwash deposited during advancing and retreating phases of the Vashon ice sheet. Beneath the Vashon age sediments multiple radiocarbon age dates and petrographic analyses provide evidence for a significant sequence of previously unrecognized non-glacial Olympia Formation deposits. The Olympia age sediments are interpreted to consist primarily of river channel sands and gravels, lahars, and flood plain overbank and lacustrine fine-grained sediments based on samples obtained from an extensive network of borings drilled over a multi-year timeframe. Calibrated age dates range from about 24,000 to 44,000 years before present. Olympia age deposits have been documented over an elevation interval exceeding 280 feet, and extend over an area of about 7 square miles. Petrographic analysis of sand thin sections demonstrates the presence of Mt. Rainier provenance volcanics and are consistent with the non-glacial origin of the deposits.

The Olympia Formation deposits are proposed to receive highly treated wastewater effluent, discharged from a membrane bioreactor plant (MBR), suitable for landscape irrigation using a "purple-pipe" infrastructure in select public landscape areas of the approximately 4,700-acre Tehaleh Master Planned Employment Based Community. Analysis of data obtained during deep infiltration testing of select media backfilled Underground Injection Control (UIC) wells completed in unsaturated Olympia Formation channel deposits indicate bulk hydraulic conductivity values generally range from about 30 to 60 feet per day. Specific capacity values range from about 3.5 to over 9.0 gallons per minute per foot of head rise in test wells, and tested well capacity ranges from about 120 to 200 gallons per minute depending on source water conveyance methods. Vertical downward flow through the channel deposits in the unsaturated zone is retarded by laterally discontinuous fine-grained interbeds. Nitrate tracer data indicate travel times through an approximately 200-foot-thick unsaturated interval to the underlying Plateau Aquifer have a broad range due to a combination of shallow low permeability lodgement till and the interbedded nature of the Olympia Formation. Historic unsaturated zone travel times are estimated to range from about 4 to 18 months, and are interpreted to be related to the presence or relative absence of "windows" through the low permeability lodgement till and underlying Olympia fine-grained interbeds. Deep infiltration of the treated waste-water ultimately encounters the underlying Plateau Aquifer interval, formed in Olympia and older channel deposits, before flowing to the north-northwest and discharging as subsurface flow to the Puyallup River valley via highly permeable Vashon recessional outwash delta deposits.

The Rise and Fall of a Nitrate Plume - From a LOSS to an MBR and Future Reclaimed Water Use

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The Tehaleh Master Planned Employment Based Community (Tehaleh) encompasses approximately 4,700 acres on the Orting Lake upland in eastern Pierce County, Washington. Wastewater was originally conveyed to a 500,000 square foot community drainfield (Drainfield) functioning as a Large On-site Sewage System (LOSS) following conventional septic tank treatment. A modular interim Wastewater Treatment Plant (WWTP) was installed to improve the quality of treated effluent as project build-out was underway. A permanent membrane bioreactor (MBR) WWTP is currently providing highly treated wastewater to the Drainfield. The planning, design, and permitting processes for MBR system upgrades to accommodate future full build-out have been initiated using guidance for indirect groundwater recharge projects identified in the 2019 Reclaimed Water Facilities Manual – The Purple Book prepared by the Washington State Department of Ecology.

Treated wastewater pumped from the MBR discharges through the Drainfield system into a relatively thin interval of highly permeable Vashon recessional outwash (Qvr) deposits. Very low permeability Vashon lodgement till (Qvt) is present immediately beneath the Qvr resulting in the formation of a shallow perched water zone from treated wastewater infiltration. A map of the top of the Qvt surface was developed from subsurface exploration and seismic refraction survey data. Nitrate tracer data combined with the top Qvt surface indicated a significant component of southerly flow toward an apparent "window" through the Qvt, allowing for deep infiltration through a thick unsaturated zone to the underlying Plateau Aquifer. The Plateau Aquifer flows to the north about 200 feet deep beneath the Drainfield and discharges via subsurface pathways to the adjacent Puyallup River valley.

Nitrate concentrations at Tehaleh have been monitored from surface water stations and groundwater wells since the early 1990's in support of the original project Environmental Impact Statement process. Background nitrate concentrations in the Plateau Aquifer were typically below 1 mg/L in groundwater wells located far from older off-site unsewered development areas. Capture zone mapping shows a significant amount of Plateau Aquifer flow discharges at a spring zone forming the headwaters of Canyonfalls Creek. Nitrate concentrations in Canyonfalls Creek obtained over a multi-year period prior to development at Tehaleh demonstrated the offsite unsewered areas located northeast of Tehaleh were contributing nitrate to the surface water resource. During subsequent development of the Tehaleh site an extensive network of monitoring wells was installed to monitor nitrate concentrations from the Drainfield. The monitoring data showed a significant increase in nitrate concentrations in the Plateau Aguifer immediately beneath the Drainfield as the project buildout expanded. The trend of increasing nitrate concentrations was reversed following installation of the interim WWTP and the permanent MBR systems.

Groundwater flow and solute transport modeling simulated and closely matched the increase and subsequent decrease in nitrate concentrations obtained from the monitoring well network. Additional drilling, testing, monitoring, and model simulations are currently underway to update the conceptual and numerical

hydrogeologic models. Ultimately the project proposes to reuse treated wastewater to provide irrigation of public landscape using a network of purple pipes which have been installed during site development activities.
14th Washington Hydrogeology Symposium

Potential Implications of Drilling Method on Well Performance

Michael Piechowski, Terraphase Engineering, Inc.

In 2019, Robinson & Noble assisted an industrial client with drilling, construction, and testing of two large-capacity wells in the Longview, Washington area. Though they met the client's needs, with each well capable of supplying more than the plant's current and future water requirement, they were somewhat less productive than other nearby wells in the same aquifer. Over the following three years, the performance of both wells declined markedly, reaching a point where both wells operating in conjunction were not sufficient to provide the required water for plant operations.

Well video inspections did not identify any fill in the screens or blockage of the well screens. An aggressive well rehabilitation program was recommended, utilizing a surge and bail approach with occasional pumping of the wells to clear the water column, essentially the same approach as was used during the initial construction and development of the wells. Re-development mobilized a considerable amount of fine sand, something that was not seen during the initial construction and development.

While considerable sand was produced, the well performance also improved significantly. More than five cubic yards of fine sand were removed from each of the wells during redevelopment. After pump reinstallation, testing indicated that the production capacity of both wells was improved far beyond where it was during initial testing, reaching a point where it was consistent with the other large-capacity wells in the immediate area.

These two wells are the only two recent large-capacity wells in the area that have been drilled with air-rotary drilling. One of the others was drilled with fluid-rotary, the remainder were all drilled with cable-tool. Interestingly – the cable-tool wells were highly efficient to start and have experienced no apparent decline in efficiency (and there are five nearby wells of larger capacity all drilled with cable-tool). I'll close this presentation with a discussion of the theory I have as to why the air-rotary wells were less efficient and failed so soon after drilling.

Overview of Turbidity Sensor Technology for Water Quality Assessment

Bill Mann, In-Situ Inc.

Kerry Caslow, In-Situ Inc.

Turbidity sensors play a pivotal role in environmental monitoring, aiding in the assessment of water quality by measuring the cloudiness or haziness caused by suspended particles. This presentation provides an overview of turbidity sensor technology, spanning its historical evolution, operational principles, integration within multiparameter sonde platforms, data telemetry methods to cloud-hosted platforms, calibration techniques, and strategies for discerning maintenance needs from sensor data.

The historical backdrop of turbidity sensor technology unveils a progression from early rudimentary methodologies to sophisticated modern sensor designs. Turbidity sensing technology has evolved to meet diverse environmental monitoring needs, empowering researchers and regulatory bodies to gauge water quality with enhanced precision.

Understanding the operational mechanisms of turbidity sensors illuminates their functionality. Utilizing principles of light scattering or absorption, these sensors quantify suspended particles in a liquid by analyzing the light transmitted through the medium. Their ability to detect minute changes in light scattering aids in assessing the turbidity levels of water bodies accurately.

Integration of turbidity sensors within multiparameter sonde platforms enhances their utility by combining various sensing capabilities into a singular monitoring system. This integration allows for simultaneous measurement of multiple water quality parameters, providing a comprehensive understanding of aquatic environments.

For effective data management, telemetry of turbidity sensor data to cloud-based hosting platforms or servers proves instrumental. Leveraging telemetry protocols, such as cellular networks, facilitates real-time data transmission, enabling swift analysis and decision-making for water quality management.

Calibration stands as a critical aspect in ensuring the accuracy and reliability of turbidity sensor readings. Implementing best practices for calibration involves periodic verification against standardized reference materials or employing calibration solutions of known turbidity levels. A well-calibrated sensor system ensures data integrity and precision in water quality assessments.

Interpreting sensor data aids in identifying signs indicating the need for sensor servicing or maintenance. Anomalies or drifts in the data patterns could signify potential issues with the sensor, requiring recalibration or maintenance. Careful analysis of trends and deviations assists in preemptive measures, ensuring continuous accurate monitoring.

Understanding the historical progression, operational principles, integration within monitoring systems, data telemetry methods, calibration techniques, and data interpretation guidelines of turbidity sensors underscores their pivotal role in water quality assessment. Harnessing these insights facilitates efficient and reliable environmental monitoring, enabling informed decision-making for the preservation and management of aquatic ecosystems.

Multi-well Testing Program in a Tidally Influenced Variable Density Aquifer

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Brian Zanco, Haley & Aldrich Blake Lytle-Goldstein, Haley & Aldrich Roy Jensen, Haley & Aldrich

Aquifer testing and analysis was performed to support construction and environmental design of a major new marine facility in Puget Sound, Washington. Lessons learned will be presented from conducting a multiple well testing program in a tidally influenced variable density aquifer.

Geology beneath the site consists of fill and glacial deposits. Glacial deposits ranging from clay/silt to sandy gravel were deposited in lacustrine and fluvial environments. The target zone for aquifer testing consisted primarily of silty sand and frequent interbeds of fine to coarse sand and silt. The aguifer is over 200 feet thick. The aquifer is hydraulically connected to the Puget Sound which experiences semidiurnal tides, which vary by as much as 16 feet.

Four test wells were constructed. Two upland test wells were located within 500 feet of the shoreline and two test wells were located offshore on piers in 50 feet of marine water. A network of observation wells and vibrating wire piezometers were installed to monitor the tests. The test wells were constructed with 6-inch PVC casing with dual screens. The screens were installed at depths of 50 to 70 feet and 120 to 150 feet below sea level. During the tests the screens were isolated using a hydraulic packer.

At each test location, aquifer testing was conducted on the upper and then the lower screen interval. Water levels in observation wells were monitored with pressure transducers. The discharge from the test pumping was monitored for general water quality parameters, including conductivity.

Aquifer testing began with 3 to 4 step drawdown tests to establish the pumping rate for the constant rate test. The duration of the constant rate test was about 48 hours with a 12-hour recovery phase. The data was analyzed using analytical solutions and MODFLOW simulations.

Conductivity of the upland test discharge varied from fresh to brackish and the offshore tests from brackish to salt water.

Applications of 4D Electrical Resistivity Tomography for Monitoring Vadose Zone Water Migration at the **Hanford Site**

Tim Johnson, Pacific Northwest National Laboratory

Jon Thomle, Pacific Northwest National Laboratory Judith Robinson, Pacific Northwest National Laboratory Emily MacDonald, Central Plateau Cleanup Co. Rob Mackley, Pacific Northwest National Laboratory

Recent advances in time-lapse electrical resistivity tomographic imaging are being leveraged to investigate vadose zone contaminant fate and transport at the Hanford Site. Electrical resistivity tomography is a geophysical method of imaging the electrical conductivity of the subsurface, which is governed in part by pore fluid electrical conductivity and saturation in the vadose zone. Time-lapse electrical resistivity tomography enables changes in subsurface electrical conductivity to be monitored over time, such as those induced by changes in saturation as water migrates through the vadose zone. In that case, changes in electrical conductivity can be used as a proxy for changes in saturation. In this presentation we show two examples of how autonomous, 3-dimensional time-lapse electrical resistivity tomography was used to efficiently address the challenging problem of monitoring water migration pathways from the surface to the water table at the Hanford Site.

The first example involves imaging migration of water discharged to Hanford's Treated Effluent Disposal Facility (TEDF), which consists of two adjacent ponds permitted for the disposal of process water. TEDF is assumed to overly a confined aquifer unit, such that samples from nearby monitoring wellbores screen within the aquifer are not representative of TEDF discharge water, which is assumed to perch on the upper confining unit. Consequently, to renew the TEDF discharge permit, site operators were required to install a new monitoring well capable of sampling perched TEDF discharge water. To optimize placement of the new sampling well, time-lapse ERT was used to identify the primary discharge water flow pathways. Results revealed consistent and focused vertical pathways beneath each pond, presumably leading to the region of greatest perched water mounding ideal for monitoring well locations.

The second example involves imaging in-situ soil flushing to remediate vadose zone chromium contamination at Hanford's 100K-East Reactor Area. Shallow chromium contamination in the K-East Area was previously removed via excavation. Deeper contamination is being remediated using soil flushing, whereby the excavation pit was back-filled and clean flush water is applied at the surface above the contaminated zone. As flush water migrates through the backfill and native soil, chromium is mobilized and transported to the water table where it is extracted and treated through a pump and treat system. During flushing, autonomous electrical resistivity tomography was used to monitor flush water migration through the vadose zone in 3D. Results revealed that the excavation backfill materials significantly altered flow paths, with focused 'finger flow' in the backfill and redistribution of flush water along the boundary between the backfill and native soils.

Analysis of King County Monitoring of Stream Discharge and Precipitation Over Decadal Time Spans

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The long-term investment of King County in environmental monitoring (in some locations extending over 20 years) provides a unique opportunity to investigate the impact of development and climate variability on urban to rural watersheds. Measurements of precipitation and stream discharge from the King County Hydrology web site are automatically processed by water year. A two-parameter recursive digital filter with back projection is used to determine baseflow and runoff volumes. With knowledge of watershed area and local precipitation determinations, components of the annual water budget of each watershed are quantified and variations in these components are tracked over the duration of monitoring. At the level of individual storm events, the efficiency of the watershed in storing or discharging water is determined. In illustration of this analysis, the two largest watersheds on Vashon-Maury Island are considered. The Judd Creek (3220 acres) and Shinglemill Creek (1940 acres) watersheds encompass mixed forest, pasture/farming, and housing. Stormwater from the Vashon town center drains directly into Shinglemill Creek. A network of precipitation gauges allows adequate quantification of rainfall over each watershed. Shinglemill Creek discharge has been monitored since 1999. Records for Judd Creek extend back to 2006. About 40% of the precipitation is accounted in the discharge of each stream with nearly equal fractions of runoff and baseflow. Baseflow fractions are less variable from year to year than runoff, consistent with the idea that heavier storm events result in more runoff relative to infiltration. Assuming a nominal evapotranspiration rate of 45%, about 15% of the water in each watershed infiltrates to aquifers that discharge directly into the Puget Sound. No climatic trends are apparent with annual precipitation and stream discharge volumes covarying and no long-term trend in the runoff fractions is apparent. The baseflow recession coefficient is essentially the same for both watersheds and has not changed over time. Results of the analysis for these two watersheds provide a baseline for comparisons to other King County watersheds where development has been more significant. Continued monitoring and analysis is essential in order to identify trends that may impact stream remediation efforts.

