6th Washington Hydrogeology Symposium

Program

May 1-3, 2007
The Greater Tacoma Convention & Trade Center

Organized by:

Washington State Department of Ecology

U.S. Geological Survey

6th Washington Hydrogeology Symposium

GENERAL SCHEDULE

May 1-3, 2007

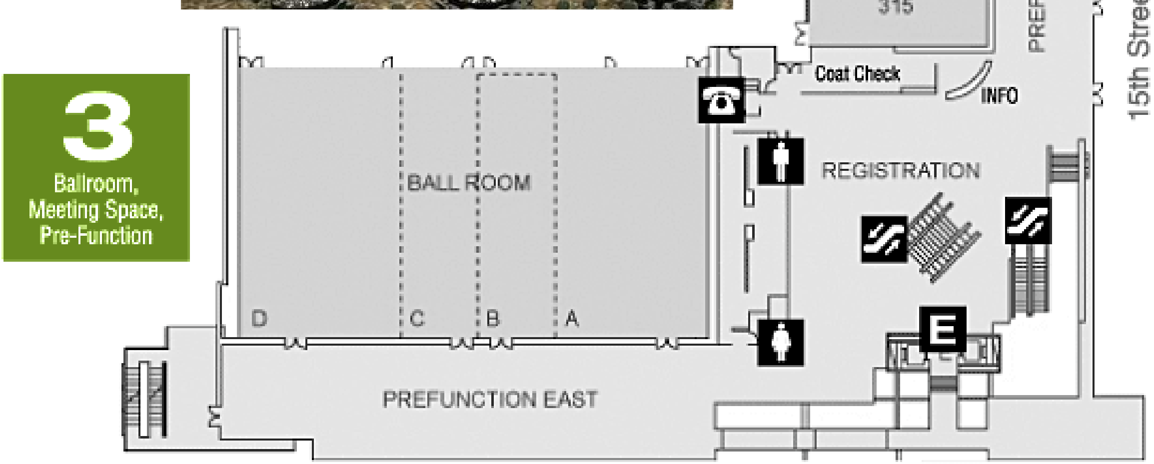
Detailed schedule on p. 4

DATE	ACTIVITY
Saturday, April 28	Field Trip 1: Hydrogeology of the Walla Walla Basin (7 a.m. Start Day 1).
Sunday, April 29	Field Trip 1 (cont.): Hydrogeology of the Walla Walla Basin (Day 2: 7 p.m. end). Field Trip 2: Hydrogeology of Mt. Rainier (8 a.m. to 6 p.m.).
Monday, April 30	Field Trip 3: Low Dissolved Oxygen Hood Canal (8 a.m. to 5 p.m.).
Tuesday, May 1	1st Day of Symposium: Registration 7:30 a.m.; Opening Plenary Session 9:00 a.m. (Keynote 1: Dr. Robert Glennon, Water Follies). Lunch (Provided); Keynote 2: Dr. Paul Johnson (Vapor Intrusion); Reception (Hearty Hors D'oeuvres): 5:30 to 8:00 p.m.
Wednesday, May 2	2nd Day of Symposium: Plenary Session 8:30 a.m.; Keynote 3: Dr. John Priscu (Earth's Icy Biosphere); All Day Talks & Poster. Lunch (Provided). Evening: Coastal Geology Dinner Cruise 5:30 to 8:00 p.m.
Thursday, May 3	3rd Day of Symposium: 8:30 to Noon (Talks); Workshops: Geochem, Tidal GW, EIM Data Base, Heterogeneity (1:30 to 4:30 p.m.).

GREATER TACOMA CONVENTION CENTER

1500 Broadway, Tacoma, WA 98402 Tel: 253.830.6601 Fax: 253.573.2363

Email: contact@tacomaconventioncenter.com



MAP AND DIRECTIONS:

The Greater Tacoma Convention & Trade Center is at 1500 Broadway, Tacoma, WA 98402. Directions are available online at *http://www.tacomaconventioncenter.com/plan_directions.html* or by phone at *(253) 830-6601*

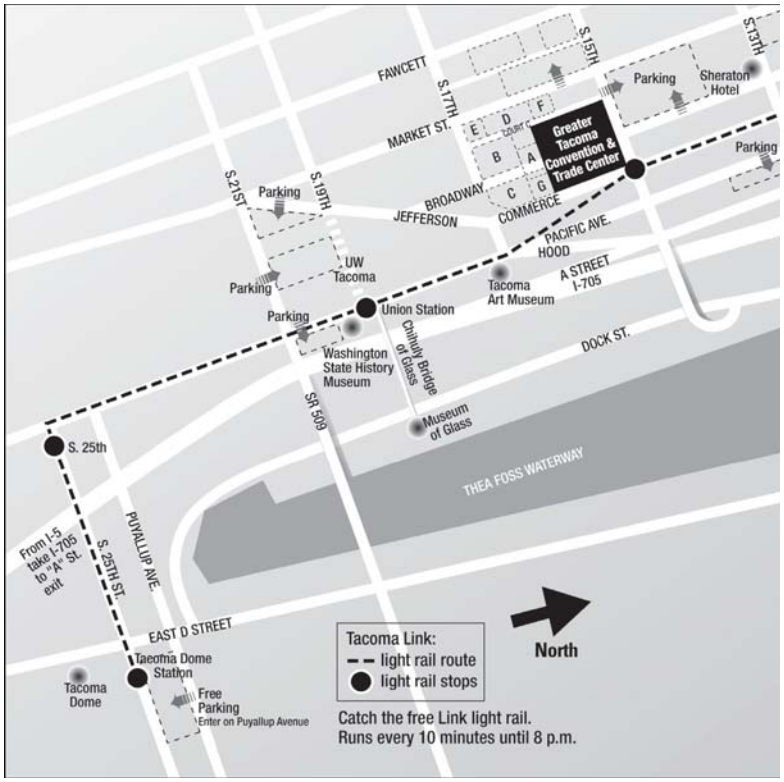


Table of Contents

Welcome!

Welcome to the 6th Washington Hydrogeology Symposium! We have a brand new venue this year – the new Greater Tacoma Convention and Trade Center. It's lighter, brighter, and more comfortable than the old convention center, with spectacular views of the surrounding area.

We have a record 90 talks and 25 poster presentations this year, including such topics as Environmental Forensics, Age-Dating Groundwater, and Impacts of Climate Change on Water Resources. We also have five exciting field trips, ranging from the hydrogeology of Mt. Rainier to that of the Walla Walla basin - plus a hands-on demonstration concerning low dissolved oxygen in Hood Canal. Four workshops will be presented, including Groundwater in Tidally Influenced Aquifers and Geochemical Modeling of Hydrocarbons and Invasive Waters on Groundwater Systems.

We are delighted to have three distinguished keynote speakers, including Dr. Robert Glennon, author of "Water Follies: Groundwater Pumping and the Fate of America's Fresh Waters" and Morris K. Udall Professor of Law and Public Policy, University of Arizona. We also have Dr. John Priscu of Montana State University, who is currently conducting research on life associated with Antarctic ice and its relationship to global change and astrobiology in the permanently ice-covered lakes of the McMurdo Dry Valleys, Antarctica. Additionally, Dr. Paul Johnson will give a lunch-time talk on the Subsurface Contaminant Vapor to Indoor Air Pathway. Dr. Johnson is Executive Dean of the Ira A. Fulton School of Engineering and Professor Department of Civil & Environmental Engineering at Arizona State University.

The Symposium provides a unique opportunity to connect with other professional hydrogeologists, geologists, and hydrologists from throughout the Pacific Northwest. Over 400 people attended the previous Symposium. Please make plans now to join us this year.

Sincerely,

Charles San Juan, LHG

2007 Symposium Chair
Washington Department of Ecology

Left to right: (Top) Gary Walvatne, Mark Freshly, Brian Drost, Sandy Williamson;
(Bottom) Bob Miller, Marcia Knadle, Laurie Morgan, Charles San Juan.

6th Washington Hydrogeology Symposium Steering Committee

Board Members:

Charles San Juan - *Washington Department of Ecology, Chair*
Bob Miller - *Robert D. Miller Consulting, Inc., Vice-chair*
Brian Drost - *U. S. Geological Survey (retired), Treasurer*
Laurie Morgan - *Washington Department of Ecology, Secretary*
Sandy Williamson - *U.S. Geological Survey, 2003 Chair*
Mark Freshley - *Pacific Northwest National Laboratory*
Gary Walvatne – *Tech Law, Inc., West Linn, OR*
Christine Neumiller - *Washington Department of Ecology, Webmaster and Board alternate*

Other Members:

Donna Freir - *Washington Department of Health, Poster Coordinator*
Marcia Knadle - *U. S. Environmental Protection Agency*
Sue Kahle - *U. S. Geological Survey, Field Trip Coordinator*
Lauren Patton - *City of Portland Bureau of Environmental Services, Volunteer Coordinator*
Carol Johnson - *WA Department of Ecology, Mailing List*

FINAL SYMPOSIUM SCHEDULE

TUESDAY MAY 1, 2007 – REGISTRATION 7:30 AM

9:00-10:00 AM Welcome & Keynote 1: Dr. Robert Glennon – Ground Water Pumping Impacts (Ballroom A&B)

BREAK 10-10:30 AM (Glennon Book Signing)

SESSION 1 (Tue, May 1, 10:30-11:40 AM)

1A – GROUND WATER DATA MANAGEMENT (Tue, May 1, 10:30-11:40 AM, Rm 316)

New Database Technologies to Advance Hydrologic Science: *Alex (Sandy) Williamson, U.S. Geological Survey.*

The Development of a Standardized Data Structure and Management System for Borehole Geophysical Logs at the Hanford Site: *Rick McCain, S M Stoller Corp.*

Integration and Management of Subsurface Data to Support Remedial Decisions: *G. V. Last, Pacific NW Nat' l Lab-PNNL*

1B – CLIMATE CHANGE (Tue, May 1, 10:30-11:40 AM, Rm 317)

Glacier Mass-Balance Fluctuations in the Pacific Northwest and Alaska, USA: *Edward Josberger, U.S.Geological Survey*

Deep Aquifer Storage as a Possible Solution to Changing Water Distribution Patterns Resulting from Global Warming Induced Climatic Changes: *Floyd Hodges, Amphigory Associates*

Late 20th Century Ice Loss in the Vicinity of the Goat Rocks, Tieton River Basin, Washington: *Bill Bidlake, U.S. Geological Survey*

1C – WATER RIGHTS / GROUND WATER DATA MANAGEMENT (Tue, May 1, 10:30-11:40 AM, Rm 318)

Analysis of Exempt Well Location, Use, and Timing: *Ken Johnson, King Co. Metro*

Why Is Better Management of Groundwater So Elusive? *Carl Hauge, Retired - CA Dept. Wa Res.*

Streamflow Augmentation using Multiple Water Sources as Mitigation for a New Water Right, North Bend, Washington: *Nicole DeNovio, Golder Assoc. Inc.*

Rain Harvesting Impacts: *Chris V Pitre, L., Golder Assoc. Inc.*

LUNCH (BALLROOM A&B) Tue, May 1, 11:40-1PM (Keynote 2: Dr. Paul Johnson, Vapor Intrusion Pathway)

SESSION 2 (Tue, May 1, 1-2:30 PM)

2A – HANFORD TANK FARM VADOSE ZONE: I (Tue, May 1, 1-2:30 PM, Rm 316)

Hanford Tank Farm RCRA Corrective Action Program: *John Kristofzski, CH2M Hill Hanford Group*

New Characterization Tools Used In and Around Hanford's Single-Shell Tank Farms: *David Myers, CH2M Hill*

Subsurface Geophysical Exploration Within and Around Hanford's Tank Farms: Examples from T and S Farm: *Marc Levitt, hydroGEOPHYSICS, Inc.*

High-Resolution Resistivity Applied to Characterization and Leak Detection at Two Single Shell Tank Farms (SST) at the Hanford Site: *Joseph Caggiano, WA Dept. of Ecology*

2B – GROUND WATER CONTAMINANT CHARACTERIZATION (Tue, May 1, 1-2:30 PM, Rm 317)

Biogeochemical Controls on Spatial and Temporal Variability of Arsenic Concentrations in Shallow Groundwater, Seattle-Tacoma International Airport: *Dimitri Vlassopoulos, S.S. Papadopulos & Assoc.*

Environmental and Compound-Specific Stable Isotopes: Geochemical Forensic Tools with Application to Site Characterization in a Complex Hydrogeologic Situation: *Dimitri Vlassopoulos, S.S. Papadopulos & Assoc.*

High Chromium Levels in Landfill Monitoring Wells: *Lee Huckins, Oregon DEQ*

Initial Test Results of a Passive, Discrete Multi-Level Sampling Device for Vertically Defining Groundwater Contamination in Monitoring Wells: *David Herzog, Cambria Environmental Tech, Inc.*

2C – ENVIRONMENTAL GEOLOGY (Tue, May 1, 1-2:30 PM, Rm 318)

Cedar Moraine Safety Study: *Eric Weber, Landau Associates*

Dewatering Design and Implementation for the Sound Transit Beacon Hill Station Tunnel, Seattle, Washington: *Kate Stalker, Shannon & Wilson*

It's Not Nice to Fool Mother Nature: Highway Design and Jökulhlaupsat White River Glacier, Mount Hood, Oregon: *Kenneth Cameron, Oregon DEQ*

Volatile Organic Compounds groundwater Plume Delineation Using Waterloo profiler Technology at the Tacoma landfill: *Calvin Taylor, L.H.G., City of Tacoma*

BREAK 2:30-3PM

SESSION 3 – (Tue, May 1, 3-5 PM)

3A – HANFORD TANK FARM VADOSE ZONE: II (Tue, May 1, 3-5 PM, Rm 316)

Developing Software to Streamline Hanford Tank Closure Risk Assessment Activities: *David Watson, CH2M Hill Hanford Group*

Characterization of the 241-C Tank Farm and Recent Groundwater Contamination at the Hanford Site, Washington: *Stanley Sobczyk, Nez Perce Tribe*

Groundwater Contamination Resulting from Tank Leaks at Hanford: A Growing Problem. *Floyd Hodges, Amphigory Associates*

Sensitivity/Uncertainty Analysis Developed for The Initial Single-Shell Tank System Performance Assessment for the Hanford Site: *Michael Connelly, CH2M Hill Hanford Group*

Demonstration of an Interim Surface Barrier Covering the T-106 Tank Release: *Frank Anderson, CH2M Hill Hanford Group*

3B – GROUND WATER MODELING (Tue, May 1, 3-5 PM, Rm 317)

Three-Dimensional Groundwater Flow Model of an Underground Gold Mine near Republic, Washington: *Peter Sinton, URS Corp.*

A Re-Examination of Groundwater Flow in Stratified Aquifers Induced by Vertical Recirculation Wells: *John Lambie, E-pur*

Hydrogeologic Conceptualization and Numerical Groundwater Flow Modeling Techniques for Fractured Bedrock Systems: *Alexis Clark, Golder Assoc. Inc.*

Got a Persistent Plume? How to Simulate Back Diffusion using Analytical & Numerical Methods: *Peter Bannister, Aspect Consulting LLC*

Computer Modeling of an Open Loop Geoexchange Wellfield: *Gary Andres, PBS&J*

3C – GROUND WATER INTERACTION-TIDALLY INFLUENCED SURFACE WATER (Tue, May 1, 3-5 PM, Rm 318)

Ground Water, Sediment, and Surface Water Contamination from Chemical Manufacturing Waste Disposal at the Mouth of Hylebos Waterway, Tacoma, WA: *Jonathan Williams, EPA*

Nature and Extent of Ground-Water Contamination Beneath the Mouth of Hylebos Waterway, Tacoma, WA: *Roy Jensen, Hart Crowser*

Measurements of Hydraulic Conductivity Using Slug Tests and Sediment Samples for Two Streams in the Pacific Northwest, USA: *Colette R. McKenzie, Central Washington University (CWU)*

Quantifying Submarine Ground-Water Discharge and Nutrient Loading into the Lynch Cove Area of Hood Canal: *F. William Simonds, U.S. Geological Survey*

MTCA and Shoreline LNAPL: A Poor Marriage: *Jay Lucas, GeoEngineers, PHYSICS, Inc.*

5-5:30 PM BREAK – EXHIBITORS RECEPTION
5:30-8 PM RECEPTION, Hearty Hors D'oeuvres (Provided) and Cash Bar, BALLROOM A&B

WEDNESDAY MAY 2, 2007 – REGISTRATION 7:30 AM

8:30-9:30 AM Keynote 3 - Dr. John Priscu, Earth's Icy Biosphere (Ballroom A&B)

BREAK 9:30-10 AM

SESSION 4 – (Wed, May 2, 10-11:30 AM)

4A – HANFORD GROUNDWATER CHARACTERIZATION (Wed, May 2, 10-11:30 AM, Rm 316)

Locating the Source of a Chromium Groundwater Plume at the Hanford Site: *Scott Petersen, Fluor Hanford, Inc.*

Monitoring the Influence of River Stage on Contaminant Concentrations in the Hyporheic Zone of the Columbia River at the Hanford Site's 300 Area: *Greg Patton, Pacific NW Nat' l Lab-PNNL*

Effect of Changing River Stage on Uranium Flux through the Hyporheic Zone of the Columbia River along the Shoreline of the 300 Area of the Hanford Site: *Brad Fritz, Pacific NW Nat' l Lab-PNNL*

4B – GROUND WATER SUPPLY (Wed, May 2, 10-11:30 AM, Rm 317)

Estimates of Ground-Water Recharge to the Yakima River Basin Aquifer System, Washington, for Predevelopment and Current Land-Use and Land-Cover Conditions: *J. J. Vaccaro, U.S. Geological Survey*

Estimates of Ground-Water Pumpage from the Yakima River Basin Aquifer System, Washington, 1960-2000: *J. J. Vaccaro, U.S. Geological Survey*

Future Groundwater Supplies for Three Municipalities in the McAllister & Yelm Sub-Basins of Thurston County, Washington: *Stephen Thomas, Golder Assoc. Inc.*

Ground Water Supply Potential of a Deep Confined Aquifer, North-Central Whatcom County, Washington: *Bridget August, Assoc. Earth Sciences, Inc.*

4C – WATER QUALITY (Wed, May 2, 10-11:30 AM, Rm 318)

Pharmaceuticals and Personal Care Products In Water: *Melanie Kimsey, WA Dept. of Ecology*

Water Quality Credit Trading in Oregon: *Sonja Bjorn-Hansen, Oregon DEQ*

Water Quality Credit Trading in Oregon: *(Continued)*

Assessment of Impacts from an Infiltration Gallery for Treated Groundwater Discharge: *Eric Marhofer, EA Engr. Sci & Tech., Inc.*

Use of Stable Isotopes of Strontium and Lead to Assess the Fate of Storm and Reclaimed Water in Groundwater Systems: *Richard W. Hurst, Hurst & Associates Inc.*

LUNCH (PROVIDED) NO SPEAKERS 11:30-1 PM Ballroom A&B

POSTER SESSION (Authors Present, Wed, May 2, 1-2 PM)

SESSION 5 – (Wed, May 2, 2-3:30 PM)

5A – HANFORD GROUND WATER REMEDIATION (Wed, May 2, 2-3:30 PM, Rm 316)

Supplemental Groundwater Remediation Technologies to Protect the Columbia River at Hanford, WA: *Mike Thompson, US Dept. of Energy*

Uranium Stabilization through Polyphosphate Injection: 300 Area Uranium Plume Treatability Demonstration Project. *Dawn Wellman, Pacific NW Nat' l Lab-PNNL*

Technical Challenges to the Hanford Site Groundwater Remediation: *Dib Goswami, WA Dept. of Ecology*

Treatability Test for Removing Technetium-99 from 200-ZP-1Groundwater, Hanford Site: *Mark Byrnes, Fluor Hanford, Inc.*

5B – GROUND WATER SOURCE REMEDIATION (Wed, May 2, 2-3:30 PM, Rm 317)

Treatment of a TCE Source Area beneath an Active Storm Water Detention Basin Using Electrical Resistance Heating: *Jerry Ninteman, Landau Associates*
Time-Sensitive Response, Characterization, and Remediation of an Intentional Release Directly to an Existing Monitoring Well: *John Hildenbrand, Robinson, Noble & Saltbush Inc.*
Ten Years of Recovery of a 6-Acre Diesel/Bunker C Plume in the Tacoma Tideflats, Washington: *Suzanne Dudziak, Greylock Consulting*
Innovative In-situ Groundwater Remediation Technologies: High Volume LNAPL Recovery Techniques in a Tidally-Influenced Aquifer: Todd Shipyards, Seattle, WA: *Thomas Colligan, Floyd Snider*

5C – IMPLICATIONS OF RECHARGING STORMWATER OR TREATED WATER (Wed, May 2, 2-3:30 PM, Rm 318)

Prognosis on Storm Water Infiltration – Moving from Disposal to Reclamation: *Daniel Scarpine, Storm water Rx, LLC*
Storm Water Infiltration Risks and Benefits: *Laurie Morgan, WA Dept. of Ecology*
Evaluating Subsurface Discharge of Treated Municipal Effluent to Mitigate Potential Impacts to Surface Water Quality, Hermiston, Oregon: *Dennis Orlowski, Kennedy / Jenks Consultants*
Subsurface Discharge of Treated Municipal Effluent for Cooling and Ammonia Treatment Prior to Indirect Surface Water Discharge: *Stuart Childs, Kennedy/Jenks Consultants*

BREAK 3:30-4 PM

SESSION 6 – (Wed, May 2, 4-5:30 PM)

6A – AQUIFER STORAGE & RECOVERY (ASR): Part I (Wed, May 4-5:30 PM, Rm 316)

Shallow Aquifer Recharge (SAR) Projects in the Walla Walla Basin, Washington and Oregon: Efforts to Reverse Dropping Stream Flows and Groundwater Levels: *Bob Bower, Walla Walla Basin Watershed Council & Groundwater Solutions*
Aquifer Storage and Recovery Permits in Washington State: *Douglas Wood, WA Dept. of Ecology*
Water Storage in the Eastern Palouse Basin, Washington: *Bryony Stasney, Golder Assoc. Inc.*
Sammamish Plateau Water and Sewer District's ASR Program: *Scott Coffey, Camp Dresser & McKee*

6B – IN SITU REMEDIATION (Wed, May 2, 4-5:30 PM, Rm 317)

Status and Prospects for Bioremediation of Chlorinated Ethene Dense Non-aqueous Phase Liquids (DNAPLs): An ITRC Perspective: *R. Wymore, Camp Dresser & McKee*
Innovative In Situ Groundwater Remediation Technologies – Anaerobic Bioremediation of Groundwater Using Edible Oil Substrate EOS® In an Unconfined Groundwater Aquifer: *John Sankey, P.E., True Blue Technologies. Inc..*
Bioremediation of a DNAPL Source Zone Through Injection of Food-Grade Vegetable Oil: *Clinton Jacob, Landau Associates*
In Situ PCE and TCE Remediation Using Groundwater Recirculation Systems: *Craig Dockter, Hart Crowser, Inc.*

6C – GEOCHEMISTRY AND CONTAMINANT MOBILITY (Wed, May 2, 4-5:30 PM, Rm 318)

Laboratory-Scale Bismuth Phosphate Extraction Process Simulation to Track Fate of Fission Products: *R. Jeff Serne, Pacific NW Nat'l Lab-PNNL*
Unsaturated Flow of Hanford Tank Waste Leachate Effects on Transport of Cs and Sr: *Kenton Rod, Pacific NW Nat' l Lab-PNNL*
Complexation of Technetium by Radiolytic Degradation Products of Organic Molecules: Implications for Subsurface Transport: *Jonathan Icenhower, Pacific NW Nat' l Lab-PNNL*

6C (cont).
Development of Analytical Methods for Anionic Fission Products and Application to Sediment and Groundwater Samples from Tank Farm Waste Management Areas: *Chris Brown, Pacific NW Nat' l Lab-PNNL*

BREAK 5:30 PM

FIELD TRIP #4: DINNER CRUISE

THURSDAY MAY 3, 2007 – REGISTRATION 8:00 AM

SESSION 7 – (Thur, May 3, 8:30-10AM)

7A - AQUIFER STORAGE & RECOVERY: PART II (Thur, May 3, 8:30-10 AM, Rm 316)

Hydrologic Impacts of a Proposed Infiltration Recharge Gallery on Groundwater-Flow Conditions Near Richland, Washington: *Marcel Bergeron, Pacific NW Nat' l Lab-PNNL*
Lakehaven Utility District's OASIS Project: An Update: *Joseph Becker, Robinson, Noble & Saltbush Inc.*
Implications of ASR Recharge in a Basalt Aquifer, City of Walla Walla: *Michael Klisch, Golder Assoc. Inc.*
The City of Beaverton's Basalt-hosted ASR Project: A Successful Case Study: *Larry Eaton, Groundwater Solutions Inc.*

7B – GEOLOGY (Thur, May 3, 8:30-10 AM, Rm 317)

Basaltic Clay Chemistry of the Puget Sound: Relevance of Chemical and Optical Petrography to Hydrostratigraphy and Environmental Analysis: *Nadine Romero, South Puget Sound Com. Coll. (SPSCC)*
Characterizing the Hydrogeology of the Hyporheic Zone along the 300 Area of the Hanford Site, Washington: *Rod Mackley, Pacific NW Nat' l Lab-PNNL*
Geologic Framework of the Suprabasalt Sediment Aquifer System, Columbia Basin Groundwater Management Area (GWMA), East-Central Washington: *Kevin Lindsey, Groundwater Solutions, Inc.*
Effects of Ice Age Flooding on the Hydrogeology of the Hanford Site: *Bruce Bjornstad, Pacific NW Nat'l Lab-PNNL*

BREAK 10-10:20 AM

SESSION 8 – (Thur, May 3, 2-3:30 PM)

8A – MONITORED NATURAL ATTENUATION (Thur, May 3, 10:20-11:50 AM, Rm 316)

Separating Naturally Occurring Tidal Dilution from Degradation Processes in a Natural Attenuation Analysis at a Nearshore Site: *Mike Riley, S.S. Papadopulos & Assoc.*
The Concept of Enhanced Attenuation of Chlorinated Solvents in Groundwater: *Judie Kean, WA Dept. of Ecology*
In-Situ Treatment of Hexavalent Chromium and TCE at the Boomsnub/Airco NPL Site in Vancouver, WA: *Glenn Hayman, EA Engr. Sci & Tech., Inc.*
Using Dissolved Hydrogen Measurements to Assess and Monitor Biodegradation of Chloroethenes in Ground Water: *Stephen Cox, U.S. Geological Survey*

8B – GROUND WATER-SURFACE WATER INTERACTIONS (Thur, May 3, 10:20-11:50 AM, Rm 317)

Modeling Surface/Ground Water Interactions in Whatcom County, Washington: *Erik Pruneda, WSU Water Research Ctr.*
Hanford Site Groundwater and the Columbia River, South-Central Washington State: *R. E. Peterson, Pacific NW Nat'l Lab-PNNL*

8B (cont).

Stable Isotopic Constraints on Surface Water-Groundwater Interactions in the Upper Yakima River Basin, Washington: *Carey Gazis, Central WA Univ.*

Effects of Columbia River Discharge on Groundwater Elevations, Central Hanford Site, Washington: *John McDonald, Pacific NW Nat' l Lab-PNNL*

11:50 AM CLOSING REMARKS and Door Prize Drawing (Rm 315)

END OF SYMPOSIUM

1:30-4:30 PM WORKSHOPS AND FIELD TRIP

WORKSHOP #1: *Geochemical Modeling of Hydrocarbons and Invasive Waters on Groundwater Systems (Dr. Richard W. Hurst, Hurst and Assoc.). DATE / TIME:* ***Thursday, May 3, 1:30-4:30 PM, Rm 315***

WORKSHOP #2: *Groundwater in Tidally Influenced Aquifers (Roy Jensen, LHG, Hart Crowser). DATE / TIME:* ***Thursday, May 3, 1:30 to 4:30 PM, Rm 316***

WORKSHOP #3: *Want to Know How Do Get Data into That Ecology EIM Data Base? Come to this Workshop! Chris Neumiller, LHG, Ecology. DATE / TIME:* ***Thursday, May 3, 1:30 to 4:30 PM, Rm 317***

WORKSHOP #4: *Subsurface Heterogeneity: Why It Is Important, Why We Usually Ignore It, and What to Do About It (Dr. Gary Weissman, Univ. New Mexico). DATE / TIME:* ***Thursday, May 3, 1:30 to 4:30 PM, Rm 318***

FIELD TRIP #5 – CHARACTERIZING SUBMARINE GROUND WATER DISCHARGE (Thur, May 3, 1:30-4:30 PM)

KEYNOTE BIOS

Dr. Robert J. Glennon[1]

Morris K. Udall Professor of Law and Public Policy
University of Arizona

"Water Follies: The Impact of Groundwater Pumping on the Environment"

The excessive pumping of our aquifers has created an environmental catastrophe known to only a few scientists, a handful of water management experts, and those unfortunate enough to have suffered the direct consequences. As our groundwater use has increased, pumping has caused rivers, springs, lakes, and wetlands to dry up, ground beneath us to collapse, and fish, birds, wildlife, trees, and shrubs to die. This talk will illustrate the scope of the problem with stories from around the country. These water follies are tales of human foibles including greed, stubbornness, and, especially, the unlimited human capacity to ignore reality.

---

[1] *Dr. Glennon is the Morris K. Udall Professor of Law and Public Policy in the Rogers College of Law at the University of Arizona. He has more than 30 years of professional experience and specializes in constitutional law, American legal history, and water law. Glennon's funded research activities have included two National Science Foundation grants. He had held many administrative positions, such as trustee, director, or chair for various institutional organizations. His professional activities include serving as Water Policy Advisor to Pima County, Arizona; as a member of American Rivers' Science and Technical Advisory Committee; and as a commentator and analyst for various television and radio programs. Glennon is the author of many books, articles, and other writings. His best-known work is Water Follies: Groundwater Pumping and the Fate of America's Fresh Waters (Island Press, 2002), the first book ever published to focus on the environmental problems caused by groundwater pumping. Glennon received numerous accolades for Water Follies from such publications as Scientific American, The Washington Post, and The New York Review of Books. He lectures widely around the United States. He holds a J.D. from Boston College Law School and an M.A. and Ph.D. in American History from Brandeis University. He is also a member of the bars of Arizona and Massachusetts.*

Dr. Paul Johnson[1]

Arizona State University's Ira A. Fulton School of Engineering

The Subsurface Contaminant Vapor to Indoor Air Pathway - Do Conventional Risk Assessment Paradigms Make Sense?

Federal, state, and local agencies have recently developed, or are in the process of developing, guidance for assessing potential adverse impacts associated with the vapor intrusion to indoor air pathway. They are also developing tables of compound-specific clean-up numbers for soil, groundwater, and soil vapor that are presumed to be protective of possible exposures resulting from this pathway. Most of these regulatory approaches mimic other conventional pathway-specific approaches, in the sense that decision-making is based on spatially and temporally discrete sampling and some type of data extrapolation. These approaches are also being developed and enforced at a time when our understanding of the pathway is still evolving and there are a wide range of opinions. This talk will review the current state of understanding of the pathway and discuss whether or not the use conventional characterization and risk assessment paradigms make sense for this pathway. This talk will also discuss studies needed to advance our understanding of the pathway.

[1] *Dr. Paul Johnson is executive dean of Arizona State University's Ira A. Fulton School of Engineering and a professor of civil and environmental engineering since 1994. Much of Johnson's most notable research has focused on the physical, chemical and biological aspects o alleviating environmental contamination. He is listed as the inventor or co-inventor on 12 U.S. patents based on his research. He was cited for, among other things, leading a research team that is the first to implement a successful full-scale engineered bioremediation system to cleanup the contaminant chemical MTBE. He is editor-in-chief of the National Ground Water Associations journal, Ground Water Monitoring and Remediation. He also serves as a consultant to the U.S. Environmental Protection Agency, the Department of Defense, state regulatory agencies and industry. Recently, he has been given a Lifetime Achievement Award from the International Conference on Soils, Sediments and Water. The award recognizes "significant contributions to the understanding and solution of soil, sediment and groundwater pollution problems."*

Dr. John C. Priscu[1]

Montana State University Land Resources & Environmental Sciences

Earth's Icy Biosphere

Earth's biosphere is cold, with 14% being polar and 90% (by volume) cold ocean <5°C. More than 70% of Earth's freshwater occurs as ice and a large portion of the soil ecosystem (~20%) exists as permafrost. Paleoclimate records for the past 500,000 years have shown that the surface temperature on Earth has fluctuated drastically, with four major glaciations occurring during this period. Strong evidence also exists showing that the Earth was completely ice-covered during the Paleoproterozoic and Neoproterozoic periods. New discoveries of microbial life in cold (-5°C) and saline lakes, permanent lake ice, glacial ice and polar snow are extending the bounds of our biosphere. The recent description of potential bacterial life in Lake Vostok, and the discovery of at least 100 other Antarctic subglacial lakes extend the known boundaries for life on Earth even further. Despite the spatial and temporal records for icy systems on Earth, little is know of their geobiology and many textbooks limit their definitions of the biosphere to the region between the outer portion of the geosphere and the inner portion of the atmosphere, neglecting icy habitats. Clearly, we must extend the bounds of what is currently considered the "Earth's biosphere" to include icy systems. The next 5-10 years should prove to be an interesting time of discovery for Antarctic science, one that follows the Antarctic tradition of melding interdisciplinary and international science. We can expect studies on the geobiology of glacial environments to be at the forefront of such discovery since these systems remain one of the last unexplored frontiers on our planet. I will present information showing that Earth's icy systems, particularly the Antarctic ice sheet and related subglacial environments, hold a large and potentially active carbon pool that has yet to be considered. Clearly, these recent findings have changed the way we view Antarctica.