Groundwater Level and Climate Variable Trends and Implications for Groundwater Resources in Oregon

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Nora Herrera, U.S. Geological Survey

Increasing groundwater demand and changing climate in Oregon have led to concerns about existing and future groundwater supplies that support humans and ecosystems. Trends in groundwater level and climate variables were calculated for 1990–2019 and compared with future climate projections to improve understanding of recent and potential future changes in groundwater systems across the state of Oregon. Downward trends in groundwater level were observed in more than 70 percent of wells. Downward trends were observed more frequently in wells >200 feet below land surface (ft bls) when compared to wells ≤200 ft bls. Groundwater-level trends were generally downward in basins along the Columbia River and east-central Oregon, whereas trends in groundwater level west of the Cascade Range and in central Oregon were more variable. Upward trends in winter minimum temperature were determined for most of the Cascade Range and in eastern Oregon; in general, no significant trends were identified across the rest of the state. Winter precipitation generally trended upward in the eastern half of Oregon, whereas no significant trends were observed for most of the western half of Oregon. Despite upward trends in winter precipitation in across large areas, downward trends in snow-water equivalent (SWE) were observed for most sites in Oregon. Projections of climate and hydrology for 2040-69 predict a deficit in water availability within the Cascade Range but across the rest of the state, changes in net water availability are more uncertain. Future water availability deficits in the Cascade Range, upward trends in temperature, and downward trends in SWE across the state could adversely affect future groundwater recharge over large areas of Oregon.

Evaluating Groundwater Elevation Trends in Wells Completed in Basalt and Basin-fill, Walla Walla River Basin, **Washington-Oregon**

Amy Yoder, U.S. Geological Survey, Oregon Water Science Center

Amanda Garcia, U.S. Geological Survey, Oregon Water Science Center Jennifer Woody, Oregon Water Resources Department

Walla Walla River Basin (WWRB) groundwater is vital to the area's agricultural irrigation, domestic and municipal users, and in providing baseflow to streams, but levels have been declining since the 1940s. Trends in groundwater levels measured during 1933—2023 in 43 wells completed in basalt ('basalt wells') and 17 wells completed in basin fill ('basin-fill wells') in the WWRB are being evaluated to provide a better understanding of these declines. Significant trends (p-value ≤ 0.1) were observed in 24% of the basalt wells and 13% of the basinfill wells analyzed. Over periods ≥30 years, the mean rates of water-level change for basalt and basin-fill wells decreased and were -1.8 ± 2.2 ft/yr and -0.1 ± 0.1 ft/yr, respectively. However, during the last 15 years, mean (\pm standard deviation) rates of water-level change for basalt and basin-fill wells increased and were 0.1 ± 2.8 ft/yr and 1.3 ± 4.1 ft/yr, respectively. These preliminary findings indicate that throughout the WWRB, water level rates of change were positive in both aquifer types over the last 15 years, but long-term mean rates of water level change showed declines that were an order of magnitude faster in basalt wells than in basin-fill wells. These results highlight important differences between basalt and basin-fill groundwater systems, potentially related to hydraulic properties, structure, water use, recharge mechanisms, and other environmental factors.

Climate Change Resilience and Adaptability for Water Supply

Daniel O'Neill, Washington State Department of Ecology

In 2023, the Washington State Legislature passed RCW 70A.05, directing Ecology and other state agencies to update the state's Integrated Climate Response Strategy. As part of this work, Ecology's Water Resources Program is strategically evolving its information base, as well as our approach to planning, investments, and water management decisions in light of the challenges presented by our changing climate. The Water Resources Program will be communicating our approach over the next year via a series of publications. By April 2024, we will have published a document that starts the conversation assessing the state of preparedness of Washington's water resources. During the summer of 2024, we will release a companion documents summarizing climate science as it applies to our state's water supplies, as well as continuing the conversation about our water supplies' preparedness, resiliency, and adaptability in the face of climate change.

Mitigating the Impacts of Drought with Local Drought Preparedness Plans

Drought is just one of the impacts of climate change. The state's approach to the episodic impacts of drought is two pronged. First, there is emergency drought response. Drought emergency declarations are determined by rule and statute. Ecology has a process by which we declare a drought emergency and contingencies for drought emergency grants. The second prong is drought preparedness. Early in 2023, the state legislature authorized funding to pilot state-wide drought planning and preparedness work. Ecology will make up to \$1.8 million available state-wide for competitive grants that will be used to incentivize eligible and interested entities to prepare Local Drought Preparedness Plans. By April 2024, Ecology will be evaluating applications with a goal of offering grant acceptance letters to grantees in Summer 2024.

The Complex Hydrogeology of the West Plains, Spokane County

Ben Lee, Landau Associates, Inc.

Ben Lee, PE, CWRE; Landau Associates, Inc. Tom Briggs, PE, LHG; Landau Associates, Inc.

In 2008, trichloroethylene (TCE) was detected in two deep supply wells at Spokane County's Spokane Raceway Park (Site), which led to Ecology requiring the County to conduct remedial investigations through the Voluntary Cleanup Program. Installation of deep monitoring wells confirmed the presence of TCE in deep groundwater beneath the Site despite no significant indication of surface or shallow soil/groundwater contamination at the Site. After almost a decade of monitoring, the County petitioned Ecology for a No Further Action (NFA) determination for the Site. In response, Ecology required the County to demonstrate a plausible off-site source and contaminant transport mechanism to account for the onsite contamination. While a comprehensive conceptual groundwater framework had not been developed for the West Plains, much work had been completed to describe the hydrogeologic conditions and environmental contamination in smaller discrete areas (e.g., for Fairchild Airforce Base, the City of Airway Heights, etc.), which allowed the County and Landau Associates the opportunity to connect the dots to develop a more comprehensive hydrogeologic conceptual model that provides an explanation for the source of contamination at the Site.

Join us as we describe the fascinating and complex hydrogeologic setting of the West Plains, including groundwater flow and contaminant fate and transport of TCE and other volatile organic compounds. The hydrogeologic setting of the West Plains includes a complex arrangement of Columbia River basalt and associated water-bearing interflow zones; paleochannels carved into the basalt during the repeated releases from the glacial Lake Missoula and subsequently filled with unconsolidated outburst flood deposits (sand and gravel); and more recent alluvium and wind-blown loess. We compiled a large body of previous on-site and offsite investigations regarding geology, hydrogeology, and known or suspected contamination releases to build a conceptual model that demonstrated that the TCE likely originated at a waste disposal landfill located upgradient of the Site—which was documented as having historically been used to dispose of TCE (and other contaminants)—and migrated downgradient through advection and dispersion forming a groundwater plume that reached the Site. It was a logical conclusion but only after a long hard look at the evidence. This study provides valuable insight into the larger West Plains hydrogeologic setting that may be relevant to other groundwater contamination issues there.

Tidal Wave Attenuation in a Coastal Aquifer

Steve Graham, S. Graham Engineering and Geology, Inc.

A large work area was created by fill comprised of sand, silt and crushed slag along the shore of a fjord at an aluminum smelting facility at Kitimat BC. Contaminants from the slag leached into groundwater flowing through the fill aquifer. The source of the groundwater was onflow from the steep mountain slopes above the facility, and direct precipitation onto the work area. The average annual precipitation at the site exceeds sration ix feet.

The site investigation included a study oft tidal wave characteristics in the aquifer under the work area. The tidal range on the eastern side of the site is about 16 meters (52 feet), so the potential of the tide to affect local groundwater speed, and associated dispersion, weas not insignificant.

As the contaminant in the groundwater was conservative at the relevant timescale, the concentration attenuation would be related to regular dispersion resulting from the net nontidal groundwater speed plus that from oscillatory flow due to the tidal wave. Thus a larger tidal wave range in the aquifer and larger area of tidal influence prior to discharge to the receiving water body (the fjord) would be beneficial.

Fortunately there were numerous groundwater monitoring wells already installed over the site, and the aluminum smelter had a full-time environmental department and crew with the necessary water depth logging equipment on hand.

The experimental procedure entailed identifying a string of monitoring wells located approximately normal to the seawall of the work site, and installing a recording water depth probe in each of them. The recording frequency of the probes was set to 1 minute in order to resolve the wave characteristics. The probes were set to run over the entire time that a tidal wave passed by all the probes. As the recording probes were digital, the changes in wave characteristics as the wave traveled across the aquifer could be calculated and compared readily using a spreadsheet analysis.

The main results were that (1) the tidal wave could be detected and measured clearly as it traveled through the aquifer, (2) there was a substantial reduction in the amplitude of the tidal wave as it moved from the sea into the aquifer (from about 16 m to 1 m at a point near the shore), (3) the wave was detected for a distance of about 100 m (300 ft) inland, (4) the wave amplitude decreased approximately exponentially, and (5) the wave celerity (speed) remained fairly constant along the path of wave advance.

In summary, the shoreward extent of the tidal wave was fairly small notwithstanding the forcing tide at the marine boundary was fairly large. However, as the regulatory point of compliance in BC is 10 meters (33 feet) from the receiving water body, the additional dispersion afforded by the oscillatory flow landward of this point is helpful in meeting water quality objectives.

Groundwater Surface Water Interactions at a Tidally Influenced Cleanup Site

Courtney Savoie, Maul Foster Alongi

Amanda Bixby, Maul Foster Alongi

Background/Objectives: Groundwater and sediments are impacted by environmental contamination at a former lumber mill facility in Aberdeen, Washington (the Site). The Site is located along the banks of the estuarine Chehalis River, at the confluence with Shannon Slough, and is the subject of an ongoing remedial investigation to characterize environmental impacts associated with historical sawmill operations. This investigation was conducted in order to characterize the flow regime of shallow groundwater and to evaluate interactions between groundwater and tidally-influenced surface water at the Site, and to inform application of appropriate screening levels to areas where groundwater is significantly influenced by surface water from the Chehalis River.

Approach/Activities: Pressure transducers were installed in ten monitoring wells across the Site and in a staff gauge in the Chehalis River adjacent to the Site. Transducers measured water levels, conductivity and temperature in 15 minute intervals for approximately 18 months. Because the Site is tidally influenced, synoptic water level measurements do not capture the net effect of tidal fluctuations on hydraulic gradients and groundwater flow. To evaluate the mean hydraulic gradient between upland monitoring wells and the Chehalis River, MFA used the Serfes filtering method to calculate averaged water levels for the Chehalis River and each monitoring well. To evaluate groundwater surface water interactions, MFA identified a 48-hour period during each season and performed a detailed evaluation of data logged by the transducers at each monitoring location, including water level elevations, conductivity, and temperature.

Results: Multiple lines of evidence indicate that significant interaction between surface water and groundwater are limited to three monitoring wells which are located immediately adjacent to the Chehalis River, or the Shannon Slough. The available data indicate that groundwater-surface water interactions at these three monitoring wells are dominated by processes including chemical dispersion and diffusion, and propagation of pressure waves upland from fluctuating hydraulic head in the Chehalis River. The data suggest that physical advection of surface water into upland groundwater, driven by temporary reversals of the hydraulic gradient, is very limited both spatially and seasonally. Although the data indicate that there is some interaction between surface water and groundwater at monitoring wells located immediately adjacent to the Chehalis River, the concentrations of contaminants measured at these wells are representative of groundwater and are therefore most appropriately compared to groundwater screening levels.

Evaluating Remedial Progress in the River Corridor: Contaminant Rebound in the Unconfined Aquifer Underlying Hanford's 100-H North Study Area

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The U.S. Department of Energy Hanford Site is a 1,502 km2 (580 mi2) federal facility located in Washington State. The 100-HR-3 Operable Unit (hereinafter called 100-D/H) is part of Hanford's 100 Area that borders the Columbia River. 100-D/H is home to deactivated nuclear reactors, 100-H, 100 D, and 100-DR, that produced plutonium from 1944 to 1967. During reactor operations, groundwater was contaminated with hexavalent chromium (Cr(VI)) during handling of the sodium dichromate solution that was used in reactor cooling water to prevent corrosion.

The remedy selected to address Cr(VI) contamination in the 100-D/H unconfined aquifer is extraction and treatment by ion exchange (i.e., pump and treat [P&T]). P&T remediation began in 1997 with the HR-3 and DR-5 facilities, and in 2010 treatment capacity expanded with the addition of the HX and DX facilities. HR-3 and DR-5 were decommissioned in 2011, while HX and DX P&T systems continue operating today. Between HX and DX, there are currently 60 extraction wells and 39 injection wells treating the unconfined aquifer.

Separate rebound studies in six discrete areas of 100-D/H have been planned to evaluate the progress of active remediation against the cleanup levels (CULs), identify any areas of residual soil contamination that represent continuing sources of Cr(VI) contamination to groundwater, and determine if active P&T operations should resume or transition to long-term monitored natural attenuation. Three of those studies have begun as of the end of 2023, and the first, at 100-H North, has concluded.

100-D/H rebound studies involve evaluation of contaminant concentrations, hydraulic and hydrochemical changes under ambient aquifer conditions (no active P&T remediation) for at least one full river stage cycle (i.e., 12 months) to ensure adequate understanding of contaminant migration due to river stage and seasonal transition periods. The first 100-D/H rebound study started in October 2022 with the 100-H North Subarea where two suspect areas (183-H Solar Evaporation Basins and the 100 H 46 waste site) have been identified as potential secondary sources of Cr(VI). Eight P&T wells were deactivated for the study and a total of 24 wells and aquifer tubes were sampled at monthly or bimonthly frequencies. Water-level data was collected from sensors installed in the idle injection and extraction wells and from those monitoring wells equipped with automated water-level network transducers.

Preliminary Cr(VI) data for the majority of the wells and aquifer tubes show predictably variable trends that remain below the inland CUL of 48 μ g/L (a subset also displaying trends below the near river CUL of 10 μ g/L) throughout the river cycle. Cr(VI) concentrations at one well within the footprint of the 183 H waste site briefly increased tenfold immediately after the peak high river stage in June 2023 but fell almost as quickly as the river level receded. Moving forward, the data collected will be evaluated using spatially interpretive techniques, statistical evaluations, and modeling to assess groundwater conditions post-shutdown, the need for continued P&T operation, and bound the magnitude and extent of the continuing source in consideration of possible additional remedial action decisions.

Using USGS MODFLOW Results to Improve Calibration of the VELMA Ecohydrology Model for Modeling Streamflow

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For many coastal areas around the Puget Sound, the interplay between weather, surface water, soils, evapotranspiration and groundwater flows is critical to modeling stream flow and predicting quantity and timing of flows under climate change. In this presentation, we introduce an approach developed by the Suquamish Tribe that uses results from an existing USGS groundwater model for the Kitsap Peninsula to improve calibration of EPA's Visualizing Ecosystem Land Management Assessments (VELMA) eco-hydrology model that estimates changes in stream flow and water quality, based on near-surface (<5-meter) hydrodynamics. We briefly describe how the VELMA model works and how the Kitsap Peninsula MODFLOW groundwater model worked. We describe a new groundwater capability recently added to VELMA 2.2 and explain how we used this with the results from the MODFLOW model to improve calibration of the VELMA model against observed gage readings. We discuss results for simulations of stream flow on the Big Beef Creek watershed on the Kitsap Peninsula from 2000-2012 calibrated against observations from the USGS gage at Seabeck. Finally, we discuss how inclusion of groundwater (aquifer) dynamics in VELMA can be used to better inform management and policy decisions affecting ground and surface water resources.

Using Water Budget Informed Model Design to Assess Rising Groundwater Conditions in the Golden Valley Subbasin, Nevada

Don Malkemus, Terraphase Engineering, Inc.

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Residents of Golden Valley, Washoe County, Nevada, use domestic wells for water supply. Declining water levels in the 1970s and 1980s led to initiation of the Golden Valley Artificial Ground Water Recharge Program, which consisted of the injection of Truckee River water into Golden Valley aquifers through four injection wells in the upper portion of the basin. The program is funded through fees collected from area residents under Washoe County Ordinance 1548. Potable imported water was injected from 2002 through 2016, at which time the program was suspended due to rising groundwater levels. In some areas of the basin, groundwater levels have continued to rise through the present, while groundwater levels have declined in other areas of the basin.

On behalf of Washoe County, Terraphase performed an aquifer recharge assessment to gain a better understanding of the hydrogeologic conditions of the basin and provide input on the future need for an aquifer recharge program in Golden Valley. The assessment included development of a Conceptual Site Model (CSM); construction and calibration of a new 3-dimensional groundwater flow model (MODFLOW); and predictive simulations to evaluate when re-starting the injection program may be needed and whether the recharge program could be modified to increase its effectiveness.