---

[1] *Professor; Ph.D. 1982, University of California, Davis; M.S. 1978, University of Nevada, Las Vegas; B.S. 1975, University of Nevada, Las Vegas. Microbial biogeochemistry in aquatic systems emphasizing the roles of nitrogen and phosphorus in microbial growth. Life associated with Antarctic ice and its relationship to global change and astrobiology.* jpriscu@montana.edu

Oral Abstracts

New Database Technologies to Advance Hydrologic Science

Alex K. (Sandy) Williamson[1]

I will demonstrate how new data technologies in two areas, web services and handhelds make it more possible to do excellent hydrologic science.

Web services for data- This would benefit us in access to data and access to specific applications. Web services enable database search services to search numerous databases across the internet, dynamically returning a combined retrieval. This enables all entities to maintain their own data, yet facilitate data sharing. See http://www.cuahsi.org/, http://www.exchangenetwork.net/, and the **Pacific Northwest** Water Quality **Data Exchange**. Similar technology is allowing simultaneous display of database query results on top of map elements from different mapping web services across the internet, see water.usgs.gov/nawqa/data Web application servers enable the user to use applications and data that would be hard to install on their own machine. For example establishing a new sampling location or checking for the existence of data at a site, it is very hard to manually determine which site is really the same or not. An application service could take one or a table of stream locations and names you provide and check it against a master site name server to see which nearby sites are likely to be already established by others, enabling data sharing. The application could also return a numerical index of how likely the match is.

Handheld data entry-USGS has been developing software for handheld computers, both PocketPC's and PC tablet/laptops for several years. Some of the software currently in use will be demonstrated on screen using simulator software during the talk.

Ground-Water Levels Program -- The Multi Optional Network Key Entry System (MONKES) is a series of programs used to input and process ground-water level measurements in the field. Version 3.1 has been expanded to include the collection of site-visit information at wells with digital recorders. Surface water forms for use on the PocketPC:

- Q-Calc -- for discharge measurements using Price meters
- Inspections -- for routine inspections of stream gages
- Levels -- for routine station leveling (could also be used with GW sites)

PCFF is an acronym for "Personal Computer Field Form." PCFF is Windows-based software to enter field-derived water quality sample-collection data into electronic USGS field forms. PCFF uses the inflection point titration method to find equivalence points in the titration data. There is also an handheld satellite version supporting part of the laptop/tablet functionality. Prototype versions of the Biological Electronic Field Forms (BioEFF) for entering NAWQA habitat samples on a tablet or laptop PC are now ready.

[1] *U.S. Geological Survey, NAWQA National Data Base Team Leader, 934 Broadway, Suite 300, Tacoma, WA 98402; Phone (253) 552-1683; E-mail akwill@usgs.gov Fax (253) 552-1581*

- Currently the USGS is using Visual.Net products to produce forms targeting our basic data collection. more info on Visual Studio .Net
- In addition to the Visual.Net we are using the Smart Device Framework Extensions (part of OpenNETCF). more on OpenNETCF

The Development of a Standardized Data Structure and Management System for Borehole Geophysical Logs at the Hanford Site

Rick McCain[1], Jim Lunde[2], George Last[3], and Rob Mackley[4]

Thousands of boreholes have been drilled at the Hanford Site over the past six decades to investigate vadose zone and groundwater contamination. From the beginning, they have been logged to detect contaminants in the subsurface and to assess geologic properties. A wide variety of logs are available, but gamma measurements in cased holes constitute the bulk of the available data. Log data quality varies from individual borehole measurements recorded manually to high resolution spectral gamma measurements. These data constitute an invaluable resource in assessing the current nature and extent of vadose zone contamination, and in evaluating the past history of contaminant movement, from which projections can be made regarding future behavior.

At the present time, geophysical log data exist in a variety of formats, and are stored in a number of locations, maintained by several Hanford contractors. Much of it is not easily accessible to end users. Log interpretation is typically carried out on a project level, but the close proximity of individual waste sites and operable units means that data from individual boreholes may be useful to multiple projects. A standardized geophysical log data format has been proposed, which allows both historical and future log data to be incorporated into the existing Hanford Environmental Information System (HEIS) database. In addition to making the data available to all users, the geophysical log format will facilitate consistent and accountable interpretation of subsurface conditions by all parties.

The data format is flexible enough to accommodate a wide variety of geophysical log data and includes provisions for tracking data input and changes. Currently, the format is being finalized and an electronic data deliverable (EDD) specification is being prepared to ensure that future log data can be readily entered into the database. This presentation will describe the basic elements of the log data format and illustrate how it improves utilization of Hanford geophysical log data.

[1] *Hanford Geophysical Logging Project, S M Stoller Corp, 1100 Jadwin Ave, Suite 300, Richland, WA 99352; 509-376-6435; fax 509-3766460; rmccain@stoller.com*
[2] *Integrated Environmental Services, Inc; 22932 El Toro Road, Lake Forest, CA 92630; 949-460-7000; fax 949-460-7019; jlunde@iesinet.com*
[3] *Pacific Northwest National Lab, P O Box 999, K6-81, Richland, WA; 99352, 509-376-3961; fax 509-376-5638; george.last@pnl.gov*
[4] *Pacific Northwest National Lab, P O Box 999, K6-96, Richland, WA; 99352, 509-373-5197; fax 509-376-5638; rob.mackley@pnl.gov*

Integration and Management of Subsurface Data To Support Remedial Decisions

G. V. Last[1], R. Khaleel[2], C. J. Murray[3], and T. W. Fogwell[4]

Remedial decisions at the Hanford Site are strongly dependent on an evaluation of the baseline risk and evaluation of the effectiveness of potential remedial alternatives. The complexity of these analyses are dependent on the temporal and spatial scales of a specific assessment. Given the variety of projects at Hanford, assessments are often performed independently based on the professional judgment of a particular assessment team and based on diverse sets of data assembled independently by that team. This has lead to inconsistencies and at times poor traceability and defensibility of conceptual models, assumptions, parameterization, and supportive documentation used in these assessments.

The US Department of Energy (DOE) recognized the need for a systematic approach to develop conceptual models and parameter assumptions based on, and traceable to, a consistent set of data. To this end, the Groundwater Remediation Project (managed by Fluor Hanford, Inc.), with participation from various DOE offices and coordination boards, has been charged with development and maintenance of common databases, parameterization, and parameter estimates that form the basis for the various environmental assessments.

Over the last 60 years, the Hanford Site has generated a vast amount of highly variable subsurface data, including field and laboratory data from over 7500 boreholes. Borehole data provides the primary basis for interpreting the subsurface framework and the spatial distribution of physical, hydrologic, and geochemical properties. These data are of mixed types and quality, ranging from qualitative field observations (driller's logs), to quantitative borehole geophysical logs, and physical and geochemical analyses of borehole samples. These data have been collected using a variety of procedures and formats that are often difficult to incorporate into an electronic database. Efforts are currently ongoing to assemble, integrate and manage (under configuration control) the vast amounts of raw data and to develop rigorous interpretation and translation tools to produce conceptual models and assessment-specific parameterization and parameter estimates that are traceable, reproducible, defensible, and internally consistent.

[1] *Pacific Northwest National Laboratory, P. O. Box 999, K6-81, Richland, WA 99352; Fax (509) 376-5368 Phone (509) 376-3961; E-mail george.last@pnl.gov*
[2] *Fluor Government Group, 1200 Jadwin Ave., E6-17, Richland, WA 99352; Fax (509) 376-5396; Phone (509) 376-6903; E-mail Raziuddin_Khaleel@rl.gov*
[3] *Pacific Northwest National Laboratory, P. O. Box 999, K6-81, Richland, WA 99352; Fax (509) 376-5368 Phone (509) 376-5848; E-mail Chris.Murray@pnl.gov*
[4] *Fluor Hanford, Inc., P. O. Box 1000, KE6-35, Richland, WA 99352; Fax (509) 373-3974; Phone (509) 373-3812; E-mail Thomas_Fogwell@rl.gov*

Glacier Mass-Balance Fluctuations in the Pacific Northwest and Alaska, USA

Edward G. Josberger[1], William R Bidlake[2], Rod S. March[3] and Ben W. Kennedy[4]

The mass balance of mid-latitude glaciers of the Pacific Northwest and southern Alaska fluctuates in response to changes in the regional and global atmospheric climate. More than 40 years of net and seasonal mass balance records by the U.S. Geological Survey for South Cascade Glacier, Washington, and Wolverine and Gulkana Glaciers, Alaska, show annual and inter-annual fluctuations that reflect the controlling climatic conditions. South Cascade and Wolverine Glaciers are strongly affected by the warm and wet maritime climate of the Northeast Pacific Ocean, and the winter balances are strongly related to the Pacific Decadal Oscillations (PDO). Gulkana Glacier is more isolated from maritime influences and the net balance variation is more closely linked to the summer balance. By the late 1970's, mass-balance records for the three were long enough to reflect the 1976-77 shift in PDO from negative to positive. Both maritime glaciers responded, with net balance of South Cascade Glacier becoming consistently negative and that of Wolverine Glacier becoming predominantly positive. The overall trend of negative mass balance continued through 2005 for South Cascade Glacier, where the 1977 to 2004 cumulative net balance was about -24 meters water equivalent (mweq). The warm dry summers of 2003, 2004, and 2005 (and likely 2006) yielded the most negative mass balances on record. For Wolverine Glacier, the trend of positive net balance ended in 1989 after a gain of about 7 mweq. Beginning in 1989, net balance trend for Wolverine Glacier became predominantly negative and the cumulative net balance for 1989 to 2004 was about -14 mweq. Net Balance of Gulkana Glacier did not respond appreciably to the 1976-77 PDO shift. The cumulative net balance for Gulkana Glacier from the beginning of the record (1966) through 1988 was about -3 mweq. The major change in trend of mass balance occurred in 1989, when net balance became almost exclusively negative. The cumulative net balance during 1989 through 2004 was about –13 mweq. As a result trends in net balance had become strongly negative for more than a decade at all three bench mark glaciers.

US Geological Survey, Washington Water Science Center 934 Broadway, Suite 300, Tacoma WA, 98402
[1] ejosberg@usgs.gov, 253-552-1643 [2] wrbidlake@usgs.gov, 253-552-1641,
Alaska Science Center, Fairbanks, AK, 99701, [3] rsmarch@usgs.gov, 907-479-5645 x241,
[4] bkennedy@usgs.gov, 907-479-5645 x244.

Deep Aquifer Storage as a Possible Solution to Changing Water Distribution Patterns Resulting from Global Warming Induced Climatic Changes

Floyd N. Hodges[1]

Global warming forecasts, predicting a significant decrease in Cascade winter snow pack and a concomitant increase in winter run-off, represent a potentially serious problem for Eastern Washington. Historically, melting of the snow pack has fed streams and reservoirs, maintaining stream flow and providing irrigation water during dry summer months. The loss of summer run-off is a problem that could result in the loss of a significant portion of agricultural production in Eastern Washington. In addition, competition for dwindling water resources could result in severe environmental damage.

Large scale surface storage has been proposed as one solution to this problem; however, proposals such as the Black Rock Reservoir would be very expensive, both in terms of construction and of pumping water into and out of the reservoir; would lose significant quantities of water through evaporation and infiltration; and would have potentially serious environmental consequences. An alternative possibility is to use deep basalt aquifers to store excess winter run-off for use during drier summer periods.

A number of aquifers within the Columbia River basalts are used for irrigation throughout the region. Access to these aquifers has been restricted because of relatively slow recharge and fears of depleting this limited water supply. <u>If these aquifers could be recharged more rapidly, it would be possible to withdraw water at a much higher rate to support irrigation needs and lower stress on surface water resources.</u> The Columbia and Yakima Rivers pass through most of the sub-basin within the region and it may be possible to artificially recharge these deep aquifers using excess run-off during the winter months. Large diameter wells, located near the rivers within each sub-basin, could act as inverse artesian wells and supply large quantities of water to the underlying aquifers. The added water could then be tapped for irrigation throughout the basin.

Hydraulic, engineering, and economic studies are needed to evaluate the viability of this option. If basalt aquifer injection is a viable alternative it should be pursued as a high priority project. It will take time to get the monetary support and the regulatory acceptance/approval to make it possible. Global warming is a reality and if we are to avoid major problems we must be ahead of the curve. One year without water would be a major disaster for our orchards, vineyards, and fisheries.

[1] *Amphigory Associates, 5403 S. Olympia St., Kennewick, WA 99337; Phone (509) 582-6748; E-mail fhodges@3-cities.com*

Late 20th Century Ice Loss in the Vicinity of the Goat Rocks, Tieton River Basin, Washington

William R. Bidlake[1]

A little studied assemblage of glaciers and snow fields near the Goat Rocks of the south Washington Cascade Range was investigated to improve the understanding of regional glacier change and to assess the importance of the ice masses for late-summer runoff from the 484-km2 upper Tieton River basin. Vertical aerial photography from 2004 indicated three named glaciers—Conrad, Mead, and McCall Glaciers, and one unnamed glacier—had a total area of 1.651 km2. Additional stereo photography from 1955 and 1970, available for Conrad Glacier and the unnamed glacier, and for part of Mead Glacier, indicated that at least one of the glaciers, Conrad Glacier, retreated during 1955–70, and all three retreated during 1970–2004. Detailed photogrammetric analysis revealed that the area of Conrad Glacier and the unnamed glacier decreased during 1970–2004 by 49 and 14 percent, respectively. Glacier thinning accompanied the decreases in glacier area, resulting in smaller glacier volumes in 2004 than in 1970. Estimates of late-summer glacier and snow field melt indicated those ice masses have been a long-standing runoff source that has tended to maintain base flow in the upper Tieton River.

---

[1] *U.S. Geological Survey, Washington Water Science Center*
934 Broadway Suite 300; Tacoma, Washington 98402
Phone: (253) 552-1641; Fax: (253) 552-1581; E-mail: wbidlake@usgs.gov

Analysis of Exempt Well Location, Use, and Timing

Ken Johnson[1]

In recent years many Water Resource Inventory Area (WRIA) basins in Washington have been closed to new water rights for additional withdrawals. However, demands for scattered development in rural areas have encouraged reliance on exempt wells. These water supply wells are designated for limited domestic uses, mainly at individual residences. Such wells are "exempt" in that they do not go through a formal process to obtain a water right.

To allow a more accurate assessment of potential impacts from exempt wells in King County, a GIS database was created that can relate the locations of wells to other information or in relation to other features of concern. The basic source material for the database was information on drillers' logs for water wells, obtained from the Washington Department of Ecology's Well Log Viewer Internet site. In order to focus specifically on present day conditions, only those wells that have been completed since January 1, 2000, were selected for location enhancement and more detailed analysis.

The proposed use of each well was compiled from the well log. The most populated category (70%) was found to be wells for individual domestic supply. The second most common (14%) was dewatering wells, usually considered only temporary during construction activities but occasionally reported anecdotally as remaining in use permanently. The third most frequent proposed use (10%) was for irrigation, perhaps partially to avoid high utility bills that may result from conservation-oriented water pricing policies. Municipal and group domestic public water system wells comprise about 4% of the database. Smaller numbers of industrial, test, or other uses were also reported. The large category of resource protection wells was excluded from consideration in the database as not resulting in water withdrawals.

Location information such as address and parcel identification number was also compiled. Using these data allowed refinement of the well locations to parcel-level accuracy (median uncertainty < 200 feet) from the reported Quarter-Quarter Section in the Public Land Survey system (median > 500 feet). The greater accuracy may allow estimation of buffer distances from sensitive features such as salmon-bearing streams. Estimates were also prepared of the number of wells drilled within Coordinated Water Supply Service Areas of large Public Water Systems.

Dates of installation were also analyzed to indicate that a steady rate of approximately 150 domestic wells total per year are drilled in King County during recent years.

[1] *King County Department of Natural Resources & Parks, Water & Land Resources Division, 201 S. Jackson St, Suite 600, Seattle, WA 98104; Telephone (206) 296-8323; Fax (206) 296-0192; e-mail ken.johnson@metrokc.gov*

Why Is Better Management of Groundwater So Elusive?

Carl J. Hauge[1]

Scrutiny of the subject matter of the previous 5 symposia and the proposed subject matter of the 6th symposium shows that we know a lot about the technical details of groundwater flow, contamination, the fate of contaminants, and the results of certain management and monitoring programs. None of these papers discuss programs that are successful at better management of groundwater, nor do any of these papers discuss methods for moving political forces toward better management in terms that are meaningful: providing a good quality and sustainable supply of groundwater.

Why?

Because unlike the scientific issues discussed at the Hydrogeology Symposia, non-scientific issues surrounding groundwater are the issues that political decision makers focus on. These focus issues for political decision makers include political issues, legal issues, institutional issues, technical issues and economic issues. A sixth issue is the educational or knowledge level of the decision maker and the people who influence that decision maker. All of these issues are complex social issues that many people consider to be outside the field of expertise or the responsibility of speakers at the Hydrogeology Symposia.

But are they?

No. Groundwater and its relationship to surface water were mysteries in the 19th century. But groundwater and surface water are the same resource and use of either groundwater or surface water will affect the other. In the 21st century we know a lot more, but this increased knowledge has not been transferred to the policy makers for effective resource management.

Why not?

Because there is a disconnect between the technical specialists and the policy makers. This disconnect can be rectified only by the active participation of groundwater specialists in political education activities.

So the question is, “Does your organization, or do you, talk to your local and state representatives about groundwater management?”

[1] *Retired from California Department of Water Resources, P.O. Box 942836, Sacramento, CA 94236 Phone (916) 456-2009; (360) 426-5161 E-mail tuleluke@earthlink.ne; or chauge@water.ca.gov*

Streamflow Augmentation using Multiple Water Sources as Mitigation for a New Water Right, North Bend, Washington

Nicole DeNovio[1], Robert Anderson[2], Alan Keizur[3], Marketa McGuire, Jay Pietraszek

New water usage in many river basins throughout the United States is regulated by minimum instream flow requirements at one or more river locations. The minimum instream flows were created to facilitate sustainable water resource utilization for multiple beneficial uses. In some hydrologic systems, instream flow requirements limit the development of new water supplies for human consumption unless mitigation is developed. In Washington, a "drop-for-drop" or "water-balance neutral" approach is preferred, which requires either moving water from one basin to another to offset new consumptive use or developing deeper groundwater resources that do not impact surface-water flows. A river impact and mitigation analysis has been completed for the City of North Bend that determined both the streamflow depletion from a proposed new groundwater source, and the real-time mitigation requirements for a basin-transfer as the basis for a water right mitigation proposal.

The City of North Bend has identified a shallow, unconfined, alluvial aquifer with high-quality drinking water to develop as an additional water supply. The future drinking-water-production well lies between the North and South Forks of the Snoqualmie River. During water withdrawals from this shallow aquifer, river depletion in both forks of the Snoqualmie River is predicted. To determine the extent and timing of river depletion, a simple model of a pumping well with two river reaches was developed using a new stream depletion tool developed in the United Kingdom (IGARF). The model incorporates the various aquifer and streambed properties, as well as hydraulic boundaries, and allows daily impact of groundwater withdrawals to be calculated, which provides a "real-time" basis for mitigation planning.

To achieve the real-time mitigation of stream depletion when minimum instream flows are not met, two water mitigation sources will be utilized: a spring with high-quality water in an adjacent river basin and a groundwater well. Both sources are permitted under senior water rights. When mitigation is necessary, the water will be piped to the Snoqualmie River system from one or both sources. Projections of mitigation source availability have focused on determining the variability in average monthly and daily spring flows to determine annual source availability and peak-daily mitigation supply.

Through the combination of simple system models and data collection and analysis a real-time mitigation approach has been developed that ensures a new water supply for the City of North Bend and sustainable water resource utilization in the Snoqualmie River Basin.

Golder Associates Inc., 18300 NE Union Hill Road, Suite 200, Redmond, WA 98052, (425) 883-0777. [1]ndenovio@golder.com, [2]banderson@golder.com, [3]akeizur@golder.com.

Rain Harvesting Impacts

Chris V Pitre, L.Hg.[1]

Background: Rain harvesting of any amount currently requires a water right. Processing water right applications for rain harvesting presents a significant potential administrative burden to the Washington State Department of Ecology (Ecology). One approach to relieve the potential burden is to exempt rain harvesting, within guidelines, from requiring an administratively-issued water right. This has not happened yet, in part due to the unknown hydrologic impacts caused by harvesting and the concern of potential impairment of other water rights and habitat. To obtain some context of potential impacts, the Washington State Department of Ecology commissioned a quantitative study of potential impacts of rain harvesting.

Analysis: The Barker Creek drainage on the Kitsap Peninsula was selected as a case study. Average roof top size, domestic demand patterns and precipitation were assumed. Full buildout with maximum development density was assumed, with every parcel containing a rain harvesting system serving an average residence. Storage tank size ranging from 1,000 gallons to 20,000 gallons, and use for exterior landscape irrigation only or for year-round residential use was simulated. The effects of combining septic system discharge with rain harvesting, and comparison with impacts from the direct groundwater withdrawal from the first confined aquifer that is typically tapped by exempt wells were considered.

Results: Seasonal streamflow impacts were:

	Winter Stream Flow	**Summer Stream Flow**
Rain harvesting	Decrease	Decrease
Rain harvesting with septic system	Decrease	Increase
Well	Decrease	Decrease
Well with septic system	Increase	Decrease

The most common primary limiting factor for salmon habitat on the Kitsap Peninsula is peak winter flows, followed by summer low flows. Streamflows were decreased in all seasons and scenarios, with two exceptions. Well withdrawals combined with septic system use increased winter streamflow due to septic system return flows. Rain harvesting combined with septic system use increased summer streamflow, and improved streamflow conditions for salmon in both seasons. The negative impacts of rain harvesting on streamflows were always less than direct groundwater withdrawals. Replacement of direct groundwater withdrawals with rain harvesting provided the maximum streamflow benefits. Storage tank size did not affect the relative magnitude of impacts.

[1] *Golder Associates Inc., 2200 Sixth Avenue, Suite 600, Seattle, WA; 98121; fax (206) 267-1172*
Phone (206) 267-1166, e-mail cpitre@golder.com

Hanford Tank Farm RCRA Corrective Action Program

John G. Kristofzski[1], Frederick M. Mann[2], and Frank Anderson[3] and Robert W. Lober[4]

As a consequence of producing special nuclear material for the nation's defense, large amounts of extremely hazardous radioactive waste was created at the U.S. Department of Energy's (DOE) Hanford Site in south central Washington State. A little over 50 million gallons of this waste is now stored in 177 large, underground tanks on Hanford's Central Plateau in tank farms regulated under the Atomic Energy Act and the Resource, Conservation, and Recovery Act (RCRA). Over 60 tanks and associated infrastructure have released or are presumed to have released waste in the vadose zone.

In 1998, DOE's Office of River Protection established the Hanford Tank Farm RCRA Corrective Action Program (RCAP) to

- Characterize the distribution and extent of the existing vadose zone contamination,
- Determine how the contamination will move in the future,
- Estimate the impacts of this contamination on groundwater and other media,
- Develop and implement mitigative measures, and
- Develop corrective measures to be implemented as part of the final closure of the tank farm facilities.

Since its creation, RCAP has major advances in each of these areas, which will be summarized in this paper and discussed further in other papers at this symposium. Also the talk will provide a general background to the Program.

[1] *CH2M Hill Hanford Group, Inc., P.O. Box 1500, Richland, Washington 99352; Phone: (509)373-4225, fax: (509)376-3833; E-mail: John_G_Kristofzski@rl.gov.*
[2] *CH2M Hill Hanford Group, Inc., (509)373-3978; fax: (509)373-3833; E-mail: Frederick_M_Mann@rl.gov.*
[3] *CH2M Hill Hanford Group, Inc., (509)373-3971; fax: (509)373-3833; E-mail: Frank_J_Anderson@rl.gov.*
[4] *U.S. Department of Energy, Office of River Protection, 2440 Stevens Dr., Richland, Washington 99354; (509)373-7949; fax: (509)373-1313; E-mail: Robert_W_Lober@orp.doe.gov.*

New Characterization Tools Used In and Around Hanford's Single-Shell Tank Farms

David A. Myers[1] and Harold A. Sydnor[2]

Traditional tools used to characterize the environmental status of the vadose zone beneath the Hanford single-shell tanks are time consuming, expensive, and provide an opportunity for excess radiological exposure. Two new techniques have been tested and implemented to enhance the completeness of investigations, speed the collection of data and reduce the overall cost of characterization. These tools, surface geophysical exploration (SGE) and focused sampling using a hydraulic hammer direct push drill system, are used in tandem, and in an iterative manner to more completely characterize the entire subsurface of the tank farm Waste Management Areas.

SGE consists of a suite of tools than may be applied; the primary tool is high resolution resistivity (HRR), other tools include ground penetrating radar (GPR), electromagnetic induction (EMI) and magnetic gradiometry (MG). All data are spatially controlled by tying the position of the geophysical tool to a survey grade GPS receiver. In farm HRR electrodes have evolved to a design that remains in the ground in case a subsequent interrogation is needed.

The hydraulic hammer direct push system consists of a commercial Euro-Drill drive head mounted on a small, highly maneuverable backhoe. The casing and sample system is a custom designed by Maverick Environmental and uses 2.5-in OD drive pipe and a 1.38-in ID by 1.5 ft long drive sampler. Specially designed drive shoes with a disposable tip allow placement of deep electrodes for SGE investigation. Maximum length of casing driven, in the Hanford environment has been 110 ft. The system has been adapted to work at angles of 30^{o}, 45^{o}, and 60^{o} from the vertical allowing investigation beneath existing structures. Small diameter geophysical logging sondes are used to capture and record gamma activity, moisture content and hole position via gyroscope. As these pushes are decommissioned, small diameter, isolated electrodes are frequently emplaced; these electrodes are then used in subsequent SGE surveys to further refine the interpretation of subsurface conditions.

CH2M Hill Hanford Group, Ic., PO Box 1500, Richland WA, 99352
[1]Phone: (509) 373-3972 E-mail: David_A_Myers@rl.gov
[2]Phone: (509) 373-3967 E-mail: Harold_A_Sydnor@rl.gov

Subsurface Geophysical Exploration within and Around Hanford's Tank Farms: Examples from T and S Farm

Marc Levitt[1], Colin Henderson[2] Chris Baldyga[1], Brian Cubbage[1], Shawn Calendine[1], and Dale Rucker[1]

The Hanford Site, located in eastern Washington, is the center of an extensive clean-up operation. The clean-up is a result of waste generated during the irradiation of uranium in one of nine reactors and the reprocessing of plutonium in one of five chemical processing facilities. The reprocessing required the use of bismuth phosphate, nitric acid, sulfuric acid, sodium hydroxide and other inorganic solvents which eventually became liquid waste. The waste was disposed or stored in a number of ways, including single- and double-shelled underground storage tanks, cribs, trenches, French drains, reverse wells, and ponds. The waste, due to its ionic strength, is highly electrically conductive relative to the resistive sand that is pervasive throughout the complex.

To understand the fate and transport of these inorganic solvents, a subsurface geophysical exploration (SGE), which mainly included high resolution resistivity (HRR) and electrical resistivity inversion, was conducted in and around a number of tank farms, including T and S Farm. These farms are highly complex, including pipes, tanks, wells, fences, and other cultural features that present both logistically and geophysically difficult environs in which to work. To overcome the logistical difficulty, CH2M Hill Hanford Group and Hanford site operators were involved in the survey set up, design, and data collection. To overcome the geophysical challenges, the infrastructure was used in the measurement process. Vadose zone monitoring wells and groundwater wells were used as both current transmission and voltage measurement points for resistivity measurements, and the data were modeled to recreate the distribution of electrical properties. These electrical properties were then related to the distribution of waste through petrophysical relations that relate analyte concentration to resistivity.

The results of the T Tank Farm SGE survey showed that coincident surface resistivity conducted over areas with few infrastructural interferences adjacent to the tank farm compared favorably with resistivity data obtained using the infrastructure (wells). The method was then applied to the tank farm itself with interpreted resistivity plumes using the wells matching hydrologic expectations from known source areas. The results of the S Farm SGE survey also confirmed the location of historic source areas. Moreover, the S Farm study included a controlled fluid injection experiment adjacent to tank S102, with pre- and post-injection SGE surveys showing the migratory path of the fluid.

[1] *hydroGEOPHYSICS, Inc. 2302 N Forbes Blvd, Tucson AZ 85745 email: marc@hydrogeophysics.com*
[2] *Columbia Energy & Environmental Services, Inc. 1806 Terminal Drive Richland, WA 99352*

High-Resolution Resistivity Applied to Characterization and Leak Detection at Two Single Shell Tank Farms (SST) at the Hanford Site

Joseph A. Caggiano[1]

Hanford's 149 singled-shelled tanks (SSTs) have stored high-level radioactive mixed waste since 1944. The SSTs are out of service, unfit for use and have exceeded their design life. The tanks contain saltcake and sludge which is being retrieved and transferred to safer, newer double-shelled tanks (DST). Waste is being retrieved to reduce long-term risk and to meet legal obligations in the Hanford Federal Facility Agreement and Consent Order (TPA) signed by the U.S. Department of Energy (DOE), the Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology). Waste retrieval uses various liquids to dissolve, suspend and transport the retrieved waste to the DSTs. However, the addition of liquids could lead to new waste releases.

The SSTs are buried and at least 200 feet above the water table of an unconfined aquifer which discharges to the Columbia River. At least 67 of the SSTs are assumed to have leaked approximately 1 million gallons; thus, leak detection during retrieval is essential to minimize new leaks. After field evaluation of several methods, High Resolution Resistivity-Leak Detection and Monitoring (HRR-LDM) was selected as a potential leak detection method within the tank farms. A recent HRR-LDM test of a simulated tank leak, in which 13,500 gallons of waste simulant was injected through a modified drywell near Tank S-102 in the S Tank farm, indicated that HRR-LDM can detect a leak in a timely manner and give a reasonable approximation of the volume released. Traditional monitoring methods, such as drywell monitoring with neutron logging before, during, and after the test, detected no change during the 5 month long injection test, demonstrating its limitations for leak detection.

Alternatively, HRR-SGE (subsurface geophysical exploration) proved effective during testing to delineate the volume of a vadose zone plume at a liquid waste disposal site (the 216-B-BC cribs) that is relatively free of infrastructure. HRR-SGE was adapted for a tank farm, where infrastructure (steel and concrete) presents challenges for electrically-based geophysics. A test of HRR-SGE at T Tank Farm and vicinity has delineated a large resistivity plume corresponding to NO_3, a surrogate for mobile contaminants (e.g. Tc-99). Surface and deep electrodes were used to define a plume whose vertical extent needs refinement. Delineating a plume and "hot spots" facilitates future characterization.

HRR is a promising tool to detect leaks during waste retrieval and to help characterize past releases adjacent and beneath Hanford tank farms.

[1] *WA State Dept. Ecology, Nuclear Waste Program, 3100 Port of Benton Blvd, Richland, Washington 99354, FAX (509) 372-7971 Phone (509) 372-7971; E-mail jcag461@ecy.wa.gov*

Biogeochemical Controls on Spatial and Temporal Variability of Arsenic Concentrations in Shallow Groundwater, Seattle-Tacoma International Airport

Dimitri Vlassopoulos[1], Michael J. Riley[2], John Strunk[3] and Paul Agid[4]

Groundwater quality data collected as part of a multiyear baseline groundwater monitoring program in the vicinity of the Third Runway Project at Seattle-Tacoma International Airport have shown that arsenic concentrations exhibit significant spatial and temporal variability (<0.5 to 59 μg/L), with seasonal peaks and a spatial association with sporadic peat deposits in the area, but exceed the federal MCL for drinking water (10 μg/L) routinely in only one well. Interestingly, an ambient/natural background arsenic source is implicated by the absence of point sources or activities involving arsenic-containing materials in the area.

Because arsenic mobility in soil and groundwater is strongly dependent on its speciation, which is influenced by microbial redox reactions, terminal electron accepting process (TEAP) indicators were evaluated to place the occurrence of elevated arsenic within the context of the sequence of groundwater biogeochemical redox processes. Elevated arsenic levels are generally found to occur under moderately to strongly anaerobic conditions (iron-, arsenate-, and/or sulfate-reducing). The development of the observed sequence of TEAPs appears to be driven by the microbial oxidation of natural organic matter present in nearby peat, while the extent to which reducing conditions are developed at a given place and time is determined by the balance between rate of recharge of the aquifer by relatively oxygenated water and extent of peat deposits directly upgradient of monitoring locations. Elevated dissolved arsenic is strongly correlated with dissolved iron, consistent with a mechanism of release of adsorbed arsenic from soil iron oxides during reductive dissolution, although arsenic is not elevated at all locations where conditions are iron-reducing, suggesting that adsorbed arsenic is heterogeneously distributed in the soils. During periods of low recharge, localized excursions to very reducing conditions result in release of adsorbed arsenic from soil due to dissolution of iron oxides, while during periods of high recharge, conditions tend to more aerobic, thereby restabilizing iron oxides which adsorb arsenic, and resulting in an essentially reversible cyclic process. Geochemical reaction modeling results indicate that the observed groundwater concentrations are generated by the release of less than 1% of the natural background soil arsenic (7 mg/kg), and that concentrations as high as 200 μg/L are possible under extreme reducing conditions.

[1]S.S.Papadopulos & Associates, 815 SW 2nd Ave, Suite 510, Portland, OR 97204; (503) 222-6639; E-mail dimitri@sspa.com
[2] S.S.Papadopulos & Associates, 101 N Capitol Way, Suite 107, Olympia, WA 98501; (360) 709-9540
[3] Aspect Consulting, 179 Madrone Lane N, Bainbridge Island, Washington 98110; (206) 780-9370
[4] Port of Seattle, 17900 International Boulevard, Seattle, WA 98112; (206) 439-6604

Environmental and Compound-Specific Stable Isotopes: Geochemical Forensic Tools with Application to Site Characterization in a Complex Hydrogeologic Situation

Dimitri Vlassopoulos[1], Mark Conrad[2], Michael J. Riley[3], Terry Belunes[4] and Patty Boyden[5]

Past industrial activities in the vicinity of the Port of Vancouver, WA, have resulted in soil and groundwater contamination by volatile organic compounds (VOCs) including TCE and PCE that impact a regionally important alluvial aquifer. Three known sources of VOCs in the area are under remedial investigation. Determination of groundwater flow directions and contaminant transport pathways by direct measurement has proven challenging due to the highly transmissive nature of the aquifer and consequently very small hydraulic head gradients. Groundwater flow and transport modeling indicates that contaminant plumes originating from the three source areas are drawn several thousand feet towards a nearby industrial production well field located adjacent to the Columbia River. Particle track modeling also predicts that the aquifer receives significant recharge from the river due to operation of the production wells.

Stable oxygen ($\delta^{18}O$) and hydrogen (δD) isotope ratios of groundwater and compound-specific stable carbon isotope ratios ($\delta^{13}C$) of chlorinated ethenes (TCE and PCE) were determined and used to provide independent lines of evidence in support of the site conceptual model and to verify model predictions regarding origins of water (river *vs* precipitation recharge) and sources and commingling of VOC plumes. Stable isotope signatures clearly distinguish groundwater recharged from the river ($\delta^{18}O \approx -16‰$) from that derived from infiltration of local precipitation ($\delta^{18}O$ = -9 to -11‰). The spatial distribution of $\delta^{18}O$ and δD maps out areas recharged by river water and provides direct verification of the groundwater flow model. Multivariate VOC signatures, in combination with compound-specific $^{13}C/^{12}C$ ratios of TCE and PCE, reflect the nature of chemical releases and effects of degradation of the different sources. Unique and distinguishable contaminant fingerprints can be defined for each source area, and the distribution of chemical/isotopic signatures in wells across the study area provides a record of the downgradient transport, transformation, and commingling of VOCs from the three source areas. This integrated analysis supported the site conceptual model development, provided independent verification of the numerical groundwater transport model, and a quantitative basis for apportioning the contamination among the three sources for cost allocation.

[1]*S.S.Papadopulos & Associates, 815 SW 2nd Ave, Suite 510, Portland, OR 97204; (503) 222-6639; E-mail dimitri@sspa.com*
[2] *Center for Isotope Geochemistry, Lawrence Berkeley National Laboratory, Berkeley, CA*
[3] *S.S.Papadopulos & Associates, 101 N Capitol Way, Suite 107, Olympia, WA 98501; (360) 709-9540*
[4] *Parametrix, 700 NE Multnomah, Suite 1000 Portland, OR 97232; (503) 233-2400*
[5] *Port of Vancouver, 3103 Lower River Road, Vancouver, WA 98660; (360) 992-1103*

High Chromium Levels in Landfill Monitoring Wells

Lee N. Huckins[1], Oregon Department of Environmental Quality

Knott Landfill is located in Bend, Oregon. Bend is a rapidly expanding city and is encroaching on the landfill as land becomes a valuable commodity. Homes are located adjacent to the landfill and a public middle school is located across the street about a half mile to the northwest of the site.

Public concern and outcry about the landfill began when the County proposed to expand the landfill to the north of the site in 2003. Expansion of the landfill would allow the landfill to stay open until 2029. Local citizen action groups voiced their concerns over the detection of high chromium levels in the landfill's monitoring wells. Chromium had been detected in the landfill's groundwater monitoring wells over the federal drinking water standard and state reference levels in concentrations ranging from 0.05 to 0.135 mg/L. In an effort to allay the public's concerns, the Department asked the landfill to conduct a preliminary assessment on the chromium exceedances.

Landfill leachate is usually high in total dissolved solids, chloride, alkalinity, iron, manganese, and volatile organic compounds. This was not seen, when the chromium exceedances were detected. With chromium concentrations in the leachate ranging from 0.003 mg/L to .021 mg/L, the Department believed that these chromium exceedances did not indicate a release from the landfill.

Time series plots indicated that when a chromium exceedance did occur, elevated concentrations of iron, nickel, manganese and bicarbonate were also detected. These exceedances were repeated throughout the time series data set. A literature search suggested that corrosion of stainless steel might be the source of the chromium in the wells.

The pump columns within the monitoring wells are made of stainless steel Type 304L and the pump rod ferrals are made of stainless steel Type 316L. Stainless steel Types 304L and 316L have been well documented to corrode in groundwater contributing chromium, iron, manganese and nickel into groundwater samples. The Department and the County pulled one of the pumps and found that the stainless steel pump columns corroded due to the ferrals of the pump rods rubbing against the pump columns. This rubbing caused the chromium oxide layer to degrade and the iron component to be oxidized causing rouge or rust to appear.

The Department shared this information with the adjacent neighborhoods and the citizen's action group. All parties were relieved that the chromium exceedances were not found to originate from the landfill and that the groundwater could be remediated.

[1] *Lee N. Huckins is a Senior Hydrogeologist for the Oregon Department of Environmental Quality located in the Columbia River Gorge. His address is 400 E. Scenic Dr., The Dalles, Oregon 97058 (541)298-7255 ext. 33, Fax (541)298-7330, email - huckins.lee@deq.state.or.us*

Initial Test Results of a Passive, Discrete Multi-Level Sampling Device for Vertically Defining Groundwater Contamination in Monitoring Wells

David W. Herzog, P.G.[1]

A new passive multi-level groundwater sampling device developed by Cambria Environmental Technology, Inc. was tested to determine its ability to collect representative concentrations of various chemical constituents, and to evaluate its ability to vertically define groundwater contamination in existing monitoring wells. Reliable vertical definition of groundwater contamination is important for risk-based evaluations, and for the application of targeted, cost-effective remedial solutions. The first phase of testing (bench-scale) involved collecting samples of water from experimental standpipes containing known concentrations of benzene, methyl tert-butyl ether (MTBE), and trichloroethylene, which were chosen based on being common constituents of concern. Results from the first phase of testing indicate that the sampling device is capable of collecting representative chemical concentrations, and in a couple cases, appeared to better preserve contaminant concentrations versus samples collected with a bailer.

In the second phase of testing (field-scale), sampling devices were deployed in groundwater monitoring wells with documented petroleum hydrocarbon and MTBE contamination. Test wells were chosen based on soil stratigraphy indicating that channeling and preferential segregation of contaminants along specific horizons may be present. Historical groundwater monitoring data from the test wells, which were collected by traditional purge-and-sample methods, indicated that each well was impacted, but did not define the vertical distribution of contaminants. Deployment of the sampling devices involved hanging them in series along the screened interval of the monitoring well, with each device partitioned across a discrete section of the well screen; a vacuum pump was used at the surface to activate each device and collect groundwater samples. The partitioning of each sampling device in the well allows for the collection of a sample from a discrete interval while avoiding excess agitation and vertical mixing of the water column, which may dilute the sample and prevent reliable vertical definition. Initial field test results show variation of contaminant concentrations in test wells, suggesting that the device may be reliable for vertically defining groundwater contamination.

[1] *Cambria Environmental Technology, Inc., 2000 Opportunity Drive, Suite 110, Roseville CA 95678; Telephone (916) 677-3407; Fax (916) 677-3687; dherzog@cambria-env.com*

Cedar Moraine Safety Study

Eric F. Weber[1], L.G., and James A. Wilson[2], P.E.

The Cedar River Watershed has been developed and managed as a source of water and power by the City of Seattle for about 100 years. A roller-compacted concrete dam founded on glacial deposits impounds the Chester Morse Reservoir. To increase storage the Masonry Dam was built downstream creating the Masonry Pool Reservoir. The Masonry Dam is founded on bedrock, however the bottom and northerly rims of the reservoir are formed in the glacial deposits referred to as the Cedar Moraine embankment. Instability of the northern slope of the Cedar Moraine embankment (about 5000 ft from the Pool) has been linked to the seepage lost from the Masonry Pool. Excess pore-water pressure during the initially filling of the Masonry Pool resulted in a massive landslide in 1918 called the Boxley Burst.

The City of Seattle retained several experts and consultants to study the geology and groundwater hydrology in the embankment. However, no detailed study has been made to link water levels in the Masonry Pool to groundwater levels in the embankment and overall safety levels of the slopes. Current operating guidelines limit the operating water level at the Masonry Pool to an elevation of 1560 ft with a maximum water level not to exceed 1570 ft. Masonry Dam was originally design to operate at pool elevations as high as 1590 ft. The goal of this study is a multi-disciplinary effort to enable reservoir operating procedures to be further optimized without posing an unacceptable risk of instability of the embankment slopes.

To accomplish this goal, a detailed field investigation was conducted to increase our understanding of the embankment geology and hydrogeology. A LiDAR based digital elevation model of the embankment was developed, continuous soil samples from roto-sonic drilling method was obtained, and piezometers were installed and equipped with vibrating wires piezometers and data loggers. Based on previous and this current study, a conceptual model of the embankment hydrogeologic features was developed. The conceptual model was converted to a numerical groundwater model and a statistical slope stability analysis was conducted for various Masonry Pool water levels and seismic events. A risk analysis was conducted based on probability of a failure and the calculated consequences of a failure. The results of the analyses were used to provide operational recommendations to the watershed management team.

Landau Associates, 950 Pacific Avenue, Suite 515, Tacoma WA 98402; Fax (253) 926-2531
[1] Phone (253) 926 2493; E-mail eweber@landauinc.com
[2] Phone (253) 926 2493; E-mail jawilson@landauinc.com

Dewatering Design and Implementation for the Sound Transit Beacon Hill Station Tunnel, Seattle, Washington

Kathryn E. Stalker[1] and Richard J. Martin[2]

The Sound Transit Light Rail project includes construction of a tunnel and underground station through Beacon Hill, south of downtown Seattle. The Beacon Hill Station, an underground structure 160 feet below ground surface, was constructed in complex stratigraphy with multiple water bearing units. Groundwater was of great concern because lenses of water bearing highly permeable glacial outwash sands and gravels were irregularly dispersed between layers of glacial tills and glacial marine deposits with low permeabilities. A series of thirty-five dewatering wells were installed in the vicinity of the Beacon Hill station to remove groundwater and reduce hydrostatic pressure by 40 to 80 feet in the water bearing units. In addition to the dewatering wells, jet grouting was used to stabilize a sand unit dipping into the crown of the tunnel; this unit raised concern that the tunneling could experience soil loss or collapse. In conjunction with the jet grouting, dewatering wells were installed in the area of the low dipping sand unit to reduce hydrostatic pressures and therefore reduce risk of jet grout failure. The dewatering system removed water that could have seeped into the tunnel, and improved stability of the soils surrounding the tunnel in preparation for the sequential excavation mining (SEM) tunnel activity. Challenges in the design and implementation of the dewatering well system included placing the wells to avoid the tie-back lateral wall supports of the shafts. Additional challenges to the project were ensuring that the above ground elements of the dewatering system were not damaged by the contractor, due to the tight work area provided for the massive construction project, and making sure the system was effectively operated and maintained.

Shannon & Wilson, Inc., 400 North 34th Street, Suite 100, Seattle, WA 98103; Fax (206) 695-6777
[1] Phone (206) 695-6675; E-Mail kes@shanwil.com
[2] Phone (206) 695-6787; E-mail rjm@shanwil.com

Unanticipated Effects of a Wetland Restoration Project, Union County, Oregon

Paul F. Pedone[1]

[WITHDRAWN]

[1] *Paul F. Pedone*
State Geologist for NRCS in Oregon and Idaho
1201 NE Lloyd Blvd., suite 900
Portland, OR 97232
(503) 414-3249
FAX (503) 414-3277
paul.pedone@or.usda.gov

It's not nice to fool Mother Nature: Highway design and jökulhlaups at White River Glacier, Mount Hood, Oregon.

Kenneth A. Cameron[1]

Mount Hood possesses the greatest volume of glacial ice and permanent snowfields in the Oregon Cascades; 345 million cubic meters when last determined in 1981. It also has the greatest incidence of jökulhlaups or glacial outburst floods (GOF), with 31 recorded since 1926. These have originated from 6 of its 11 glaciers and at least one of its permanent snowfields. The most recent event originated in Palmer Snowfield in July, 2006, and flowed into the headwaters of the Salmon River. White River Glacier is the most common host for GOF, owing to a combination of geographically controlled solar insolation and volcanic activity which isolated much of its zone of accumulation at the beginning of the last century. Seventeen GOF have been documented from White River Glacier

A single road, Oregon State Highway 35, gives access to the south and east side of Mount Hood and crosses the White River 6 km from the toe of the glacier. At this point the active outwash plain was originally 512 meters wide. In order to reduce the size of the span needed to bridge the river, berms were constructed outward from both valley walls and the bridge itself now spans an active channel area only 35 meters wide. In addition, the area upstream of the western berm, which once contained a distributary channel, was filled to form a parking lot for skiers. Where once the debris flows from a GOF could spread over the anastomosing channels of a large alluvial apron, they are now confined to a narrow channel pointing directly at the highway bridge.

GOF are usually of interest to the general public only if they result in monetary damage or loss of life. Luckily, there have been no deaths associated with GOF from White River Glacier, but the Highway 35 bridge has run up a sizable repair record. It was destroyed or required repair during three periods: 1926 – 1931 (5 times), 1946 – 1967 (7 times), and 1998 to present (5 times). The most recent event occurred in 2005 when the channel under the bridge was plugged and the bridge itself overtopped by debris to a depth of about 1 meter. The highway was closed for 10 days for repairs. Based on air photo interpretation, none of these events appear to have been of exceptional size; their impact was due to poor highway design which placed a man-made structure in an area of obvious hazard time and again. A simple geomorphic analysis of the debris apron by a qualified geologist would have shown the existence of this hazard. At some point the cost of a permanent solution should outweigh the effort of continuing repair. As with most hazard mitigation the question remains: Is long range planning a better solution than a reactive approach to hazardous geologic events?

[1] *14222 SE Laurie Avenue, Milwaukie Oregon 97267 503-229-5251 (phone) 503-229-6945 (fax) cameron.kenneth@deq.state.or.us*

Volatile Organic Compounds groundwater Plume Delineation Using Waterloo profiler Technology at the Tacoma landfill

Calvin Taylor[1], L.H.G., Eric Weber[2], L.G.

The City of Tacoma Sold Waste Management Division operates the Tacoma Landfill at South Mullen Street in Tacoma. The landfill began accepting residential, commercial, and industrial waste in 1960. The site is part of the Commencement Bay/South Tacoma Channel Superfund Site. Site remediation is conducted under a Consent Decree with the U.S. Environmental Protection Agency (EPA) and Department of Ecology issued in March 1991. Groundwater contaminant migration is managed with a groundwater extraction and treatment system (GETS) which began operation in 1992. The primary groundwater contaminant plume constituents were chlorinated volatile organic compounds. Twenty-two extraction wells were installed to capture the plume at the point of compliance along the western landfill boundary. Thirteen additional edge of plume extraction wells were installed west of the landfill in the vicinity of Leach Creek to capture the offsite plume. The offsite groundwater plume had two generally lobe shaped areas known as the north and south plume areas. The GETS effectively remediated the groundwater contaminant plume to Consent Decree groundwater performance standards with the exception of the offsite north and south residual plume areas. The primary constituent of concern in the north plume area is vinyl chloride; the primary constituent of concern in the south plume area is 1,2-dichloroethane. Consequently, a field program was initiated to evaluate whether the remaining VOC plumes in the north and south areas were residual plumes from the previous more extensive groundwater plumes or whether there is an ongoing source of contamination leaking through the point of compliance GETS wells. The scope of work for the field program consisted of advancing a series of Waterloo Profilertm (profiler) boreholes to collect multiple vertically spaced groundwater samples and groundwater parameters in each borehole. The profiler provides a vertical water quality profile over discrete intervals. The profiler, combined with an onsite laboratory, also provides same day borehole water quality assessment. The profiler field work was completed over a two week period and provided sufficient information to delineate the north and south residual VOC plumes. In addition the information provided additional support for a request to shutdown the offsite extraction wells.

[1] City of Tacoma, Environmental Services, Tacoma, Washington
[2] Landau Associates, Tacoma, WA.

Developing Software To Streamline Hanford Tank Closure Risk Assessment Activities

David J. Watson[1] and Michael P. Connelly[2]

Decision Management Tool, a comprehensive problem-specific, software-based risk assessment system, has been developed to meet the specific analytical needs of Hanford Site single-shell tank closure. The software reduces risk assessment generation time from weeks to hours, provides a means to rapidly analyze all potential risk scenarios, contains a user interface allowing users with minimal training to create complex tank farm closure scenarios, and supplies critical data management capabilities.

A critical element in the closure process is to perform risk assessments estimating the potential future impacts to human health. Calculating the peak cumulative risk from a single-shell tank farm is a several step process requiring hundreds of megabytes of data. Using traditional methods, this process can take days; even longer if specific sensitivity calculations are identified. Decision Management Tool uses an object-oriented data structure to optimize processor and RAM usage, providing these calculations within seconds. This virtually real-time computation allows analysts to perform multiple sensitivity analyses and create risk assessments in a fraction of the time previously required. Analysts can now compare risk from various closure scenarios within minutes, and examine all possible remediation options. Comparisons of potential impacts of remediation can now be performed in seconds.

The sheer volume of the data used in tank closure risk analyses precludes traditional spreadsheet analysis for timely risk assessment. Additionally, data used in risk assessment can change with new analyses or as retrieval progresses. Decision Management Tool provides critical data management capabilities by organizing these large numerical data sets of various formats and different origins into a single location. The software is designed to facilitate addition of emergent data without any code modifications, allowing for system expansion to accommodate risk assessments of any contaminated site for which the appropriate input data is available.

Decision Management Tool's graphical interface and data flexibility allows outside reviewers to perform their own human health risk calculations in real time. Independently obtained data can easily be added to produce risk calculations for comparison to risk assessment documentation.

1 CH2M Hill Hanford Group, Inc., PO Box 1500, Richland WA, 99352, phone: (509) 373-1633, E-mail: David_J_DJ_Watson@rl.gov

[2] CH2M Hill Hanford Group, Inc., PO Box 1500, Richland WA, 99352, phone: (509)373-3981, E-mail: Michael_Connelly@rl.gov

Characterization of the 241-C Tank Farm and Recent Groundwater Contamination at the Hanford Site, Washington

Stanley M. Sobczyk[1]

Large plumes of contaminated groundwater are a consequence of Cold War plutonium production at the Hanford Site, Washington. The plumes origin has been attributed primarily to the intentional release of radioactive waste to the soil rather than leaks from underground storage tanks. Ongoing degradation of groundwater quality underneath the 241-C single-shell tank farm in the 200 East Area has been occurring since the late 1990s. This long-term degradation of the groundwater underneath these storage tanks indicates the persistent migration of tank waste through the vadose zone to groundwater. The development of this new groundwater plume is particularly troubling as the travel time to the Columbia River has been estimated as short as 6 to 7 years.

The 241-C tank farm was constructed during 1943 and 1944 to contain waste resulting from the process of separating plutonium from the irradiated reactor fuel. Four of the 12 530,000 gallon tanks in the 241-C tank farm are known or "assumed leakers" and have leaked various amounts of high-level radioactive liquid waste to the soil.

A series of visualizations and cross sections are derived from spectral gamma ray logging of 71 drywells and five groundwater monitoring wells to document the structure and stratigraphy of the sediments and extent of gamma ray emitting contamination underlying the 241-C tank farm. High level radioactive wastes from the leaking tanks have been migrating vertically and laterally to the northeast, which is down stratigraphic dip. The movement of ^{60}Co in the subsurface has been observed for decades, and it is reasonable to assume that ^{60}Co is moving along with other radionuclides (i.e. ^{99}Tc). The bulk of the ^{137}Cs contamination is interpreted as being contained within the backfill and the finer sediments of the Upper Hanford H2.

At the present time, the 241-C-101 tank leak should be considered the source of the ^{60}Co detected in the deep vadose zone (126 ft to 150.5 ft below ground surface) southeast of the 241-C tank farm fence at well 299-E27-14 and a potential source of the groundwater contamination. The spectral gamma logging also detected trace amounts of ^{60}Co near groundwater in the interval between 248 and 250 ft below ground surface. This ^{60}Co in the deep vadose zone represents the deepest detection of radionuclides in the C tank farm area with the exception of ^{99}Tc in groundwater underneath the farm. The estimated leak of 20,000 gallons from Tank C-101 is the closest known vadose zone source in C tank Farm to well 299-E27-14.

[1] *Nez Perce Tribe, Environmental Restoration and Waste Management Program, P.O. Box 365, Lapwai, ID 83540; Fax (208) 843-7378; Phone (208) 843-7375 ext. 2337; E-mail stans@nezperce.org*

Groundwater Contamination Resulting from Tank Leaks at Hanford: A Growing Problem

Floyd N. Hodges[1]

Plutonium production at the Hanford Site has left a legacy of leaking single-shell waste tanks that have caused significant vadose zone and groundwater contamination. These carbon steel tanks, constructed over 50 years ago, are decades past their design life and will present a continuing environmental threat until all waste has been removed.

Tank leaks have resulted in significant vadose zone contamination. Past spectral gamma logging in "dry wells" around waste tanks indicates that vadose zone contamination is wide spread, penetrates deep into the vadose, and is mobile. Unfortunately, the distribution of "dry wells" is less that ideal and none penetrate to the water table. More recently, preliminary electrical resistivity studies carried out by the Department of Energy at the T Tank Farm indicate that vadose zone contamination is much more wide spread and deeper than previously expected.

Waste leaks from tanks have resulted in major groundwater contaminant plumes at four of the tank farms (B-BX-BY, S-SX. T, and TX-TY) and there is indication of groundwater contamination at the remaining three tank farms (A-AX, C, U). At the present time the most significant contaminants are technetium-99 and chromium; however, a significant uranium plume is also presented at B-BX-BY.

Although all of the single-shell waste tanks have been "interim stabilized," they still contain large amounts of soluble waste and interstitial liquid. This may not leak if undisturbed; however, addition of water through either human error or a natural event could result in further leakage into the vadose zone. Present plans are to remove waste from the single-shell tanks into higher integrity double-shell tanks. However, there is limited double-shell tank volume and without an operating vitrification plant it will not be possible to remove waste from most of the single-shell tanks in a reasonable time frame.

A groundwater remediation program is need to treat contaminant plumes leaving tank waste management areas. Steps must be taken to slow or stop downward migration of contaminants within the vadose zone. Barriers to infiltration over tank farm areas are a good short term answer; however, given the long half-lives of the radionuclides in the waste, other, longer-term solutions are needed. Finally, if delays in completion of the vitrification plant impacts the tank clean-up schedule, new double-shell tanks will be needed to hold the excess waste.

[1] *Amphigory Associates, 5403 S. Olympia St., Kennewick, WA 99336;Phone (509) 582-6748; E-mail fhodges@3-cities.com*

Sensitivity/Uncertainty Analysis developed for The Initial Single-Shell Tank System Performance Assessment for the Hanford Site

Michael P. Connelly[1a], William J. McMahon[1b], Marcus I. Wood[2] and Anthony J. Knepp[3]

The Initial Single-Shell Tank System Performance Assessment for the Hanford Site (SST PA) evaluated tank farm closure conditions that incorporated a defense-in-depth safety philosophy that requires multiple barriers that control waste release into the accessible environment and attain expected performance metrics. The specific barriers addressed in the SST PA include two major engineering barriers (a surface barrier and the grouted tank structure) and one natural barrier (the vadose zone) to control waste release into the accessible environment and attain expected performance metrics. To estimate the effectiveness of barrier and total system performance, barrier-specific properties and processes that influence contaminant migration through the subsurface were identified and represented in the analysis by parameters and parameter values. A singular set of parameter values were selected for a “reference” case.

The SST PA implemented a formalized sensitivity/uncertainty analysis to examine the effects of inherent variability in the parameters. Heterogeneities in the natural system, long-term degradation of engineered barrier performance, and future human actions contribute to system variability. Such variability generates uncertainty about contaminant migration characteristics and limits the ability to portray adequately those system features and processes that affect future environmental contamination levels. Because tank closure system variability cannot be completely resolved, a suite of parameter sensitivity/plausible alternative cases were formulated to envelope the reference case values. Changes in estimated groundwater contamination levels caused by the effects of tank closure system variability provided ranges of plausible future contamination levels about the reference case results. Such changes were calculated with respect to variability in single parameters, multiple parameters, total barrier performance, and plausible alternatives. The results provide insight into a number of fundamental issues:(1) How well can the performance of the closure system be estimated? (2) How important are the “barriers” to the performance of the system? (3) What is the value of additional information to reduce estimated uncertainty?

[1] CH2MHill Hanford, P. O. Box 1500, MSIN H6-03, Richland WA 99352; Fax (509) 373-3833
[1a] Phone (509) 373-3981; E-Mail Michael_P_Connelly@rl.gov
[1b] Phone (509) 373-4495; E-Mail William_J_Mcmahon@rl.gov
[2] Fluor Hanford Inc., P. O. Box 1000, MSIN H8-44, Richland WA 99352; Fax (509) 372-1441 Phone (509) 373-3308; E-Mail Marcus_I_Wood@rl.gov
[3] YAHSGS LLC, 3100 George Washington Way, Suite 103, Richland WA, 99352, Fax (509) 375-6275 Phone (509) 438-6453; E-Mail tknepp@yahsgs.com

Demonstration of an Interim Surface Barrier Covering the T-106 Tank Release

Frank J. Anderson (1) and Curtis D. Wittreich (2)

The U.S. Department of Energy's Office of River Protection is about to construct an interim surface barrier to minimize the amount of infiltrating water entering the contaminated soil associated with a 1973 leak from single-shell tank 241-T-106. This 115,000 gallon leak contained approximately 37.4 Curies of technetium-99, and is the largest leak that is associated with the single shell tanks at Hanford. Technetium-99 is known to be highly mobile in both the vadose zone and groundwater, and it is often used as the indicator of groundwater contamination. Construction of the barrier is estimated to reduce the magnitude of the projected peak groundwater impacts by a factor of 2 to 3.

The goals of this two-year demonstration are: to significantly reduce the quantity of infiltration, to demonstrate cost effective design and construction, and to determine whether or not the barrier is effective for its design life of at least 30 years.

The material selected for the barrier is a polyurea/polyurethane mixture sprayed on an underlying geotextile base. The barrier and its drainage control system will be constructed to minimize "edge effects" and to capture and divert runoff to down-gradient uncontaminated areas. Material selection goals include: significant infiltration reduction, effective over a wide range of temperatures, low unit weight, minimal degradation due to ultra-violet radiation or truck traffic, ease of application and repair, not prone to cause safety-related accidents, effective for at least 30 years, access to dry wells and tank monitoring equipment, and not limiting options for final closure of the tank farm.

A design and build contract is being used to implement requirements contained in a System Specification document and a Material Evaluation Study. Moisture-related goals include: soil moisture levels in the shallow vadose zone should remain constant throughout the winter wet season, no infiltrating water should be detected after barrier installation, and capillary increase of moisture under the cap is acceptable. Two clusters of moisture monitoring instruments were installed in August 2006 and two more will be installed in May 2007 to help evaluate the barrier effectiveness. An Interim Surface Barrier Demonstration Evaluation Report will be completed in September 2008, and made available to the Washington Department of Ecology through the Office of River Protection.

CH2MHill Hanford, P. O. Box 1500, MSIN H6-03, Richland WA 99352; Fax (509) 373-3833
(1) Phone (509) 373-3971; E-mail Frank_J_Anderson@rl.gov
(2) Phone (509) 372-9641; E-mail Curtis_D_Wittreich@rl.gov

Three-Dimensional Groundwater Flow Model of an Underground Gold Mine near Republic, Washington

Peter O. Sinton[1], James H. Flynn[2], Ron M. Dixon[3], David Banton[4] and Leslie Smith[5]

A comprehensive, three-dimensional, groundwater flow model has been developed using FEFLOW to predict future groundwater conditions that may result from proposed underground mining of the gold deposit beneath Buckhorn Mountain. The model is calibrated to satisfy statistical and semi-quantitative criteria for two independent sets of information: groundwater levels and stream baseflows. Future groundwater conditions were predicted to characterize time-dependent changes in groundwater levels and baseflows over a wide range of precipitation and recharge conditions based on the historic precipitation records. The analysis considers average annual conditions, and the influence of both seasonal variations in groundwater recharge and year-to-year fluctuations in total precipitation, including multi-year drought conditions. To address effects of uncertainties arising from different factors (e.g., recharge, permeability, seasonal effects and drought), a transient predictive sensitivity analysis was completed. Model predictions include transient changes in the groundwater system during and after mining, including: water levels, baseflows, capture zones, and mine dewatering and flooding rates.

[1] URS Corp., Denver Technological Center, 8181 East Tufts Avenue, Denver, CO 80237; Phone (303) 694-2770, Fax (303) 694-3946; E-mail peter_sinton@urscorp.com

[2] URS Corp., Century Square, 1501 4th Avenue, Suite 1400, Seattle, WA 98101; Phone (206) 438-2700, Fax (206) 438-2699; E-mail james_flynn@urscorp.com

[3] Department of Ecology, Central Regional Office, 15 West Yakima Avenue, Suite 200, Yakima, WA 98902; Phone (509) 575-2490, Fax (509) 575-2809; E-mail rdix461@ecy.wa.gov

[4] Golder Associates, Inc., 18300 NE Union Hill Road, Suite 200, Redmond, WA 98052; Phone (425) 883-0777; Fax (425) 882-5498; E-mail dbanton@golder.com

[5] (third-party review) University of British Columbia, Dept of Earth & Ocean Sciences, 6339 Stores Road, Vancouver, B.C., V6T 1Z4, Canada; Phone (604) 822-4108; Fax (604) 822-6088; E-mail lsmith@eos.ubc.ca

A Re-examination of Groundwater Flow in Stratified Aquifers Induced by Vertical Recirculation Wells

John M. Lambie[1], Chris Neville[2], and Michael Harrington[3]

Groundwater recirculation wells were re-examined mathematically in a series of highly stratified sedimentary aquifers to evaluate the predicted circulation patterns under a different stratigraphic conditions. The sedimentary aquifers were created mathematically using the USGS MODFLOW code with Groundwater Vistas™ by Environmental Simulations, Inc. as the pre- and post-processor for data sets. Multiple isotropic layers, up to 50, were used in the evaluation cases and contrasted with a secondary model with an equivalent composite horizontal to vertical anisotropy in three layers. This was done to evaluate the mathematics and physical effects of layered-contrasts in the hydraulic conductivity rather than the common assumption of vertical anisotropy within the sedimentary layers.

The relationship of horizontal hydraulic conductivity (K_x) to vertical hydraulic conductivity (K_z) was examined in relation to the corresponding head losses across adjoining isotropic layers with differing hydraulic conductivity. The composite relationship of head loss for vertical and horizontal conductivity does not provide a detailed examination of the head losses and the attendant circulation patterns for the individual strata. In this evaluation we have examined head losses along and across the individual stratigraphic layers. Vertical recirculation wells which extract and inject water over these layers of differing hydraulic conductivity while imposing a uniform head gain or loss at the well demonstrate a pronounced recirculation in the more permeable layers. This leads to enhanced vertical flow compared to a homogeneous but anisotropic system with similar hydraulic characteristics.

Layered stratigraphy was used to represent conditions typical in both western and eastern Washington. A case study for aquifer recirculation in Poulsbo, Washington was developed for comparison and is presented herein.

[1] *E-pur, 4061 SW Chesapeake Avenue, Portland, Oregon 97239, (503) 381-6043, john.lambie@alum.mit.edu*
[2] *S.S. Papadopulos & Associates, 90 Frobisher Drive, Unit 2B, Waterloo, ON N2V 2A1, Canada, (519) 579-2100, cneville@sspa.com*
[3] *Sound Environmental Strategies, 2400 Airport Way South, Suite 200, Seattle, WA 98134-2020, (206) 306-1900, mharrington@soundenvironmental.com*

Hydrogeologic Conceptualization and Numerical Groundwater Flow Modeling Techniques for Fractured Bedrock Systems

Alexis Clark[1], Thomas Doe[2], and David Banton[3]

Fractured bedrock typically presents challenges for developing realistic hydrogeologic conceptualizations and numerical models of groundwater flow. Flow in fractured rock occurs through a discrete fracture network (DFN), which may behave as a highly compartmentalized system or as equivalent porous medium (EPM) depending upon aquifer properties including flow geometry, transmissivity, storativity, diffusivity, and fracture intensity and connectivity. A local example within the Columbia River Basalt Group (CRBG) is provided to illustrate an approach designed to better understand a compartmentalized aquifer. Another example is given to demonstrate an upscaling approach used to represent highly fractured tonalite in southern California using a combination of DFN and EPM modeling approaches.

A hydrogeologic investigation was conducted in a fractured basalt aquifer in the Pacific Northwest. The field geophysics program included surface and borehole time domain electromagnetic (TDEM) surveys and a very low frequency (VLF) electromagnetic surface survey to identify fracture or fault zones. Aquifer testing was conducted using site wells to provide information about aquifer geometry, transmissivity, storativity, and diffusivity. Derivative methods were used to analyze aquifer test data, suggesting a high degree of compartmentalization and hydraulic barrier regional boundary condition. These findings were corroborated by the geophysics results.

DFN and EPM numerical modeling techniques have been integrated to represent regional groundwater flow and transport for a fractured tonalite system. DFN modeling was performed using deterministic methods to accurately represent highly conductive fractures associated with mapped VLF lineament features and stochastic methods for background fracture generation. An EPM approach (using MODFLOW) was needed for computational efficiency and to upscale to a regional model that allows for a phreatic water table surface. Calibrated numerical model results supported the conceptual model and field testing that upward flow components are present at depth and lineament regions are associated with discharge areas.