As part of the CSM, we constructed a 30-year water budget (1991 – 2021) for the basin, which helped identify the drivers for changing groundwater conditions, and provided insight into how the drivers relate to specific areas experiencing groundwater level rise or decline. The CSM and water budget served as the basis for construction of the numerical model, which simulates transient boundary conditions in the basin over the 30-year period. We calibrated the model to observed groundwater elevations from more than 60 domestic and monitoring wells. The model provides a predictive tool for groundwater management in the Golden Valley Basin with the ability to simulate various climatic conditions to determine when and where an aquifer recharge program would be needed.

The assessment revealed that changes in regional municipal pumping and long-term climatic conditions are major drivers of groundwater conditions within the basin, and that specific areas experiencing groundwater level rise or decline appear to be controlled by natural conditions, and not by the recharge program. We found that groundwater travel times through the basin are slow, and it may take decades for the elevated water levels to decline under normal climatic conditions. Our analysis was used to help communicate to Golden Valley residents about their water supply and to address concerns about rising or falling groundwater levels in the basin.

Tracer-constrained estimates of groundwater recharge to the Columbia River Basalt in the upper Umatilla River basin, Oregon

Henry Johnson, U.S. Geological Survey

Henry Johnson, U.S. Geological Survey Oregon Water Science Center Kate Ely, Confederated Tribes of the Umatilla Indian Reservation Anna-Turi Maher, U.S. Geological Survey Oregon Water Science Center

Multiple isotopic tracers were used to determine the recharge rate to the Columbia River Basalt (CRB) groundwater system in the 2,300 sq km upper Umatilla River basin (Oregon). Results of the study contradict several interpretations about the rate and mechanism of recharge to the CRB groundwater system that have been reported in the literature.

Across the study area, the CRB groundwater system is vertically stratified by age. The mean age of groundwater increased with depth, with a vertical gradient of about 60 years per meter. The vertical age gradient was similar across the study area and varied little with elevation, surficial geology, the amount of annual precipitation, or proximity to streams. The consistency of the age gradient across the study area indicates recharge largely occurs through vertical infiltration with minimal lateral input where interflow zones are exposed at land surface. Where interflow zones are exposed at the surface (primarily in the Blue Mountains), the ubiquitous horizontal lines of vegetation and springs indicate interflow zones largely discharge groundwater rather than provide routes for recharge.

Tracer-based recharge rates were less than 3 mm/yr, which is one to two orders of magnitude lower than most previously published estimates. Rates were calculated from the infiltration velocity at each well (depth of the well bottom / mean age of groundwater from the well) and a range of effective porosity values for oceanic and continental flood basalts obtained from the literature. Recharge rates were similar among all wells in the study despite differences in completion depth (16 m – 545 m), well construction, annual precipitation (400 mm – 1,500 mm), surficial geology, and proximity to perennial or intermittent streams. The recharge rate effectively was decoupled from the available water at land surface, i.e. precipitation and streamflow loss. This decoupling likely is due the thick, dense, low-permeability interiors of CRB flows which severely limit the vertical movement of water. The study found little evidence for fault-enhanced vertical infiltration but substantial evidence that major faults inhibit the lateral movement of groundwater.

Prediction and Management of Perched Water at a Proposed Managed Aquifer Recharge Facility

Jason Keller, GeoSystems Analysis, Inc.

Michael Milczarek, GeoSystems Analysis, Inc. Robert Rice, GeoSystems Analysis, Inc.

A calibrated three-dimensional unsaturated/saturated numerical flow model was developed to simulate the amount of surface water that could be successfully recharged at a proposed surface spreading managed aquifer recharge facility in Arizona. A characterization program consisting of near-surface test pits, boreholes, in-situ hydraulic conductivity measurements, and laboratory physical and hydraulic properties provided an extensive evaluation of the project site and vicinity subsurface hydrogeology. The hydrostratigraphy within the model area is characterized by generally sandy material at the near surface with an approximately 10 to 60-foot-thick finegrained layer at variable depths of 40 to 60 feet below ground surface and sloping downward in a northerly direction away from the proposed site. The fine-grained layer is a low permeability unit that could limit aquifer recharge operations if a perched water mound rises into the bottom of the recharge basins. Additionally, perched water has the potential to migrate laterally and intersect an adjacent gravel quarry. A numerical model was developed to predict recharge basin infiltration rates that can be achieved over a range operating conditions at the proposed facility, while concurrently limiting the perched water mounding below the recharge basins and preventing the daylighting of water in the adjacent gravel quarry. Numerical model results were compared against an analytical solution for steady-state perched water mounding. The analytical model predicted greater perched water mounding than the numerical model due to the analytical solution assumption of a flat and infinitely deep low permeability unit. Model results indicate perched water mounding can be generally controlled by alternating recharge within different basins and that numerical modeling of perched water conditions should be considered if low permeability units are sloping, discontinuous, or thin.

Implementing Improved Pump and Treat Remediation and Performance Monitoring of Groundwater **Contamination within Discrete High-Concentration Zones**

Rebecka Bence, Pacific Northwest National Laboratory

Frederick Day-Lewis, Pacific Northwest National Laboratory Rob Mackley, Pacific Northwest National Laboratory

Understanding the locations of persistent, high-concentration zones in an aquifer is critical for quantifying contaminant mass and optimizing groundwater pump and treat (P&T) strategies. These zones are challenging to identify, particularly where wells are screened over large depth intervals (>10 meters). Groundwater samples collected from fully screened extraction wells (generally irrespective of pump intake depth) provide a permeability-weighted average concentration for the entire saturated screened interval. High hydraulic conductivity (K) zones contribute the most water to pumped samples. Since water is extracted preferentially from these more permeable zones, they often have lower contaminant concentrations relative to low-K zones. Samples taken from a fully-screened well within a heterogeneous aquifer with a vertical concentration profile can thus be diluted and may not accurately quantify contaminant mass residing in low-K zones. These low-K zones can act as continuing sources of contaminants to the aquifer and prolong remediation efforts. To evaluate the influence of hydraulic conditions and aquifer/well exchange on sampled concentrations, laboratory and field studies were conducted at the Hanford Site in eastern Washington. Studies involved borehole flow measurements using a wireline electromagnetic flowmeter under ambient and pumped conditions and sampling contaminant concentrations vertically. Initial data collected under ambient conditions in a monitoring well screened over three separate intervals indicate the presence of inflow and outflow zones within the lower-upper and upper-middle screens. An analytical model and inversion framework will be utilized to estimate the vertical distribution of contaminant mass within the aquifer based on the collected flow logs and sampled concentrations. This work will demonstrate the benefit of collecting additional hydraulic and contaminant profile information in existing long-screened wells to inform effective groundwater P&T remedies.

An Analytical Modeling and Inversion Framework to Estimate Vertical Concentration Profiles Around Longscreened Wells

Frederick Day-Lewis, Pacific Northwest National Laboratory

Rob Mackley, Pacific Northwest National Laboratory Rebecka Bence, Pacific Northwest National Laboratory

Concentration samples taken in long-screened wells (LSWs) provide only limited information about the vertical concentration profile (VCP) in the surrounding formation. In the presence of intraborehole flow—under ambient or pumped hydraulic conditions—sampled concentrations represent weighted averages of aquifer pore-fluid concentrations, where the weights depend on the flows between the well and surrounding aquifer layers (or fractures). Recently, an inverse modeling approach was developed to combine borehole flowmeter logs and concentrations sampled under one or more ambient and/or pumped conditions to estimate the VCP; however, the data-analysis framework was limited to equilibrium concentration conditions. Here, that analytical model and inverse approach are extended to consider time-series concentration data, thus enabling the collection and analysis of samples under non-equilibrium transport conditions. The analytical model developed previously is reformulated in discrete time, and the inverse framework is extended to utilize time-series concentrations sampled at arbitrary locations and times. Samples collected under different hydraulic conditions (e.g., different pump intake locations, low-flow sampling from different depths, passive sampling, etc.) can be pooled together for joint inversion. The approach is demonstrated for synthetic datasets and shown to provide valuable information to understand the VCP in the formation surrounding a LSW. Our framework is extensible for application to dilution or fluid-replacement logging and thermal logging experiments, in which time-series data are collected under one or more hydraulic conditions for the purpose of estimation the formation VCP.

Numerical Model Results for Groundwater Sample Interpretation

Amber Nguyen, Pacific Northwest National Laboratory

Christian Johnson, Pacific Northwest National Laboratory

Groundwater chemistry data provides important information about groundwater contaminant plumes and remedy performance, but challenges exist in the interpretation of data from groundwater samples, particularly when the well is not designed specifically for monitoring a small discrete zone. The three-dimensional (3D) context is key for understanding the distribution of a contaminant plume. However, older wells or wells designed as injection or extraction wells can have relatively long (> 10 ft) screens that may intersect multiple hydrogeological units. Thus, water may enter/leave the borehole at different rates correlated with transmissivity of the intersected unit. Groundwater samples collected in such wells through standard methods represent some averaged mixture of water from the different hydrogeological units, making it difficult to interpret the vertical extent of contamination and the contaminant mass flux in the subsurface. Based on a recent paper describing equations and data needed to better interpret groundwater concentrations for long-screened wells, this work used the FloPy Python package to construct a set of MODFLOW and MT3DMS models for groundwater flow and contaminant transport. The resultant set of simulations provided a library of data sets with known inputs and known outputs that could be used to test data interpretation equations or approaches to assess their suitability and any limitations.

A Deep Learning Surrogate Model for Efficient Groundwater Pump-and-Treat Optimization

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Xinming Lin, Pacific Northwest National Laboratory Jason Hou, Pacific Northwest National Laboratory Mark Rockhold, Pacific Northwest National Laboratory Bryan He, Pacific Northwest National Laboratory Inci Demirkanli, Pacific Northwest National Laboratory Rob Mackly, Pacific Northwest National Laboratory

Pump-and-treat (P&T) is a common groundwater remediation technique that involves extracting contaminated groundwater in an aboveground treatment system. The design and operational strategy for the extraction well network is crucial for the effectiveness and efficiency of the P&T system in terms of both hydraulic control and contaminant mass removal. However, optimization of the P&T well network poses significant computational challenges due to the complex and dynamic subsurface processes that govern groundwater flow and contaminant transport. Physics-based numerical models, commonly employed for simulating these processes, often prove to be computationally demanding, particularly for applications involving a large spatial extent or extended time periods. These challenges are further intensified by the need for multiple simulation runs during optimization evaluations.

In this study, we present a novel approach that integrates analytical solutions for groundwater flow and contaminant transport with a deep learning framework, U-Net, to simulate the P&T well network. U-Net is a powerful image-to-image translation model that can learn the nonlinear relationships between input and output images. Analytical flow solutions provide physical prior knowledge and constraints as inputs to the U-Net model, which can help reduce bias and improve the accuracy of the predictions. The aquifer's hydraulic response to pumping is based on analytical solutions derived from the superposition principle and the Thiem equation. The output images are the plume distribution and concentration at different time steps, which are obtained from numerical simulations during the deep learning model training stage. The trained deep learning model can then be used to predict the outcomes of various well network designs, using only the related analytical solutions as input.

This approach was applied to simple, yet highly transient, 2D synthetic models. It was also applied to complex 3D heterogeneous models of the Hanford Site to demonstrate performance and efficiency. The U-Net model can predict the plume distribution and concentration with high fidelity and reliability (less than 0.1% error in mass recovery) and can significantly reduce the simulation time compared to the numerical models (over 1000 times faster). This approach is being used to improve P&T well network design to enhance mass recovery and reduce remediation time of Hanford 200 West Pump and Treat. Additionally, it can be used to streamline decisionmaking, encourage more efficient and sustainable adaptive site management practices, and reduce remediation costs.

Lower Yakima Valley Groundwater Management Program

Sheryl Howe, Washington State Department of Health

Groundwater in the Lower Yakima Valley contains concentrations of nitrate that exceed the national drinking water standard of 10 mg/L. Groundwater provides drinking water for as many as 56,000 residents in the lower Yakima Valley and poses a public health issue for vulnerable populations. Sources of nitrate include past and present agricultural practices, failing septic systems, residential and municipal fertilizers, irrigation, and commercial activities.

The Lower Yakima Valley Groundwater Management area was created in 2011 to develop a program to reduce sources of nitrates, improve aquifers to meet drinking water standards, and educate residents about the problem and how they protect themselves. The program was approved by the Washington State Department of Ecology in 2021 and work started to implement the 64 recommended actions in the program.

Work in the Lower Yakima Valley is a collaborative effort between the Yakima Health District, South Yakima Conservation District, Yakima County Public Services and the Washington State Departments of Agriculture, Ecology, Health. This presentation will provide an overview of the numerous efforts underway in the Lower Yakima Valley to reduce sources of nitrates and improve the overall health outcomes for the residents in the area.

Improving Wellhead Protection Area Delineations for 20 Lower Yakima Valley Group A Wells

Ben Lee, Landau Associates, Inc.

Nicole Mehr, Landau Associates, Inc.

Public water systems supplied by groundwater are required to implement a wellhead protection program to assess and mitigate the risk of environmental contamination for each of their source of supply wells. Two of the primary components of a wellhead protection program are a wellhead protection area (WHPA) delineation and a contaminant source inventory (CSI) for each well. WHPAs are zones of contributing area of groundwater flow to a supply well, typically delineated in 6-month, 1-year, 5-year, and 10-year time-of-travel increments. CSIs are intended to provide a catalogue of known and potential contaminant sources within the delineated WHPAs so that the water system can better understand – and subsequently mitigate – the risk of environmental contamination for each of their source wells. Accurate and realistic WHPAs, therefore, are an important tool for water system managers to maintain safe and reliable drinking water supplies for their customers.

WHPAs can be delineated using multiple techniques, from the simple and crude Calculated Fixed Radius (CFR) method to numerical modeling. Many water systems have WHPAs delineated by the CFR method, for the primary reason of ease of implementation. However, the CFR method does not always provide realistic representations of the contributing area to a well, especially in places with a moderate to strong groundwater hydraulic gradient or for high-capacity wells or for complex hydrogeologic settings. Most times, a more detailed delineation approach – based on numerical modeling, analytical equations, or hydrogeologic conditions – provides a stronger risk management tool.

In the Lower Yakima Valley – an area with multiple moderately sized population centers—the majority of groundwater-dependent public water systems have WHPAs delineated using the simple CFR method. At the same time, the hydrogeologic conditions in the LYV, including groundwater flow patterns for the multiple aquifer units, are well studied by the USGS, the LYV Groundwater Management Area, and others. Please join us as we present how grant funding from the Washington Department of Health Source Water Protection Program was leveraged to improve the WHPA delineations for 20 Group A water system supply wells in the Lower Yakima Valley, using a mixed analytical-hydrogeologic conceptual model approach, and develop a CSI for each well using publicly available information.

Lower Yakima Valley: Ambient Groundwater Monitoring Network

Melanie Redding, Washington State Department of Ecology

Groundwater in the Lower Yakima Valley is contaminated with elevated nitrate and is the primary drinking water source for over 56.000 residents. A community-based group worked for over seven years to develop a detailed plan with 64 recommended actions to achieve the goal of reducing nitrate concentrations in groundwater.

This plan addresses all nitrogen sources, including agriculture. Approximately 70% of the land use is irrigated agriculture which contributes two billion dollars annually to the state economy. Agricultural commodities include dairy, hops, apples, wine grapes, cherries, corn, alfalfa, and other forage crops.

Washington State Department of Ecology developed an Ambient Groundwater Monitoring Network to measure the health of the aquifer over time. This network is comprised of 170 wells including 34 monitoring wells. We recently completed two years of quarterly sampling.