[1] Golder Associates Inc., 9 Monroe Parkway, Suite 270, Lake Oswego, OR 97035; Phone (503) 607-1820; Fax (503) 607-1825; E-mail aclark@golder.com
Golder Associates Inc., 18300 NE Union Hill Road, Suite 200, Redmond, WA 98052; Phone (425) 883-0777; Fax (425) 882-5498;
[2] E-mail tdoe@golder.com
[3] E-mail dbanton@golder.com

Got a Persistent Plume?: How to Simulate Back Diffusion using Analytical & Numerical Methods

Peter Bannister[1] and Joel Massmann[2]

Most groundwater simulations of contaminant transport include only advective dispersion and disregard the role of molecular diffusion. However, diffusion into low-permeability materials can be a significant transport mechanism, both in terms of plume development and restoration. During plume development, contaminants are transported by chemical diffusion and stored in low-permeability materials across the area of the plume. Following source removal and/or groundwater remediation, the contaminant mass stored in the low-permeability materials diffuses back out. By not including this 'back diffusion' when modeling contaminant transport in heterogeneous aquifers, simulations of plume behavior may be problematic to calibrate, and can lead to under-prediction of restoration timeframes.

We have used analytical and numerical models to show the distinctive effects of diffusion on a chlorinated VOC plume in an aquifer in Lewis County. The thin (1- to 3-foot thick) aquifer (termed the ‘Deep Zone’) is bounded above by a thick sequence of low-permeability materials (termed the ‘Intermediate Zone’) and below by a thick bedrock aquiclude. Evidence of diffusion-dominated transport was documented through multi-depth groundwater sampling at several locations along the length of the plume. Although the hydraulic gradient is generally downward due to areal precipitation recharge, concentrations of contaminants in the Intermediate Zone were highest next to the Deep Zone and decreased upward.

An analytical model was used to show that diffusion could account for the observed upward transport of contaminants within a reasonable timeframe (~40 years). The analytical model also showed the effects of back diffusion on restoration timeframes following source removal. However, simplifying assumptions for the analytical model constrained its use for predicting restoration timeframes for remediation alternatives.

A numerical model of the site was constructed, and used highly discretized layers (1 foot thick) to accurately simulate vertical diffusion. Successful model calibration allowed for defensible prediction of restoration timeframes for various levels of treatment. Simulations of groundwater remediation showed the effects of back diffusion, including concentration rebound. For persistent plumes in complex aquifers, including diffusion as a transport mechanism may help explain otherwise unpredictable plume behavior.

[1] Aspect Consulting LLC, 179 Madrone Lane North, Bainbridge Island, WA 98110; Phone (206) 780-7728; Fax (206) 780-9438; E-mail pbannister@aspectconsulting.com
[2] Keta Waters, 6520 E Mercer Way, Mercer Island, WA 98040; Phone (206) 236-6225; E-mail joel@ketawaters.com

Computer Modeling of an Open Loop Geoexchange Wellfield

Gary E. Andres[1], Bruce Anderson[2], and Laura Howe[3]

The University of Montana has in place a number of open-loop geoexchange well systems for heating and cooling at the campus facilities. Continued expansion of the university includes plans for additional geoexchange systems. To assist in management decisions regarding the location and operation of the existing and new well systems a computer model was developed to simulate the heat transfer dynamics of the groundwater system.

The computer code SWIFT was used to simulate production and injection well behavior. An existing Modflow groundwater flow model was used to assist in the construction of the SWIFT model and to help define model parameters. An extensive amount of pumping and water temperature data were used to calibrate the model, particularly in areas where changes in groundwater temperatures have been observed.

The calibrated model was then used for a variety of simulations. Water temperature data from some of the well locations suggest the presence of thermal interference between injection and production wells in the form of an increase in groundwater temperature. Simulations of the existing well systems included evaluations of proposed and potential revised locations and pumping/injection strategies of the wells.

Additional simulations were completed to evaluate acceptable locations for future wells. These simulations looked at the feasibility of well locations identified by university staff based on surface logistics, as well as alternative placement.

The model developed for the university represents a valuable tool that staff can employ to assist with management decisions of the geoexchange wellfield. This modeling approach may also be helpful for other locations where similar geoexchange systems are in place or planned.

[1] PBS&J, P.O. Box 990, Veradale, WA 99037; Phone 509-939-6228; email gandres@PBSJ.com
[2] PBS&J, 1120 Cedar, Missoula, MT 59807; Phone 406-721-0354; email banderson@pbsj.com
[3] Assistant Director for Utilities and Engineering, Facilities Services, Building 32, Campus Drive, Missoula, MT 59812; Phone 406-243-2127; email Laura.Howe@mso.umt.edu

Ground Water and Sediment Contamination from Chemical Manufacturing Waste Disposal at the Mouth of Hylebos Waterway, Tacoma, Washington

Jonathan Williams[1], Leon Wilhelm[2], Larry Vanselow[3], Stan Leja[4], Curt Black[5]

Ground water contaminated by historic chemical manufacturing waste disposal has been migrating into and beneath Hylebos Waterway for decades. Historic site characterization and remediation efforts tended to view upland ground water and adjacent Hylebos Waterway sediment contamination separately. In 2003-4, new information and insights identified the need to characterize the nature and extent of groundwater and sediment contamination in a more integrated manner. Results from these investigations, conducted 2003-06, are described in two subsequent talks.

The tidally-dominated Hylebos Waterway has been dredged into Holocene Puyallup River deltaic sediments. Sediments onshore and beneath the waterway portion of the site, being located toward the distal portion of the delta, are generally composed of sand with thin and discontinuous silt interbeds; no continuous aquitard has been identified. In addition to subtle geologic controls, ground water discharge through bottom sediments is complicated by tidal fluctuations and fluid density differences.

[1] Remedial Project Manager, U.S. Environmental Protection Agency; 1200 Sixth Avenue, Seattle, WA 98101; Phone (206) 553-1369; E-mail williams.jonathan@epa.gov
[2] Project Manager, Washington State Department of Ecology, Olympia, WA 98101; Phone (360) 407-6362; E-mail leow461@ecy.wa.gov
[3] Project Manager, Weston Solutions, Seattle, WA; Phone (206) 521-1369; E-mail larry.vanselow@westonsolutions.com
[4] Hydrogeologist, Washington State Department of Ecology, Olympia, WA 98101; Phone (360) 407-6345; E-mail slej461@ecy.wa.gov
[5] Hydrogeologist, U.S. Environmental Protection Agency, 1200 Sixth Avenue, Seattle, WA 98101; Phone (206) 553-1262; E-mail black.curt@epa.gov

Nature and Extent of Ground-Water Contamination Beneath the Mouth of the Hylebos Waterway, Tacoma, Washington

Roy E. Jensen[1], Larry Vaneslow[2], Jonathan Williams[3], Leon Wilhelm[4], Stan Leja[5]

Chlorinated hydrocarbons and ground water with high pH have been migrating into and beneath the Mouth of Hylebos Waterway as the result of waste disposal practices from the operations of a chemical manufacturing facility. Historic site characterization efforts have been limited largely to upland portions of the site (elevation 15 feet MLLW). The Hylebos Waterway is about 450 feet wide and its dredged channel depth is at elevation- –40 MLLW)

Since June 2005, more than 90 borings, completed from barges and spaced either 75 or 150 feet apart, have been advanced beneath the Waterway. The deepest ground water samples have been collected from an elevation of -165 feet MLLW. The offshore sampling program has been supplemented with an additional 42 upland explorations. Ground water samples were analyzed for volatile organics (VOCs), PCBs, metals and field water quality parameters including pH. The results of the study allow a 3-dimensional delineation of the distribution of VOCs and high pH contamination across the site.

The VOC plume extends about 1000 feet from the inferred principal source area(s), across the Hylebos Waterway, and is found as deep as -160 MLLW. The extent and composition of the VOCs plume changes with distance from the inferred source area(s) reflecting the vertical distribution of DNAPL in the source area, varying ground water density, the nature of the formation, mobility of individual chemicals, and reductive dechlorination. The high (8.5 to 13+)pH plume extends about halfway across the waterway, which roughly parallels the VOCs plume, and plunges with distance from the inferred source area(s).

[1] *Senior Hydrogeologist, Hart Crowser, Inc., 1910 Fairview Ave. East, Seattle, WA 98109; Phone (206) 324-9530; E-mail roy.jensen@hartcrowser.com*
[2] *Project Manager, Weston Solutions, Seattle, WA; Phone (206) 521-1369; E-mail larry.vanselow@westonsolutions.com*
[3] *Remedial Project Manager, U.S. Environmental Protection Agency; 1200 Sixth Avenue, Seattle, WA 98101; Phone (206) 553-1369; E-mail williams.jonathan@epa.gov*
[4] *Project Manager, Washington State Department of Ecology, Olympia, WA 98101; Phone (360) 407-6362; E-mail leow461@ecy.wa.gov*
[5] *Hydrogeologist, Washington State Department of Ecology, Olympia, WA 98101; Phone (360) 407-6345; E-mail slej461@ecy.wa.gov*

Contaminated Ground Water Flow from Upland Areas to the Mouth of the Hylebos Waterway, Tacoma, Washington

Stan Leja[1] Tong Li[2], Michael Easterly[3], Curt Black[4]

[WITHDRAWN]

[1] *Hydrogeologist, Washington State Department of Ecology, Olympia, WA 98101; Phone (360) 407-6345; E-mail slej461@ecy.wa.gov*
[2] *Hydrogeologist, Groundwater Solutions, Seattle, WA; Phone (425) 644-6968; E-mail tongligws@comcast.net*
[3] *Hydrogeologist, U.S. Army Corps of Engineers, Seattle, WA 98101; Phone (206) 764-6075; E-mail michael.m.easterly@NWS02.usace.army.mil*
[4] *Hydrogeologist, U.S. Environmental Protection Agency, 1200 Sixth Avenue, Seattle, WA 98101; Phone (206) 553-1262; E-mail black.curt@epa.gov*

Measurements of Hydraulic Conductivity Using Slug Tests and Sediment Samples for Two Streams in the Pacific Northwest, USA

Colette R. McKenzie[1], Joan Q. Wu[2], and Michael E. Barber[3]

Seasonal water shortages can be highly detrimental to aquatic habitats. As agricultural and municipal water demands increase and global climate change continues to alter spatial and temporal hydrologic response, there is a growing concern over the adequacy of water resources for sustaining fish habitat in many areas in the US Pacific Northwest. Even in areas relying on ground water, the interaction of ground water and surface water can significantly affect in-stream flow. If the in-stream flow becomes too low, there can be a negative impact on spawning rates. In recent years, hydrogeologists and ecologists have increasingly recognized that subsurface properties of natural streambeds have a high degree of spatial variability, which directly affects surface- and ground-water exchange. Within Whatcom County, Washington, Bertrand and Fishtrap watersheds are two areas that have experienced significantly lower stream-water levels during the June–September dry season. To ensure a sustainable ecosystem, information on surface- and ground-water interaction is needed for developing strategies to optimize the use and management of available water resources.

Studies investigating streambed hydraulic properties, such as the streambed conductance, are essential in predicting surface- and ground-water interchange. A slug test is a common method for field-determination of streambed hydraulic conductivity (*K*). However, this method tends to be costly. Additional methods and guidance for estimating *K* are needed. In this paper, *K* of the streambed will be determined at 13 locations within the Bertrand and Fishtrap Creek basins through slug tests and analyzed using the Bouwer-Rice method. The results will be compared to the *K* values determined using four empirical equations based on particle size and porosity of the streambed sediment. From these results, methods that are cost effective and yield reliable *K* values will be identified.

Washington State University, Pullman, WA 99164

[1] *M.S. Student, Department of Biological Systems Engineering, phone (509) 680-0631, fax (509) 335-2722, email cmckenzie@wsu.edu (corresponding author)*
[2] *Associate Professor, Biological Systems Engineering Department, phone (509) 335-5996, fax (509) 335-2722, email jwu@wsu.edu*
[3] *Director, State of Washington Water Research Center and Associate Professor, Civil and Environmental Engineering, phone (509) 335-5531, fax (509) 335-1590 email meb@wsu.edu*

Quantifying submarine ground-water discharge and nutrient loading into the Lynch Cove area of Hood Canal

F. William Simonds[1], Peter Swarzenski[2], Chris Reich[2], Jason Greenwood[2], and Don Rosenberry[3]

Low dissolved oxygen concentrations in the waters of Hood Canal threaten marine life in late summer and early autumn. Eutrophication in the landward reaches of the canal has been linked to phytoplankton growth, which is controlled by nutrients (primarily nitrogen) that enter the canal from various sources. Although seawater entering the canal is the largest source of nitrogen, ground-water discharge also contributes significant quantities particularly during summer months when increased nutrient availability in the canal directly effects eutrophication. The amount of nutrients entering Hood Canal from ground water is being estimated using direct and indirect measurements of ground-water discharge and analysis of nutrient concentrations. Ground-water discharge to Hood Canal is variable in space and time because of local geology, the hydraulic gradient in the ground-water system adjacent to the shoreline, and a large tidal range of 3 to 5 meters. Streaming resistivity surveys along the coastline of Lynch Cove and measurements of ground-water seepage and hydraulic-head gradients in the shallow near shore areas were used to characterize the spatial variability of submarine ground-water discharge and identify areas of enhanced ground-water discharge. In areas with confirmed ground-water discharge, shore-perpendicular resistivity profiles, continuous electromagnetic seepage-meter measurements, and continuous radon measurements were used to characterize temporal variations in ground-water discharge over several tidal cycles. The results of these investigations show that ground-water discharge into the Lynch Cove area of Hood Canal is highly dynamic and strongly affected by the large tidal range. In areas with a strong hydraulic gradient, ground-water discharge is spatially concentrated in or near the intertidal zone with increased discharge during low tide. Areas with a weak hydraulic gradient have lower discharge rates and more spatial variability. Although nutrient concentrations in ground water are small, the flux of ground-water discharge may be large in some areas of the Hood Canal coastline; therefore, understanding the relative load of nutrients entering the canal from the ground-water pathway is potentially important.

[1] U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Suite 300, Tacoma, WA 98401; Phone (360) 772-5245; Email wsimonds@usgs.gov
[2] U.S. Geological Survey, Florida Integrated Science Center, 600 4th St. South, Saint Petersburg, FL 33701; Phone (727) 803-8747; Email pswarzen@usgs.gov; creich@usgs.gov; jgreenwood@usgs.gov
[3] U.S. Geological Survey, National Research Program, PO Box 25046 Den. Fed. Ctr. MS413, Denver, CO 8022; Phone (303) 236-4990; Email rosenber@usgs.gov

MTCA and Shoreline LNAPL: A Poor Marriage

Jay Lucas[1] and Stephen Woodward[2]

Washington's Model Toxic Control Act (MTCA) cleanup regulations provide incomplete guidance for deriving cleanup levels at shoreline sites with light aqueous phase liquids (LNAPL). Deriving cleanup levels is even more problematic at shoreline sites with both upland and aquatic contamination due to the need to apply both Sediment Management Standards (SMS) and MTCA cleanup standards. This case study discusses deriving cleanup levels for the total petroleum hydrocarbon (TPH) components related to a free product plume at a former wood treatment site located adjacent to Bellingham Bay.

Diesel-range carrier oil (P-9 oil) from former wood treatment operations accumulated in a free product plume along approximately 350 feet of shore near Bellingham, Washington. The site is underlain by fill composed of dredge sand and wood waste (sawdust, wood chips) unrelated to the former wood treatment operations. Tidal fluctuations have produced a thick smear zone (10 feet) along the shore. Erosion of the shore exposed portions of the plume and released free product to the aquatic zone in February 2000. Progressive shoreline erosion also exposed petroleum-contaminated sediment (the LNAPL "smear zone") to direct contact with tidal waters of the Bay. The shoreline area was stabilized by interim remedial measures, consisting primarily of a sheet pile barrier with limited shoreline soil excavation, in 2000. The residual LNAPL and free product are the primary potential sources of ongoing contamination to surface water, via the soil to groundwater to surface water pathway.

The complications in establishing cleanup standards at this site are related to 1) integrating MTCA TPH cleanup requirements with SMS criteria and surface water cleanup standards that do not include TPH, 2) applying MTCA's four-phase partitioning model to the wood waste fill and "back calculating" soil cleanup levels based on protection of surface water, and 3) determining mobility of oil in the thick smear zone. The TPH cleanup standards proposed for the site include a performance-based standard for free product mobility in both upland and aquatic portions of site, combined with surface water standards for individual TPH components in groundwater applied at a point of compliance near the groundwater-surface water interface.

[1] *GeoEngineers Inc., 600 Stewart Street Suite 1700, Seattle, WA 98101*
Phone (206) 239-3321; E-mail jlucas@geoengineers.com
[2] *GeoEngineers Inc., 600 Stewart Street Suite 1700, Seattle, WA 98101*
Phone (206) 239-3321; E-mail jlucas@geoengineers.com

Locating the Source of a Chromium Groundwater Plume at the Hanford Site

Scott W. Petersen[1], Christopher Murray[2], and K. Michael Thompson[3]

Sodium Dichromate was used during operations at the Hanford Site 100 Areas, part of the Department of Energy facility located along the Columbia River in southern Washington State. The sodium dichromate was delivered to water treatment plants in bags, rail cars, barrels, and through local pipelines in a stock solution that was up to 25 wt. % hexavalent chromium. Inevitably, some of this chemical was spilled during handling and/or leaked from the pipelines, and migrated through the vadose zone to the groundwater. The chromium was driven 80 ft through the vadose zone by natural precipitation, perhaps assisted by leaks in buried water lines, disposal of large volumes of water into cribs and trenches, and/or concentrated runoff from roads or buildings. There are several chromium groundwater plumes at Hanford's 100 Areas caused by accidental or intentional releases of dichromate; this paper describes an investigation of one of these plumes, located in the 100-D Area.

Records of spills were generally not kept during the production years, so locating the site of these spills must be done through field investigations. The source could be very localized, so finding small spills in the vadose zone using conventional characterization technology is problematic. In 2000, two boreholes were drilled and several deep trenches excavated in an attempt to find chromium in the vadose zone. Samples were also obtained from surface soils and test pits excavated in 2004 near the suspected source. These efforts were not successful in finding elevated chromium in the vadose zone, so an alternate approach was undertaken in 2006 involving direct measurements of groundwater chemistry. A number of boreholes were drilled to groundwater and monitored for hexavalent chromium and other constituents. Pressure transducers were also installed in these boreholes to monitor water levels and automatically record the data and transmit the readings through an existing wireless communication network.

The data from these wells are being used in a modeling and geostatistical study to refine a conceptual model for chromium in the vadose zone and groundwater. Once the area of the chromium source has been determined to <1 ha, remediation of the source will be conducted. Remediation technologies that will be considered include surface infiltration of a strong reductant (e.g., calcium polysulfide) through the vadose zone and circulation of a reducing gas (e.g., hydrogen sulfide) through wells in the vadose zone.

[1] *Fluor Hanford, Inc., P.O. Box 1000, Richland, WA 99352; voice 509-372-9126; fax 509-373-3974; email Scott_W_Petersen@rl.gov*
[2] *Pacific Northwest National Laboratory, PO Box 999, Richland, WA, 99352; voice 509-376-5848; fax 509-376-5368; email Chris.Murray@pnl.gov*
[3] *U.S. Department of Energy, P.O. Box 550, Richland, WA, 99352; voice 509-373-0750; fax 509-372-1926; email K_M_Mike_Thompson@rl.gov*

Monitoring the Influence of River Stage on Contaminant Concentrations in the Hyporheic Zone of the Columbia River at the Hanford Site's 300 Area

Greg Patton[1], Brad Fritz[2], and Donny Mendoza[3]

Past operations at the 300 Area of the Hanford Site have resulted in the release of contaminants to the soil column. These contaminants have migrated to the groundwater and ultimately to the Columbia River shoreline. Groundwater levels along this shore are heavily influenced by river stage. Significant river stage changes occur over daily, weekly, and seasonal cycles, with variations up to 2 m within a few hours. Bank storage of river water affects the contaminant concentrations of near-shore groundwater, riverbank spring water, and Columbia River water. The contrast in specific conductivity of river water (<135 μS/cm) with groundwater (>400 μS/cm) provides an indicator of river water and groundwater mixing.

This study characterized the radiological and chemical contaminants existing in the hyporheic zone by analyzing river water, riverbank spring water, and shallow groundwater collected from piezometer-style aquifer tubes. At selected aquifer tube locations, continuous measurements of river stage and specific conductivity were conducted using in situ probes. These in situ measurements were coupled with high-frequency water sampling. Water samples were analyzed for uranium and gross alpha radioactivity. The extent of groundwater–river water mixing was correlated with changes in specific conductivity, contaminant concentrations, aquifer tube depth, and river stage.

In addition, a network of aquifer tubes covering 300 m of shoreline with depths ranging from approximately 1 m to 9 m below river bottom were analyzed for uranium concentrations. Uranium concentrations were influenced by existing river stage conditions, depth, and proximity to a confining layer of tight Ringold Formation sand. Variations in the depth to this confining layer and the influence of bank storage above and below this layer have an important influence on contaminant transport through the hyporheic zone at this location.

[1] *Pacific Northwest National Laboratory (PNNL)y, Richland, Washington 99352, (509) 376-2027, FAX (509) 376-2210, gw.patton@pnl.gov*
[2] *PNNL-Richland*
[3] *PNNL-Richland*

Integration of Borehole Data to Investigate Complex Contaminant Patterns in a Deep Aquifer

Susan M. Narbutovskih[1], George V. Last[2], Rob D. Mackley[3] and Rick McCain[4]

[WITHDRAWN]

Pacific Northwest National Laboratory
3110 Port of Benton Blvd, Richland, WA 99352 FAX (509) 376-5368
[1]Phone (509) 376-9235; E-mail susan.narbutovskih@pnl.gov
[2]Phone (509)376-3961; E-mail george.last@pnl.gov
[3]Phone (509) 376-5197; E-mail rob.mackley@pnl.gov
Hanford Geophysical Logging Project; S. M. Stoller Corporation
1100 Jadwin Avenue, Suite 300, Richland, WA 99352
[4]Phone (509) 376-6460; E-mail rmccain@stoller.com

Effect of changing river stage on uranium flux through the hyporheic zone of the Columbia River along the shoreline of the 300 Area of the Hanford Site

Brad G Fritz[1] and Evan V. Arntzen[2]

At the Hanford Site near Richland, Washington, a contaminated groundwater plume exists under the 300 Area of the site. This contamination plume originated from operations in support of the Hanford mission. The primary contaminant of concern is uranium, which exists at concentrations in excess of 100 micrograms per liter. The flux of uranium contaminated groundwater into the Columbia River along the shoreline at the 300 Area varies according to changes in the hydraulic gradient caused by rapidly fluctuating river stage. The river stage changes in response to operations of dams on the Columbia River. Piezometers were installed in the hyporheic zone to measure changes in the hydraulic gradient over an extended period. This data was used to calculate water and uranium fluxes into the Columbia River. In addition, concurrent measurements of the water level in the near shore unconfined aquifer were used to better understand the relationship between fluctuating river stage and uranium flux. The changing river stage caused head fluctuations in the unconfined aquifer, which resulted in the fluctuating hydraulic gradient measured in the hyporheic zone. Further, influx of river water into the unconfined aquifer caused reduced uranium concentration in near shore groundwater because of dilution. The calculated water flux through the hyporheic zone ranged between 0.3 and -0.5 L/min/m^2. The flux of uranium through the hyporheic zone was generally on the order of 3 to 5 μg/min/m^2 over the course of this study, but occasionally exceeded 30 μg/min/m^2. It was also found that for this location, the top 20 cm of the hyporheic zone constituted the most restrictive portion of the aquifer, and controlled the flux of water through the hyporheic zone.

Pacific Northwest National Laboratory, 902 Battelle Blvd. Richland, Wa 99354
[1] Phone (509) 376-0535 Fax (509) 376-2212 E-mail Bradley.fritz@pnl.gov
[2] Phone (509) 373-0478 Fax (509) 372-3515 E-mail Evan.arntzen@pnl.gov

Estimates of Ground-Water Pumpage from the Yakima River Basin Aquifer System, Washington, 1960-2000

J.J. Vaccaro[1] *and S.S. Sumioka1*

Ground-water pumpage in the Yakima River Basin, Washington, was estimated for eight categories of use for the 1960-2000 as part of an investigation to assess ground-water availability in the basin. Methods used, pumpage estimates, reliability of the estimates, and a comparison with appropriated quantities are described.
The eight categories of pumpage were public water supply, self-supplied domestic (exempt wells), irrigation, frost protection, livestock and dairy operations, industrial and commercial, fish and wildlife propagation, and ground-water claims. Pumpage estimates were based on methods that varied by the category and primarily represent pumpage for ground-water rights.

Washington State Department of Ecology's digital database has 2,874 active ground-water rights in the basin that can withdraw an annual quantity of about 529,231 acre-feet during dry years. Irrigation rights are for irrigation of about 129,570 acres. All but 220 of the rights were associated with well drillers' logs, allowing for a spatial representation of the pumpage. Five-hundred and sixty of the irrigation rights were estimated to be standby/reserve rights. During this study, another 30 rights were identified that were not in the digital database. These rights can withdraw an annual quantity of about 20,969 acre-feet; about 6,700 acre-feet of these rights are near but outside the basin.

In 1960, total annual pumpage in the basin, excluding standby/reserve pumpage, was about 115,776 acre-feet. By 2000, total annual pumpage was estimated to be 395,096 acre-feet, and excluding the standby/reserve rights, the total was 312,284 acre-feet. Irrigation accounts for about 60 percent of the pumpage, followed by public water supply at about 12 percent. The smallest category of pumpage was for livestock use with pumpage estimated to be 6,726 acre-feet. Total annual pumpage in 2000 was about 430 cubic feet per second or about 11 percent of the surface-water demand. Maximum pumpage is in July and August and during 2000, was about 100 cubic feet per second each month.

During 2000, non-standby/reserve pumpage associated with ground-water rights was estimated to total 253,454 acre-feet, or about 198,290 acre-feet less than the appropriated quantity. The unused part of the appropriated value is about equivalent to the irrigation pumpage for primary rights.

[1] U.S. Geological Survey, 934 Broadway, Suite 300

Estimates of Ground-Water Recharge to the Yakima River Basin Aquifer System, Washington, for Predevelopment and Current Land-Use and Land-Cover Conditions

J.J. Vaccaro[1] and T.D. Olsen[2]

Ground-water recharge to the Yakima River Basin aquifer system, Washington, was estimated for predevelopment (estimate of natural conditions) and current (a multi-year, 1995-2004, composite) land-use and land-cover conditions using two different models. The models were the Precipitation-Runoff Modeling System (PRMS) and the Deep Percolation Model (DPM) that are contained in the U.S. Geological Survey's Modular Modeling System. Daily values of recharge were estimated for Water Years 1950-1998 using previously developed PRMS-watershed models for four generally forested upland areas, and for Water Years 1950-2003 using DPM applied to 17 semiarid to arid areas in the basin.

The mean annual predevelopment recharge was estimated to be about 12.1 in. or 5,547 ft^3/s (about 4 million acre-ft) for the entire 6,200 mi^2 basin. In the modeled areas, recharge ranged from 0.08 in. (1.2 ft^3/s) to 34 in. (2,825 ft^3/s). About 97 percent of the recharge occurred in the 3,663 mi^2 included in the upland-area models, but much of this quantity is not available to recharge the bedrock hydrogeologic units. Only about 0.4 in. or 187 ft^3/s (about 0.14 million acre-ft) was estimated to occur in the 2,554 mi^2 included in the semiarid to arid lowland modeled areas.

The mean annual current recharge to the aquifer system was estimated to be about 16.5 in. or 7,315 ft^3/s (about 5.3 million acre-ft). The increase in recharge is due to the application of irrigation water to croplands. The annual quantity of irrigation was more than five times the annual precipitation for some of the modeled areas. Mean annual actual evapotranspiration was estimated to have increased from predevelopment conditions by more than 1,700 ft^3/s (about 1.2 million acre-ft) due to irrigation.

U.S. Geological Survey, 934 Broadway, Suite 300
Tacoma, WA 98402
[1]Phone (253) 552-1620; Email jvaccaro@usgs.gov
[2]Phone (253) 552-1652; Email tdolsen@usgs.gov

Future Groundwater Supplies for Three Municipalities in the McAllister & Yelm Sub-Basins of Thurston County, Washington

Stephen D. Thomas, L.Hg.[1], Alexis Clark, L.Hg.[2], and Phil Brown, L.Hg.[3]

Recent population growth in northern Thurston County has increased the demand for water supply and added stress to the surface water and groundwater resources, particularly within the Lower Nisqually watershed. Faced with continued growth, three cities (Olympia, Lacey and Yelm) have each developed a set of supply strategies to meet their individual, long-term future needs. Each of these plans involves application for new water rights and transfers of existing rights.

Olympia intends to reduce its reliance on the natural McAllister Spring by developing a 20 million gallon per day (MGD) wellfield, to be located upgradient from the Spring. The McAllister Springs supply is located within highly-transmissive, unconfined gravels and is therefore highly susceptible to contaminants released at land surface. Lacey's plan uses newly constructed wells in three growing subdivisions, requiring an additional 5 MGD. Further south, Yelm is evaluating the feasibility of a new, 8 MGD wellfield located outside of the downtown area, satisfying their supply needs to 2036. All three cities are exploring deeper groundwater to minimize impacts to surface hydrology.

Numerical modeling was identified as a best management tool for evaluating the feasibility of each wellfield individually, and predicting potential hydrologic impacts. The USGS code *MODFLOW* was used to simulate groundwater flow within the region's complex, multi-layered glacial aquifer system. Olympia developed a regional groundwater flow model in 2001 which contained sufficient detail and representation of groundwater hydrology to predict impacts from changes in pumping in the McAllister Sub-basin. Of particular hydrologic and economic importance are the two regional rivers (the Nisqually and Deschutes), natural springs (notably the McAllister and Kalama Creek Springs), and several smaller surface water features and glacial lakes that are all supported by groundwater discharge.

With additional field data, the conceptual understanding of the system has evolved and the model improved and updated to include refinement in the Lacey Uplands and Yelm Sub-basin areas. The three cities, in conjunction with the Nisqually Watershed Planning Group, are currently developing strategies collaboratively to evaluate future needs in accordance within the established watershed planning framework.

[1]Golder Associates Inc., 2200 6th Avenue, Suite 200, Seattle, WA 98101; Phone (206)267-1166; Fax (206) 267-1172; E-mail sdthomas@golder.com
[2,3]Golder Associates Inc., 9 Monroe Parkway, Suite 270, Lake Oswego, OR 97035; Phone (503) 607-1820; Fax (503) 607-1825; [2]E-mail aclark@golder.com; [3]E-mail pabrown@golder.com

Ground Water Supply Potential of a Deep Confined Aquifer, North-Central Whatcom County, Washington

Bridget A. August[1], Charles S. Lindsay[1] and Dale Buys[2]

The Delta Water Association provides water to approximately 150 customers including several large farming operations in a service area located just north of the City of Lynden in Whatcom County, Washington. The District currently obtains its water supply from two shallow production wells located approximately 1.5 miles south of the US/Canada border. Over the past several decades the Association has seen a consistent increase in nitrate-nitrogen concentrations in their water supply. The elevated nitrate-nitrogen concentrations are likely the result of current and historical agricultural practices common in this region of Whatcom County and south-central British Columbia. Recently, the Association initiated a program to identify and develop a ground water source that could be used to either replace or assist in the treatment of their existing source.

A review of geologic information for the project area indicated that several deep confined aquifers may be present in Fraser and pre-Fraser-age sediments located below elevation –200 feet. A refraction survey completed by Interpre' Tech/Seis Pulse produced a profile of buried bedrock topography over an approximate 8-mile long east to west section through the Association service area. The refraction survey indicated that a broad depression in the bedrock surface was located over an approximately two mile long section of the survey route beginning roughly 0.5 miles west of the existing Association production wells.

Based on our preliminary hydrogeologic evaluation and the results of the refraction survey, an exploration well was sited approximately 1.5 miles west of the Association production wells. The well was drilled to a total depth of 750 feet (Elevation –630 feet). The well encountered approximately 100 feet of glacial outwash (Sumas stade) overlying roughly 200 feet of glaciomarine (Everson interstade) drift. The glaciomarine drift was underlain by approximately 150 feet of Vashon-stade glacial till and advance outwash, which were underlain by a thick sequence of pre-Fraser glacial/non-glacial sediments.

Several potential ground water producing zones were encountered in the well below elevation -200 feet. Short-term aquifer tests were conducted in three of the aquifer zones. The well testing program indicated aquifer transmissivities ranging from 700 to 1,000 ft2/d and short-term specific capacities of 2.0 to 4.0 gpm per foot of drawdown. Preliminary water quality testing indicated variable water quality with chloride concentrations exceeding 1,000 mg/l in some aquifer zones.

[1]*Associated Earth Sciences, Inc., 2911 ½ Hewitt Avenue, Suite 2, Everett, Washington 98201; Fax (425) 252-3408, Phone (425) 256-0522; Email baugust@aesgeo.com; Email clindsay@aesgeo.com*
[2]*Reichhardt & Ebe Engineering, Inc., 423 Front Street Suite 201, Lynden, Washington 98264; Fax (360) 354-0407; Phone (360) 354-3678; Email dale@recivil.com*

Pharmaceuticals and Personal Care Products in Water

Melanie Redding[1]

Traditionally the focus of water quality studies has been aimed at the impact of conventional and priority pollutants on water quality. There are other chemicals, such as pharmaceuticals and personal care products (PPCP's), which are ubiquitous, continually released into the environment, and which can cause damaging effects even at very low concentrations. PPCP's include prescription drugs, over-the-counter drugs, veterinarian drugs, controlled substances, cosmetics, fragrances, lotions and other personal care products that we all use on a daily basis. Some PPCP' are persistent while others have the effect of being persistent as they are used and introduced into the environment on a continual basis. There is increasing evidence that the accumulation of these drugs in the environment and sustained exposure may result in the disruption of endocrine systems in human and wildlife populations.

This is an overview based on the relatively limited literature on this emerging topic. Understanding the origin, the treatability, the fate and transport in the environment, the concentration ranges and the most prevalent PPCP's will help Washington State tailor their initiatives with respect to source control and surface and ground water quality protection.

[1] *Washington Department of Ecology. 360-407-6254.*

Water Quality Credit Trading in Oregon

Sonja Bjorn-Hansen[1]

Oregon's Department of Environmental Quality (DEQ) has explored a number of variations on trading and has successfully implemented a temperature trade with the sewerage agency for Washington County, Clean Water Services (CWS). The trade involves flow augmentation and a projected 35 miles of stream restoration (12 miles completed to date).

This trade has in turn led to the formation of the Willamette Partnership. The Willamette Partnership is an organization dedicated to assisting buyers and sellers of conservation credits throughout the Willamette basin that will produce benefits to the entire ecosystem at less cost than could be accomplished under individual fragmented programs.

The challenges encountered by DEQ and CWS in developing the model temperature trade and the work being undertaken by the Willamette Partnership will be discussed. Other efforts to identify different types of trading in Oregon will also be described, and the lessons learned from all of these efforts, successful and otherwise, will be shared.

[1] *Oregon Department of Environmental Quality, 611 SW Sixth Avenue, Portland, OR 97204*
Phone 503-229-5257, Fax 503-229-5408, Email biorn-hansen.sonja@deq.state.or.us

Assessment of Impacts from an Infiltration Gallery for Treated Groundwater Discharge

Eric Marhofer[1], EIT, Michael S. Resh[2]

The Boomsnub/Airco Superfund Site is a federal lead Superfund Site located in Vancouver, Washington. The facility extracts and treats approximately 230,000 gallons per day of contaminated groundwater from commingled trichlorethene and hexavalent chromium plumes. Through 2005, the facility discharged treated groundwater to the City of Vancouver's sanitary sewer system. In February 2006, the Site began discharging to a new infiltration gallery, saving more than $350,000 per year in avoided sewer charges. The infiltration gallery is designed to discharge treated groundwater back into the alluvial aquifer from which it was pumped.

Extensive negotiations were conducted with both the US Environmental Protection Agency and the Washington State Department of Ecology, to obtain approval of the infiltration gallery concept. Of primary concern to both regulatory bodies was the potential impact of the discharge on the local groundwater quality. Site specific discharge limits, stricter than WAC 173-200 groundwater quality criteria, were established for the system. To meet these limits, upgrades to the existing groundwater treatment system were required.

To assess the physical impacts of the infiltration gallery, the groundwater model developed for the Site's remediation activities was used. A test pit investigation was conducted to verify that conditions at the infiltration gallery site were consistent with the input parameters for the model. Two 10- by 10-ft test pit were excavated to a 10-ft depth (near the proposed base of the infiltration gallery. Soil samples were collected from the base of the excavation and tested for grain size analysis and hydraulic conductivity. In addition, a double ring infiltrometer (ASTM D3385-03) test was conducted in each test pit to measure potential infiltration rates. Once the model was calibrated for site-specific conditions, it was used project the extent (lateral and vertical) of mounding that was likely to occur under the infiltration gallery.

The infiltration gallery has performed well in the 10 months since system startup, even during one of the wettest winters on record in the Vancouver area. Mounding related to the infiltration gallery was within the limits predicted by the groundwater model. Treatment plant upgrades have reduced contaminant levels in the effluent to less than 20 percent of current groundwater quality criteria.

EA Engineering, Science, and Technology, Inc. 12011 NE 1st St., Suite 100, Bellevue, WA 98005. Telephone (425) 451-7400, Fax (425) 451-7800,
[1]Email: sbailey@eaest,com,
[2]Email: emarhofer@eaest.com
[3]The BOC Group, 575 Mountain Ave, Murray Hill, NJ 07974, Telephone 800-932-0803 x1452, Fax 908-771-1203, Email: mike.resh@boc.com

Use of Stable Isotopes of Strontium and Lead to Assess the Fate of Storm and Reclaimed Water in Groundwater Systems

Richard W. Hurst[1]

Both storm and reclaimed waters have the potential to severely impact groundwater given the presence of contaminants of concern in each. Specifically, storm water may literally be a hydrologic garbage can as runoff scours the surface indiscriminately picking up sediment as well as any inorganic/organic contaminant it encounters. Reclaimed water may also pose a threat to groundwater resources if it contains pathogens. Hence, understanding interactions between these waters and local groundwater systems is imperative.

Although general mineral analyses of groundwater, coupled with graphical plots of groundwater data (e.g. Stiff, Piper Diagrams etc.) and hydrologic modeling are important components in studies bearing on the potential impact of such waters, deleterious impacts may not be observed, in all cases, until the impact is significant. However, by employing stable isotopic techniques, where analytical uncertainties and sensitivities far exceed those of general mineral analyses, potential impacts may be detected long before those that would be observed via general mineral analyses.

In this presentation, a series of case studies will be addressed that demonstrate the potential utility of both strontium and lead (Sr, Pb, respectively) to issues associated with storm and reclaimed water impacts on local groundwater systems. In the first case, both Sr and Pb isotopes were employed to evaluate the fate of runoff from coal-fired power plant fly ash waste ponds on Colorado River water in eastern California. The second study used strontium isotopes exclusively to trace reclaimed water that entered groundwater systems via spreading basins in the Whittier Narrows (east of Los Angeles) and Los Angeles River Water on groundwater aquifers near Long Beach. The third utilized stable isotopes of lead to assess the discriminate between sources of lead derived either from a smelter or vehicle emissions (i.e. gasoline) in Tacoma.

In each case study, comparisons will be made between general mineral results, which could not detect any impact with those of the isotopic analyses where impacts, although not severe at the time, could be detected.

---

[1] *Hurst & Associates, Inc., 9 Faculty Ct., Thousand Oaks, CA 91360*
Phone: (805) 492-7764; Fax: (805) 241-7149; E-mail alasrwh@aol.com

Supplemental Groundwater Remediation Technologies to Protect the Columbia River at Hanford, WA

K. Michael Thompson[1], Scott W. Petersen[2], John S. Fruchter[3], Calvin C. Ainsworth[4], Vince R. Vermeul[5], Dawn M. Wellman[6], Jim E. Szecsody[7], James E. Amonette[8], and Philip E. Long

For fiscal year 2006, the United States Congress authorized $10 million for "…analyzing contaminant migration to the Columbia River, and for the introduction of new technology approaches to solving contamination migration issues." Nine projects have been selected, targeted at one of four major Hanford groundwater contamination issues: hexavalent chromium, strontium-90, carbon tetrachloride or uranium. Five of the selected projects are directed toward hexavalent chromium contamination in Hanford's 100-D Area groundwater. Another of the projects will measure the hydrolysis rates at various temperatures in order to provide data used to predict the movement of carbon tetrachloride from the 200 West Area. Two additional projects address surface infiltration of an apatite solution and phytoremediation technology to treat strontium-90 near the Columbia River. The final project is addressing uranium in groundwater in the 300 Area near the Columbia River and will perform laboratory and subsequent field tests using long-chain polyphosphate materials. Each of these projects is performing laboratory and field-scale studies to evaluate their potential to remediate Hanford groundwater contamination.

[1] U.S. Department of Energy, Richland Operations, P.O. Box 550, Richland, WA 99352; Phone (509)373-0750; E-mail: K_M_Mike_Thompson@rl.gov
[2] Fluor Hanford, Inc., P.O. Box 1000, Richland, WA 99352; Phone (509)372-9126; Email: Scott_W_Petersen@rl.gov
[3] Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352: Phone: (509)376-3937; Email: john.fruchter@pnl.gov
[4] Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352; Phone: (509)376-6706; Email: calvin.ainsworth@pnl.gov
[5] Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352; Phone (509)376-8316; Email: vince.vermeul@pnl.gov
[6] Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352; Phone (509)375-2017; Email: Dawn.Wellman@pnl.gov
[7] Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352; Phone (509)372-6080; Email: jim.szecsody@pnl.gov
[8] Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352; Phone (509)376-5565; Email: jim.amonette@pnl.gov
Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352; Phone (509)372-6090; Email: philip.long@pnl.gov

Uranium Stabilization through Polyphosphate Injection: 300 Area Uranium Plume Treatability Demonstration Project

[1]Dawn M. Wellman, [2]Vince R. Vermeul, and [3]Jonathan S. Fruchter

A groundwater plume containing uranium, from past-practice discharges of liquid waste associated with nuclear fuel fabrication activities, has persisted beneath the Hanford Site 300 Area for many years. The persistence of this plume is enigmatic for several reasons, including: (1) discharges of uranium-bearing effluent to ground disposal sites ended in the mid-1980s; (2) contaminated soil was removed during the 1990s, with backfilling complete by early 2004; and (3) the aquifer is comprised of highly transmissive fluvial sediment, suggesting rapid movement of groundwater. Despite these activities, dissolved uranium concentration exceed the EPA MCL concentration of 30 ug/L. Maximum concentrations in the plume are <250 μg/L, with mode values ranging from 30 to 90 ug/L. The plume currently covers an area of ~0.4 km2 (0.15 mi2) and is just upstream of the City of Richland municipal water supply intake on the Columbia River.

The use of soluble polyphosphate compounds has been demonstrated to delay the precipitation of phosphate phases:

- autunite {$X_{3-n}^{(n)^{+}}$ [(UO2)(PO4)]2-1•nH2O}, and
- apatite.

Precipitation of phosphate minerals occurs when polyphosphate compounds hydrolyze to yield the orthophosphate molecule (PO43-). Based on the hydrolysis kinetics of the polyphosphate polymer, the amendment can be tailored to act as a time-released source of phosphate for lateral plume treatment, immediate and sustained remediation of dissolved uranium, and to preclude rapid precipitation which could result in a drastic change in hydraulic conductivity of the target aquifer.

Integration of site-specific characterization data with laboratory testing is being utilized to optimize the polyphosphate technology for implementation of a field-scale demonstration. Column tests and 31P NMR are being utilized to optimize the polyphosphate amendment to provide sufficient control over the precipitation kinetics of insoluble phosphate minerals, creating a condition where injection and mixing with the target contaminant plume can be performed effectively under subsurface conditions. Kinetic dissolution tests have been conducted to evaluate the stability and understand dissolution mechanisms of the phosphate minerals under conditions relevant to the Hanford subsurface.

Presently focused application of polyphosphate is proposed in source or “hot spot” areas that would significantly reduce the inventory of available uranium that contributes to the groundwater plume. Field-scale demonstration includes (1) collection of baseline groundwater chemistry samples, (2) hydraulic testing, (3) electromagnetic borehole flowmeter (EBF) testing to assess vertical heterogeneities, and (4) a conservative tracerinjection test to further evaluate formation heterogeneities, assess aquifer transport properties, refine the polyphosphate injection design, and test operational procedures.

Pacific Northwest National Laboratory, 902 Battelle Blvd., PO Box 999, MS K3-62, Richland, WA 99354
[1]Phone (509) 375-2017; E-mail dawn.wellman@pnl.gov; [2]Phone (509) 376-8316 ; E-mail vince.vermeul@pnl.gov; [3]Phone (509) 376-3937 ; E-mail jonathan.fruchter@pnl.gov

Technical Challenges to the Hanford Site Groundwater Remediation

Dibakar (Dib) Goswami, Ph.D.[1]

Over 440 square kilometers (170 square miles) of groundwater beneath the Hanford Site are contaminated with by hazardous and radioactive waste, out of which almost half is above state and federal drinking water standard. The plumes are often mixed and the remediation is challenged by limited available technologies, poor understanding of conceptual models and subsurface contaminant behavior. In the early nineties, the Washington State Department of Ecology, Environmental Protection Agency and US Department of Energy (USDOE) developed an initial comprehensive site wide groundwater remediation strategy with a vision to address major contaminated plumes of hazardous and radioactive waste. The strategy was based on qualitative risk to reduce immediate risk to the human health and the environment, commonly held values of stakeholders and tribal nations, and use of available technologies. Accordingly, the strategy addressed major plumes found in the reactor areas adjacent to the Columbia River to protect the river from major contaminants of chromium, strontium-90, and uranium. It also includes containment of major plumes found in the central plateau region that contain chlorinated solvents and radionuclides. The strategy emphasized the development of cost effective alternative technologies wherever applicable.

With the passage of more than a decade of active remediation, the results are often found to be mixed. While the application of “pump and treat” has been found to provide a meaningful approach to the solution of the certain target contaminants, it was found to be smaller in scale and in certain cases cost prohibitive. During this time frame, additional severe groundwater and vadose zone contamination under the tank farms were discovered which now necessitates modification of the overall strategy of the remedial approach not only to address the groundwater contamination but also its sources in the shallow and deep vadose zone. The modification should involve a complete integration of the past practice plumes and the tank farm vadose zone and groundwater characterization and remediation activities. Innovative technologies to address various contamination in the vadose zone as well as in groundwater-especially for chlorinated solvents, chromium and specific radionuclides such as technetium-99, uranium and strontium-90 need to be developed and deployed with better understanding of the associated site specific physical and geochemical concepts.

[1] *Nuclear Waste Program, WA State Dept. of Ecology, 3100 Port of Benton Blvd.; Richland, WA 99354; Ph: 509-372-7902; fax: 509-372-7971; E-Mail: dgos461@ecy.wa.gov*

TREATABILITY TEST FOR REMOVING TECHNETIUM-99 FROM 200-ZP-1 GROUNDWATER, HANFORD SITE

Mark E. Byrnes[1], Scott W. Petersen[2], Wanda Elliott[3]

The 200-ZP-1 Groundwater operable unit (OU) is one of two groundwater OUs located within the 200 West groundwater aggregate areas of the Hanford Site. A pump-and-treat (P+T) system for this OU was implemented in 1995 to control the 2,000 ug/L contour of a five square mile carbon tetrachloride plume associated with the Plutonium Finishing Plant. The primary contaminants within the 200-ZP-1 OU include carbon tetrachloride and technetium-99 (Tc-99). Carbon tetrachloride is removed from groundwater by the current P+T system through evaporative treatment (air stripping).

Ten extraction wells and five injection wells operate at a combined rate of ~300 gpm. Groundwater from two of these wells (299-W15-765 and 299-W15-44) began to show increasing concentrations of Tc-99 in 2005. Potential sources for this Tc-99 include: 216-T-19 Crib, 221/224-T Plant, and TX-TY Tank Farms. The Tc-99 concentrations from the mixed groundwater from all ten extraction wells is greater than one-half of the MCL for Tc-99 (900 pCi/L) and is increasing rapidly. If the water continues to remain untreated for Tc-99 there is a concern that the water re-injected into the aquifer could exceed the MCL standard. Tc-99 exists in groundwater in a fully oxidized form (Tc^{+7}), which is referred to as pertechnetate (TcO_4^-).

Multiple treatment technologies were recently reviewed for selective removal of pertechnetate from 200-ZP-1 groundwater including: membrane separation, electrocoagulation, selective adsorbents, zero-valent iron, and ion exchange. Of these, only ion exchange was determined to be highly selective for pertechnetate, commercially available, and relatively low in cost. Through research funded by the U.S. DOE, the ion exchange resin Purolite® A-530E is recommended for removal of pertechnetate even in the presence of competing anions (i.e., nitrate, sulfate). For this and other reasons, Purolite® A-530E was selected for treatability testing.

The initial treatability test shall involve the installation of a Purolite® A-530E resin filter to the discharge line from extraction wells 299-W15-765 and 299-W15-44. A routine sampling and analysis program will then be implemented to monitor the performance of the resin.

[1] Fluor Hanford, Groundwater Remediation Project, PO Box 1000, Richland, WA 99352; Telephone (509) 373-3996; E-mail mark_e_byrnes@rl.gov
[2] Fluor Hanford, Groundwater Remediation Project, PO Box 1000, Richland, WA 99352; Telephone (509) 372-9126; E-mail scott_w_petersen@rl.gov
[3] Environmental Quality Management, Inc., 1777 Terminal Drive, Richland, WA 99352; Telephone (509) 946-4985, WandaE@eqminc.com

Treatment of a TCE Source Area beneath an Active Stormwater Detention Basin Using Electrical Resistance Heating

Jerry R. Ninteman[1], Clinton L. Jacob[2], Kenneth J. Reid[3], Y. Nicholas Garson[4], Alan K. Sugino[5], Daniel C. McCormack[6], and Chad D. Crownover[7]

This paper evaluates the effectiveness of electrical resistance heating (ERH) in treating a trichloroethene (TCE) source area located beneath an active stormwater detention basin at the Boeing Commercial Airplane Company's manufacturing plant in Everett, Washington. This remedial effort targets an approximate 14,000 ft^2 source area within an unconfined, advance outwash aquifer of sand and silty sand from 10 to 75 ft below the bottom of the basin. The maximum measured concentration of TCE within the source area is 31,000 µg/L. A TCE plume in groundwater extends up to 2,700 feet downgradient of the source area. This remedial action is being implemented as an interim action under a Model Toxics Control Act (MTCA) agreed order between the Washington State Department of Ecology and the Boeing Company.

ERH involves electrical heating of the aquifer to boil off aqueous phase, sorbed phase, and non-aqueous phase liquid (NAPL) contaminants; collection of contaminant vapors in the vadose zone; and treatment of the vapors. An electrical current is passed through the aquifer between a series of electrodes installed within the treatment area. Resistance to the flow of electrical current heats the aquifer and boils target contaminants, which are collected in vapor recovery wells co-located with the electrodes. Low hydraulic conductivity units, difficult to remediate by other methods, are preferentially heated by ERH. A total of 50 electrode/vapor recovery wells were installed within the detention basin along with 11 multi-depth completion groundwater monitoring wells. Installation activities were conducted July to September 2006 within a paved detention basin that had been pumped dry for this project.

Operation of the ERH system began in October 2006 and is expected to continue into late Winter or Spring 2007. System performance will be tracked through several means including automated daily recording of subsurface temperatures at multiple locations and depths, monitoring of volatile organic compound (VOC) concentrations in vapor extraction system effluent, and periodic monitoring of VOC concentrations in the detention basin groundwater monitoring wells. This presentation will provide the results of this monitoring and assess the effectiveness of ERH in treating the TCE source area.

Landau Associates, 130 2nd Ave South, Edmonds, WA 98020; Phone (425) 778-0907; Fax -6409
[1]jninteman@landauinc.com, [2]cjacob@landauinc.com, [3]kreid@landauinc.com
The Boeing Company, P.O. Box 3707, MC 1W-12, Seattle, WA 98124-2207; Fax (206) 544-7297
[4]Nick.Garson@Boeing.com, [5]alan.k.sugino@boeing.com, [6]daniel.c.mccormack@boeing.com
Thermal Remediation Services, 6501 24th Ave N.W. #302, Seattle, WA 98117; Phone (206) 783-0159
[7]ccrownover@thermalrs.com

Time-Sensitive Response, Characterization, and Remediation of an Intentional Release Directly to an Existing Monitoring Well

John F. Hildenbrand[1] *, Thomas W. Smith*[2]

While most environmental professionals dealing with contaminant investigation and cleanup have dealt with numerous scenarios involving impacted ground water, a lesser number have dealt with impacts caused by recent releases (spills), especially spills that directly impact ground water. Rarer still are responses to spills that enter ground water via an existing groundwater monitoring well through a malicious act. While conducting routine groundwater monitoring activities for a client as part of a Voluntary Cleanup Program (VCP) monitoring effort to achieve a “no further action” determination, a previously “clean” monitoring well was found to contain non-aqueous phase liquids (NAPL). Subsequent investigation yielded visual and physical evidence that an unknown material was intentionally placed into the monitoring well.

Initial response efforts included documentation of physical, visual and chemical evidence of the nature of the release, including chemical profiling, fingerprinting, and collection of samples for possible future evidentiary analysis. Additional efforts included coordination/communication with law enforcement and regulatory agencies as well as emergency NAPL recovery operations.

During NAPL recovery actions, contaminant transport modeling was conducted to facilitate the determination of contaminant plume boundaries and appropriate groundwater remediation methods. Subsequent soil and groundwater sampling provided data required to appropriately design a remedial strategy using oxygenation compounds to stimulate biodegradation of contaminants. An enhanced groundwater monitoring network was also placed. The progress of remediation is currently being monitored, and the criminal investigation is still ongoing.

[1] *Robinson, Noble & Saltbush, Inc., 3001 S. Huson Street, Suite A, Tacoma, WA 98409; telephone (253) 475-7711; Fax (253) 472-586; Email jhildenbrand@robinson-noble.com*
[2] *Robinson, Noble & Saltbush, Inc., 3001 S. Huson Street, Suite A, Tacoma, WA 98409; telephone (253) 475-7711; Fax (253) 472-586; Email tsmith@robinson-noble.com*

Ten Years of Recovery of a 6-Acre Diesel/Bunker C Plume in the Tacoma Tideflats, Washington

Suzanne Dudziak[1] and Brian C. Peters[2]

In 1996, the Port of Tacoma installed a large-scale groundwater recovery system to remove diesel and bunker C product from groundwater. This product had been spilled by the former Milwaukee Railroad over a 6-acre area in the early 1900s from its historic operations. The Port installed this system in accordance with the requirements of a Department of Ecology Pre-Purchase Consent Decree.

The recovery system was originally designed as a bioslurping system. Upon start-up and operation it became clear that modifications needed to be made in order to improve product recovery and to meet effluent requirements prior to reinjection back into the ground. Modifications were made over the ensuing years and the system was converted to a more standard vacuum-enhanced recovery system. The original system consisted of 34 recovery wells connected to approximately 6.4 miles of subsurface piping that converged at a treatment compound on the site. In 1996, the treatment compound consisted of a sedimentation tank followed by an oil/water separator, bioreactor, sand filter, and aeration tank. The primary problem with the original design was the lack of appropriate retention time for settlement of solids. Additionally, the bioreactor was not able to treat the effluent to a level appropriate for discharge to the ground. To meet the appropriate effluent levels, the following components were modified: Baker tanks were added to the treatment system to provide more retention time, the bioreactor was converted to a retention tank, and the sand filter was back-flushed on a frequent basis. Also, the well designs were modified to improve product recovery. The original design consisted of one double diaphragm pump used to extract groundwater and product from all 34 recovery wells at the site. Drop tubes located within the wells were positioned to allow extraction of both water and product while vacuum was exerted on each of the wells to enhance movement of the product. Since January 2001, the system has been operating in the current configuration, which includes 10 double diaphragm pumps operating on individual wells (selected based on recovery production) with the drop tubes lowered by 14 inches and check valves installed on all drop tubes to prevent reverse flow of fluids.

The recovery system has been in operation for approximately 10 years. From October 1997 through October 2006, the system has recovered approximately 61,200 gallons of product. All product recovered from this site has been recycled. The site was paved in February 2005, which has reduced both infiltration and product recovery significantly. It is anticipated that in the near future this site will transition from active pumping to long-term monitoring.

[1] *Greylock Consulting LLC, P.O. Box 23254, Federal Way, WA 98093; Phone: 253-266-2838; Fax 253-941-2705; E-mail: greylockllc@comcast.net.*
[2] *Shaw Environmental and Infrastructure,19909 120th Ave. NE, Ste. 101, Bothell, WA 98011; Phone: 425-402-3205, Fax: 425-486-9766; E-mail: Brian.Peters@shawgrp.com*

High Volume LNAPL Recovery Techniques in a Tidally-Influenced Aquifer: Todd Shipyards, Seattle, WA

Thomas Colligan[1] and Stephen Bentsen[2]

Since 1998, Todd Pacific Shipyards (Todd) has recovered over 260,000 gallons of pure phase petroleum product from a tidally-influenced aquifer. We present the technology and techniques involved in the recovery of this large amount of "floating" product. The presence of LNAPL was first identified at Todd during the Harbor Island Remedial Investigation in the 1990s. Todd initiated LNAPL recovery efforts in late 1998 using a 4-well dual phase system (*i.e.,* groundwater and LNAPL separately pumped). Vacuum enhancement was added to the system in 2001, which doubled to tripled the LNAPL recovery rates (up to 100 gallons per day per well). Testing revealed that the balance point between LNAPL recovery and groundwater drawdown was obtained with moderate groundwater drawdown (1 to 3 feet) and moderate vacuum (typically 20 inches water).

Initial recovery efforts were hampered by iron fouling in the groundwater extraction system (a jet pump suction system that introduced air at the well head) and the air stripper. Attempts to control fouling included very frequent cleaning, biocides, and sequestrants. These strategies were only mildly successful, eventually resulting in the replacement of this system with individually-controlled submersible pumps that pressurized the system. The use of a pressure system allowed the stripper to be replaced with granular activated carbon. These changes eliminated iron fouling as a significant operational issue.

In 2003, following several years of continually increasing recovery volumes, the extent of the LNAPL was better delineated and found to be larger then originally estimated. Numerous core samples were collected to identify extent and the true thickness of the LNAPL-saturated interval. Cores were analyzed for saturation percentage and LNAPL was found to occur up to 35% saturation. The true thickness of the LNAPL intervals was often less than the thickness that accumulated in piezometers placed directly in the core holes. An estimate of the remaining LNAPL was determined using true formation thickness and the measured LNAPL saturation.

In 2005, 3 additional recovery wells were added, and this expanded system recovered over 6,000 gallons per month for approximately 5 months. A steady decline has recently been observed, with two wells no longer recovering LNAPL. LNAPL has also been completely eliminated in several wells that formerly contained as much as 3 to 4 feet of LNAPL.

Floyd|Snider, 601 Union Street, Suite 600 Seattle, WA 98101; Fax (206) 682-7867
[1]Phone (206) 292-2078 ext. 2166; E-mail tom.colligan@floydsnider.com
[2]Phone (206) 292-2078 ext. 2167; E-mail stephen.bentsen@floydsnider.com

Prognosis on Stormwater Infiltration – Moving from Disposal to Reclamation

Daniel Scarpine, P.E.[1] and Calvin Noling, P.E. [2]

Infiltration of urban and industrial stormwater is often considered a best management practice for stormwater "disposal". However, stormwater "disposal" now appears to be a significant groundwater and surface water contamination pathway. Even more disturbing, several current superfund sites have shown recontamination pathways exist in the stormwater and groundwater. This presentation will focus on the art and science of stormwater reclamation tailored to stormwater/groundwater/surface water interaction. During the talk we'll discuss the changing stormwater regulatory environment, present an overview of stormwater chemistry as it pertains to groundwater, and provide insights into tactics to prioritize selection of stormwater best management practices for pretreatment before infiltration. Finally, we'll share some real-world case histories of stormwater best management practices and practical considerations for infiltration and pretreatment design.

StormwateRx LLC, 3685 SE Malden, Portland, OR 97202, 800-680-3543, www.stormwaterx.com
[1] daniels@stormwaterx.com, 503-407-9320
[2] caln@stormwaterx.com, 503-545-7038

Stormwater Infiltration Risks and Benefits

Laurie Morgan[1]

Infiltrating stormwater into the ground where it may recharge groundwater is an important idea with benefits and risks. Counties and cities face the trade-off between encouraging recharge and facing a contamination risk for their aquifers.

Untreated stormwater that is too polluted to discharge into a lake, stream or Puget Sound may also pose a risk to groundwater quality without treatment.

The Clean Water Act requires that stormwater discharges to surface water be controlled. The Safe Drinking Water Act addresses "Underground Injection Control Wells," which includes stormwater discharges into drywells. With this law, untreated polluted stormwater could not be simply re-routed from surface water into the ground without consideration of the effect on groundwater quality.

Washington State regulates stormwater drywells under the Underground Injection Control (UIC) Program, within the Water Quality Program of the Dept. of Ecology. In 2006, the UIC rule was amended and the Technical Guidance for UIC Wells that Manage Stormwater was published. Pollution prevention and pre-treatment are used to protect water quality.

This talk will illustrate risks and benefits of stormwater infiltration with respect to hydrology and water quality, along with how the relevant groundwater quality laws and regulations function.

[1] *Hydrogeologist, Washington Department of Ecology, e-mail: lmor461@ecy.wa.gov, pH: (360)407-6483*

Evaluating Subsurface Discharge of Treated Municipal Effluent to Mitigate Potential Impacts to Surface Water Quality, Hermiston, Oregon

Dennis Orlowski[1], Stuart Childs[2]

The City of Hermiston, Oregon currently discharges treated effluent from its municipal wastewater treatment plant (WWTP) directly to the Umatilla River. With its current direct discharge system, the City is concerned that it will not be able to meet certain NPDES permit limits for its discharged effluent, in particular temperature during late summer months. As a means to mitigate potential water quality impacts to the Umatilla River, the City is investigating the feasibility of discharging a portion of its treated effluent, via either rapid infiltration basins or subsurface discharge galleries, to land adjacent to the WWTP. Subsurface cooling and polishing of treated effluent prior to its introduction to surface water bodies is a promising method to simultaneously meet NPDES discharge limits while maintaining or increasing flows in surface water systems.

Field pilot tests were conducted at a site adjacent to the Hermiston WWTP to evaluate the infiltration capacity of shallow sediments at the site, and to assess the fate and transport characteristics of applied water. The infiltration tests were performed by maintaining a constant level of potable water or treated effluent in an infiltration trench excavated in shallow sediments at the test site. During testing, water level and water quality parameters were periodically measured in fourteen site monitoring wells and the Hermiston Drain, a minor tributary of the Umatilla River that is adjacent to the test site and is a likely groundwater discharge location. Electrical conductivity and temperature were found to be effective natural tracers for the test water due to significant differences in these parameter values between the test water and native groundwater.

Results from the preliminary infiltration tests indicate that discharging a portion of the City's treated effluent via subsurface infiltration appears to be feasible. During the tests groundwater continued to flow towards the Hermiston Drain, and thus a significant volume of effluent is likely to be returned to the Drain and thus the Umatilla River system after being conditioned in the shallow aquifer system. Data obtained from the initial tests, specifically head and temperature changes measured in site monitoring wells, were used to calibrate a VS2DHI numerical model developed to simulate fluid flow and energy transport at variable scales of infiltration. Long-term testing and evaluation enabled the City to:1) estimate infiltration capacity of the site; 2) quantify reductions in temperature and possibly other constituents of the effluent as it mixes with and migrates through the shallow aquifer; 3) assess the reversibility of temporary subsurface heating; and 4) better understand the relationship between the shallow groundwater system and adjacent surface water.

Kennedy/Jenks Consultants, 200 SW Market Street, Suite 500, Portland, Oregon 97201
[1] Phone : (503) 423-4071; E-mail : DennisOrlowski@KennedyJenks.com
[2] Phone : (503) 423-4002; E-mail : StuartChilds@KennedyJenks.com

Subsurface Discharge of Treated Municipal Effluent for Cooling and Ammonia Treatment Prior to Indirect Surface Water Discharge

Stuart Childs[1], Dennis Orlowski[2]

Subsurface discharge of treated effluent has long been practiced as an effective and low cost method of wastewater renovation and disposal. Both on-site systems for homeowners or other small flow dischargers and municipalities using rapid infiltration basins use subsurface flow to discharge treated effluent and provide some amount of additional water quality improvement. These systems are currently being proposed in the Pacific Northwest because they are effective in lowering effluent temperature, a key water quality concern for surface water.

When designing subsurface discharge systems, there are competing objectives that affect site selection. Two key ones are a) use of highly permeable sites with high water flow rates to minimize system size versus use of lower permeability sites that provide additional water quality improvements during flow and b) locating discharges to provide indirect recharge to surface water for flow augmentation versus discharge in locations that will discharge primarily to groundwater.

In this presentation, results from four field trials of subsurface discharge are presented to show the range of flow pathways and water quality effects. These include domestic wastewater discharge from a drainfield at a food processing facility, municipal treated effluent discharge in gravels adjacent to a river, municipal treated effluent discharge via rapid infiltration in sandy deposits 200 feet from surface water, and municipal treated effluent discharge in a floodplain hyporheic zone. Field data are presented to assess effects on temperature and nitrogen. Analysis of fields results are further evaluated using heat and water flow models to assess surface water – groundwater interactions and develop design parameters for subsurface discharge facilities.

Kennedy/Jenks Consultants, 200 SW Market Street, Suite 500, Portland, Oregon 97201
[1]Phone : (503) 423-4002; E-mail : StuartChilds@KennedyJenks.com
[2] Phone : (503) 423-4071; E-mail : DennisOrlowski@KennedyJenks.com

Shallow Aquifer Recharge (SAR) Projects in the Walla Walla Basin, Washington and Oregon: Efforts to Reverse Dropping Stream Flows and Groundwater Levels

Bob Bower[1] and Kevin Lindsey[2]

The Walla Walla Basin of southeastern Washington and northeastern Oregon is a structural and topographic basin in which basalt bedrock has been down-dropped and covered by up to 800 feet or more of Miocene (>10 million years old) to Recent alluvial strata. These alluvial strata consist of pebble to cobble gravel and conglomerate, sand and sandstone, weakly indurated mudstone, silt, and clay. An unconfined to semi-confined aquifer system displaying varying degrees of hydrologic connection with the Walla Walla River and its tributaries is hosted by these alluvial strata.

Historically, streams draining the adjacent Blue Mountains became braided as they entered the Walla Walla Basin. During the winter and spring wet season, as these streams spread out across the basin, a portion of stream flow infiltrated into the ground and recharged the alluvial aquifer system. During the dry summer and autumn season, groundwater returned to streams as base flow. Human modifications to this hydrologic system, including increased well pumping, stream modifications and diversions, and irrigation efficiency, have reduced the recharge to the shallow alluvial aquifer and ultimately base flow to streams. Several SAR pilot projects currently are underway to assess the feasibility of groundwater recharge, in conjunction with other efforts, to address water resource management issues in the Walla Walla Basin.

Multiple stakeholders, including watershed management groups, irrigations districts, non-profit groups, and local government are involved in these SAR projects. The oldest of these projects, the Hudson Bay Project which began in 2003, is actively testing the feasibility of recharge and its beneficial effects on water level and water quality via existing irrigation canals and a series of newly-constructed spreading basins in Oregon. In the early spring of 2006 the Hall-Wentland project, building on earlier private landowner efforts, began recharging the shallow aquifer via existing ditches and spreading of water on fields. A third project, the Locher Road project planned for start up in the winter of 2006/2007, will use an existing gravel pit as a locus of shallow groundwater recharge. All of these projects use fall-winter-spring peak stream flows as the primary water source and are attempting to replace historical groundwater recharge lost because of historical changes to the Basin hydrologic system. The results of these testing efforts will be used to build a practical understanding of the use of SAR as another tool for conjunctively managing the Walla Walla Basin’s surface and ground water resources issues.