Analysis of our data found seasonal variability in most wells with some wells having annual variations of over 5 mg N/L. Spatial distribution was also evaluated. It is important in an area of over 175,000 acres to know where we need to prioritize future efforts and community outreach. There is a strong correlation of nitrate and well depth, with 90% of wells exceeding the drinking water standard of 10 mg N/L if they are completed less than 22 feet below land surface. Furthermore, there were no wells which exceeded the drinking water standard below 250 feet. These wells are typically in a confined aquifer.

This Ambient Groundwater Monitoring Network acts as a giant measuring stick that will help determine the effectiveness of other collaborative efforts to reduce nitrogen loading to groundwater.

All of our data is publicly accessible and already has been used to launch other projects in the Lower Yakima Valley by other cooperative agencies, including a health risk assessment, nitrate contouring in groundwater, and refinement of wellhead protection areas for public water systems.

Updated Hydrogeologic Conceptual Model in the East-Moxee Black Rock area of the Yakima Basin

Dawn Chapel, Aspect Consulting

Ian Lauer, Aspect Consulting Seann McClure, Aspect Consulting

Groundwater in the East-Moxee Black Rock (EMBR) area east of the City of Yakima has been declining by as much as 13 feet-per-year in the Columbia River Basalt Group (CRBG) aguifers for the last several decades with hundreds of feet of decline measured in some supply wells. The EMBR is home to over 7,400 acres of farmland, dairies, a USDA Agricultural Center, commercial businesses, and hundreds of residences. Local groundwater users have responded to the declines with conservation, changing crop types, deepening of wells and pumps, and fallowing of lands. However, conservation efforts alone have not mitigated the continued declines in local aquifers.

Current studies are being funded/conducted by the Selah Moxee Irrigation District, U.S. Bureau of Reclamation, Washington Department of Ecology, and Yakima County to evaluate the feasibility of importing surface water and developing a new water bank to reduce stresses on local aquifers. Project feasibility is also being discussed with the Yakima Basin Integrated Plan and its alignment with basin project and goals. There are several elements to the feasibility study, but a key element is to provide an updated hydrogeologic conceptual model of the study area and to estimate the future risk to local users if groundwater pumping continues as usual.

The EMBR is located within the Yakima Fold and Thrust Belt of the Columbia Plateau – an area characterized by a complex series of faults and folds in the CRBG that can act as hydraulic barriers to groundwater flow effectively isolating or "compartmentalizing" the aquifers. Groundwater declines in the EMBR were first noted in the late 1970's and since then an extensive monitoring network of over 50 wells have been documenting the long-term spatial distribution of declines throughout the study area. A prior 1993 study by Department of Ecology provided the first evaluation of groundwater declines in the study area and noted the role of local faults and folds. In this current study, we are updating the hydrogeologic conceptual model of the study through review of extensive data sets including - decline trends since 1993, groundwater use (pumping) by aquifer, observed aquifer responses from pumping tests, and well constructions that may penetrate multiple aquifers. We are also reviewing and updating the USGS stratigraphic model for the study area. The results will be used to delineate the study area into hydrogeologic subunits -isolated areas within the study area with unique hydrologic characteristics and responses to groundwater pumping. A trend and deficit analysis will then be conducted for each subunit area to evaluate the level of future risk to different groundwater users in the study area.

To learn more about the study please visit: moxeegroundwater.org.

Simulating Groundwater Response to Two Future Groundwater Use Scenarios in the Harney Basin, Southeastern Oregon

Stephen Gingerich, U.S. Geological Survey, Oregon Water Science Center

Darrick Boschmann, Oregon Water Resources Department Gerald Grondin, Oregon Water Resources Department (ret.) Halley Schibel, Oregon Water Resources Department (fmr.)

Since the early 1990s, groundwater levels declined as much as 100 feet in some areas of the 5,240 mi2 Harney Basin in SE Oregon. Declines are largely due to tripling of groundwater pumpage during 1991–2018, increasing from 51,000 acre-ft/yr to about 150,000 acre-ft/yr. Groundwater pumpage has exceeded recharge since about the mid-1980s, resulting in groundwater storage depletion (discharge minus recharge) of about 840,000 acrefeet and declines of groundwater discharge through evapotranspiration and springs and streams.

Using a newly developed groundwater flow model for the basin, two scenarios were used to investigate (1) the effects of continuing groundwater pumpage at 2018 rates and (2) the potential for groundwater-flow system recovery if all pumping for irrigation was curtailed after 2018. Both scenarios assume that future recharge will be the same as it was during 1982–2016. The model shows that pumpage at 2018 rates until the year 2100 (scenario 1) results in an expansion of the areas of decline and an increase in the groundwater-level declines in already affected areas of the lowlands. For example, the decline in one of the most heavily pumped areas is projected to increase from 100 ft in 2018 to more than 210 ft in 2100. Groundwater levels in most areas were continuing to decline at the end of the simulation in 2100, indicating that areas of decline were continuing to expand throughout the lowlands, and a new steady-state condition had not yet been reached.

Scenario 2 considers the opposite alternative future in which all irrigation pumping was set to zero after 2018 to evaluate the spatiotemporal recovery of groundwater levels in Harney Basin. With most of the pumping stress eliminated, groundwater levels across the lowlands recover half of the declines from 1990 levels within 10–15 years in most areas. Recovery occurs relatively quickly due to equilibration of the large head gradients between the large pumping centers and the surrounding low-permeability deposits. Full recovery to 1990 groundwater levels takes longer and varies across the basin. Some of the most heavily pumped areas take the longest to recover, needing more than 60 years to recover to 1990 levels. Most of the groundwater levels in other parts of the lowlands recover in 20 to 30 years.

A New, Un-Mitigated 1,600-Acre Irrigation Groundwater Right in Eastern Washington

Eric Weber, Landau Associates, Inc.

Ben Lee, PE, Landau Associates, Inc.

Benchmark Farms (Benchmark) received a new state groundwater right for irrigation of 1,600 acres in an area of Grant County, Washington known as the High Hill that was previously dry-land farmed and/or undeveloped. The High Hill is located adjacent to the Lower Grand Coulee and Soap Lake (both the town and the lake) within the federal (U.S. Bureau of Reclamation) Columbia Basin Irrigation Project (CBP). The High Hill was originally held out from receiving CBP surface water deliveries due to concerns associated with Soap Lake flooding from irrigation return flow (i.e., the "Soap Lake Problem"). Soap Lake sits at the end of Lower Ground Coulee and at the base of the High Hill. The lake is a regional groundwater discharge sink without a surface water or groundwater outlet. Discharge is solely from evaporation which results in the saline and meromictic character of the lake. After completion of the CBP in the 1950s, leakage from constructed reservoirs and canals along with irrigation return flow increased groundwater levels and caused flooding of Soap Lake. In response, the Bureau installed a series of extraction wells to control groundwater discharge to the lake and maintain its saline character.

Benchmark's water right application sought to leverage a portion of the large volumes of groundwater in the system. To support the application, Landau Associates developed a detailed hydrogeologic conceptual model of groundwater occurrence and flow in the High Hill and Soap Lake area. The model is based on extensive historical data collected by state and federal agencies as part of design and construction of the CBP in the 1940s and 50s. We also relied on extensive recent groundwater and surface water data collected as part of the CBP operation. The technical presentation and extensive database resulted in the backing of crucial stakeholders; the City of Soap Lake, the Bureau of Reclamation, and the Quincy-Columbia Basin Irrigation District. Two large-scale 5-day pumping tests – one at 2,800 gpm and another at 5,200 gpm – with multiple observation wells - were conducted under a preliminary permit issued by the Department of Ecology for the purposes of verifying the hydrogeologic conceptual model. Based on pumping tests results and associated hydraulic analysis, Ecology issued a water right permit for 10,000 gpm and 5,600 acre-ft per year for the irrigation of 1,600 acres. Because of the unique hydrogeologic setting of the project area, no mitigation was required.

Two years after permit approval, Benchmark has fully built out the project - mostly for high-value organic food crops – and put the water to full beneficial use. Groundwater monitoring and annual reporting continues in compliance with provisions of the permit. Join us for a summary of this interesting project, where you'll learn about the fascinating geologic and hydrogeologic setting of the Lower Grand Coulee and Soap Lake, the long water right permitting process, stakeholder engagement that led to project approval, and the results of on-going groundwater level monitoring following project completion.

Oregon Groundwater Allocation Rules Update

Travis Brown, Oregon Water Resources Department

Ben Scandella, Oregon Water Resources Department Justin Iverson, Oregon Water Resources Department

The Oregon Water Resources Department is proposing to update its administrative rules governing the allocation of new groundwater rights. The primary goals of the proposed new rules are to promote more sustainable groundwater use and to improve protection of existing water users. In this presentation, staff from the Groundwater Section of the Oregon Water Resources Department will review the need for rulemaking, the statutory and administrative framework for groundwater appropriation in Oregon, and the scientific and conceptual basis upon which the proposed new rules were drafted. This rulemaking is ongoing and has the potential to significantly affect the process by which new permits for groundwater use are issued in Oregon.

Simulating Potential Impacts of Proposed Water Supply Wellfield Extraction from Deep Puget Sound Aquifer

Nathan Cutler, EKI Environment & Water Presenting work performed at Shannon & Wilson Todd Kincaid, Shannon & Wilson Jim Bailey, Shannon & Wilson

Washington State requires new groundwater appropriations to demonstrate no impairment to senior water right holders and listed minimum instream flows. Evaluating potential impacts is challenging when the proposed withdrawal is from deeper aquifers. Regional U.S. Geological Survey hydrogeologic models describe the deepest hydrogeologic unit in the Puget Sound basin, Unit G, as a thick heterogeneous package of unconsolidated deposits that include water-bearing and non-water-bearing strata, yet the models represent it as a single homogeneous layer.

We adapted the hydrostratigraphy from one of those models, the Puyallup River Watershed model, to include subdivisions of the otherwise undifferentiated Unit G defined from data that were not included in the USGS modeling effort. This allowed us to more reasonably simulate potential impacts stemming from a proposed new water supply wellfield completed in Unit G. The proposed wellfield would be located near the Port of Tacoma, with total extraction at a rate of 16 million gallons per day.

We calibrated a steady-state version of the adapted model to locally observed heads in the vicinity of the proposed new water supply wellfield while limiting changes to simulated heads elsewhere in the model. We therefore added detail to the USGS model, enabling it to better represent observed hydrogeologic conditions while allowing the revised model to honor the USGS interpretations outside of the project area. Our adaptations relied on observations of lithology and water level responses to pumping collected from a new deep (1800-foot) test well completed in the deeper part of Unit G, as well as lithology recorded in other nearby deep wells.

We analyzed impacts to groundwater levels and flows stemming from various production withdrawal scenarios by examining the simulated drawdown in each of the simulated water-bearing zones in the adapted Unit G and each of the overlying aquifers across the model domain. Sources of the water supplying the simulated withdrawal were identified through flow budget analyses and particle tracking. These included assessments of the potential impact to the surficial aquifer system and its associated surface water features.

Simulations showed that greater than 99.9% of the proposed withdrawal would originate as recharge to Unit G from beyond the model boundary; recharge that is understood to be vertical leakage into Unit G dispersed across the greater Puget Sound basin. No more than 0.05% of the proposed groundwater withdrawal, or 1,014 cubic feet per day, was simulated to come from the surficial aquifer system, which would include induced seepage into the aquifer from the regulated portions of the surface waters within the model boundaries as well as seepage from unregulated water bodies and from the surficial aquifer directly connected to Puget Sound. In some of the evaluated scenarios, the magnitude of those impacts was less than the model error; in others, it was very close. Even though the model did not show zero impacts, our conclusion based on the modeling was that the proposed new withdrawal would not cause impairment to surface waters with established minimum flows or closures, nor to senior water rights holders.

Fall City Floodplain Restoration Influence on Groundwater-Surface Water Connections, Streamflow, and River **Temperatures**

Scott Kindred, Kindred Hydro, Inc.

Matthew Baerwalde, Snoqualmie Tribe

The Snoqualmie Tribe received funding from the King County Flood Control District Cooperative Watershed Management grant program to collect groundwater level and temperature data before and after construction of the Fall City floodplain restoration project, conducted in 2022 and 2023. The Tribe has cultivated and cared for the natural resources of this area for centuries, and the Tribe continues to build programs that focus on monitoring and managing those lands and their resources. The mission of the Tribe's Environmental and Natural Resources Department ("ENR") is to protect, preserve, and enhance the environment of the Snoqualmie Reservation and traditional Tribal lands. This mission is achieved through ENR's continued efforts to expand habitat restoration, water quality, environmental, and cultural programs in conjunction with other various programs within the Tribe.

The Fall City floodplain restoration project restored almost one-half mile of river edge habitat, re-connected the river to approximately 134 acres of floodplain, constructed approximately 2,500 feet of floodplain side channel, and restored native plants on more than 80 acres. The purpose of the restoration project is to help address recovery goals for four species listed under the Endangered Species Act. These species are part of northwest heritage and important for the culture, economy, and food sources of local Indian tribes.

The goal of the groundwater monitoring project was to help improve understanding of how floodplain reconnection projects in the Snoqualmie may influence groundwater-surface water connections and affect streamflow and river temperatures. The groundwater monitoring project includes installation of 12 shallow groundwater wells within and near the Restoration Project and collection of groundwater elevation and temperature data before and after floodplain restoration.

Groundwater flow is away from the river during floods with a steeper groundwater gradient on the southwest side of the river and a flatter gradient on the northeast side of the river. This difference may reflect the larger spread of surface flood water on the northeast side of the river. During normal river stages, groundwater flows downstream and towards the river, as expected. The late summer/early fall river stage was almost a foot lower in 2022 than in 2020 and 2021. Although the unusually long drought during the summer of 2022 is the likely explanation for the lower water level in the fall of 2022, it's possible that the floodplain modifications during the summer may have influenced the river stage. Flooding can cause groundwater temperatures to spike both up and down, depending on the season, and is caused by vertical migration of flood waters into the subsurface. Other than spikes due to floods, temperatures in most of the wells were highest in early winter and experienced a steady temperature decline through late winter and early summer. Groundwater temperatures rise during late summer and early fall. This delay in groundwater temperatures compared with river temperatures can be explained by latent heat storage in the subsurface. Encouraging groundwater discharge into the river in the late summer may be useful for creating low-temperature refuges or general river cooling to benefit cold-water fishes.

Augmentation from Irrigation Canal System to Enhance Yakima Basin Tributary Flow and Improve Stream **Habitat**

Urban Eberhart, Kittitas Reclamation District

Since the inception of the Kittitas Reclamation District's (KRD) Tributary Supplementation Program in 2015, the KRD has used the irrigation canal system to augment flows to upper Kittitas County tributaries experiencing intermittent or low flows due to extraordinary drought and other conditions in the Yakima Basin. The tributaries are intersected by the Main and South Branch canals (Tucker, Little, Big, Tillman, Manastash, and Taneum Creeks). Enhancing tributary flow helps the macroinvertebrates that serve as food for several fish species, provide shade and preserve and enhance the riparian habitat, and increase salmonid rearing and spawning habitat. Additional important components of the program include water quality and fish monitoring with an emphasis of flow, water temperature, dissolved oxygen, pH, and relative abundance by Species. In July 2020, KRD partnered with the Yakama Nation's Yakima/Klickitat Fisheries Project to release 1,000 tagged juvenile Coho salmon into Tucker Creek. The results showed that flow augmentation improved fish migration in May and June that otherwise would have been extremely limited or non-existent. Tucker Creek also had its first documented Coho redd in modern times. KRD continues to coordinate with fish entities in the basin (Yakama Nation, US Fish and Wildlife Service, National Marine Fisheries Services, Washington State Department of Ecology, Washington Department of Fish and Wildlife, Trout Unlimited, and Kittitas County Conservation District and our other Yakima Basin Integrated plan partners) to plan/implement projects designed to improve channel complexity. In 2021, KRDbegan transporting spawning Coho salmon to many of these flow supplemented tributaries in cooperation with Yakama Nation Fisheries. By the terminus of 2023, KRD in coordination with our partners will have placed a significant number of spawning Coho in an effort to reestablish healthy Coho salmon populations in the Upper Yakima Basin.