[1] Walla Walla Basin Watershed Council, P.O. Box 68, ,Milton-Freewater, Oregon 97862, ph. (541) 938-2170, fax (541) 938-2170, bob.bower@wwbwc.org
[2]Groundwater Solutions, Inc., 1020 North Center Parkway, Suite F, Kennewick, Washington 99336, ph. (509) 735-7135, fax (509) 735-7067, klindsey@groundwatersolutions.com

Aquifer Storage and Recovery Permits in Washington State

Douglas H. Wood[1]

Chapters 90.03 and 90.44 of the Revised Code of Washington (RCW) were amended in 2000 to include Aquifer Storage and Recovery (ASR) project permitting under RCW 90.03.370, Water Code section that covers reservoir permits. These amendments authorized Ecology to formulate rules governing the permitting of ASR projects and these rules became effective in 2003 as Chapter 173-157 of the Washington Administrative Code (WAC).

ASR projects are defined under RCW 90.03.370(3) as “any project in which it is intended to artificially store water in the ground through injection, surface spreading and infiltration, or other department-approved method, and to make subsequent use of the stored water.” Exceptions include irrigation return flows, artificial recharge resulting from irrigation projects, water reclaimed under RCW 90.46, and to return flows regulated under RCW 90.44.130 and associated regulations for groundwater areas and sub-areas.

Chapter 173-157 WAC provides a framework within which applicants evaluate recoverable storage and impacts to existing water rights and the environment under conditional permits during project pilot stages. After completion of the pilot phases, projects are evaluated and permits may be extended, with recovery quantities and mitigation established based on interpretation and modeling of pilot project monitoring data.

The ASR Rule requires applicants to provide evidence that they have rights to the water which will be stored, provide a conceptual model (hydrogeological description) of the storage aquifer or aquifer system, submit a project operational plan, describe the legal framework for the project, evaluate potential environmental impacts, provide for mitigation when impacts are expected, and provide a project monitoring plan designed to fully test project feasibility and impacts.

Since 2003 the Northwest Regional Office of Ecology’s Water Resources Program has reviewed and approved three ASR permits and is currently reviewing a fourth. Other Ecology regional offices along with local entities are currently evaluating proposals for projects in the Walla Walla, Palouse, Wenatchee, Columbia and Yakima basins in Eastern Washington and in the Dungeness and Chimacum basins in Western Washington.

[1] Washington State Department of Ecology, Water Resources Program-Northwest Region, 3190 160th Ave. SE, Bellevue, WA 98008; Phone (425) 649-7077; Fax (425) 649-7098; E-mail dwoo461@ecy.wa.gov

Water Storage in the Eastern Palouse Basin, Washington

Bryony Stasney, L.HG.[1], Robert Buchert[2], Phil Brown, R.G., L.HG.[3]

The Eastern Palouse includes the westerly flowing drainages of the North Fork and South Fork of the Palouse Rivers and the communities of Pullman, Colfax and Palouse, WA and Moscow, ID. The drainages occur within Water Resources Inventory Area (WRIA) 34 and are divided by the north-south Washington – Idaho state line. Watershed Planning (Chapter 90.82 RCW) is underway in WRIA 34. Although this is a Washington State funded process, the WRIA 34 Planning Unit includes stakeholders and voting members from both Idaho and Washington. This membership reflects the cooperative working and planning relationships that occur within each state and across the state line.

Water supply for population, considering protection of water quality, was identified by the WRIA 34 Planning Unit as the primary water quantity concern in the Eastern Palouse. Significant groundwater level declines have been observed within the Grande Ronde basalt aquifer. The Grande Ronde basalt aquifer is the primary groundwater supply aquifer for the communities of Pullman, Moscow, Colfax and Palouse. The WRIA 34 Planning Unit elected to assess the preliminary feasibility of two water storage options for the Eastern Palouse to address their water quantity concern: 1) aquifer recharge to recover aquifer levels over the long term using enhanced surface infiltration at the contact between the basalts and crystalline basement rocks; and, 2) aquifer storage and recovery (ASR) to meet water demand and to offset groundwater use.

The concept of enhanced infiltration was developed on the south side of Kamiak Butte, over the geologic contact between the crystalline basement and basalts, where the basalts occur relatively close to the surface. The study recommends that the feasibility of enhanced infiltration be further developed, with preference for an infiltration ditch that would follow the contact between the basalt and the basement rocks.

The concept of Aquifer Storage and Recovery (ASR) considered: suitable receiving aquifers for storage water; availability of source water with acceptable water quality; collection and treatment alternatives for source water; and, potential locations for ASR wells. The study outlines the steps necessary to develop an ASR system, with a phased approach that uses existing information in conjunction with monitoring and targeted technical evaluations or tests that are necessary for permitting or design.

[1] Golder Associates Inc., 1200 West Ironwood Drive, Suite 102, Coeur d'Alene, ID 83814. Telephone (208) 676-9933; Fax (208) 676-8602; E-mail: bstasney@golder.com.

[2] Palouse Conservation District, 325 NW State Street, Pullman, WA 99163. Telephone (509) 332-4101; Fax (509) 332-0459; E-mail: palousecd@pullman.com.

[3] Golder Associates Inc., 9 Monroe parkway, Suite 270, Lake Oswego, OR 97035. Telephone (503) 607-1820; Fax (503) 607-1825; E-mail: pabrown@golder.com.

Sammamish Plateau Water and Sewer District's ASR Program

Scott Coffey[1]

On January 14, 2003, Washington State adopted a new chapter in the Administrative Code (WAC 173-157). This chapter establishes the standards for reviewing and permitting ASR project applications. As a result, water purveyors considering ASR as a water resource management tool are subject to increased, monitoring, evaluation, and reporting efforts.

Camp Dresser & McKee Inc. (CDM) recently prepared and obtained two 10 year ASR permits for the Sammamish Plateau Water and Sewer District for pilot testing to evaluate the effectiveness of an ASR program within its service area.
A key rule element for evaluating the program is determining the chemical and physical composition of the source waters injected and their compatibility with the naturally occurring water of the receiving aquifer.

In 2005, the District connected to a regional water supply comprised of treated surface water and initiated chlorine and fluoride treatment to its groundwater sources. The District uses both sources for the operation of its ASR program, which has produced various changes to the natural groundwater chemistry of the receiving aquifers during ASR pilot testing.

CDM and the District have collected water quality data during several pilot tests and developed a numerical groundwater model. Using the water quality data and the numerical groundwater model, CDM has simulated ASR testing to answer pressing environmental and storage/recovery assessment questions involving the ASR program.
In the presentation, CDM will:

- Provide an overview of the District's ASR program.
- Describe the District's monitoring and operational plan to track water quality changes as a result of ASR.
- Describe how SPWSD is using water quality and level monitoring data to evaluate storage and recovery.
- Illustrate the path of the recharged water using the numerical groundwater model to develop plan and cross-section time-series plots of the recharge water particles moving through the aquifer system.
- Illustrate the response to native water quality conditions recorded during the injection, storage and recovery phases.
- Describe and illustrate positive results of recharging treated surface water into an aquifer with naturally elevated arsenic levels.

[1] *Camp Dresser McKee (CoffeySE@cdm.com)*

Status and Prospects for Bioremediation of Chlorinated Ethene Dense Non-aqueous Phase Liquids (DNAPLs): An ITRC Perspective

R. Wymore[1], N. Akladiss[2], Dibakar (Dib) Goswami[3], P. Hadley[4], P. Harrington[5], E. Hausamann[6], E. Hood, C. Lebron[7], D. Major[8], F. Payne[9], K. Sorenson[10], H. Stroo[11], L. Syverson[12], A.Willet[13], I. Tasker[5], and J. Brannon[5]

In 2004, the Interstate Technology & Regulatory Council (ITRC) established a Bioremediation of Dense Non-Aqueous Phase Liquids (DNAPLs) Team to develop a technical and regulatory guidance document on this topic by the end of 2007. The first effort was to review the status of the technology, culminating in publication of a *Technology Overview of In Situ Bioremediation of Chlorinated Ethene Dense Non-Aqueous Phase Liquids (DNAPLs) in Groundwater*. This document, available at www.itrcweb.org, presents a technological overview of in situ bioremediation (ISB), including design issues for an ISB system targeting chlorinated ethene DNAPL source zones. It reviews basic microbiological, physical, and chemical fundamentals underlying ISB for source zones, and engineering options available for technology implementation. It also presents a review of applications to date, which show that ISB is cost competitive with other source depletion technologies, and has often resulted in impressive mass removal or reductions in groundwater concentrations. Finally, the document summarizes the advantages and disadvantages of ISB for source zones, and provides initial guidance on it efficacy in differing hydrogeological settings and source characteristics.

Building on the *Technology Overview*, a Case Study Forum was held in March 2006 to document a thorough and critical review of six DNAPL bioremediation projects by a panel of invited experts from industry, academia, and the regulatory community. The panel recognized that bioremediation is not applicable for all DNAPL sites; niches of most confident application include sites with relatively low strength sources, relatively homogeneous and permeable subsurface environments, sufficient time to use this slower technology, sufficient access for substrate injections, hydraulic capture or sufficient down gradient buffer zones to ensure treatment effects do not impact potential receptors and cost as a major technology-selection factor

1-Camp Dresser & McKee; 2- Maine Department of Environmental Protection; 3- Washington State Department of Ecology, 4- California Environmental Protection Agency; 5- EnDyna, Inc.; 6- New York State Department of Environmental Conservation; 7- GeoSyntec Consultants, Inc.; 8- U.S. Naval Facilities Engineering Service Center; 9-ARCADIS; 10- HydroGeoLogic, Inc; 11- Virginia Department of Environmental Quality; 12- Haley & Aldrich, Inc; 13-Northern New Mexico Citizen's Advisory Board
Point of Contact:: Dibakar (Dib) Goswami, WA state Department of Ecology, 3100 port of Benton Blvd., Richland, WA 99354; Ph: 509-372-7902; fax; 509-372-7971; E-Mai:dgos461@ecy.wa.gov

Anaerobic Bioremediation of Groundwater Using Edible Oil Substrate EOS® In an Unconfined Groundwater Aquifer

John Sankey[1], P.E., Matt Sedor, M.S. and Yonathon Yoseph[2], P.G., C.H.G., Jeff Baker[3]

To treat groundwater contaminants in situ, enhanced anaerobic bioremediation processes can be stimulated through addition of soluble substrates. At a dry cleaners site located in San Jose, California, the goal was to find a substrate that is long lasting and easily distributed into the saturated soils. After evaluating several alternatives, in situ bioremediation using an emulsified edible oil substrate (EOS®) was selected as the preferred alternative for groundwater remediation.

At this site, the impact of injecting substrate into the upper aquifer was observed in an unconfined groundwater aquifer. Tetrachloroethene (PCE) breakdown was monitored at three locations across the site. The highest PCE and trichloroethene (TCE) concentrations in the January 2005 pre-EOS injection-sampling event were detected in well MW-1A at concentrations of 8,500 µg/L and 200 g/L, respectively. The highest cis-1,2-dichloroethene (cis-DCE) was detected in well MW-1A at concentration of 160 µg/L. Trans-1,2-DCE (trans-DCE) was also detected and only small amounts of VC were detected in the groundwater prior to treatment.

After 2.5 months post-injection (July 2005), the PCE concentration in MW-1A was reduced to 18 µg/L and the TCE concentration was reported to be 100 µg/L. The concentration of cis-DCE had increased in MW-1A to 1,200 µg/L, suggesting the presence of enhanced bioremediation. No PCE, TCE, or 1,1-DCE was detected in the shallow wells during the October 2005 sampling event (6-months post-injection). Conversely, the concentration cis-DCE continued to increase and was detected in well MW-1A at 2,300 µg/L. By six months after treatment, VC was readily detected in each of the monitor wells at concentrations of 39, 200, and 35 µg/L in MW-1A, MW-2, and MW-3, respectively.

Sub-reportable levels of PCE, TCE, and 1,1-DCE were detected again in the shallow wells during the January 2006 sampling event (9-months post-injection) The concentration of cis-DCE also began to decrease and was detected in well MW-1A at 630 µg/L. By nine months after treatment, VC was readily detected in each of the monitor wells at concentrations of 300, 40, and 88 µg/L in MW-1A, MW-2, and MW-3, respectively. By 12 months ethane was detected.

The results of the pre- and post-injection sampling of three wells in the treatment zone showed the rapid conversion of the aquifer to anaerobic reducing conditions favorable for reductive dechlorination to occur. The enhanced conditions resulted in rapid disappearance of PCE from 8,500 µg/L to below the MDL, reductions in TCE, and a measurable increase of cis-DCE and VC at all the shallow zone wells. Some methane is being produced, but ethane or ethene production has yet to be detected. The emulsified oil substrate (EOS®) is expected to continue to sustain favorable conditions for an extended duration. Continued monitoring is expected to eventually document to complete remediation of the site.

[1] *True Blue Technologies Inc.*
[2] *Remediation Sciences, Inc. msedor-rsi@sbcglobal.net*
[3] *Vironex, Inc.*

Bioremediation of a DNAPL Source Zone Through Injection of Food-Grade Vegetable Oil

Clinton L. Jacob[1], Benni Jonsson[2], and Henning D. Larsen[3]

Full-scale treatment of a trichloroethene (TCE) source zone began in August 2005 beneath an active manufacturing building near Portland, Oregon through injection of food-grade vegetable oil. This remedial effort targets an approximate 4,000 ft^2 source zone within a shallow, unconfined, alluvial aquifer of sand and gravel present from 10 to 30 ft below ground surface (BGS). Dense non-aqueous phase liquid (DNAPL) from a former vapor degreaser and TCE supply line was observed during drilling activities and the maximum baseline TCE concentration in groundwater (1,170,000 µg/L) exceeds the TCE solubility limit. Baseline monitoring documented complete reductive dechlorination (RD) of TCE to ethene in the source zone but less than desired levels of dissolved organic carbon concentrations to support long-term source zone depletion by RD.

Injection of the vegetable oil in the source zone is designed to sequester and treat contaminants through three primary mechanisms (Henry et al. 2004): 1) A reduction in source zone hydraulic conductivity and groundwater flux through the source zone due to emplaced oil. 2) Partitioning of dissolved TCE from groundwater and dissolution of contacted DNAPL to the vegetable oil organic carbon. Vegetable oil will slowly ferment, releasing partitioned/dissolved TCE back to groundwater under ideal conditions for complete RD. 3) Fermentation of the vegetable oil will release organic acids and hydrogen (electron donor) resulting in highly reduced aquifer redox and enhanced RD within the source zone and for some distance downgradient. This source zone treatment method was selected over other technologies on the basis of mass destruction vs. mass transfer, cost, and implementability beneath the active facility.

Comparison of baseline and post-injection groundwater monitoring indicates achievement of more highly reduced aquifer conditions, enhanced RD of TCE and breakdown products, and significant partitioning/dissolution of TCE mass to vegetable oil. At 10 months post injection, total organic carbon (TOC) concentrations have increased significantly in the source zone and up to 430 ft downgradient. Baseline nitrate- to sulfate-reducing conditions have progressed to methanogenic conditions. Complete RD of TCE through ethene and ethane end products is observed in the source zone and up to 430 ft downgradient. Vegetable oil recovered from the source zone aquifer contains up to 20,200 mg/kg of TCE (2 percent) reflecting significant DNAPL dissolution and partitioning.

[1] Landau Associates, 130 2nd Ave South, Edmonds, WA 98020; Phone (425) 778-0907; Fax(425)778-6409; cjacob@landauinc.com
[2] bjonsson@landauinc.com
[3] Oregon Department of Environmental Quality, 2020 SW 4th Ave, Suite 400, Portland, OR 97201; Phone (503) 229-5527; Fax (503) 229-6945; larsen.henning@deq.state.or.us

In Situ PCE and TCE Remediation Using Groundwater Recirculation Systems

Craig Dockter, R.G.[1] *and Joe Westersund, E.I.T.*[2]

In situ biological processes for breaking down tetrachloroethene (PCE) and trichloroethene (TCE) have been known for several years. Under the right conditions, some bacteria are able to remove chlorine atoms from these molecules, turning PCE into TCE, TCE into dichloroethene (DCE), DCE into vinyl chloride (VC), and VC into ethene. This biological treatment pathway transforms PCE and TCE contamination to a safe-end product. Bacteria can be added if necessary, but indigenous bacteria at most or perhaps all sites already have the capability for this anaerobic reductive dechlorination process. This discussion will focus on *in situ* treatment systems designed to create the conditions indigenous bacteria need to degrade PCE and TCE. Successful *in situ* treatment requires an understanding of: 1) site hydrogeology, 2) competing electron acceptors and their reactions, 3) the food source, and 4) nutrients needed for bacterial growth. At many sites, a groundwater recirculation system can control all of these parameters, often using existing monitoring wells or groundwater pump and treat systems. The advantages of a recirculation system include maintaining hydraulic control of contaminants, increasing the hydraulic gradient across the site, providing a controllable source of food and nutrients, and ensuring the food source comes in contact with the contaminants. Case studies at two former dry cleaning facilities are presented.

Hart Crowser, Inc., Five Centerpointe Drive, Suite 240, Lake Oswego, Oregon 97035; Fax (503) 620-6918
[1] *Phone (971) 327-9102; E-mail craig.dockter@hartcrowser.com*
[2] *Phone (971) 327-9107; E-mail joe.westersund@hartcrowser.com*

Laboratory-Scale Bismuth Phosphate Extraction Process Simulation to Track Fate of Fission Products

R. Jeff Serne[1], Mike J. Lindberg[2], and Tom L. Jones[3]

Four simulations of the bismuth phosphate precipitation process were performed to evaluate the fate of fission products through the first plutonium precipitation step and subsequent neutralization of the metals waste solution. The fate of the fission products in various bismuth phosphate process streams were analyzed using ICP-MS and gamma energy analysis techniques. Results show that <0.7% of Tc-99, <1% of Cs, and <2% of the Sr carry down with the plutonium product. Thus these isotopes should have remained almost exclusively within the metals waste stream that after neutralization was sent to Hanford's single shell tanks. These results on the fate of these key fission products suggest that past estimates of quantities (10% of each beta emitter) disposed to cribs with the first and subsequent cycle waste streams are inflated. The fate of other fission products such as lanthanides, trivalent actinides, zirconium, and selenium will be discussed.

The chemical composition of the neutralized metals waste, formed by pH reduction with sodium- hydroxide and carbonate was also determined. The fate of key fission products after neutralization follows. Technetium remains in the dissolved state from fuel dissolution through metals waste solution neutralization, thus ~99% of the technetium in dissolved irradiated fuel would have been disposed in the single-shell tanks. About 88% of the strontium in the metals waste solution precipitates during neutralization and thus would be found in suspended solids that would settle in the single-shell tanks. 63 to 73% of the cesium present in the metals waste solution remains in the dissolved state after neutralization. About 20 to 40% of the uranium found in the metals waste solution remains in the supernatant solution after neutralization. The amount of uranium present in the metals storage waste is so large that tens of grams per liter remain in the supernatant solution after neutralization.

The solids that settled out of the neutralized metals waste solution were washed in distilled water and characterized by XRD, SEM-EDS, and XRF. The process wherein acidic metals waste solution is neutralized prior to being sent to single-shell tanks for storage caused the precipitation of sodium uranyl phosphates and perhaps sodium(?)-uranyl carbonate and sodium-uranyl sulfate solid phases. The neutralized solids characterization and the chemical composition of the neutralized supernatant solution should prove valuable information to the ongoing studies of the uranium-rich fluids that were lost to the subsurface to the east of Tank BX-102 during an overfill event in 1951.

Pacific Northwest National Laboratory, K6-81, Richland, WA 99354; FAX (509) 376-4890
[1] Phone (509) 376-8429; E-mail jeff.serne@pnl.gov
[2] Phone (509) 372-2483; E-mail michael.lindberg@pnl.gov
[3] Phone (509) 544-0486; E-mail thomasjones0486@charter.net

Unsaturated Flow of Hanford Tank Waste Leachate Effects on Transport of Cs and Sr

Kenton A. Rod[1], R. Jeffrey Serne[2], and Wooyong Um[3]

A series of unsaturated column experiments were conducted to investigate the effect of simulated leaking tank waste on radionuclide transport through sediment from the Hanford site in Washington, USA. Previous studies have shown that the caustic simulated tank leachate (STL) solution with high ionic strength (I=2-8 M $NaNO_3$) and high pH (~14) dissolves primary minerals (quartz and clays) and forms secondary precipitates on mineral surfaces. The secondary precipitates include zeolite, cancrinite and sodalite. The dissolution followed by precipitation reactions alters the sediment pore structure as well as the soil surface properties.

Radioisotope mobility is affected by the combined reactions (dissolution and precipitation) occurring in the sediment as well as the solution saturation level of the columns. Past studies have demonstrated that adsorption of cesium to soil surfaces is higher than that of strontium. However, we found that strontium was retarded more than cesium when being transported with the STL. This is likely due in part to secondary precipitates incorporating the strontium into its structure, while cesium sorption is excluded by high Na concentration. The combined effect is that the majority of the retardation for strontium is due to secondary precipitation; not adsorption. Solution saturation levels, of the sediment, also impacted the retardation of both Sr and Cs, with lower saturation flow creating greater retardation.

Pacific Northwest National Laboratory, Applied Geology and Geochemistry, PO Box 999, P7-22, Richland, WA 99352; Fax (509) 376-4890
[1] Phone (509) 373-3077; E-mail kenton.rod@pnl.gov
[2] Phone (509) 376-8429; E-mail jeff.serne@pnl.gov
[3] Phone (509) 376-4627; E-mail wooyong.um@pnl.gov

Complexation of Technetium by Radiolytic Degradation Products of Organic Molecules: Implications for Subsurface Transport

Jonathan P. Icenhower[1], Bruce K. McNamara[2], Christopher F. Brown[3], and Ray E. Clayton[4]

Tank waste at Hanford, Washington State, contains radioactive elements as well as an assortment of co-disposed organic materials housed in single-shell (SS) or double-shell (DS) tanks. Many of the radionuclides are sequestered in the sludge fraction of the waste, but Tc, Cs, I and Sr reside in either the supernate or in voids in the saltcake. The combination of a high radiation field, high pH (>12), salinity, and heat has, over time, produced meta-stable and stable products that are difficult to anticipate by standard geochemical models.

Leaks from the SS tanks have contaminated vadose zone sediments with Tc in an unidentified form that is incompletely mobilized by 1:1 water extracts. Acid extracts of sub-samples reveals a higher concentration (by up to 50%) of Tc compared to the water extracts. Extracts taken over time intervals indicate that the difference cannot be attributed to a diffusion-limited process. The extract behavior is surprising since Tc is expected to be in the pertechnetate form (TcO_4^-) and should, therefore, be indifferent to the identity of the solution extract.

A possible explanation for the behavior of Tc is that a fraction of it exists as a reduced aquo (H_2O) organometallic complex with carbonyl (CO), nitrosyl (NO^+) or other simple radiolytic degradation products. Such organometallic complexes have been tentatively identified in supernatant samples from DS tanks based on x-ray absorption near-edge structure (XANES) measurements. These molecules possess an overall positive or neutral charge and would, therefore, interact with sediment particles differently than pertechnetate.

Our experiments reveal the stability of simple organometallic complexes. We performed batch partition coefficient (K_d) and saturated column tests to elucidate the transport behavior of the organometallic complexes of Tc. Our data explains the immobility of a fraction of the Tc in contaminated soils and show that the amount of Tc thought to be present is an underestimate of the true value. Slow oxidation and release of this

fraction of Tc may occur over time, resulting in a continuous source of Tc to groundwater. Fate and transport models for Tc may, accordingly, need to be adjusted.

[1]*Pacific Northwest National Laboratory, Applied Geology and Geochemistry, 902 Battelle Blvd., MSIN: K8-81, Richland, WA 99352; FAX (509) 376-5368; Phone (509) 372-0078; E-mail jonathan.icenhower@pnl.gov*
[2] *Phone (509) 376-1408; E-mail bruce.mcnamara@pnl.gov*
[3] *Phone (509) 376-8389; E-mail Christopher.brown@pnl.gov*
[4] *Phone (509) 372-2526; E-mail ray.clayton@pnl.gov*

Development of Analytical Methods for Anionic Fission Products and Application to Sediment and Groundwater Samples from Tank Farm Waste Management Areas

Christopher F. Brown[1], P. Evan Dresel[2], Keith N. Geiszler[3], and R. Jeffrey Serne[4]

99Tc is a contaminant of interest at numerous nuclear facilities because it is quite mobile in subsurface environments and is a key contributor to long-term risk. However, as a mono-isotopic fission product, 99Tc is limited in its use as a signature to differentiate between different waste disposal pathways that could have contributed to subsurface contamination at these facilities. Ruthenium fission-product isotopes are attractive analogues for the characterization of 99Tc sources because of their direct similarity to technetium with regard to subsurface mobility, their large fission yields, and low natural background concentrations. We developed an inductively coupled plasma mass spectrometry (ICP-MS) method capable of measuring ruthenium isotopes in groundwater samples and water extracts of vadose zone sediments. Samples were analyzed directly on a Perkin Elmer ELAN DRC II ICP-MS after a single pass through a 1-ml bed volume of Dowex AG 50W-X8 100-200 mesh hydronium-based cation exchange resin. Precise ruthenium isotopic ratio measurements were achieved using a low-flow Meinhard-type nebulizer and long sample acquisition times (150,000 ms). Relative standard deviations were maintained at less than 0.5% when the total ruthenium solution concentration was 0.1 ng/ml or higher. Application of this method using groundwater samples and vadose zone sediment water extracts from the Hanford Site showed that vadose zone sediments from borehole C4104 (emplaced adjacent to tank T-106) were contaminated by a single leak event. Further evaluation of groundwater samples collected from Waste Management Area T indicated that multiple sources (at least two) of contamination were present in the aquifer to the east of the T Tank Farm. The shallow groundwater samples had ruthenium isotopic ratios consistent with those measured in vadose zone samples from borehole C4104. Analysis of ruthenium isotopic ratios in depth-discrete groundwater samples collected from wells adjacent to (299-W11-25B) and east of (299-W11-45) the T Tank Farm, respectively, resulted in two distinct sets of isotopic ratio data. These results have led to the inference that a yet unidentified source, distinct from the T-106 tank leak in 1973, is responsible for the high 99Tc concentrations observed with depth in the aquifer underlying Waste Management Area T.

Pacific Northwest National Laboratory, PO Box 999, Richland, WA 99352;
[1] MS: P7-22; Phone (509) 376-8389; Fax (509) 376-4890; E-mail christopher.brown@pnl.gov
[2] MS: K6-96; Phone (509) 376-8341; Fax (509) 372-1704; E-mail evan.dresel@pnl.gov
[3] MS: P7-22; Phone (509) 376-3427; Fax (509) 376-4890; E-mail keith.geiszler@pnl.gov
[4] MS: P7-22; Phone (509) 376-8429; Fax (509) 376-4890; E-mail jeff.serne@pnl.gov

Hydrologic Impacts of a Proposed Infiltration Recharge Gallery on Groundwater-Flow Conditions Near *Richland, Washington*

Marcel P. Bergeron[1], Frank A. Spane[2]
David Tedeschi[3], and Michael Price[4]

Energy Northwest (ENW) is proposing reusing the existing infrastructure at the WNP-1 and/or WNP-4 power plants and additional new facilities located on the Hanford Site north of Richland, Washington to withdraw and store water from the Columbia River for eventual use by the communities of Richland, West Richland, Kennewick, and Pasco under their existing Quad-Cities water permit. A requirement of the water permit is to return one-third of the water pumped (mitigation water) back to the Columbia River during low-flow months (i.e., July and August). Several storage and mitigation water-facility design systems are currently being considered by ENW; however, maximizing use of recharge/infiltration galleries (coupled with a surface-water storage facility) for returning mitigation water to the river is the favored design option.

Analytical and numerical models were used to assess the hydrologic impact of a proposed ENW groundwater-recharge/infiltration gallery. Based on a maximum, upper recharge volume of 42,980 acre-ft and anticipated operational facility conditions, the effects of the proposed ENW infiltration gallery are expected to impose only temporal, localized impact on the existing Hanford Site groundwater-flow conditions. A high percentage of the infiltrated water is predicted to discharge to the Columbia River during the active discharge period to the gallery and the following recovery period prior to the next infiltration cycle. The modeling results also indicate that the anticipated predicted mound height from the infiltration gallery is highly dependent on the hydraulic conductivity (permeability) and, to a less extent storativity (specific yield) of the Hanford formation underlying the site. This sensitivity of mound height with respect to these parameters emphasizes the importance of characterizing the hydraulic and storage characteristics of this highly permeable hydrogeologic unit over the planned facility area, so that the infiltration gallery system can be optimally designed and located.

Pacific Northwest National Laboratory P. O. Box 999, Richland, WA; Fax (509) 372-6089
[1] Pacific Northwest National Laboratory Phone (509) 372-6104; E-mail marcel.bergeron@pnl.gov
[2] Pacific Northwest National Laboratory, Phone (206) 376-8329, E-mail frank.spane@pnl.gov
[3] SAF Productions Phone(509) 554-6131; E-mail david@safproductions.net
[4] Energy Northwest, Inc. Phone (509) 377-8341, E-mail MWPRICE@engergy-northwest.com

Lakehaven Utility District's OASIS Project: an Update

Joseph E. Becker[1]

In the early 1980s, Lakehaven Utility District began well production from the highly transmissive Mirror Lake Aquifer. Incomplete recovery from production led to the idea of using the aquifer for Aquifer Storage and Recovery (ASR) purposes. Following initial testing of an ASR well in the late 80s and early 90s, the District seriously began to investigate the possibility of using the aquifer for large-scale ASR. The concept was titled "Optimization of Aquifer Storage for Increased Supply" or OASIS. A feasibility study in 1994 concluded that 29,000 acre-feet of water could be artificially recharged and later produced from the aquifer during annual production/recharge cycles using 27 dual-purpose ASR wells. During the following years, the OASIS project was not pursued due largely to the lack of clear water law regarding the ownership of artificially recharged water. In 2000, the Washington Legislature clarified the issue, largely as a direct response to the OASIS project, and later that year, the District submitted a water right reservoir application for the project. Following rule-making at the Department of Ecology, Ecology began processing the application in 2003 providing the District and other stakeholders with a draft ROE in September 2005. Following negotiations with the District and tribal interests, an amended ROE was written in May 2006. A final approved Reservoir Permit for the project was received by the District in September 2006.

The permit is phased, with two 6-year pilot phases and eight 6-year operational phases. The permit was initially issued for the pilot phases (12 years). Ecology approval and SEPA processing must be accomplished to proceed to subsequent phases. The maximum Qa during the pilot phases is 5,000 acre-feet. Qa is added with each additional phase, so that under the final phase, the permit allows the District to use the Mirror Lake Aquifer to store up to 29,000 acre-feet of water. Injected water must come from existing ground and surface water rights and can occur from November to May at a rate of 54,000 gpm at full build out. Recovery, also at rates up to 54,000 gpm, is allowed from June through October. The permit is conditioned such that the District must address Ecology's concerns including induced leakage from surface water bodies and overlying aquifers, slope stability, potential land-surface subsidence and/or uplift, and water quality changes. As part of the conditions, the District is required to conduct additional field investigations and do extensive monitoring and reporting. The District has begun work on Phase 1. This phase will set up field monitoring of springs and local streams, construct additional monitor wells, install a new ASR well, conduct ASR testing using ground water as a source, and model the aquifer. The second phase will expand on the testing, using surface water as a source. In related work, the District has investigated the feasibility of infiltrating highly treated, reclaimed wastewater on the Federal Way Upland to offset projected declines in upper aquifer water levels resulting from the operation of OASIS.

[1] *Robinson, Noble & Saltbush, Inc., 3011 S. Huson Street, Suite A, Tacoma, WA 98409; Telephone (253) 475-7711; Fax (253) 472-5846; E-mail jbecker@robinson-noble.com*

Implications of ASR Recharge in a Basalt Aquifer, City of Walla Walla

Michael Klisch, L.Hg.[1] and David Banton, L.Hg.[2]

The City of Walla Walla has been operating an Aquifer Storage and Recovery (ASR) system since 2000, recharging over 3 billion gallons of treated drinking water to the Columbia River Basalt aquifer, at rates up to 900 MGal per year. Since the start of ASR, the City has been monitoring water levels and water quality to evaluate changes in the water balance and water quality.

Recharge of the basalt aquifer, in conjunction with stabilization of pumping, has helped offset declining water levels in portions of the basalt aquifer, particularly near Wells No. 1 and 4. Flowing artesian conditions were re-established at Well No. 4 and an irrigation well when ASR operations started at Well No. 6 in 2003. Stored water is withdrawn first during pumping, rather than native groundwater in the basalt aquifer.

Analytical and numerical modeling indicate that recharge to the basalt aquifer results in leakage to the overlying sand and gravel aquifer, which has good continuity with surface water. The magnitude of leakage depends on the duration of recharge and the length of the storage period, with greater leakage occurring with longer storage durations. Thus, ASR operations could result in increased discharge to area streams, providing an environmental benefit. In comparison with pumping without recharge, ASR reduces the amount of water withdrawn from storage in the basalt and reduces leakage from the overlying aquifer.

There are slight differences in water quality between the recharge water and native groundwater. Recharge introduces colder water with residual chlorine and dissolved oxygen. During recharge and storage, the recharge water mixes with the native groundwater. Disinfection byproducts are detected at low levels during the later part of the storage period. Concentrations of disinfection byproducts decreased during the recovery period, and the composition of the recovered water evolves to the composition of native groundwater. There have been no customer complaints during recovery of the stored water.