Water Conservation efforts are a key component of this program that is reliant on relationships built with a diverse stakeholder group bringing fresh thinking on how water projects can be implemented within the Yakima Basin benefiting both fish and farms. The KRD continues to work with the Yakima Basin Integrated Plan partners to implement additional conservation measures (canal piping and lining), freeing up capacity in the KRD canal system to expand the supplementation program. Current totals show over 53,000 linear feet of canal that has been piped or lined conserving over 9,300-acre feet of water put forth to the Supplementation program. Integrated Plan projects, like surface and groundwater storage, will make additional water available in drought years for added stream flows in the tributaries and storage for fish purposes. All made possible through conservation and collaboration that allows for the use of the KRD canal to deliver water to both farms and fish as well as create a future that is resilient to climate change.

Groundwater Replenishment and Water Management on the Yakama Reservation

Danielle Squeochs, Confederated Tribes and Bands of the Yakama Nation

As a sovereign nation, the Confederated Tribes and Bands of the Yakama Nation (Yakama Nation) have the authority to implement management actions to ensure water supplies provide for current and future needs. The Yakama People have always understood that groundwater and surface water are connected, as one resource, and that water management is critical for the protection of instream flows, cultural plants and foods, domestic uses, and irrigation. The religious, cultural, personal, and ecological significance of water guides the appropriate use, management, and protection of water resources, and conditions all water and land use activities in the watersheds and drainage basins of the Yakama Reservation.

Groundwater replenishment is a critical component of future water management on the Yakama Reservation. Starting with the Toppenish Fan Shallow Aquifer Recharge Project (implemented in 2015), the Yakama Nation have developed the first indigenous led regional groundwater recharge program. A suite of recharge projects have been developed to sustain water supply for future domestic, habitat and irrigation needs, in a manner that is congruent with the Yakama Nation's values.

Most recharge actions fall solely under the jurisdiction of the Yakama Nation Water Code. Unlike Washington State and other similar regulatory structures, the Yakama Nation Water explicitly identifies groundwater recharge as a beneficial use; eliminating the need for projects to focus on "storage and recovery" rather than the "recharge."

Through an integrated basin wide groundwater replenishment program, we are working to improve the reliability of municipal and domestic water supply, restore our deeper aquifers and to plan for aquifer depletion due to climate change, and reduced recharge due to more efficient irrigation delivery methods. Together, we are working to manage water for the benefit of current and future generations.

Evapotranspiration and Floodplain Aquifer Storage in Taneum Creek

Carey Gazis, Central Washington University

Edward Vlasenko, Central Washington University Emily Polizzi, Central Washington University Lisa Ely, Central Washington University

Over the past two decades, numerous stream restoration projects have been undertaken in the upper Yakima River tributaries. These projects often involve the placement of large woody debris and beaver dam analogs and are aimed increasing stream complexity, improving habitat, and reconnecting incised channels with their floodplain. One potential benefit of this restoration is increased groundwater storage in the floodplain aguifer. However, the restoration efforts often lead to increased vegetation in the floodplain which will in turn lead to greater loss of water through evapotranspiration. Thus, it is often uncertain what the net impact of this stream restoration is on the overall water budget of the floodplain aguifer.

This project examined evapotranspiration rates and floodplain aquifer storage on Taneum Creek. Large wood was emplaced in Taneum Creek in 2008. Assisted by a 100-year flood in 2011, the wood was repositioned and has increased channel complexity including new side channels and associated beaver activity. Taneum Creek is considered to be a particularly successful restoration effort because of the obvious geomorphic and vegetation changes that have been observed.

To quantify evapotranspiration at Taneum, a monitoring site was established to measure relevant hydrological and environmental parameters in a meadow which contains a new side channel and a series of beaver dams. The monitoring site included an evaporation station, and two soil monitoring locations, "riparian" and "meadow", representing relatively wet and relatively dry areas within the Taneum floodplain respectively. This monitoring equipment provided ground-truthing estimates of evapotranspiration that were compared to satellite-based estimates generated using the OpenET online platform. In addition, Taneum Creek floodplain stratigraphy was examined along stream cutbanks and combined with sediment sizes analyses to better characterize the floodplain aquifer hydraulic properties and storage capacity.

Evapotranspiration estimates were calculated using Penman-Monteith FAO-56 method with soil heat flux data and local weather data as inputs. The soil heat flux estimates were similar between the meadow and riparian site, ranging between 1 mm/day and 6 mm/day, increasing as the season progressed. These soil-heat-flux evapotranspiration estimates were consistently lower than the satellite-based evapotranspiration estimates, which range from 4-7 mm/day. The higher remote-sensing based estimates may be due to transpiration from large trees, which was not captured in the localized soil heat flux measurements. Evaporation based on pan measurements, which excludes transpiration, displayed the lowest rate of water loss, at approximately 2 mm/day across the study period. Summing estimates over the period from mid-May to mid-September yields total evapotranspiration amounts of 50 to 70 cm over this three-month period. In an unconfined aquifer with porosity of 0.3, this ET flux amounts to approximately 2 meters of head difference, a significant portion of the overall aquifer storage capacity. These results suggest that any increase in inputs to groundwater storage that result from increased channel-floodplain connectivity may well be negated by increased vegetation growth and associated evapotranspiration.

Understanding the Impacts of Pesticides on Washington State's Groundwater Resources

Jaclyn Hancock, Washington State Department of Agriculture

Yonas Demissie, Washington State University

Washington State Department of Agriculture's (WSDA) Natural Resources and Agricultural Sciences (NRAS) team studies the impacts of pesticides and nutrients on environmental quality that the agency, agricultural stakeholders, and environmental communities rely on to support agricultural viability while protecting the environment and human health. WSDA is the state lead for monitoring pesticides in groundwater and surface water. Information about pesticides and nutrients in water quality is crucial in supporting agricultural production while protecting the environment and public health. NRAS projects improve our understanding of pesticides and nutrients and their impacts on water quality; the work includes data collection, data analysis and interpretation, design of monitoring networks, and targeted research studies to support Washington agriculture.

A clear understanding of the impacts of agrichemicals on Washington State's groundwater quality presents a significant data gap. In Washington, over 60% of residents rely on groundwater for drinking water supplies. Ongoing data collection in Washington State regarding pesticides in groundwater is limited to the Department of Health (DOH) drinking water dataset that monitors public systems. WSDA reviewed this dataset for 2019-2020 and learned that many of the locations do not regularly analyze drinking water for pesticides. For systems that do screen for pesticides, the analyte list and sampling frequency present limitations. Historically WSDA projects have entailed analysis of existing datasets, localized follow up investigations, and education and prevention programs in partnership with DOH, conservation districts, and the Washington State Department of Ecology.

In 2023, WSDA acquired funding from the state legislature to begin a Regional Groundwater Quality Monitoring Program. The primary goal of the new program is to determine the impacts of pesticides on groundwater quality in Washington State in agriculturally dense regions. This involves identifying the presence and concentration of pesticides via groundwater sampling in private domestic wells. The resulting data will be utilized to understand the extent and severity of contamination in the regions selected for monitoring and provide useful public health information to homeowners participating in the program. To optimize the information given the sampling costs, WSDA is partnering with Washington State University (WSU) to develop statistical and data-driven approaches for the new monitoring program. This work will develop optimized sampling strategies to effectively characterize the spatial and temporal extents of pesticides in groundwater in agriculturally dense regions in WA while minimizing sampling costs and maintaining sampling accuracy. The WSU sampling design will inform the WSDA program framework to be deployed in one or more monitoring regions beginning in 2024. This project will entail partnerships with WA residents, local conservation districts, agricultural producers, local health districts, and DOH. We will present the findings from the WSU optimization study in the symposium.

Reconstructing PFAS History of the Santa Ana River from Groundwater Concentration Data

Stephen Breen, U.S. Geological Survey, Washington Water Science Center

Russell Detwiler, Department of Civil and Environmental Engineering, University of California - Irvine

As cases of PFAS-contaminated drinking water increase around the Pacific Northwest, the scientific understanding of sources and pathways of PFAS in complex urban watersheds continues to develop. In 2019, the Centers for Disease Control and Prevention and the Agency for Toxic Substances and Disease Registry began a national Multi-Site Health Study on PFAS to help evaluate exposure through drinking water across a range of rural and urban settings, and to provide early case studies for water managers across the country. The most urban site in the study is Orange County, California, where sampling of over 500 monitoring and production wells since 2013 has revealed concentrations of a group of PFAS compounds that exceed state advisory Notification and Response levels. This has prompted the removal of dozens of production wells from service, and their supply has been replaced with higher-cost imported water. Because the basin is recharged with river water from the Santa Ana River (SAR) as part of a long-running managed aquifer recharge operation, these concentration data suggest a history of PFAS contamination in the SAR.

Here we use an extensive set of PFOS, PFOA, PFNA, PFBS, PFHpA, and PFHxS groundwater concentration measurements from across the OC basin to reconstruct the contamination history of the SAR for each compound. We represent SAR-to-well transport using the method of transfer functions, and we invert for the source history using truncated singular value decomposition. Dispersion coefficients and travel times to individual wells are determined by a hierarchy of models that includes a calibrated MODFLOW model of the basin and a set of chloride breakthrough observations. Uncertainties in historical SAR concentrations are quantified by a Monte Carlo analysis. We show that our reconstructed histories agree with recent surface water samples from the SAR. Our results may be helpful for discriminating among the many possible sources of PFAS in the SAR watershed, estimating historical exposures, and guiding investments in treatment facilities. More broadly, our reconstruction methods might be transferable to PFAS investigations in the Pacific Northwest and elsewhere.

Geochemical Modeling of PFAS Fate and Transport during Aquifer Storage and Recovery in the Pacific Northwest

Brad Bessinger, Summit Water Resources

Jason Melady, Summit Water Resources

A geochemical reactive transport model was developed to simulate the fate and transport of per- and polyfluoroalkyl substances (PFAS) during Aquifer Storage and Recovery (ASR) operations in the Pacific Northwest. The model accounted for differences in adsorption potential of PFAS compounds as well as heterogeneous aquifer conditions, which include aquifer mineralogy and organic matter content. The model evaluated how variable aquifer properties affect the temporal and spatial distribution of PFAS during injection and recovery.

The model predicted that the distribution and concentration of PFAS compounds will vary between recharge and recovered water depending on groundwater geochemistry, aquifer type (basalt vs. sand and gravel), and ASR cycling rates. The model also predicted that differences in aquifer properties within the region will influence the migration of PFAS, potentially impacting ASR effectiveness. Finally, the model predicted that ASR operational parameters can be optimized based on specific aquifer characteristics to reduce the potential transport of PFAS.

In conclusion, geochemical modeling provides a robust framework for predicting PFAS fate and transport during ASR operations. By concentrating on the interplay of geochemical processes within the Pacific Northwest, the model offers valuable insights for regional water resource managers and environmental practitioners aiming to implement effective ASR practices that safeguard water quality.

Overview of Trends and Future Requirements in State Regulations for Emerging Contaminants

Heather Gosack, WSP USA, Inc.

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Contaminants of emerging concern are a hot topic, and demands for study and regulation are increasing across the U.S. The U.S. Environmental Protection Agency (EPA) and many states have implemented mechanisms to identify and evaluate emerging contaminants; however, there is often uncertainty in how states and industry should manage these emerging contaminants.

Many state and federal agencies are currently focused on per- and polyfluoroalkyl substances (PFAS). Proposed rulemaking to designate two PFAS as federal Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) hazardous substances is expected to be finalized in Spring 2024. EPA Maximum Contaminant Levels (MCLs) for six PFAS are expected to be finalized in the first half of 2024. With federal regulations delayed, many states, including Washington, have adopted their own regulations, MCLs, and guidance pertaining to PFAS. Until federal regulations are finalized, PFAS are also considered a non-scope consideration under the latest Phase I Environmental Site Assessment (ESA) guidance, ASTM E1527-21, and this can introduce uncertainty during environmental projects.

Additionally, Washington and other states are beginning to review other emerging contaminants, such as 6PPD and its chemical by-product 6PPD-quinone, polybrominated diphenyl eithers (PBDEs) and microplastics, for potential future regulations. With a rapidly changing regulatory landscape for emerging contaminants, it can be difficult to know how to conduct risk assessments, due diligence, and environmental investigations, especially for industry with sites and projects in multiple states.

This talk will present a high-level summary of the status of emerging contaminant regulations to help the audience understand regulation trends and future requirements that may be implemented for PFAS, 6PPD/6PPDq, and other emerging contaminants. We will review:

- Published guidance documents
- Promulgated MCLs or other enforceable screening levels
- Major regulations adopted for emerging contaminants
- Existing emerging contaminant laws
- Executive orders and/or state agency orders pertaining to emerging contaminants
- State planning documents related to emerging contaminants

Virtual Learning Environment for Geologic Carbon Storage Applications: A Machine Learning Approach for **Visualizing Large Datasets for Carbon Storage**

Ashton Kirol, Pacific Northwest National Laboratory

Alexander Hanna, Pacific Northwest National Laboratory Diana Bacon, Pacific Northwest National Laboratory Maruti Mudunuru, Pacific Northwest National Laboratory

Geologic carbon storage is a method used to securely store carbon dioxide (CO2) deep in geological formations, preventing its release into the atmosphere and mitigating global warming. Class VI wells that are used to inject CO2 into deep rock formations require permits to ensure the protection of underground sources of drinking water. These permits rely on thorough site characterization to predict the extent of the injected CO2 plume and associated pressure front which delineates an Area of Review. Determining this area requires processing large geospatial datasets across multiple time steps. Traditional Area of Review calculations involve computationally intensive reservoir simulations. The Virtual Learning Environment software utilizes machine learning-accelerated reservoir simulations, enabling near real-time scenario analysis of the Area of Review. The Virtual Learning Environment was developed to allow users to visualize multivariate model outputs (CO2 saturation, pressure increase) across multiple realizations and time steps with the capability to view them in relation to site topography or geographic location at the surface. Users can dynamically visualize the evolution of the Area of Review to assess associated variability and uncertainty across multiple scenarios. This facilitates interactive discussions between applicants and regulators. Machine learning-based fast predictive models for pressure and CO2 plumes will be used to develop effective plans for monitoring during and after injection. This will allow users to quickly assess a range of scenarios to aid in permitting applications as well as site monitoring throughout the lifetime of geologic carbon storage projects.

Characterizing Groundwater Chemistry in the Columbia River Basalt Group of Central and Eastern Washington

Ellen Svadlenak, Washington Geological Survey

Lee Florea, Washington Geological Survey

The Columbia River Basalt Group (CRBG) is an important source of potable and irrigation water in the Columbia Basin of central and eastern Washington, and is of growing interest for geologic carbon sequestration and thermal energy storage. The CRBG consists of Miocene age flood basalts that are separated into four formations, from oldest to youngest; the Imnaha, Grande Ronde (the largest by volume and aerial extent), Wanapum, and Saddle Mountains. Each formation comprises stacked basalt flows with the highest permeability in the "interflow zones" between the individual lava flows and in the adjoining vesicular flow margins. The result is a layered set of stratiform basalt aquifers that are semi-confined or confined. Though the basalts were laterally extensive during emplacement, they have been faulted and folded through time, truncating and rerouting groundwater flow paths, compartmentalizing the aquifers, and leading groundwater chemistry to vary spatially and with depth. Our study of 1,468 groundwater samples from basalt wells in the Columbia Basin builds upon prior water quality studies by expanding the dataset to include wells at the basin margin, oil and gas wells, and over 200 samples from 126 water wells completed in the Grande Ronde Formation. This is a contrast to earlier studies focused primarily on the central basin, Saddle Mountains and Wanapum formations, and surface water-groundwater connectivity.

Principal component and hierarchical cluster analyses of groundwater chemistry in the basalts identifies three distinct chemical groups: 1) earth alkaline waters ([Ca2+] = 57.8 ± 27.7 mg/L; [HCO3-] = 257.2 ± 116.6 mg/L; [Na+] = 43.7 ± 23.2 mg/L; [Cl-] = 36.7 ± 43.6 mg/L), 2) earth alkaline waters with excess alkalines ([Ca2+] = 3.9 ± 4.4 mg/L; [HCO3-] = 149 ± 44.6 mg/L; [Na+] = 314.2 ± 65.0 mg/L; [Cl-] = 36.7 ± 43.6 mg/L), and 3) waters with intermediate chemistry (([Ca2+] = 18.7 ± 11.3 mg/L; [HCO3-] = 167.6 ± 44.4 mg/L; [Na+] = 41.0 ± 34.6 mg/L; [Cl-] = 13.5 ± 44.4 mg/L). Elevated [Ca2+] and [HCO3-] in Group 1 is primarily found in shallow basalt wells (<120m deep) and represents reactions between meteoric recharge water and overlying alluvium. Excess alkalis in Group 2, including [Si] (49.4 ± 10.1 mg/L) and [F-] (30.2 ± 13.6 mg/L) are found exclusively in Grande Ronde wells with elevated temperatures (53° C $\pm 7.86^{\circ}$ C) and depths >500m. Many of these Group 2 wells are located near Hanford, where the basalt aquifers may be highly compartmentalized by faulting and folding. Depleted [Ca2+] and [HCO3-] and elevated [Na+] and [Si] in these waters reflect decreased carbonate solubility and increased silicate solubility with increasing temperature and depth. Elevated [Cl-] and [F-] in these wells may be sourced from marine sediments and crystalline basement underlying the CRBG, and/or lacustrine sedimentary interbeds. Continued investigations will further link deep groundwater chemistry, residence time, and aquifer compartmentalization due to geologic structures.

Enhancing Geomechanical Risk Assessment in Geological Carbon Storage with NRAP-wSOSAT: A Web-based State of Stress Analysis Tool

Wenjing Wang, Pacific Northwest National Laboratory

Jeffrey Burghardt, Pacific Northwest National Laboratory Delphine Appriou, Pacific Northwest National Laboratory Ryan Haagenson, Pacific Northwest National Laboratory Swasti Saxena, Pacific Northwest National Laboratory Micah Taylor, Pacific Northwest National Laboratory

Geologic carbon sequestration involves injecting CO2 into saline aquifers or depleted oil/gas reservoirs, but this process causes pressure buildup, which could potentially lead to unintended initiation and propagation of hydraulic fractures and faults, resulting in subsequent CO2 or brine leakage into groundwater aquifers. To quantify and manage geomechanical risks, and prevent impacts to groundwater aquifer, such as unintended brine migration and aquifer contamination, a web-based tool known as NRAP-wSOSAT has been developed. This user-friendly tool serves as a valuable resource for guiding the design and operation of carbon sequestration systems. Initially, it utilizes Bayesian uncertainty quantification to constrain the joint probability of horizontal stresses in the subsurface within a user-defined region of interest. This quantification is based on user-selected stress constraints, including fault friction, regional faulting regime trends, breakout presence, drilling-induced tensile fractures presence, and minimum horizontal stress measurements. Subsequently, using the quantified stresses and a user-predetermined pore pressure associated with CO2 injection across the region, the tool calculates the probability of fault activation and hydraulic fracture initiation, presenting the results as heatmaps across the region. On one hand, the stress information generated by NRAP-wSOSAT could be a valuable mechanical input for hydrogeological models. These models, which are governed by equations, such as Darcy's law, depends on spatial pressure difference information to study the distribution and movement of aquifers. On the other hand, geomechanical risk heatmaps calculated by NRAP-wSOSAT act as crucial aids in evaluating carbon sequestration systems for site selection and decision making, aiming to minimize their adverse environmental impacts.

Geologic Carbon Sequestration: What is the Status of Underground Injection Control Class VI?

William Gallin, Washington Geological Survey

Lee Florea, Washington Geological Survey

Carbon sequestration projects must obtain an Underground Injection Control Class VI permit in order to construct (or convert) and operate a CO2 injection well. We summarize the history, process, and examples of Class VI permits nationally and address concerns specific to the Pacific Northwest. Class VI applicants must understand permit requirements in order to compose a cogent submission, and reviewers must understand geologic data in order to compose an efficacious Request for Additional Information. Applicants and reviewers must understand the role of public input and be prepared for an iterative process that exceeds two years. EPA is the agency that reviews and issues Class VI permits, except in two states where EPA granted Class VI primary enforcement responsibility (primacy): North Dakota and Wyoming. Nationally, as of November 2023, EPA has issued two Class VI permits, both in Illinois, and there are 169 applications submitted to EPA, mostly in Louisiana, Texas, California, Indiana, and Illinois. Currently, there are no submissions from the Pacific Northwest (EPA Region 10: Alaska, Idaho, Oregon, Washington, and 271 Tribal Nations), but hydrogeologists in this region should be aware of potential questions arising about Class VI as federal tax incentives and grants and state emissions disincentives spur interest in geologic carbon sequestration.

PFAS Forensics: Fingerprinting PFAS Sources and AFFF Impacts to Fish in Columbia Slough

Jennifer Field, Oregon State University

Per- and polyfluoroalkyl substances (PFAS) are classes of contaminants that continue to receive locate, state, federal and international attention. Current state and pending federal limits on PFAS have made identifying the environmental PFAS sources a high priority. Source tracking is the accurate characterization and differentiation of multiple sources contributing to PFAS contamination in the environment. Tracking PFAS sources requires a basic knowledge of their unique chemistry combined with detailed chemical characterization (fingerprinting) of known PFAS sources. Known sources of PFAS to the environment include aqueous film forming foams (AFFF), biosolids and landfill leachate, and municipal and industrial wastewater effluents. The complex data sets (fingerprints) require interpretation that relies on multivariate statistics. The talk will highlight a PFAS forensics project aimed at fingerprinting PFAS sources funded by the Strategic and Environmental Restoration and Development Program as well as a study on AFFF-impacted fish from the Columbia Slough conducted in partnership with the US Geological Survey (Portland), Oregon Department of Environmental Quality, and the Oregon Health Authority.

PFAS Contamination of Drinking Water near the Yakima Training Center in Central Washington

Greg Caron, Washington State Department of Ecology

Kurt Walker, Washington State Department of Ecology

Per- and poly-fluorinated alkyl substances (PFAS) contamination has been found above Washington State and Federal human health limits in drinking water wells near the Yakima Training Center. PFAS are a large group of manufactured chemicals that are toxic, water soluble, mobile, and extremely persistent. The toxicity of PFAS is not completely understood. Human effects include probable links to immune system toxicity, high cholesterol, reproductive and developmental issues, endocrine system disruption, thyroid issues, certain cancers, and pregnancy-induced hypertension.

PFAS are used to make coatings and products resistant to oil and water, and are found in many everyday products, such as carpets, cookware, food packaging, clothing, and cosmetics. PFAS also have many industrial applications and are used to make aqueous film-forming foam (AFFF), a critical firefighting agent used to quickly suppress petroleum fires.

Firefighting foam has been used for decades at the Yakima Training Center. As part of a nationwide effort to assess all military bases for PFAS, the U.S. Army reviewed PFAS use at the base, including soil and groundwater sampling. In April 2021, the Army indicated that PFAS were found to be present in soil and groundwater on base.

In July 2021, the Army notified nearby rural property owners of the issue and sought permission to sample private drinking water wells to determine if PFAS had migrated off base. Initial testing of 108 private wells identified 56 homes with PFAS levels greater than the Federal health advisory limit of 70 parts per trillion. These residents were provided bottled water for drinking and cooking.

Subsequent tests of more than 350 different private wells in the five-square mile area of interest revealed: Eighty-five homes are above the Federal health advisory limit of 70 ppt. Of these, twenty-six wells have PFAS concentrations greater than 400 ppt. However, 62 wells have PFAS present below the Federal health advisory limit and are not eligible for bottled water under Department of Defense policy. These homes received point of use filters provided by local and state health departments.

In February 2023, Ecology issued an Enforcement Order requiring a remedial investigation, feasibility study, and a draft cleanup action plan under the State's Model Toxics Control Act. Multiple U.S. Army environmental programs, consultants, and the U.S. Geological Survey are involved in the assessment, mitigation, and investigation of PFAS at the site.

PFAS Panel Discussion: Cleanup under WA MTCA, Unsaturated Soil Leaching, and More

Panelists:

Kim Wooten, Washington State Department of Ecology Bonnie Brooks, Washington State Department of Ecology Mike Means, Washington State Department of Ecology Charles Schaefer, CDM Smith

Many environmental professionals have questions about what the regulatory requirements are for per- and polyfluoroalkyl substances (PFAS) and how to address PFAS contamination in the environment. This panel will feature Kim Wooten, Washington Department of Ecology, and Charles Schaefer, CDM Smith, who will give a brief overview of the regulatory status of PFAS and the uncertainties around PFAS in unsaturated vadose zone soils. Then the floor will be open to questions from the audience on PFAS that may range from Chemical Action Plans, State Action Levels, cleanup under the Model Toxics Control Act, factors related to migration of PFAS in soils/groundwater such as adsorption and leaching, sampling for PFAS in environmental media, treatment technologies, and beyond.

Methods for Predicting the Capacity of Stormwater Infiltration Drywells

Scott Kindred, Kindred Hydro, Inc.

Mehrad Kamalzare, California State Polytechnic University, Pomona Ali Sharbat, California State Polytechnic University, Pomona

The Washington State stormwater manuals do not provide infiltration test methods for estimating the capacity of stormwater drywells. This presentation summarizes the results of recent studies to develop methods for predicting the capacity of stormwater infiltration drywells. These studies, funded by EPA and Los Angeles County Safe Clean Water Program, include numerical simulations and field studies in both Washington State and California. The test methods rely on steady-state infiltration tests in small diameter boreholes and produce an estimate of saturated hydraulic conductivity that can be used to reliability predict the performance of largediameter drywells. The methods were validated by testing small-diameter and large-diameter test wells in close proximity using three different drilling methods.

This presentation will describe how to properly design and conduct a borehole infiltration test that will accurately represent the performance of a drywell. The field-testing results demonstrate that small-diameter wells installed using Sonic drilling methods do not appear to be clogged, but larger diameter casing and well screen may be necessary to minimize head loss at high flow rates. Test wells installed using hollow-stem auger methods are often clogged and are not suitable for predicting the performance of full-scale drywells. Drop pipe that discharges below the water level is required when testing in 2-inch diameter casing (requires 1-inch diameter drop pipe) and recommended when testing in 4-inch diameter casing (suitable for 2-inch diameter drop pipe) to minimize air-entrainment. Because full-scale drywell capacity can be significantly greater than hydrant capacity, it is important to maximize the flow rate when testing small-diameter test wells in permeable soils. Hydrant flow rate can be maximized by using 2-inch diameter drop pipe rather than smaller diameter drop pipe and removing the filter, meter, and valve assembly at the well head. The rate of falling head after the test can provide important information regarding the degree of perching and groundwater mounding. If the test well drains slowly relative to the steady-state test capacity, then more conservative correction factors should be used for estimating the capacity of full-scale drywells.

A Graphical Interface to Quantify and Visualize Streamflow Depletion

Jessica Rogers, S.S. Papadopulos and Associates, Inc.

Doug Hayes, S.S. Papadopulos & Associates, Inc. Gilbert Barth, S.S. Papadopulos & Associates, Inc.

Quantifying streamflow depletion is a critical component of riparian resource management; however, accurate and cost-effective estimates are often not available to inform stakeholders and decision makers. SSP&A developed a readily adaptable, map-based Graphical User Interface (GUI) allowing users to rapidly generate estimates of stream depletion and groundwater level changes. The GUI software platform is model-independent and highly customizable. This talk will demonstrate the Analytical Interface (Ani), which combines a novel analytical depletion function (ADF; Zipper et al., 2019) approach to calculate streamflow depletion and the Theis equation to calculate drawdown. The ADF approach applies the Glover-Balmer equation and apportions depletion based on proximity of the river network to the pumping location. With a basic understanding of the underlying hydrogeology, users can rapidly evaluate impacts associated with water resource management alternatives including quantity, location, and timing of estimated streamflow depletions. This talk will include demonstrative scenario analysis for management alternatives such as changes in pumping locations and quantity. The ADF approach utilized in Ani is just one of the method options to assess depletions. The GUI software platform may be configured to perform analytical calculations using a broad variety of underlying methodologies or programs, run a numerical model, or both (e.g., impacts of a pumping well outside of the active numerical-model domain are estimated using analytical methods).

Ecology's New Well Report Application: My Driller Portal

Malone Scott, Washington State Department of Ecology, Well Construction and Licensing Office Chip Wilson – Washington State Department of Ecology, Water Resources Program

The Department of Ecology is developing a new well reporting application that allows drillers to submit reports via the web. We are calling it My Driller Portal. The new application retrieves data previously submitted from notices of intent to streamline the workflow and allows reports from similarly constructed wells to be multiplied and then modified to save time. Drillers can employ new tools that speed up the process and validate their information, limiting errors and providing better information. Ecology will spend less time scanning and capturing report data and more time improving the database. Currently, Ecology manually captures some of the information on a well report. With the new application Ecology will be collecting all the information on the report digitally through automation. Additional phases in the project will provide new features such as tools for administrators at drilling companies and adding maps and as-built diagrams to well reports. My Driller Portal, combined with the recent requirement for coordinates on well reports, will begin a new era in well reporting possibilities.

Water table estimates for Underground Injection Control Analysis, Clover Creek watershed, Pierce County, Washington

Elise Wright, U.S. Geological Survey, Washington Water Science Center

Andrew J. Long, U.S. Geological Survey Washington Water Science Center

In Pierce County, Washington, stormwater runoff is increasingly managed by underground injection control (UIC) structures such as dry wells, infiltration structures, and catch basins. UICs protect stream health by preventing poor-quality water from entering streams, but there is potential to degrade groundwater quality when stormwater that exits UIC structures enters the unsaturated zone and percolates downward toward the water table. Given enough time and vertical distance, the unsaturated zone above the groundwater table can filter and attenuate contaminants and sediments before they enter the aquifer's saturated zone. Regulatory requirements dictate UIC parameters. One of these requirements is to have adequate vertical distance between the bottom of the UIC structure and the water table to provide the time and distance for filtration and attenuation. Since the depth of the water table cannot be measured unless a well is present, a new approach is needed to fill the data gaps and estimate the water table depth at all existing and potential locations of UIC structures. In cooperation with Pierce County, the U.S. Geological Survey (USGS) developed a method to use output from a recent groundwater flow model combined with measured water levels in wells to estimate the depths of the highest and average levels of the water table in the upper part of the Clover Creek watershed. These high and average water table estimates will provide local communities, water resource managers, and natural resource agencies with information regarding expected depths to shallow groundwater for managing stormwater UIC and have the added benefit of being useful for managing groundwater availability and understanding the interaction of groundwater and surface water.

Data Collection Efforts for Water Resources on Vashon-Maury Island

Eric Ferguson, King County

The King County Groundwater Protection Program has implemented data collection efforts of water resources on Vashon-Maury Island since 2001. Over the years, the County has added numerous components of water resource monitoring into this groundwater effort such as stream gaging, precipitation, stream water quality, and BIBI sampling. Additional data is collected by volunteers. The volunteer data records are some of the longest water level data for Vashon-Maury Island that add and support findings from existing monitoring wells.

The sites monitor three different aquifer zones of Vashon-Maury Island. A few sites show seasonal variability of water level data up to 10 feet, while the other sites have little to no annually change. Decreasing and increasing water level trends are present for a few sites; overall no long-term declines in water levels.

Water usage from exempt well volunteers, to date, ranges from less than 30 gallons per day (GPD) to over 800 GPD per connection. As expected, most volunteers consume more water during dry periods and less water during wet periods.