Based on the City's six years of ASR operational experience, there have been no observed adverse impacts from ASR. ASR is providing an environmental benefit to the groundwater system by offsetting groundwater level declines in the basalt aquifer and providing stored water which is withdrawn before native groundwater. There are no adverse water quality impacts during ASR.

Golder Associates Inc., 18300 NE Union Hill Road, Suite 200, Redmond WA; 98052; fax (425) 882-5498
[1] *Phone (425) 883-0777, email mklisch@golder.com*
[2] *Phone (425) 883-0777, email dbanton@golder.com*

The City of Beaverton's Basalt-hosted ASR Project: A Successful Case Study

Larry Eaton[1] and David Winship[2]

Despite western Oregon's reputation for being wet, many cities find it difficult to meet peak water supply demand during the dry summer months. The reasons: minimum stream flow requirements, difficulty finding suitable above-ground reservoir sites in urban areas, and over-drafting of aquifers. An increasing influx of new residents and businesses has added to pressures on peak demand. The City of Beaverton (City) recognized these supply hurdles in the early 1990s and opted to evaluate and test aquifer storage and recovery (ASR) to help offset peaking demand. Oregon's Water Resources Department issued an ASR limited license to the City in July 1998.

The primary source of the City's drinking water is two river systems in the Coast Range. River water is processed by the Joint Water Commission treatment plant and piped to Beaverton. During the winter months, when river flows are high, treated water is stored in the basalt-hosted aquifer beneath the City. During the summer months, treated water is recovered to help meet peak demands.

Since 1999, the City has installed three ASR wells hosted in the basalt aquifer. In 2005, the City stored approximately 450 million gallons of treated drinking water using its ASR wells. The wells can provide up to 6 million gallons per day (mgd) of peaking capacity, which is about 35 percent of the City's summer peak day demand. The City drilled another ASR test well that will provide an additional 1 mgd.

The City has monitored the dynamic response of the basalt aquifer and collected key water quality data. Overall, the City's ASR system has been immensely successful. Key lessons learned include: basalts are suitable storage reservoirs; clogging of the aquifer is a concern, but can be managed; proper design of basalt wells is important; stored water adsorbs radon quickly; disinfection by-products have not been a concern; the native groundwater system has responded positively to ASR; spring creation/reactivation is a concern; use of ASR postpones costly conventional improvements; a detailed cost-benefit analysis, comparing alternative peaking sources, shows that ASR is a cost-effective alternative for the City.

Similar hydrogeologic and infrastructure conditions exist in Washington and would be favorable for ASR development. However, Washington's ASR regulations may be contributing to the slower development of ASR in Washington compared to Oregon.

[1]Groundwater Solutions, Inc., 55 SW Yamhill St., Suite 400, Portland, OR 97204; Phone (503) 239-8799 ext. 103; ax (503) 239-8940; E-mail leaton@groundwatersolutions.com
[2]City of Beaverton, P.O. Box 4755, Beaverton, OR 97076; Phone (503) 526-2434; Fax (503) 350-4052; E-mail dwinship@ci.beaverton.or.us

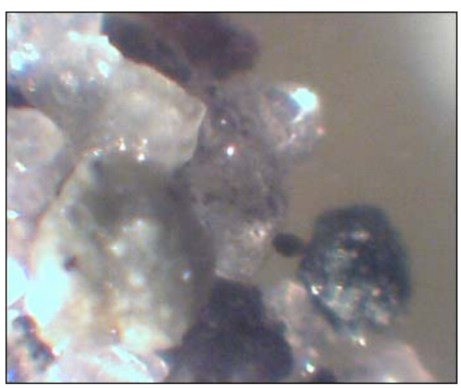
Basaltic Clay Chemistry of the Puget Sound: Relevance of Chemical and Optical Petrography to Hydrostratigraphy and Environmental Analysis

Nadine L. Romero[1]

Basaltic rocks constitute 90% of all igneous *extrusive* rocks on planet earth. In the Puget Sound the Eocene Crescent Basalt Formation (52 Ma) is a tholeiitic submarine to subaerial basalt expressed in outcrop as pillow, massive and columnar basalt forms. The volume of the unusual 'un-subducted' basalt is estimated at 12,000 cubic miles which is comparable to the Columbia Basalt volumes but considerably less than the behemoth Deccan Traps (500,00 mi^3). Despite their smaller volumetric size on a global scale they represent a significant parent rock type in the Puget Sound for chemical and mechanical weathering.

This paper explores the clay petrography of several deep weathering profiles in the Puget Sound including the Kennedy Creek Quarry basalts and new exposures unearthed in 2006 on the top of Tumwater Hill. Contributions of key anions and cations from the hydrolysis and dissolution of plagioclases, amphiboles, olivines and pyroxenes of the Crescent Basalts along with 2:1 and 1:1 clay and other by-products through springs, streams and saltwater substrate deserves more attention and will be the focus of this paper.

Sorption characteristics and sorptive behavior of sediments from weathered basalts not only affects aqueous geochemistry but may hold keys for biologists and water quality specialists about the concern for adherence and longevity of contaminants including viruses, bacteria and coliform in Puget Sound seds (a future research area).



(Plane Light 300X – Puget Sound River Silt - "Black Sand" -- Basaltic)

[1] *Principal Hydrogeologist, Ground Water Science Services, LCC (360) 786-8983*
Adjunct, South Puget Sound Community College, Olympia, WA *nadine@gwscience.com*

Characterizing the Hydrogeology of the Hyporheic Zone along the 300 Area of the Hanford Site, Washington

Rob D. Mackley[1] and Bradley G. Fritz[2]

The hydrogeologic framework of the near-shore subsurface in the 300 Area sets the template for groundwater-surface water interaction and contaminate transport. Identifying the shape and extent of the hydrostratigraphic units that control hyporheic exchange is critical in understanding and estimating the extent of contamination, identifying potentially impacted areas, and for modeling hyporheic exchange.

Recent and ongoing field investigations along the river corridor in the 300 Area are focused on defining the thickness and contacts of alluvium and sediments of the Hanford and Ringold formations. Although there are numerous existing wells in the 300 Area, they are located hundreds of meters from the river shoreline, and extending geologic interpretations from these locations requires extrapolation. A suite of land- and river-based methods are helping map the Hanford-Ringold contact in the hyporheic zone. These techniques include drive-point penetration testing, sediment coring, bathymetry, underwater video-camera surveys, sub-bottom profiling, hydrologic testing, and water sampling.

Once integrated and viewed holistically, the data collectively define a 2- and 3-dimensional interpretation of the hyporheic zone hydrogeology. The elevation of the Hanford-Ringold contact varies in elevation and depth below the ground surface along the shoreline. Underwater video and grab samples confirm that the Ringold Formation outcrops in the river channel – in places where it is not directly outcropping, it is typically overlain by a thin veneer of alluvium. Sediments above and below the Hanford-Ringold contact show several orders of magnitude difference in hydraulic conductivities as well as significantly higher uranium concentrations, which support the hypothesis that the tight Ringold sands and gravels act as a confining layer. These new results allow us to more confidently estimate the area of impact, understand hyporheic exchange, and provide geologic layers as input to transport and reactive models.

Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352
[1]Field Hydrology and Chemistry Group, MS K6-96; Phone (509) 373-5197; E-mail rob.mackley@pnl.gov
[2] Environmental Characterization and Risk Assessment Group, MS K6-75; Phone (509) 376-0535;
E-mail bradley.fritz@pnl.gov

Geologic Framework of the Suprabasalt Sediment Aquifer System, Columbia Basin Groundwater Management Area (GWMA), East-Central Washington

Kevin Lindsey[1] and Terry Tolan[2]

Continental clastic sediments overlying Columbia River basalt (suprabasalt sediments) host significant quantities of relatively shallow groundwater in parts of the Columbia Basin. Where the suprabasalt sediment aquifer system is present, it commonly serves as the primary water source for individual family and small system water wells. Areas where this aquifer system commonly yields usable quantities of groundwater generally include: (1) large structural basins like the Quincy and Pasco Basins, (2) sediment-filled channeled scabland coulees, (3) areas where large-scale irrigation has occurred, and (4) low areas adjacent to the Columbia River. Because the suprabasalt sediment aquifer system generally is shallower than basalt aquifers, it is a preferred target for small-scale water supply wells but, also because of its depth it is generally more vulnerable to contamination from surface and near surface sources.

Given its value as a water resource, vulnerability to potential contamination, and frequent use by individuals and small water systems, GWMA stakeholders in 2003 decided to map the basic geologic framework of this aquifer system. The objective of this mapping was to better understand physical geologic controls on groundwater movement, distribution, and recharge. These maps include structure contour and isopach maps of major lithostratigraphic units, plus facies maps showing variations in coarse (sand and gravel) and fine (silt and clay) content. Units mapped include coarse (sand and gravel) Quaternary deposits, fine-grained Quaternary loess, Plio-Pleistocene caliche, fine-grained upper Ringold Formation strata, and coarse-grained Ringold Formation sand and conglomerate strata.

This mapping reveals basic trends having implications for groundwater occurrence, movement, and contamination in the GWMA. High porosity flood deposits, although locally widespread, are commonly restricted to narrow linear tracts. Low porosity loess caps much of the eastern GWMA region, acting to limit downward moisture movement. Caliche, although a potential local perching horizon, is discontinuous and not regionally significant. Fine Ringold strata are widespread forming an important perching horizon except where significant fluvial sand deposits are present. Conversely, Ringold conglomerate is generally not widespread, but where present can be an important water producer. Basalt highs found throughout the GWMA form lateral barriers in the sediment aquifer system, generally leading to compartmentalization with essentially no regional interconnection.

Groundwater Solutions, Inc., 1020 North Center Parkway, Suite F, Kennewick, Washington 99336; ph. (509) 735-7135; fax (509) 735-7067

[1] *Lindsey e-mail: klindsey@groundwatersolutions.com*

[2] *Tolan e-mail: ttolan@groundwatersolutions.com*

Effects of Ice Age Flooding on the Hydrogeology of the Hanford Site

Bruce N. Bjornstad[1] and George V. Last[2]

Ice Age floods, mostly from Pleistocene outbursts of glacial Lake Missoula, profoundly shaped the subsurface hydrostratigraphic framework, which controls the movement of moisture and contaminants through the vadose zone and unconfined aquifer beneath the Hanford Site. As many as 100 floods occurred during the last glacial cycle (15-20k years ago); many more floods may have occurred during previous glacial cycles over the last 1-2 million years. During each of these cataclysmic events hundreds of cubic kilometers of water rushed into the Pasco Basin, eroding the pre-existing landscape, depositing vast quantities of sand and gravel on the Hanford Site, and delivering a pressurized pulse of water (up to 300 m deep) to the vadose zone. The earliest floods debouched into the Pasco Basin onto an alluvial plain of the ancestral Columbia River, which crossed the Hanford Site and flowed through Gable Gap. With each Ice Age flood, Cold Creek bar accumulated and prograded eastward, eventually defeating the Columbia River and permanently diverting its course north of Gable Mountain. Due to temporary slowing and expansion of floodwaters in the Pasco Basin, deposition dominated over erosion, particularly to the south where flood deposits are up to 100 m thick. Most erosion was limited to the northern and eastern portions of the site where channels were cut into the Ringold Formation and Columbia River Basalts, and an anastomosing channel network developed atop the Cold Creek unit. Flood channels were partially backfilled with heterogeneous, poorly sorted mixtures of flood gravel, sand and silt. Thick sequences of horizontally laminated sand were deposited adjacent to flood channels. Around the margins of the basin graded beds ($\leq$1 m thick) of sand, intercalated with silt, were deposited during waning stages of flooding.

Today the movement of groundwater and contaminants through the unconfined aquifer is largely controlled by buried paleochannels containing high-permeability flood gravels. In contrast, migration of contaminants in the vadose-zone is strongly influenced by inherent anisotropy and complex stratigraphy, especially in the finer-grained flood facies. Fine-grained facies not only promote the lateral migration of moisture, particularly along strongly contrasting bed interfaces, but also tend to have greater cation-exchange capacity and ability to retard metal-like radiological contaminants.

Pacific Northwest National Laboratory, Applied Geology and Geochemistry Group, K6-81, Richland, WA 99354; FAX (509) 376-5368
[1] Phone (509) 373-6948; E-mail bruce.bjornstad@pnl.gov
[2] Phone (509) 376-3961; E-mail george.last@pnl.gov

Separating Naturally Occurring Tidal Dilution from Degradation Processes in a Natural Attenuation Analysis at a Nearshore Site

Michael Riley[1], Jill Lantz[2], Allison Crowley[2], Mark Larsen[2], Marilyn Guthrie[3]

Natural attenuation of petroleum contaminants in groundwater is largely due to a combination of dilution, dispersion and degradation. Washington Department of Ecology guidance for evaluating natural attenuation at petroleum contaminated sites focuses on attenuation due to degradation rather than attenuation due to dilution or dispersion. Because dilution and dispersion are naturally occurring attenuation processes in groundwater, attenuation due to these processes must be distinguished from attenuation due to degradation to be consistent with the Ecology guidance. An innovative approach using a combination of groundwater modeling and analysis of trends in groundwater quality data was developed at the Terminal 30 site in Seattle. The groundwater modeling approach used the USGS SEAWAT code to simulate saltwater intrusion at the shoreline. The attenuation of salinity inland from the shoreline was used to identify attenuation due to dilution and dispersion since salinity acts as a conservative tracer. The model was then used to simulate the dilution and dispersion of an upland dissolved-phase petroleum plume in groundwater where petroleum concentrations declined substantially between the source area and the shoreline. This modeling analysis was used to estimate the decline in concentration due to dilution and dispersion. Attenuation that was not explained by dilution and dispersion was evaluated using time-series analysis and the BIOSCREEN analytical model. Using this approach, first-order degradation rates were developed from both the time-series and BIOSCREEN analysis. This methodology provides a means of assessing natural attenuation due to degradation processes using existing data at nearshore sites.

[1]*S.S. Papadopulos & Associates, Olympia, WA 360-709-9540, mriley@sspa.com*
[2]*The Retec Group, Seattle, WA 206-624-9349, JLantz@retec.com; ACrowley@retec.com; MLarsen@retec.com*
[3]*Port of Seattle, Seattle, WA 206-728-3347, Guthrie.m@portseattle.org*

The Concept of Enhanced Attenuation of Chlorinated Solvents in Groundwater

Judie A. Kean, Dibakar (Dib) Goswami, and Kimberly A. Wilson[1]

Enhanced attenuation (EA) and enhanced bioremediation are terms being used at an increasing rate in the environmental field. While these remedial strategies are being used in combination with monitored natural attenuation (MNA), and other remedial source zone approaches, there has been no a definition or guidance for implementation at contaminated chlorinated sites.

The Interstate Technology and Regulatory Council (ITRC) Enhanced Attenuation: Chlorinated Organics (EACO) team includes members from nine state regulatory agencies, industry, federal agencies, including the Department of Energy (DOE), academia, and stakeholders. The EACO team and the DOE MNA/EA for Chlorinated Solvents project team have formed a partnership to develop the concept of Enhanced Attenuation and to provide regulators and the community with new, viable decision process for implementation of EA. One of the first products of the team was a Web-Based Survey which was sent to state regulators in 2005. Based on the information generated from that survey, the team has developed an EA Fact Sheet, Case-Study Database, Web Based Resource Guide, and a Decision Tree Diagram with supporting documentation. The EA Decision Tree provides a clear and concise pathway that includes the evaluation of plume stability, decisions on the remedial pathway, and then the evaluation of Enhancement options. It is anticipated that the EA Decision Tree will provide regulators and others with guidance in evaluating the overall site conceptual model and incorporating a phased-complete approach for site rehabilitation

[1] *Interstate Technology and Regulatory Council, 444 North capitol street, NW; Suite 445; Washington, D.C. 200001; Ph: 509-372-7902; fax: 509-372-7971; E-Mail: dgos461@ecy.wa.gov*

In-Situ Treatment of Hexavalent Chromium and TCE at the Boomsnub/Airco NPL Site in Vancouver, WA

Glenn A. Hayman, LHg[1], Sharon L. Bailey, PE[2], Eric Marhofer, EIT[3], Michael S. Resh[4]

A groundwater pump and treat system has been operating at the Boomsnub/Airco NPL Site in Vancouver, WA since 1993. This system was expanded as the extent of the hexavalent chromium (Cr^{+6}) and TCE plumes were defined. In 1997 the end, or toe, of the plume was established by EPA and extraction wells were installed.

Beginning in 2003, the toe area was pulse pumped in an attempt to remove the last of the contaminated groundwater from this area. Repeated rebounding of TCE and Cr^{+6} concentrations showed that groundwater extraction was not effective at removing the contaminants in this hot spot area. The hot spot area is believed to be located in the silt layer approximately 80 ft to 90 ft below ground surface.

Earlier studies at the site showed that in the silt and clay aquitard below the sand aquifer conditions support the natural attenuation of the TCE and Cr^{+6}. Enhancing these conditions was seen as the most viable alternative for in-situ remediation of the contaminants. Five treatment products were evaluated. Of those products, we selected EHC-M™ for the hot spot treatment. EHC-M is made by Adventus Group and combines enhanced biological treatment and ZVI technologies.

Two general treatment designs were considered: permeable reactive barrier and area treatment. We elected to proceed with an area treatment design because of the slow rate of contaminant migration. A focused geoprobe investigation was conducted to further characterize lithology and the document pre-treatment groundwater quality.

In late September 2006, the EHC-M injection was applied in the hot spot area. Application was by injection of a slurry with a geoprobe on a grid at 32 locations. Injection was in a top down fashion with 50 pounds of EHC-M injected every 2 feet into the bottom 10 feet of the aquifer for a total of 300 pounds of EHC-M per injection location.

In November, a monitoring well was installed in the treatment area so that remediation progress could be monitored. This well is sampled on a quarterly basis. Up to date results will be presented and discussed.

EA Engineering, Science, and Technology, Inc. 12011 NE 1st St., Suite 100, Bellevue, WA 98005. Telephone (425) 451-7400, Fax (425) 451-7800
[1] Email: gah@eaest.com
[2] Email sbailey@eaest,com
[3]Email: emarhofer@eaest.com
[4]The BOC Group, 575 Mountain Ave, Murray Hill, NJ 07974, Telephone 800-932-0803 x1452, Fax 908-771-1203, Email: mike.resh@boc.com

USING DISSOLVED HYDROGEN MEASUREMENTS TO ASSESS AND MONITOR BIODEGRADATION OF CHLOROETHENES IN GROUND WATER

Stephen E. Cox[1], Richard S. Dinicola[1], and Reagan L. Huffman[1]

Dissolved hydrogen concentrations have been monitored annually since 1996 in the chloroethene-contaminated ground water beneath a former landfill at Naval Undersea Warfare Center (NUWC), Division Keyport, Washington, because of their significant influence on the occurrence and rate of chloroethene biodegradation. Ground-water oxidation-reduction (redox) conditions, defined as the predominant microbial terminal electron acceptor present in the aquifer, were also determined annually using dissolved hydrogen concentrations interpreted in the context of other redox sensitive species, including dissolved oxygen, nitrate, ferrous iron, sulfate, sulfide, and methane.

Measurement of dissolved hydrogen has helped overcome difficulties inherent in using traditional geochemistry data for identifying areas favorable for different biodegradation processes. At NUWC, Division Keyport, dissolved hydrogen concentrations and redox conditions in many wells have varied considerably over time, but consistent spatial patterns and temporal trends were discernable. Areas where dissolved hydrogen concentrations exceeded 1 nanomole per liter have indicated regions of the strongly-reducing redox conditions that are most favorable for substantial biodegradation of high concentrations of chloroethenes. Changes in the extent of strongly-reducing ground-waters over time have been identified, particularly beneath the part of the former landfill where pavement was removed to facilitate phytoremediation.

[1]U.S. Geological Survey, 934 Broadway Avenue, Suite 300, Tacoma, WA 98402; Fax (253) 552-1582
Phone (253) 552-1600 secox@usgs.gov, dinicola@usgs.gov,rhuffman@usgs.gov

Modeling Surface / Ground Water Interactions in Whatcom County, Washington

Erik Pruneda[1], Michael Barber[2], Joan Wu[3], and Diana Allen[4]

During the summer and early fall months, withdrawals of ground water and surface water for municipal and irrigation uses can have adverse impacts on minimum instream flows necessary for ecosystem health. Recently, an agreement between Whatcom County, State of Washington, and the Washington State University has been established to create a tool to provide better understanding of the complex interactions between the surface- and ground-water resources in the Bertrand Creek and Fishtrap Creek watersheds. This tool will allow decision makers the opportunity to understand what impacts a placed well or wells at chosen pumping rate(s) have on the surrounding Bertrand and Fishtrap Creek instream flows. The basis of this tool will rest on response functions derived from MODFLOW modeling results.

By examining the physical settings previously identified in the basins, collection of additional field data, and using an existing regional ground-water model for the Abbotsford-Sumas aquifer to provide boundary conditions, a new local ground-water model was developed in Visual MODFLOW 4.1.

Our field investigation includes a seepage analysis of both Bertrand and Fishtrap Creeks and their tributaries, streambed hydraulic conductivity measurements, monitoring of static ground-water level in selected wells near each stream, and monitoring of stages of each stream. The seepage analysis conducted during the low-flow months of 2006 showed that both Bertrand and Fishtrap Creeks are well connected to the underlying aquifer. Streambed hydraulic conductivities were also collected at the same time to determine the rate at which water is interacting with the aquifer. Static ground-water elevations are being monitored by use of pressure transducers and will be used to calibrate the ground-water flow model. Surface water levels in each stream are being monitored using pressure transducers as well, and will be used in conjunction with the monitored static ground-water elevations to determine lag times between monitored wells and stream, as well as to develop a stage-discharge curve for each stream.

[1] *Graduate Assistant in Civil and Environmental Engineering, State of Washington Water Research Center, Washington State University, Albrook Hydraulics Lab 202B, PO Box 643002, Pullman, WA 99164-3002; Telephone (509) 335-9171; Fax (509) 335-1590; Email epruneda@wsu.edu*

[2] *Director, State of Washington Water Research Center, Washington State University, Albrook Hydraulics Lab 202B, PO Box 643002, Pullman, WA 99164-3002; Telephone (509) 335-5531; Fax (509) 335-1590; Email meb@wsu.edu*

[3] *Associate Professor; Department of Biological Systems Engineering, Washington State University, Pullman, WA 99164-6120; Telephone (509) 335-5996; Fax (509) 335-2722; Email jwu@wsu.edu*

[4] *Associate Professor and Chair, Department of Earth Sciences, 8888 University Drive, Simon Fraser University, Burnaby, B.C.; Email dallen@sfu.ca*

Hanford Site Groundwater and the Columbia River, South-Central Washington State

R. E. Peterson[1], M.D. Williams[2], and G.W. Patton[3]

The Columbia River is a gaining stream as it passes across the Hanford Site. Groundwater discharges into the river from aquifers underlying primarily agricultural land on one side of the channel, and from the aquifer beneath the Hanford Site on the other side. Because of contamination from past nuclear materials production, the discharge of groundwater from the Hanford side has received the most attention.

The Hanford aquifer discharges into the river along approximately 64 kilometers of shoreline, a portion of which is impacted by radiological and/or chemical contamination. Where defined, the thickness of the uppermost hydrologic unit along the shoreline typically falls in the range 3 to 10 meters. The river channel may incise this unit partially or completely, depending on location. Knowing the lateral limits of groundwater contamination, the lower extent of contamination, and the channel bathymetry, the area of riverbed where contaminated groundwater potentially discharges can be outlined. A subsurface zone of interaction is present where groundwater meets river water. Within this zone, variable hydraulic gradients influence the timing and rate of release of groundwater, and geochemical differences in the two water types influence the mobility of some contaminants.

Computer simulations indicate that the total discharge from the Hanford aquifer falls in the range 30 to 100 cubic feet per second (cfs). The river flows at an annual average rate of 120,000 cfs, with a typical seasonal range of 60,000 to 250,000 cfs, thus providing considerable potential for dilution of contaminants carried by groundwater. Also, release of contaminants today via the groundwater pathway is a fraction of what it was during the peak operating years (1950 through 1965), when reactor coolant was discharged at rates representing between 2 and 8 percent of the river flow, depending on stage. The coolant discharge from just one of the eight production reactors was an order of magnitude larger than the current estimate for total discharge from the aquifer.

River water quality along the Reach has been monitored since Hanford Site activities began in the 1940s. This monitoring has included coverage at the intake for the nearest downstream public water supply system (i.e., Richland). Although the influence of discharge from the Hanford aquifer is detectable, the Columbia River at the Hanford Site continues to meet all Washington State and Federal water quality criteria for human use, such as drinking water and recreation, and for protection of ecological resources.

Pacific Northwest National Laboratory, P.O. Box 999, Richland, Washington, 99352
[1] *Phone (509) 373-9020, fax (509) 376-2210; mail stop K6-75; robert.peterson@pnl.gov*
[2] *Phone (509) 376-5787, fax (509) 372-6089; mail stop K6-96; mark.d.williams@pnl.gov*
[3] *Phone (509) 376-2027, fax (509) 372-2210; mail stop K6-75; gw.patton@pnl.gov*

Stable Isotopic Constraints on Surface Water-Groundwater Interactions in the Upper Yakima River Basin, Washington

Carey Gazis[1], Sarah A. Taylor[2], Travis Hammond[3], Kathren Howarth[4]

Stable isotopes of hydrogen and oxygen provide a simple means to quantify sources and mixing ratios within a water budget. Natural isotopic variations in sources of groundwaters commonly exist. If the isotopic compositions of these source waters are known, then mass balance considerations can be applied to constrain their relative contributions to the groundwater. In this study, we use this method to understand surface water-groundwater interactions in the upper Yakima River basin.

The Yakima River is one of the largest rivers in Washington and its basin is one of the most intensively irrigated areas in the country. In the upper Yakima River basin, most irrigation is accomplished through diversion of waters from the Yakima River and its tributaries into a network of canals. These waters are applied to fields between the months of May and October, causing artificial recharge to groundwater during the summer months.

In this study, groundwater samples were collected from 25 domestic and municipal wells located along a transect perpendicular to the Yakima River through the Kittitas Valley. In addition, precipitation was sampled throughout the year and surface waters were collected from natural streams and irrigation canals. The hydrogen and isotope compositions of groundwaters were compared to the precipitation and surface water samples to constrain the origin of the groundwater samples.

Our results distinguish three different groups of groundwater samples. On the southwestern side of the transect, wells supplied by an aquifer within the Columbia River basalts are isotopically the lightest groundwaters within the basin. Their isotopic composition can be explained by recharge from spring snowmelt or by recharge from surface water derived from rivers to the east of the basin. In the center of the basin, groundwaters appear to be a mixture of spring snowmelt and local surface waters. Several shallow wells appear to be dominated by irrigation water, which is isotopically heavier than any other surface water. The third type of groundwater is found in deep municipal wells. These waters are isotopically distinct from the local meteoric water and may be derived from older precipitation or from local meteoric water that has undergone considerable evaporation.

[1] *Central Washington University, Department of Geological Sciences, 400 E. University Way, Ellensburg, WA 98926-7418; Telephone (509) 963-2820; FAX (509) 963-2821; Email cgazis@geology.cwu.edu,*
[2] *Central Washington University, taylorsar@cwu.edu*
[3] *Central Washington University, hammondt@cwu.edu*
[4] *Central Washington University, howarthk@cwu.edu*

Effects of Columbia River Discharge on Groundwater Elevations, Central Hanford Site, Washington

John P. McDonald[1]

The water-table elevation has been declining over much of the Hanford Site since the mid-1980s in response to curtailment of waste water discharges. During 2002-2003, the general declining trend was interrupted in the 200 East Area and vicinity. The rate of decline was reduced and the water-table elevation actually increased in some areas. The area affected correlated with a high conductivity paleochannel extending from the Columbia River through the 200 East Area and into the central part of the site.

Several hypotheses were investigated that could have explained this fluctuation, including 1) increased recharge from the nearby Rattlesnake Hills due to an increasing hydraulic gradient, 2) increased artificial recharge from an effluent disposal facility near the 200 East Area, and 3) decreased groundwater discharge from the study area due to a gradient effect from changes in Columbia River stage. To evaluate these hypotheses, the Thiessen polygon method was used to estimate the amount of additional water in storage above that expected if the water table had continued to decline normally. The result was 1.1×10^9 to 2.3×10^9 L for storativity values of 0.10 and 0.20, respectively.

The increase in recharge from the Rattlesnake Hills during the study period was ~1.0×10^7 L, or ~1% of the aquifer storage change estimate, thus ruling out this hypothesis. Inspection of water-level hydrographs in the 200 East Area show a visual correlation between discharges at the effluent disposal facility and the aquifer water-level response. During the study period, the volume of effluent released was 7.0×10^8 L above average, which accounted for 30 to 65% of the aquifer storage change estimate. This suggested that another factor also affected the water table.

The Columbia River stage was higher than normal during spring 2002. Even though the 200 East Area is ~10 km from the river, application of the Ferris method demonstrated that the water table could have been affected due to the presence of high conductivity sediments between the 200 East Area and the river. The discharge from the study area north toward the river was estimated to range from 3.1×10^9 to 9.6×10^9 L/yr, which is larger than the storage change estimate. Thus, a reduction in the hydraulic gradient due to a high river stage should result in a reduction of groundwater discharge from the study area toward the river, and thereby cause a relative increase in the amount of water in storage. Although not completely confirmed, high stage in the Columbia River may cause a water-table fluctuation and temporarily alter groundwater flow in the 200 East Area. This result suggests that stresses to an aquifer in high conductivity sediments may affect portions of the aquifer far away from the source of the stress.

[1] *Pacific Northwest National Laboratory, Field Hydrology and Chemistry Group, P.O. Box 999, MSIN K6-96, Richland, WA 99352; Telephone (509) 373-0362; Fax (509) 372-1704; E-mail john.p.mcdonald@pnl.gov*

6th Washington Hydrogeology Symposium

POSTERS

1. **Hydrogeologic Investigation of the Spokane Valley – Rathdrum Prairie Aquifer Study Area, Spokane County, Washington and Bonner and Kootenai Counties, Idaho:** *Sue Kahle, U.S. Geological Survey*	2. **A Longitudinal Hydraulic Analysis of River-Aquifer Exchanges:** *Christopher Konrad, U.S. Geological Survey*
3. **Hydrogeologic Investigations of the Orting Lake Plateau, Pierce County, Washington:** *Suzanne Sweet, Assoc. Earth Sciences, Inc.*	4. **The Application of In Situ Oxygen Diffusion for Remediation of Petroleum Hydrocarbons at an Active Retail Service Station in Seattle, Washington:** *Terry Crotwell, Cambria Environmental Tech, Inc.*
5. **A Stable Isotope Study of the Soil Water Budget Along a Climate Gradient:** *Travis Hammond, Central WA Univ Geology*	6. **The Liquid Effluent Retention Facility (LERF)—A Challenge for Groundwater Monitoring and Regulatory Compliance:** *Alisa Huckaby, WA Dept. of Ecology*
7. **Hydrogeologic Investigation of a Groundwater/Surface Water Interface at a Hillslope in King County, Washington:** *Sevin Bilir, King Co. DNR & Parks, Water & Land*	8. **Applications of an Electromagnetic Borehole Flowmeter for Hydrologic Characterization:** *Darrell Newcomer, Pacific NW Nat' l Lab-PNNL*
9. **Trends of Nitrate and Pesticides in Ground Water of the Columbia Basin Plateau, Washington, 1993-2003:** *Lonna Frans, U.S. Geological Survey*	10. **Measurement of Contaminant Discharge Into the Columbia River Along the Hanford Reach Using a Passive Flux Chamber:** *Donny Mendoza, Pacific NW Nat' l Lab-PNNL*
11. **Seasonal Changes in Groundwater Chemistry Due to Irrigation in the Kittitas Valley, Washington:** *Sarah Taylor, Central WA Univ Geology*	12. **Comparison of Percussion vs. Resonant-Sonic Coring Methods for Suprabasalt Sediments at the Hanford Site :** *Bruce Williams, Pacific NW Nat' l Lab-PNNL*
13. **Application of a Nitrate Fate and Transport Model to the Abbotsford-Sumas Aquifer, Whatcom County, Washington:** *Margo Burton, Western WA Univ Geology*	14. **Automated Water Level Monitoring and Three-Point Problems at the Hanford Site:** *Robert Edrington, Fluor Hanford, Inc.*
15. **Addressing Groundwater/Surface Water Interaction in Closed Basins with Regards to the Montana Water Rights Appropriations Process:** *Jane Madison, PBS & J*	16. **Macroscopic Investigation of Different Sorption Mechanisms between Selenite and Selenate on Hanford Sediments:** *Michelle Valenta, Pacific NW Nat' l Lab-PNNL*
17. **Naturally Occurring Arsenic in Groundwater from Glacial Deposits in King County, Washington:** *Eric Ferguson, King Co. DNR & Parks, Water & Land*	18. **Discrimination between Manmade and Natural Uranium with High-Resolution Spectral Gamma Logging:** *Rick McCain, S M Stoller Corp.*
19. **Effects of Timber Harvest on Groundwater Response to Precipitation Events Near Kalaloch, Olympic Peninsula, WA:** *Casey Hanell, Western WA Univ Geology*	20. **Application of Surface Complexation Modeling to Uranium (VI) Sorption on Hanford Sediments:** *Wooyong Um, Pacific NW Nat' l Lab-PNNL*
21. **The Importance of Ground-Water Discharges to the Loadings of Dissolved Inorganic Nitrogen to Lynch Cove, Hood Canal:** *Anthony Paulson, U.S. Geological Survey*	22. **Updated Carbon Tetrachloride Contamination Model in the 200 West Area, Hanford Site, Washington:** *Ken Moser, Vista Engineering Tech., LLC*
23. **Diurnal-Scale Groundwater Potentiometric Fluctuations -- a Possible Aquifer Characterization Tool:** *Ken Johnson, King Co. Metro*	24. **Technetium-99 Contamination in the Northern Part of the 200 West Area, Hanford Site, Washington:** *Virginia Rohay, Fluor Hanford, Inc.*
	25. **Importance of basalt stratigraphy in hydrogeologic studies and the compilation of stratigraphy of the Columbia River Basalt Group:** *Terrence Conlon, U.S. Geological Survey*

Hydrogeologic investigation of the Spokane Valley – Rathdrum Prairie Aquifer study area, Spokane County, Washington and Bonner and Kootenai Counties, Idaho

Sue Kahle[1] and John Covert[2]

The Spokane Valley–Rathdrum Prairie aquifer is the sole source of drinking water for more than 500,000 residents in Spokane County, Washington, and Bonner and Kootenai Counties, Idaho. The area includes the rapidly growing cities of Spokane, Spokane Valley, and Liberty Lake, Washington, and Coeur d'Alene and Post Falls, Idaho. Recent and projected urban, suburban, and industrial/commercial growth has raised concerns about future impacts on water availability and water quality in the Rathdrum-Spokane aquifer, and the Spokane and Little Spokane Rivers. The aquifer is highly productive, consisting primarily of thick layers of coarse-grained sediments—gravels, cobbles, and boulders—deposited during a series of outburst floods resulting from repeated collapse of the ice dam that impounded ancient glacial Lake Missoula.