This poster shows that long-term data can come from variety of sources: existing monitoring wells, volunteers and public water supply data. These datasets from dedicated (self-motivated) participants provide additional data. The number of volunteers who collect data has reduced over the last decade. King County continues to work with a small number of island volunteers in maintaining this effort. Future efforts to increase volunteerism will rely heavily on island resident interests, local purveyor support, and funds to support related efforts.

Monitoring Concrete Recycling to Minimize Environmental Risks

Eric Daiber, Washington State Department of Ecology

Jay Fennell, Washington State Department of Ecology

Concrete is a hydrated, hardened composite of cementitious paste and aggregates (sand, gravel, and/or crushed stone). Modern-day concrete structures are generally demolished after 50 to 100 years. The storage of large quantities of deconstructed concrete material may pose environmental risks unless the recycled concrete aggregate (RCA) leachate is properly managed and treated, as well as best management practices are correctly applied.

These environmental risks are commonly characterized by laboratory leaching methods (e.g., batch or column methods) that may fail to include important physical and chemical parameters or processes occurring in the field. Despite the discrepancy between the laboratory and field leaching, batch laboratory leaching methods have proven to be consistent, inexpensive, and simple for regulators, researchers, and facility site managers to implement for evaluation of a material's potential environmental impact.

Freshly crushed, non-carbonated concrete material is extremely alkaline, with a pH upwards of 13 standard units. The concrete material pH is inversely related to the materials' degree of carbonation (i.e. fully-carbonated RCA leachate produces a near-neutral pH). Concrete's alkaline pH may be neutralized depending on the sitespecific conditions.

We identified several inorganic and organic pollutants of potential environmental concern.

The State Department of Ecology encourages the reuse of concrete material to preserve virgin aggregate sources, reduce greenhouse gas emissions, and lessen the disposal in landfills, as well as for economic reasons. Concrete recycling process controls must be monitored to ensure environmental risks are minimized, while retaining the net benefits of concrete recycling.

Response of the Naches River to the Removal and Redesign of Nelson Dam

Chandler Sabin, Central Washington University

Lisa Ely, Advisor at Central Washington University

While there are several recent studies on large dam removals, relatively few studies have analyzed how the removal and re-engineering of small dams affect river channel processes, irrigation diversions, and fish ecosystems. Nelson Dam was built in 1920 on the Naches River in central Washington, and stood 8 ft. tall and 80 ft. wide. The dam created two miles of aggraded sediments and increased flooding upstream, with excessive incision downstream. These changes in the channel geomorphology caused ineffective irrigation diversions, and hindered fish passage and migration. Nelson Dam was removed in 2021 and replaced with a graded, roughened channel and a newly engineered diversion that was completed in 2023. The research project presented here quantifies the effects of the Nelson Dam removal and replacement on the sediment transport, sediment-size distribution, channel pattern and floodplain connectivity on the Naches River. Documenting the locations and scale of the initial response of these key geomorphic functions were used to estimate longer-term changes to the fluvial system that could be relevant to aquatic and riparian habitats.

Geomorphic change detection (GCD) software, aerial imagery, and sediment-size surveys provide the means to acquire data necessary to determine upstream and downstream changes. LiDAR from 2000, 2005, 2008, 2013, 2019, 2022, and 2023 were used in the GCD software. The GCD analysis quantifies the locations and volume of erosion and deposition both while the dam was in place, as well as changes in the sediment transport during and after the dam removal. Aerial imagery was used to document channel changes, and pebble count data tracked sediment transport following the dam removal.

Aerial imagery shows little downstream channel change in the years leading up to dam removal, but frequent, major channel shifts occurred upstream. These changes could have been caused by the removal and setback of an upstream levee accompanied by high river flows. Excess sediment deposition in this reach may have contributed to the gravel bars immediately upstream and downstream of the former dam site becoming noticeably finer from 2015 to 2023. These changes in sediment-size distribution were likely enhanced by the Nelson Dam removal. The GCD analysis further identifies areas downstream and upstream of the former dam site that have aggraded or eroded during the period of levee and dam removal. As sediment is redistributed from upstream, it is possible that the downstream reach will not increase as much in channel diversity due to the highway and bedrock constraining the lateral migration of the river.

This study provides a baseline description for future work 5-10 years from now, when additional changes may be seen in the improvement of the Naches River water resources and habitat. The results gained from this study will benefit the local region, but also supply learned knowledge toward similar rivers where communities want to remove the adverse effects of a dam while retaining some of its vital water resource functions.

Evaluating Managed Aquifer Recharge in the Yakima River Basin

Brook Bauer, Central Washington University, Department of Geological Sciences Elif Myers, Central Washington University, Department of Geological Sciences Carey Gazis, Faculty, Department of Geological Sciences, Central Washington University Lisa Ely, Faculty, Department of Geological Sciences, Central Washington University

Securing the future water supply for agriculture, domestic use, in-stream flow, and habitat in the Yakima Basin is the focus of coordinated efforts under the Yakima Basin Integrated Plan (YBIP). Managed aquifer recharge (MAR) is one sustainable and cost-effective approach to store water underground for recovery during seasonal dry periods or drought. The stored groundwater would naturally discharge and contribute water to streamflow or be available for extraction through wells during the drier summer periods.

We are evaluating two large alluvial fan aquifers formed by the Ahtanum and Manastash Creek tributaries to the Yakima River for sites suitable for MAR. Physical and hydrogeologic characteristics of the sedimentary aquifers will be assessed through analysis of existing well logs and geologic maps from previous reports and publications. New data collection will supplement existing hydrogeologic characteristics, sedimentology, and soil data within the boundaries of both alluvial fans. Measurements of water levels across study sites will assist in determining and documenting current surface water and groundwater interactions. Groundwater geochemistry will be used to determine distinct hydrochemical groups at each site and identify the areas where surface water penetrates the alluvial fan aquifer to greater or lesser depths. Identification of surface water/groundwater interactions with assessment of the unique lithologies and their hydraulic properties will aid in identifying sites with suitable infiltration rates, head space, and depth of surface water penetration into unconfined aquifers. The results will supplement previous and ongoing investigations for the YBIP into the most efficient and feasible locations for MAR.

Combination of Thermal Treatment and Microbial Reductive Dechlorination to Address Groundwater **Contaminant Rebound**

John Sankey, True Blue Technologies

David F. Alden, P.E., Tersus Environmental, Worcester, MA, USA Guilherme M. Figueiredo, MSc., Tersus Environmental, São Paulo, SP, Brazil Jeff Roberts, M.Sc., SiREM Laboratories, Guelph, ON, Canada

In-situ thermal treatment and in-situ reductive dechlorination are valuable methods for addressing chlorinated solvent contamination. However, it is rare to achieve complete contaminant removal using a single technology, as noted in Beyke et al. (2005), Löffler et al. (2013a), and Stroo et al. (2003).

In the United States, most aquifers maintain an average temperature of approximately 15°C. Notably, organohalide-respiring bacteria thrive within a temperature range of 25 to 30°C (Löffler et al., 2013b). Thermally enhanced bioremediation has been successful in combating chlorinated solvent contamination. The application of heat improves the process by reducing dissolved oxygen levels in the aquifer, aiding the release of chlorinated volatile organic compounds from the matrix, and increasing the concentrations of dissolved organic carbon (electron donors). Additionally, the added heat directly stimulates dechlorinating bacteria within their optimal temperature range.

The combination of thermal treatment and microbial reductive dechlorination offers a cost-effective solution for addressing contaminant rebound in groundwater remediation at moderate temperatures. It's important to note that Marcet et al., (2018) reported that at temperatures above 43°C dechlorination activities decrease and minimal biological or chemical destruction of chloroethenes occurs at temperatures above 50°C (Costanza et al., 2009; Stroo et al., 2012).

However, conventional in-situ heating methods (e.g., Electrical Resistance Heating - ERH, Thermal Conduction Heating - TCH) demand substantial subgrade heating equipment, vapor recovery and treatment systems, and temperature and pressure monitoring systems. All of these components must be installed and operational before the system can begin, necessitating a significant investment of labor, time, and capital. Furthermore, nonuniform heating of the subsurface often results in varying thermal signatures, particularly in zones with faster groundwater flow, which may heat more slowly. Consequently, justifying the expenses associated with traditional in-situ heating methods for heat-enhanced reductive bioremediation can be challenging, especially given the narrow effective temperature range.

Additionally, thermally enhanced bioremediation requires an assimilable carbon source. Emulsified vegetable oil (EVO) is a commonly used source because it slowly ferments, acting as an organic carbon and hydrogen source in the subsurface, stimulating organohalide-respiring bacteria that mineralize chlorinated solvents. However, experiences with numerous EVO injection events over the years have shown that EVOs effects are limited to the immediate vicinity of the injection point. Proper distribution of the correct type of fatty acids is crucial for anaerobic reductive dechlorination.

Heat-enhanced catalyzed reductive bioremediation effectively addresses two primary challenges associated with thermally enhanced bioremediation: the cost of heating the target contaminated area and the limited distribution of fatty acids in the subsurface.

Evaluating Connections between Glacial Outwash Terrace Aquifers and Skagit River Alluvial Valley Aquifers

Henry Williams, Western Washington University

Robert J. Mitchell, Geology Department, Western Washington University Jon L. Riedel, Geology Department, Western Washington University

The Skagit River, its tributaries, and unconfined glacial and alluvial aquifers are important water resources for salmonid habitat, agriculture, municipalities, and industries in the lower Skagit River basin. Unfortunately, these resources are being threatened by receding glaciers and reduced meltwater due to a warming climate compounded by increasing groundwater withdrawals driven by development and agricultural practices, which is problematic because the Skagit River has been under state instream flow rules since 2001. Previous groundwater-surface water interaction studies by the USGS and others focused on alluvial and glacial deposits within the Skagit floodplain and determined that groundwater extracted near the Skagit River reduces baseflow discharge in river. Little is known about aquifers in extensive upland glacial outwash terraces above the floodplain north of the Skagit. Our objective is to evaluate the possible connections between glacial outwash terrace aguifers and Skagit River alluvial valley aguifers between Sedro-Woolley and Concrete, in Skagit County, Washington.

To characterize the aquifer systems in the study area we examined driller well-log data, recent geomorphic maps and hydrogeologic study maps and reports, deep borehole data, and topographic data. ArcGIS surface software tools were used to develop a 3-D hydrogeologic framework and cross sections along roughly north-south alignments from the Skagit River northward into the glacial terrace deposits. Our hydrostratigraphic interpretations are limited in part by the number of wells used for each cross section, the number of gravel pit exposures, and our interpretations of the textural descriptions in well-driller logs made by well drillers. In general, the hydrostratigraphy in the glacial terrace is complex and varies greatly and includes glacial outwash and till, glacial marine drift, and lacustrine sediments. Aquifers in the glacial outwash are variable in terms of number and extent. Some are perched and others have possible physical connections with the aguifer materials near the Skagit River in the alluvial valley. To further assess the hydraulic connections, we are monitoring groundwater levels in domestic wells in the alluvial aquifers in the floodplain and in upland glacial terrace aquifers, and in shallow piezometers installed in two streams dissecting the glacial terrace.

Implementation of Updated Approaches for Slug Testing at Willamette River Site

Kristin Anderson, Floyd | Snider

Sabine Datum, Floyd | Snider

Groundwater discharge needed to be established for a shallow aquifer at a riverfront site in Portland, Oregon, to determine the potential for sediment recontamination via the groundwater pathway after a planned sediment remedy construction. Hydraulic conductivity values were used in combination with other hydrogeologic data to estimate groundwater discharge rates.

Slug testing was selected in favor of pump testing as a means to determine hydraulic conductivity at the site because a grouping of suitable pumping and observation wells was not available. Several references are available in the scientific literature that describe recommended slug test methods.

Per regulatory agency request, the updated guidance in The Design, Performance, and Analysis of Slug Tests, 2nd Edition (Butler 2020) was used to determine hydraulic conductivities by slug testing. The purpose of the updated guidance is to provide a more rigorous framework for slug test implementation and selection of analysis methods, as well as a better means to analyze nonideal data. This text presented several challenges for slug test analysis using AQTESOLV software because of differences in the general structure of the document versus the workflow of the software.

Testing was performed at five monitoring well locations screened in four different aquifer zones: unconfined shallow dredge fill, unconfined shallow native alluvium, confined deep native alluvium, and a perched zone overlying a confining overbank deposit. At each well, tests consisted of three iterations of slug in/slug out, switching between two slug sizes. Pressure transducers were installed in the wells and set to a default measurement frequency of 0.5 seconds.

Normalized displacement for all slug-in/slug-out tests was plotted first in Microsoft Excel to determine the suitability of the data. Data were rejected from tests at two wells screened in dredge fill because the normalized displacement/log time recovery curves were not coincident, and maximum displacement did not appear to be captured accurately. At these locations, tests were repeated with measurements at 0.1 seconds to more accurately capture the recovery curve.

Further analysis was performed to identify necessary correction for filter pack drainage and assess damping. Decision-tree figures 12.1 through 12.5 in Butler (2020) were used to select appropriate solutions for the recovery curves.

For wells screened in unconfined perched water and unconfined native alluvium, the Bouwer–Rice and Hvorslev linear solutions were selected to define the range of hydraulic conductivities. For the well screened in confined native alluvium, the Butler–Zahn and Cooper, et al. solutions for high K confined aquifers were selected. In dredge fill, tests were not coincident and not uniformly direction dependent; these tests were analyzed using nonlinear Dagan and Springer–Gelhar solutions. The automatic correction function in AQTESOLV was applied for filter pack drainage where observed.

Hydraulic conductivities were determined to vary in the four different aquifer zones as expected, with the dredge fill having the greatest conductivities and the perched zone the lowest. Slug test results in the dredge fill were variable and therefore include uncertainty about hydraulic conductivities. For this unit, the hydraulic conductivity value obtained is assumed to be a minimum value.

Using MODFLOW and a Mass Balance Approach to Assess Groundwater Storage Enhancement via a Floodplain **Infiltration Basin**

Lindsay Henning, Central Washington University

Carey Gazis, Central Washington University

Delaying groundwater discharge into rivers until it is critically needed during baseflow conditions provides promise for lowering elevated stream temperatures and improving habitat for aquatic species. Managed Aquifer Recharge (MAR) may potentially increase groundwater storage in locations where excess spring runoff can be captured and allowed to infiltrate into the subsurface for later beneficial use. We considered this type of MAR via a floodplain infiltration basin at a site along the Teanaway River near Cle Elum, Washington. A site-scale transient MODFLOW groundwater flow model was used to investigate the effects of a simulated infiltration basin on the existing groundwater flow regime.

Using monthly stress periods, the transient groundwater flow model incorporated site conditions over a 5-year span from 2017 to 2022 and was calibrated against 217 groundwater head observations in the last 2 years of simulation. Secondary calibration was performed against an analytic water balance over the same model domain. The analytic water balance computed an idealized water table by a least-squares plane of best-fit through the monthly mean head elevations at 9 observation wells located in the floodplain, enabling the monthly change in groundwater storage to be determined from water table fluctuations. Mass balances of the groundwater flow model and the analytic water balance agree within 10%.

Different infiltration basins varying in size from 554 m³ to 2430 m³ (0.449 acre-feet to 1.97 acre-feet) were simulated in the MODFLOW model by ephemeral ponds that were wetted during the January through April stress periods. Comparison of head elevations and mass balances between the calibrated groundwater flow model and the pond scenarios indicates that increased infiltration contributes to an increased overall volume of the system in the short term, with head elevations dissipating to 0.01 to 0.02 m higher than baseline levels by the August stress period following the drying up of the pond at the end of April. The maximum increase in groundwater elevation was 0.76 m in April at the well nearest to the infiltration basin. The total increase in volume of the system is offset by increases in discharge across the downgradient boundary of the site and to the river, and a modest increase in evapotranspiration. For the storage and hydraulic conductivity conditions of the shallow alluvial aquifer at the site, modeling indicates that MAR in the spring would not have significant lasting effects into late summer when increased baseflow is desired.

PFAS Document Abstraction using Open Semantic Search

Neil Powers, INTERA, Inc.

Corey Brumbaugh, INTERA, Inc. Kimberly Ralston-Hooper, INTERA, Inc. Jennifer Henriksen, Hanford Mission Integration Solutions

The US Department of Energy (DOE) has published guidance on how to investigate historical and current use of per- and polyfluoroalkyl substances (PFAS) at DOE owned or operated sites. The guidance is designed to improve understanding of past and present PFAS use at DOE facilities as well as to identify areas of potential release. Furthermore, the guidance ensures 1) an alignment to the goals and objectives presented in DOE's PFAS strategic roadmap and 2) that a structured, robust PFAS historical and current use investigation is conducted. The initial step of the process is to review available site information. The outlined approach is consistent with the CERCLA Preliminary Assessment (PA) process with the goal of distinguishing between sites that pose little or no threat to human health and the environment to those sites requiring further investigation. As part of the initial step, a review of Hanford historical documents was undertaken that includes an open semantic search. An open semantic search is an open-source search engine that integrates research tools for easier searching, monitoring, analytics, discovery, and text mining of heterogenous and large document sets.

The open semantic search was used to narrow the number of documents to review in the first stage of investigating historical and current PFAS use at the Hanford site. Hanford covers 580 square miles with hundreds of waste sites and buildings going back 80 years. This has generated over a million documents over the course of Hanford operations. Using keyword searches and expert judgement, the number of records was narrowed down to 150,000 documents. The contents of each file were uploaded into a database and indexed using selected keywords provided by the DOE guidance document. The search results were downloaded to a file containing the file path/name, the associated keyword, and the search category provided in the DOE guidance document. The results were reviewed and further refined reducing the number of relevant documents to 27,000. Utilizing the search results in conjunction with the indexed keywords and categories associated with each file, the number of documents was further narrowed down to 10,000 documents.

With the rising concern about the ubiquitous nature of PFAS, the need to search historical documents to find potential source locations is essential. The outlined approach used to reduce Hanford site records to manageable numbers utilizing an open semantic search will be presented. Overall, the approach is consistent with DOE guidance and CERCLA PA process. The open semantic search is an efficient way to reduce large numbers of documents to manageable numbers which can then be used to identify potential PFAS sites requiring further investigation.

Adaptive groundwater management made easy: a web-based decision support tool for the Arvin-Edison Water **Storage District**

Aaron Lewis, EKI Environment & Water, Inc.

Anona Dutton, EKI Environment & Water, Inc. Ayman Alafifi, EKI Environment & Water, Inc. Nigel Chen, EKI Environment & Water, Inc.

Groundwater management is a critical issue for water resource planners, particularly in areas where groundwater is the primary source of water supply. The Arvin-Edison Water Storage District (AEWSD), located in the heart of California's San Joaquin Valley, has historically embraced a "conjunctive use" approach to managing its local water resources whereby it operates a complex network of groundwater recharge facilities to store imported surface water supplies made available during wet hydrologic years in the local groundwater system to offset the greater groundwater demands from its agricultural customers in times of drought. This complex management framework is now further complicated by newly imposed regulatory requirements of the California Sustainable Groundwater Management Act (SGMA), which require local water agencies to manage their basins to quantitative "sustainability criteria" designed to prevent chronic groundwater level declines, land subsidence, and other "undesirable results" that threaten the sustainability of the groundwater supply and jeopardize the livelihoods of local beneficial users.

To effectively manage such a complex system, water resource planners typically rely on numerical groundwater flow models to inform key operational management decisions – such as assigning surface water delivery and groundwater pumping allocations, managing recharge operations, and implementing conservation measures – and to evaluate their impacts on the local groundwater system. However, the complexity of such models often poses a challenge for decision makers who may lack the necessary skills or resources to set up and run them. In response to this challenge, EKI and AEWSD developed an interactive decision support tool to assist in making adaptive operational management decisions under future hydrologic and water supply uncertainties. The Tool executes a dynamic, fully integrated agricultural water balance, soil moisture routing, and MODFLOW numerical groundwater flow model routine using a web-based graphical user interface built in R Shiny and Python. The goal of this Tool is to provide an easy-to-use interface for decision makers to evaluate a range of operational alternatives and plan for future drought events while ensuring continued compliance with SGMA regulations.

This user-friendly Tool runs on a web browser and allows the user to directly enter core model inputs and assumptions including annual hydrology and surface water availability, delivery routing to agricultural customers, groundwater recharge, and recovery pumping operations within the District's existing water supply infrastructure and service area boundaries. The user can save scenarios, create files for a single five-year projected model run, initiate the coupled soil moisture and MODFLOW-6 models, and post-process results in one-click. The Tool generates visualizations of key model outputs including hydrographs and mapped changes in groundwater elevations over time and at their local monitoring sites, tracks ongoing compliance with SGMA sustainability criteria, and reports management metrics such as the groundwater budget, estimated agricultural pumping demands, and groundwater bank balances. The Tool also allows for the saving and reloading of projected scenario inputs and outputs for comparative side-by-side evaluations.

This Tool provides a much-needed solution to the challenge of improving accessibility to and making informed decisions from complex numerical models. The Tool is highly portable and can be easily adapted to accommodate the specific needs and management schema of any agency. By providing decision makers with an

accessible, easy-to-use Tool for evaluating operational management alternatives and identifying water resources management optimization frameworks under future uncertainties, this Tool has the potential to improve adaptive groundwater resource management and sustainability initiatives across the globe.
14th Washington Hydrogeology Symposium

Field Trips

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Workshops

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FT 1: Creek Restoration Projects in Pierce County, Washington

Monday, April 22, 2024, 8:00 AM - 5:00 PM

Leaders: Jonathan Kemp (EnCo Environmental)

Join us on our field trip to explore three remarkable environmental restoration projects in Pierce County. These initiatives represent significant efforts to enhance the health of local ecosystems, improve flood storage capacity, and create better habitats for wildlife and fish species.

Stop 1: Puyallup Tribe Fisheries Upper Clarks Creek Bank Stabilization

The Upper Clarks Creek Bank Stabilization project experienced substantial down-cutting and in-channel erosion. This project stabilized a 12' head cut as well and roughened the channel and banks for approximately 2,000 LF to reduce continued channel degradation and downstream transport of sediment into the downstream reaches of Clarks Creek. Project objectives included 1) a reduction in sediment production and transport from eroding channel banks and bed in the headwaters of Clarks Creek and 2) an increase in flood storage capacity within Upper Clarks Creek and Upper Clarks Creek Tributary. Construction was completed about 3 years ago.

Stop 2: Pierce County Clear Creek Habitat Restoration

The Clear Creek Habitat Restoration project improved access to salmon habitat and expanded the flood storage capacity by removing sections of an existing access road that separated Clear Creek from an adjacent wetland. This 16-acre site within the Puyallup River watershed is home to many wildlife and fish species, including chinook, coho, and chum salmon, as well as bull trout, cutthroat trout, coyote, and deer. Construction was completed in November 2022.

Stop 3: Port of Tacoma Lower Wapato Creek Habitat Project

The lower Wapato Creek Habitat Project re-establishes stream and wetland habitat on approximately 20 acres of tidally influenced estuary and fish bearing stream. This is an advance mitigation project that consists of two primary fish and wetland habitat restoration elements. The project consisted of replacement of two fish-barrier culverts that convey Wapato Creek under 12th Street East with a fish-passable full-span bridge; and relocation of Wapato Creek from a ditched system to a longer, meandering stream channel and associated wetlands. This includes a variety of associated estuarine/freshwater habitats and a densely vegetated forested upland buffer to provide an increase in the quantity and quality of fish and wildlife habitat, wetlands, and flood capacity.

FT 2: Lake Tapps and Flaming Geyser State Park

Monday, April 22, 2024, 8:00 AM - 5:00 PM

Leader: Andy Long (U.S. Geological Survey)

Join us on our field trip to explore two remarkable water resource and unique geologic sites in King County. These places will enable us to observe and discuss significant improvements made to protect water quality, volume, and native fish resources for the White River and to observe and learn about several unique geologic and natural resource features along the Green River. A boxed lunch will be served at field trip Stop 2: Powerhouse.

Stop 1: Lake Tapps Headworks

The first part of the tour will include observing and discussing how Cascade Water Alliance has designed new facilities to improve how river water from the Mud Mountain Dam is diverted from the White River into Lake Tapps via a constructed water transfer flume. We will learn about the primary advantage of the on-going intake improvements for sediment control and safe fish passage. We will look at the new headwall along the White River and discuss how it was designed to reduce sediment pass through and debris diversion. We will observe the sediment sluiceway, automated sluice radial gate, and a bedload excluder wall. We will learn how the additional manually operated flow control slide gates provide and allow for the maximum diversion of water into the flume system.

Stop 2: Powerhouse

The second part of the tour will include observing and learning about the historical concrete building which contains an operating area, repair shop, subway, offices, Exciter penstock surge tanks, transformer bays, relief, safety, and water valves, water and air filters, bearings, massive piping, gear works, hydraulic pumps, lightning arrestor, switches, electric towers, and the main turbine / generator room. We will look at and discuss the details of the four massive Allis Chalmers Company of Milwaukee Wisconsin turbine / generator units which are impressive and large, but are no longer functional. Outside, we will look at the water channel leading into the powerhouse from Lake Tapps and the tailrace ditch located west of the powerhouse.

Stop 3: Flaming Geyser State Park

The tour will include looking at and discussing local outcroppings, formations, bluffs, and sedimentary layer features such as cross bedding and laminae (sedimentary rock, organic tissue, or other material) sequences. We will observe and interpret the presence of massive glacial erratics, discuss and interpret the geomorphology of an abandoned fluvial floodplain and terraces in the open meadow above the current Green River floodway and discuss stream geomorphology, and observe, from a distance, evidence of a hammer bluff along the eastern flank of the Green River valley. We will look at erosion and deformation events associated with this bluff such as slumping and observe rock units susceptible to erosion that contain kaolinites and quartz, and the more resistant units that contain clays and shales.

WS 1: Water 101 - An Overview of Washington State Water Law, Water Rights, and Related Water Resources, Tools, and Challenges

Thursday, April 25, 2024 | 8:00 AM - 5:00 PM

The Department of Ecology's Water Resources program supports sustainable water resources management to meet the present and future water needs of people and the natural environment, in partnership with Washington communities. As competing demands for our commonly owned water supplies and environmental threats such as climate change loom larger than ever, there is increasing public awareness of water supply issues across the state.

As the state agency responsible for managing water resources for Washington, we strive to ensure that there is enough water for people, farms, and fish. It's easy to say this, but the problem is more complicated. Washington has a history of water laws that date back more than 100 years.

In this one-day workshop, Ecology Water Resources staff and managers will share the latest information and insight on:

- Western water law and the four part test
- Case examples so, why is it so hard to get a water right?
- Adjudication efforts in the Nooksack (WRIA 1) and Lake Roosevelt-Middle Tributaries (WRIA 58)
- Ecology's Certified Water Rights Examiner (CWRE) program
- Ecology's Cost Reimbursement program
- Resources for estimating historical water use
- Estimating annual consumptive quantity (ACQ)
- Case examples of Cost Reimbursement Agreement water right decisions

Instructors:

- John Rose, Washington State Department of Ecology
- Andrea Lauden, Washington State Department of Ecology
- Rebecca Inman, Washington State Department of Ecology
- Ben Carr, Washington State Department of Ecology
- Noah Wentzel, Washington State Department of Ecology
- Matt Janz, Washington State Office of the Attorney General

Cost: \$175.00 for conference attendees, \$200.00 for workshop only. Early morning, mid-morning, and afternoon refreshment breaks provided.

WS 2: Python in Hydrogeology

Thursday, April 25, 2024 | 8:00 AM - 5:00 PM

Python is a popular programming language that can be used by hydrogeologists to automate repetitive tasks, perform scientific analyses, create publication-quality graphics, and develop graphical animations of scientific data and model results. The purpose of this one-day introductory workshop is to help hydrogeologists get up and running with Python. The first half of the workshop will focus on Python fundamentals, including how packages are managed and installed, strategies for writing Python scripts, and use of the popular Numpy, Matplotlib, and Pandas packages. During the second half of the workshop participants will learn to work with spatial data, solve analytical solutions of groundwater equations, create animations, and develop groundwater models. This workshop consists of hands-on exercises designed to improve overall Python proficiency. Participants will need to bring a laptop computer to the workshop; software information will be provided in advance of the class. The workshop presenter will communicate with registered participants on final content and other workshop materials.

Morning session:

- Understanding and installing Python distributions and environments
- Introduction to writing Python scripts
- Reading, processing, and plotting data using Numpy, Matplotlib, and Pandas

Afternoon session:

- · Working with spatial data
- Solving analytical groundwater equations
- Creating animations
- Constructing, running, and post-processing a MODFLOW groundwater model

Instructor:

Christian Langevin, U.S. Geological Survey

Cost: \$175.00 for conference attendees, \$200.00 for workshop only.

Early morning, mid-morning, and afternoon refreshment breaks provided.

WS 3: PFAS – Regulatory Context, Sampling Guidance, and Ex Situ/In Situ Treatment Thursday, April 25, 2024 | 8:00 AM – 5:00 PM

The PFAS Workshop will cover a broad range of aspects relevant to understanding and addressing per- and polyfluorinated substances (PFAS) in the environment. Tamzen Macbeth of CDM Smith will lead the workshop along with a team of experts covering topics to introduce the PFAS issues, guidance, and current state of knowledge for treatment. The workshop will start with an overview of PFAS chemicals, environmental release mechanisms, and why PFAS chemicals are such a challenge, spurring media references as "forever chemicals." Instructors will provide a regulatory perspective to set the context for the evolving guidance/requirements for cleanup. Methods and equipment for sampling to minimize cross contamination, collect representative samples, and obtain analysis results to the necessary detection levels will be covered. The remainder of the workshop will discuss treatment/remediation technologies and strategies, as well as disposal pathways for residual material. Current developments in technologies for ex-situ treatment of soils and water will be covered. The in-situ remediation segment will cover subsurface characterization, conceptual site models, use of modeling, and in-situ soil and groundwater remediation technologies and approaches. Select case study examples will be used to illustrate technologies/strategies. Participants should expect to come out of the workshop with a good understanding of the issues surrounding PFAS in the environment, an overview of treatment approaches, and insight into gaps and future research needs.

Instructor:

Tamzen Macbeth, CDM Smith

Cost: \$175.00 for conference attendees, \$200.00 for workshop only. Early morning, mid-morning, and afternoon refreshment breaks provided.

WS 4: Optimizing Water Wellfield Performance

Thursday, April 25, 2024 | 8:00 AM - 5:00 PM

This workshop will provide water system managers, operators, engineering consultants and well drillers some important tools for optimizing long term well performance and wellfield operation. Most problems with well performance are preventable, and start with well construction and development, and are then exacerbated by water quality conditions, well operation and rehabilitation efforts. Mr. Bailey will present the important elements that are responsible for design, construction and care of water wells. He will use real world examples that demonstrate the science to maximizing well performance. Wellfield optimization will be addressed by Todd Kinkaid, a nationally recognized numerical modeler. Todd will give practical examples that show the advantages and disadvantages of common models used and how to recognize their limitations based on the amount of available data. Brian Peck is an expert in dewatering design and the testing of water wells to determine optimal yield. He will show how proper use of pumping tests can have a significant impact on the long term operation of water wells. Completion of this workshop will provide Continuing education units (CEU) pending approval.

Instructor:

- Jim Bailey, Shannon & Wilson, Inc.
- Todd Kinkaid, Shannon & Wilson, Inc.
- Brian Peck, Shannon & Wilson, Inc.

Cost: \$100.00 for conference attendees, \$125.00 for workshop only Early morning, mid-morning, and afternoon refreshment break provided.

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