The Washington Department of Ecology, Idaho Department of Water Resources, and U.S. Geological Survey are conducting a joint investigation of the Spokane Valley–Rathdrum Prairie aquifer to develop a comprehensive data set that will provide an improved scientific basis for ground- and surface-water management. Part of this data set includes an analysis of the hydrogeologic framework of the study area using historical and recently collected data. Hydrogeologic sections illustrate the extent and characteristics of the hydrogeologic units in the study area; an elevation map of the base of the Spokane Valley–Rathdrum Prairie aquifer illustrates the approximate extent of the bottom of the aquifer; and a map of fine-grained layers illustrates the extent and thickness of clay and silt deposits within the aquifer.

(1) U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Ste. 300, Tacoma, WA 98402; Telephone (253) 552-1616; Fax (253) 552-1581; E-mail sckahle@usgs.gov
(2) Washington State Department of Ecology, Eastern Regional Office, 4601 N. Monroe, Spokane, WA 99205; Telephone (509) 329-3539; Fax (509) 329-3529; E-mail jcov461@ecy.wa.gov

Hydrogeologic Investigations of the Orting Lake Plateau, Pierce County, Washington

Suzanne Sweet[1], Curtis Koger[1], Jennifer Saltonstall[1], Stanley Thompson[1]

The Orting Lake Plateau located in Pierce County, Washington is a glaciated upland in the southern Puget Sound Lowland truncated by the Puyallup River Valley to the west, Carbon River to the south and southwest, and South Prairie Creek to the east. To the north, the upland is partially dissected by Fennel Creek. Regional studies established the Pleistocene-age stratigraphy of the plateau to include several glacial and interglacial deposits such as (from oldest to youngest) the Orting Drift, Alderton Formation, Stuck Drift, Puyallup Formation and Vashon Drift. To delineate the hydrogeologic conditions of the 5000+ acre plateau, over 40 wells have been installed and/or monitored for over 10 years. In addition, hydrogeologic field mapping and over 200 test pits were performed. Subsurface exploration encountered sediments interpreted to represent each of the glacial and interglacial units identified by regional studies and their depositional environments provide constraints on the hydrogeology and geomorphology of the plateau. Much of the current geomorphology was created by processes related to the Vashon-age glacier. These features include kettles, kame terraces, recessional meltwater channels, and Glacial Lake Puyallup deltaic deposits.

Limited surface water features have been identified on the plateau including Orting Lake and small isolated wetlands. Canyonfalls Creek originating on the northwestern portion of the site represents discharge of a major aquifer underlying the plateau. Several springs have been identified on the margins of the plateau including minor seeps on the west margin, Boatman spring on the east margin, and significant springs along the southern valley wall of Fennel Creek including the Bonney Lake springs.

Overlying the Puyallup Formation across the majority of the plateau is a thick sequence of highly permeable and largely unsaturated Vashon-age and older undifferentiated glacial sediments. The shallow aquifer system occupies the lower portion of these sediments and overlies the Puyallup Formation, perched on low permeability units such as the glacially consolidated mudflow deposits that form the resistant ledge of Victor Falls in Fennel Creek. The shallow aquifer underlying the majority of the plateau flows northwest toward discharge locations such as Canyonfalls Creek, the Bonney Lake springs, and other springs along Fennel Creek. A deep aquifer has been encountered within the Orting Drift that is also identified in some domestic wells on the plateau.

Surrounding the plateau, recent mudflow deposits from Mt. Rainier are identified including the Osceola mudflow and older potential non-cohesive lahar sediments.

[1] *Associated Earth Sciences, Inc., 911 Fifth Avenue, Suite 100, Kirkland, WA 98033 (425) 827-7701*

A Stable Isotope Study of the Soil Water Budget Along a Climate Gradient

Travis Hammond[1], Kathren Howarth[2], Carey Gazis[3]

Climate is complexly linked to the soil water budget in that it controls water and heat fluxes to the soil as well as influencing soil formation and soil properties. In this study, we are combining stable isotope geochemistry with climatic and soil physics monitoring to investigate how the soil water budget and styles of soil water movement vary across a climate gradient. Precipitation, snow melt and soil water are being monitored at sites along a climate gradient in central Washington State, between Snoqualmie Pass and Ellensburg. In this transect, annual precipitation ranges from 266 cm to 23 cm and occurs mostly as snow in the winter months. The hypothesis underlying this research is that the style in which water percolates through the soil (e.g. piston flow vs. preferential flow), the rates of evaporation versus transpiration, and the timing of deep soil water/groundwater recharge varies predictably during different hydrologic seasons across this climate gradient.

Soil water is collected and analyzed by two methods: 1) direct equilibration of soil cores with CO_2 to determine the isotopic composition of total soil water; 2) suction lysimeter to determine the isotopic composition of mobile soil water. Comparisons are made between the isotopic composition of direct precipitation and that of these vadose zone waters. Stable isotope comparisons are combined with climatic measurements and soil physics monitoring to determine amounts and residence times of mobile versus stationary soil water and to quantify evaporation rates, transpiration rates, and downward percolation fluxes. These parameters are in turn related to site characteristics such as precipitation, soil properties, and vegetation type/density. In addition, we are assessing the within-site variability in soil characteristics and soil water isotopes.

Thus, this research explores how the soil water budget in a snowmelt-dominated system is influenced by climate and fills a gap in our understanding of the detailed dynamics of water movement in the critical upper soil region. The information gained will have significant broader implications in areas such as contaminant transport, biogeochemical cycling, agricultural and forestry practices, and water management.

[1] Central Washington University, Department of Geological Sciences, 400 E. University Way, Ellensburg, WA 98926-7418; Telephone (509) 963-2820; FAX (509) 963-2821; Email: hammondt@cwu.edu
[2] Central Washington University, howarthk@cwu.edu
[3] Central Washington University, cgazis@geology.cwu.edu

Hydrogeologic Investigation of a Groundwater/Surface Water Interface at a Hillslope in King County, Washington

Sevin Bilir[1], Laura Belt[2]

Groundwater is seeping from Pre-Vashon deposits outcropping on a steep hillslope, downgradient of a closed landfill located in King County, WA. The groundwater forms intermittent and low volume creeks and flows down slope from the seepage areas, eventually being captured by a stream that discharges into Colvos Passage. Low level concentrations of volatiles and metals have been detected in the surface water formed from the seepage areas along the hillslope.

Prior to and since landfill closure in 2001, geotechnical and environmental investigations have been completed on the landfill property and of the immediately surrounding area. Ongoing groundwater monitoring provides information regarding effectiveness of environmental control and monitoring systems. Recent investigations suggested evaluating the location of saturated outcrops on the nearby hillslope and to correlate the outcrops to hydrostratigraphic units beneath the landfill. The data presented here results from a hydrogeologic investigation of approximately 13 acres of steep hillslopes. The scope of work included characterizing surficial Pre-Vashon deposit outcrops; mapping groundwater seepage areas; developing a hydrostratigraphic model of the hillslope and correlating that to the current understanding of hydrostratigraphic units underlying the landfill; collecting water quality and quantity measurements of groundwater and surface water on the hillslope; and developing a three-dimensional geomodel of the hillslope and landfill areas. The resulting data will be used to assist in evaluating the need for remediation and treatment alternatives for the low level impacts in groundwater and surface water at the hillslope.

[1] King County Department of Natural Resources & Parks, Water & Land Division, 201 S. Jackson Street, Ste 600, Seattle, WA 98104; Tel (206) 296-8029; Fax (206) 296-0192; e-mail sevin.bilir@metrokc.gov
[2] King County Department of Natural Resources & Parks, Solid Waste Division, 201 S. Jackson Street, Ste 701, Seattle, WA 98104; Tel (206) 296-8485; Fax (206) 296-8431; e-mail laura.belt@metrokc.gov

Trends of Nitrate and Pesticides in Ground Water of the Columbia Basin Plateau, Washington, 1993-2003

Lonna M. Frans[1]

Pesticide and nitrate data for ground water sampled in the Central Columbia Plateau, Washington between 1993 and 2003 by the U.S. Geological Survey National Water-Quality Assessment Program were evaluated for trends in concentration. A total of 72 wells were sampled in 1993-95 and again in 2002-03 in three well networks that targeted rowcrop and orchard landuse settings as well as the regional aquifer. The Regional Kendall trend test indicated that only deethylatrazine concentrations showed a significant trend. DEA concentrations were found to be increasing beneath the row crop landuse well network, the regional aquifer well network, and for the dataset as a whole. No other pesticides showed a significant trend nor did nitrate in the 72 well dataset. Despite the lack of a trend in nitrate concentrations within the NAWQA dataset, previous work has found a statistically significant decrease in nitrate concentrations from 1998-2002 for wells with nitrate concentrations above 10 mg/L within the Columbia Basin GWMA which is located within the NAWQA study unit boundary. The increasing trend in DEA concentrations was found to negatively correlate with soil hydrologic group using logistic regression and soil hydrologic group and drainage class using spearman's correlation. The decreasing trend in high nitrate concentrations was found to positively correlate with the depth to which the well was cased using logistic regression and positively correlate with nitrate application rates and sand content of the soil and negatively correlate with soil hydrologic group using spearman's correlation.

[1] U.S. Geological Survey, 934 Broadway Ave. Suite 300, Tacoma, WA 98467; Telephone (253) 552-1694; Fax (253) 552-1581; lmfrans@usgs.gov

Seasonal Changes in Groundwater Chemistry due to Irrigation in the Kittitas Valley, Washington

Sarah A. Taylor[1]*, Carey Gazis*[2]

Seasonal changes in groundwater chemistry of the intensely irrigated Kittitas Valley in the Upper Yakima River Basin have not previously been well characterized. During the May to October irrigation season, as surface water is drawn from the Yakima River and applied to fields, shallow aquifers in the area are recharged and undergo subsequent changes in groundwater chemistry. Knowledge of the interactions between surface water and groundwater is an important component of water resource management in the valley, especially when domestic water use depends on shallow aquifer wells.

In this study, groundwater samples were collected from domestic and municipal wells located along a transect perpendicular to the Yakima River through the Kittitas Valley. Samples were obtained from 25 wells approximately every two months from April 2005 through June 2006. The wells ranged in depth from 15 feet to 1000 feet below ground surface. Both shallow wells drilled through surficial alluvium into the Ellensburg Formation, a volcaniclastic sedimentary unit that fills the Ellensburg basin, and deeper wells drilled into the underlying upper layers of the Columbia River Basalts were examined. Major ion analyses were performed on each sample to investigate seasonal groundwater chemistry changes with particular attention paid to nitrate values which can be elevated due to agricultural practices.

Our results show that some major ion concentrations increased in shallow wells during the irrigation season. Nitrate showed the most variation with values up to 6.0 ppm prior to irrigation, increasing to 19 ppm once irrigation began. Seasonal changes in nitrate concentration suggest a cyclic pattern with a concentration decrease directly after irrigation, followed by another increase around November coinciding with a heavy rainfall event, and a final decrease in spring with winter snowmelt. In contrast, the deep municipal wells and wells drilled into basalt aquifers do not show these seasonal trends.

Although, all groundwater major ion concentrations were below EPA standards for drinking water, seasonal changes in groundwater chemistry of shallow wells were observed which correspond with local recharge events. This study demonstrates the need to characterize seasonal changes in groundwater chemistry when assessments are made of groundwater quality in an intensely irrigated area.

[1] *Central Washington University, Department of Geological Sciences, 400 E. University Way, Ellensburg, WA 98926-7418; Telephone (509) 963-2820; Email taylorsar@cwu.edu*
[2] *Central Washington University, Department of Geological Sciences, 400 E. University Way, Ellensburg, WA 98926-7418; Telephone (509) 963-2820; Email cgazis@geology.cwu.edu*

Application of a Nitrate Fate and Transport Model to the Abbotsford-Sumas Aquifer, Whatcom County, Washington

Margo Burton[1] and Robert Mitchell[2]

The Abbotsford-Sumas aquifer is a shallow, unconfined aquifer located in northwestern Washington and southwestern British Columbia. Due to aquifer characteristics and extensive agricultural land use, the Abbotsford-Sumas aquifer has had a history of nitrate contamination. As such, nutrient managers are interested in predictive tools to assist their management strategies. We explored the application of a GIS based nitrate fate and transport model developed specifically for the Abbotsford-Sumas aquifer by Almasri and Kaluarachchi (2004) as a predictive tool. The model integrates four different sub-models that collectively simulate nitrogen loading on the land surface, nitrogen soil transformations and nitrate leaching (NLEAP), groundwater flow (MODFLOW), and nitrate fate and transport (MT3D). The model was used to assess the impacts of surface activities on groundwater nitrate concentrations and to validate measured nitrate distributions in the aquifer. We also examined the influence of irrigation on groundwater nitrate concentrations.

The nitrate fate and transport model was reasonably successful at predicting groundwater nitrate concentrations similar to those measured in certain locations in the aquifer. The largest limitation of the model is that it simulates horizontal flow in a single layer aquifer. As a result, it averages soil nitrate leaching magnitudes over the entire aquifer thickness, so groundwater nitrate concentrations are in part determined by the aquifer thickness at a location. Previous work has shown that nitrate concentrations are stratified in the aquifer, thus the aquifer should be modeled with multiple layers. The model was generally sensitive to fertilizer and manure loading changes, but it is spatially and temporally too coarse to capture localized and seasonal influences. Altering the irrigation rate and nitrate concentration in the irrigation water in the model had little effect on nitrate leaching magnitudes and groundwater nitrate concentrations, which is inconsistent with previous research.

Western Washington University, Geology Department, 516 High St., Bellingham, WA 98225; Fax (360) 650-7302; Telephone (360) 650-3591
[1] *E-mail margoburton@gmail.com*
[2] *E-mail robert.mitchell@geol.wwu.edu*

Addressing Groundwater/Surface Water Interaction in Closed Basins with Regards to the Montana Water Rights Appropriations Process

Jane Madison[1], Karl Uhlig[2]

Montana, like most western states, bases water rights upon the “Prior Appropriations Doctrine” or first in time first in right. As lands were settled during the early 19th century, individuals could capture water and put it to a “beneficial use”. The date of first use established the priority date for that particular water right. When others began to utilize additional water from the same source, the senior priority right needed to be satisfied before the junior appropriators could begin using any water. When demands upon a surface water source were greater than the supply, disputes between users were settled by the District Court system in the form of Decrees.

Traditionally, surface water and groundwater were treated as separate entities. In April 2006 the Montana Supreme Court ruled that the Montana Department of Natural Resources and Conservation could not issue any new groundwater rights in the Smith River Basin (a closed basin) without considering the effects of pre-stream capture of tributary groundwater. The Court ruled that the DNRC could not issue any new use permits for groundwater wells in closed basins where pumping intercepted groundwater that otherwise would have entered the stream, causing a reduction in surface flows.

The Montana Legislature will begin meeting in early January 2007 and several bills are currently being drafted to modify the DNRC procedures and definitions. PBS&J, an innovator in groundwater investigation methods, will present a poster session describing the proposed and resulting legislation along with methods to satisfy groundwater testing requirements in closed basins in the state of Montana. Two specific projects illustrating the closed-basin water rights application process (including aquifer testing) will be presented.

[1]*PBS&J, 1120 Cedar St, Missoula, MT 59802; Phone 406-721-0354; Fax 406-721-0355; email JMadison@pbsj.com*
[2]*PBS&J, 1120 Cedar St, Missoula, MT 59802; Phone 406-721-0354; Fax 406-721-0355; email KUhlig@pbsj.com*

Naturally Occurring Arsenic in Groundwater from Glacial Deposits in King County, Washington

Eric Ferguson[1], Ken Johnson[2]

About 30% of the people in King County obtain their drinking water from groundwater. Out of a concern about the environment as well as the public health of its citizens, King County's Dept of Natural Resources and Parks has conducted monitoring of the ambient quality of its groundwater, in a range of wells that includes both individual residential wells as well as some from large public water systems, and in a variety of aquifers, by depth and location. The results of these analyses showed that arsenic was the constituent of greatest public health concern, both for the wide distribution of wells that exceed the new US Drinking Water Standard and for the concentrations at which arsenic is found. The arsenic values for the domestic wells samples ranged from 0.1 ppb (non-detect) to >70 ppb. The maximum arsenic concentration determined was from a shallow (20') monitoring well in excess of 150 ppb.

A bedrock source is suggested, by the discovery that the higher groundwater arsenic concentrations were found in deeper wells. However, some of the wells with high arsenic concentrations were noted to be shallow or in areas with deep unconsolidated sediments, where an intact bedrock source would be far away.

The ambient sampling included analysis of total phosphorus, because it is a nutrient of concern for eutrophication of several large lakes in the County. A correlation was noted between the arsenic and phosphorus concentrations. This raised the possibility that the source of the arsenic to the groundwater is a geochemical process similar to that occurring in Bangladesh (Ravenscroft et al., 2001), where buried Pleistocene peat deposits appear to be releasing arsenic through the anoxic reduction of iron oxyhydroxide.

Based on the result of the various monitoring and peat sampling, it appears that degrading periglacial peat deposits are another likely source of naturally-occurring arsenic in groundwater supplies in King County.

King County Department of Natural Resources and Parks, Water & Land Division, 201 S. Jackson Street, Suite 600, Seattle, WA 98104;
[1] Telephone (206) 263-6512; Fax (206) 296-0192; e-mail eric.ferguson@metrokc.gov
[2] Telephone (206) 296-8323; Fax (206) 296-0192; e-mail ken.johnson@metrokc.gov

Effects of Timber Harvest on Groundwater Response to Precipitation Events near Kalaloch, Olympic Peninsula, WA

Casey Hanell[1] and Robert Mitchell[2]

The Washington State Department of Natural Resources (DNR) manages approximately 8,000 km^2 of forestland in Washington, primarily for timber production. The effects of timber harvesting on physical watershed processes continue to be the subject of intense research throughout the Pacific Northwest. Work during the late 1990s resulted in important modifications to Washington's Forest Practices Act and Rules. New measures mandate rigorous evaluation of potential effects of timber harvesting on slope stability. While timber harvesting has been linked to an increase in surface erosion and mass wasting in the Pacific Northwest, most studies have focused on shallow slope failure. The loss of canopy interception and evapotranspiration associated with timber harvesting and the resulting effects on groundwater levels and deep-seated landslide movement are not well understood.

Our research site is a portion of a moderately steep watershed (2 sq-km) located 6 km southeast of Kalaloch, WA on the coast of the Olympic peninsula. Our goal is to use a two year-long time series of water table elevations from 10 bore holes and precipitation data to characterize groundwater level response characteristics at the site. The Distributed Hydrology Soils Vegetation Model will be used to model the effects of different percentages of canopy removal on the amount of water available for recharge to the groundwater table. Preliminary results indicate that a reduction in canopy may have minimal influence on groundwater peaks during the winter months.

The research site is scheduled for timber harvest with variable percentages of canopy removal in the summer of 2008. Hourly water table measurements will continue in order to characterize post-harvest groundwater level response characteristics. These data will be compared to pre-harvest data and to model predicted responses. Establishing the relationship between groundwater response to precipitation events and forest canopy percentages on groundwater levels may help forest managers better assess the risks associated with operating in areas susceptible to deep-seated landslides.

Western Washington University, Geology Department, 516 High St., Bellingham, WA 98225; Fax (360) 650-7302
[1] Telephone (360) 650-3591; E-mail caseyhanell@hotmail.com
[2] Telephone (360) 650-3591; E-mail Robert.mitchell@geol.wwu.edu

The Importance of Ground-Water Discharges to the Loadings of Dissolved Inorganic Nitrogen to Lynch Cove, Hood Canal

Anthony J. Paulson[1], F. William Simonds[2], and Carol Kendall[3]

In September and October 2004, field data were collected to estimate dissolved inorganic nitrogen (DIN) loading to Lynch Cove, the most inland marine waters of Hood Canal, Washington, that routinely contain low concentrations of dissolved oxygen in bottom waters. Most DIN discharged to the surface layer of Lynch Cove in summer and early autumn is taken up by algae, which settle. Dissolved oxygen concentrations decrease as the settling algae is consumed. Using a water-budget approach, flow of regional ground water from watersheds adjacent to Lynch Cove was estimated. This estimate of flow combined with representative ambient ground-water DIN concentrations indicates that regional ground-water contributed about one-half of the total DIN loading to the upper layer of the marine water column, defined as the layer above the pycnocline. In 2005, measurements of ground-water seepage within and below the intertidal zone were made at three sites in Lynch Cove. These measurements of ground-water seepage along with new measurements of DIN concentrations of springs and shallow ground water collected from hillsides adjacent to Lynch Cove combine to identify large gaps in our understanding of the ground-water flows of freshwater to Lynch Cove.

Surface-water discharge was estimated to have contributed about one-fourth of the DIN loading to the upper layer of Lynch Cove in autumn 2004 based on measured values of streamflow and DIN concentrations. Direct discharge from septic systems within 150 m of the shoreline was estimated to account for about one-fourth of DIN loading to the upper layer of Lynch Cove based on national averages of per-capita DIN output and seasonal population estimates. DIN in seawater entering Lynch Cove also can mix upward into the upper layer and be consumed by algae. DIN transported by marine currents in the bottom layer was estimated to have carried more than 25 times the total input of DIN contained in freshwater entering the upper layer.

Analyses of nitrogen isotopes in nitrate in the Union River, which discharges to Lynch Cove, were not useful in discerning the source of nitrate in surface water. Measurements of nitrogen and oxygen isotopes of nitrate in the nitrate-depleted waters of the lower layer of the marine water column at landward, shallow sites in Lynch Cove indicate that our understanding of the sources and sinks of DIN to Lynch Cove is incomplete.

[1]U.S. Geological Survey, Washington Water Science Center, 934 Broadway, Tacoma, WA, 98402, Telephone (253) 552-1681, Fax (253) (253) 552-1581, E-mail apaulson@usgs.gov

[2] U.S. Geological Survey, Washington Water Science Center, C/O 10615 S.E. Cherry Blossom Dr. Portland, OR 87216, Telephone (503) 251-3262, Fax (503) 251-3570, E-mail wsimonds@usgs.gov

[3] U.S. Geological Survey, National Research Program, Bldg 15, McKelvey Building, Mail Stop 434, Menlo Park, CA 94025 Telephone (650) 329-4576, Fax (650) 329-5590, E-mail ckendall@usgs.gov

Diurnal-scale Groundwater Potentiometric Fluctuations -- a Possible Aquifer Characterization Tool

Ken Johnson

Groundwater is usually assumed to travel very slowly and consequently change only gradually. As a result water levels are typically monitored only on a daily basis in order to conserve electronic memory requirements that would be considered wasted if used for repetitious measurements. It is only during times of planned aquifer stresses (such as pumping tests) that more frequent measurements are obtained. However, monitoring water levels only daily might miss data that could provide useful information about aquifer conditions or stresses.

Fluctuations were detected in a filtered record of 15-minute time interval monitoring of water levels in a former water supply well, at diurnal-scale (or higher) frequencies across a several-month record. These signals appeared to be stable, so a search for possible causative factors was attempted. There was a semi-diurnal (approximately 12-hour wave-length) component in the data that indicated against its being caused by evapotranspiration from nearby vegetation. Anthropogenic stressing from water supply wells was another cause that was considered, although no other domestic wells were thought to be located nearby.

An indirect explanatory factor was discovered to be the global atmospheric barometric pressure wave, which is similar to tidal cycles but is related to solar heating of the atmosphere rather than gravitational stresses from the sun and moon. This phenomenon has been known and investigated by atmospheric scientists since the nineteenth century and thus is adequately characterized to differentiate it from other factors. This barometric phenomenon can be used as a naturally-occurring aquifer stressor that may affect water levels through the mediation of the “barometric efficiency” of the aquifer.

The high-frequency response of water levels in a given well can be used as an indicator of aquifer confined / unconfined conditions, nearby anthropogenic stresses (water supply or irrigation recharge), or vegetative hydraulic processes.

King County Department of Natural Resources & Parks, Water & Land Resources Division, 201 S. Jackson St, Suite 600, Seattle, WA 98104; Telephone (206) 296-8323; Fax (206) 296-0192; e-mail ken.johnson@metrokc.gov

Importance of basalt stratigraphy in hydrogeologic studies and the compilation of stratigraphy of the Columbia River Basalt Group

Terrence D. Conlon[1], Tiffany R. Jacklin[2], and Leonard L. Orzol[3]

The Columbia River Basalt Group (CRBG) consists of a thick sequence of Miocene flood basalt that covered thousands of square miles in northern Oregon, eastern Washington, and western Idaho. Multiple basalt lava flows issued from fissures and vents in eastern Washington, northeastern Oregon, and western Idaho between 17 and 6 million years ago. Over 300 flows have been identified, and at least 20 made their way through the Willamette Valley to the coast. The top and bottom of individual flows may be vesicular or brecciated and commonly have intervening sedimentary deposits. These permeable interflow zones within the CRBG are an important source of water for northern Oregon and eastern Washington.

To understand ground-water flow, production zones, and transport of contamination, it is critical to identify permeable interflow zones and their hydraulic connection and extent. Interflow zones can be identified when drill cuttings or cores are visually inspected and analyzed for geochemical characteristics that are used to identify the member, formation, and individual flow units. This type of information has also been collected and used by geologists to map faults and folds in the subsurface and to evaluate the possibility of future earthquakes, especially in the Willamette Valley, Oregon.

To assist in these studies, the USGS is compiling detailed geologic logs that are based on visual and geochemical analysis of borehole cuttings in Oregon. This compilation of available stratigraphic data offers the opportunity to improve the understanding of ground-water flow in the CRBG, guide well construction and testing, and provide important information for water-resource managers. Geologic logs, driller's reports, and tables of geochemistry are available from a USGS Website (http://or.water.usgs.gov/projs_dir/crbg/). The compilation is designed to assist geologic and hydrologic investigations of the Columbia River Basalt Group. The Website will be expanded as geologic logs, geochemistry, and outcrop data in Washington and Idaho are added subject to the availability of funding.

U.S. Geological Survey Oregon Water Science Center, 10615 SE Cherry Blossom Drive, Portland, OR 97216; Fax (503-251-3470)
[1]*Phone (503) 251-3232; Email tdconlon@usgs.gov*
[2]*Phone (503) 251-3248; Email tiffany@usgs.gov*
[3]*Phone (503) 251-3270; Email llorzol@usgs.gov*

A longitudinal hydraulic analysis of river-aquifer exchanges

Christopher P. Konrad[1]

A longitudinal analysis of transient flow between a river and an underlying aquifer is developed to calculate flow rates between the river and the aquifer and the location of groundwater seepage into the river as it changes over time. Two flow domains are defined in the analysis: an upstream domain of fluvial recharge, where water flows vertically from the river into the unsaturated portion of the aquifer and horizontally in saturated parts of the aquifer, and a downstream domain of groundwater seepage to the river, where groundwater flows parallel to the underlying impermeable base. The river does not necessarily penetrate completely through the aquifer. A one-dimensional, unsteady flow equation is derived from mass conservation, Darcy's law, and the geometry of the river-aquifer system to calculate the water table position and the groundwater seepage rate into the river. Models based on numerical and analytical solutions of the flow equation were applied to a reach of the Methow River in north central Washington. The calibrated models simulated groundwater seepage with a root-mean-square error less than 5% of the mean groundwater seepage rates for three low-flow evaluation periods. The analytical model provides a theoretical basis for a nonlinear exponential base flow recession generated by a draining aquifer, but not an explicit functional form for the recession. Unlike cross-sectional approaches, the longitudinal approach allows the analysis of the length and location of groundwater seepage to a river, which have important ecological implications in many rivers. In the numerical simulations, the length of the groundwater seepage varied seasonally by about 4 km and the upstream boundary of groundwater seepage was within 689 m of its location at a stream gage on 9 September 2001 and within 91 m of its location on 6 October 2002. To demonstrate its utility in ecological applications, the numerical model was used to calculate differences in length of groundwater seepage to the Methow River under an early runoff scenario and the timing of those differences with respect to life stages of chinook salmon.

1*U.S. Geological Survey, 934 Broadway, Suite 300, Tacoma, WA 98402, telephone: 253.552.1634, fax: 253.552.1581, cpkonrad@usgs.gov*

The Application of In Situ Oxygen Diffusion for Remediation of Petroleum Hydrocarbons at an Active Retail Service Station in Seattle, Washington

Terry J. Crotwell[1]*, N. Scott MacLeod*[1]*, Christopher Martin*[1]*, Andrea Petrusky*[1]*,*
Kevin Greenfield[2]

Cambria Environmental Technology, Inc. (Cambria) manages a site that contains total petroleum hydrocarbons in the gasoline-range, benzene, and methyl-tertiary butyl ether (MTBE) in groundwater above the Model Toxics Control Act (MTCA) Method A Cleanup Levels. The normal next step would be additional soil borings and/or groundwater wells to define the horizontal and vertical extent of hydrocarbons followed by years of monitoring.

To accelerate case closure, Cambria opted to conduct interim bioremediation during the additional assessment. We used an Enhanced Oxygen Diffuser (EOD™) designed by K. Greenfield, Inc. (KGI) of Gladstone, Oregon. The EOD system provides a simple and cost-effective means for delivering controlled amounts of oxygen to groundwater at flow rates ranging from 1 to 15 mL/minute (at standard temperature and pressure). The system consists of small oxygen tanks and a down-well diffuser designed to increase oxygen concentrations in groundwater and stimulate hydrocarbon biodegradation. The system has few moving parts and is designed for long term operation with low operation and maintenance (O&M) costs.

During Third Quarter 2006, Cambria installed the EOD system within two existing groundwater-monitoring wells that had elevated hydrocarbon concentrations. The well vaults were modified to make room for the oxygen tanks and oxygen delivery tubing within the well vault. The delivery of diffused oxygen was authorized by the Washington State Department of Ecology (Ecology) through the issuance of an underground injection control (UIC) permit.

The system has operated for ___ months and reduced hydrocarbon concentrations from ___ µg/L to ___µg/L. By decreasing hydrocarbon concentrations in source area wells, we were able to significantly reduce the scope of the assessment and move the site towards closure in a more efficient manner.

[1] *Cambria Environmental Technology, Inc., 8620 Holly Drive Suite 210, Everett, WA 98208; Telephone (425)353-6670; Fax (425) 353-6443; E-mail tcrotwell@cambria-env.com; URL: www.cambria-env.com*

[2] *K. Greenfield, Inc., Gladstone, OR; Telephone (503)810-8731*

The Liquid Effluent Retention Facility (LERF)—A Challenge for Groundwater Monitoring and Regulatory Compliance

Alisa D. Huckaby(1), Joseph A. Caggiano(2)

LERF, a Resource Conservation and Recovery Act (RCRA) permitted facility, consists of three double-lined surface impoundments with primary and secondary High Density Polyethylene (HDPE) liners that drain to a sump. The LERF impoundments hold mixed liquid waste before treatment at the Treatment Effluent and Disposal Facility (TEDF). Wastes contain a mixture of dangerous and radioactive waste, including Cr, Tc-99, U, NO3, CCl4. In 1994, a four well groundwater monitoring network (1 up- and 3-downgradient) screened at the bottom of the unconfined aquifer (top of Columbia River basalt) was installed and monitored for interim status groundwater protection standards of WAC 173-303-400. Liquid discharges to the soil which artificially recharged the Hanford unconfined aquifer ceased in 1995, and the water table has declined to pre-Hanford levels, 20 – 30 feet lower. Two of the four wells are dry and can't be deepened. Each basin holds up to 7.8 million gallons; depth to groundwater exceeds 200 ft. Monitoring for environmental compliance presents a challenge that is being addressed with the U.S. Department of Energy (USDOE).

Vadose zone monitoring would immediately detect and allow faster response to any possible leak. However, specific regulatory requirements for vadose zone monitoring are absent. Vadose zone monitoring technology, is evolving; no established method exists for monitoring the entire vadose zone beneath these basins. Most instruments sense within a limited radius of the device. Retrofitting these basins with access tubes to permit neutron logging is costly.

Ecology collaboratively agreed with USDOE to evaluate: 1) hydrologic conditions beneath the facility, including use of existing wells; 2) vadose zone monitoring technologies, and 3) comparison of basin effluent with leachate to assure that the HDPE liners were functioning as designed. Only small ions should penetrate the HDPE liners; large ions should be retained in the basins. Ecology specified the use of U, Tc-99, Hg and tritium (already in effluent). USDOE's lawyers rejected this agreement, stating that radionuclides should not be included in a RCRA permit, as they are regulated by the Atomic Energy Act (AEA) only. Therefore, Ecology is modifying the RCRA facility permit to include monitoring requirements for the agreed upon leachate monitoring, a compliance schedule for evaluation of hydraulic communication with the confined aquifer system, other groundwater monitoring possibilities, and possible vadose zone monitoring.

Washington State Department of Ecology, 3100 Port of Benton Blvd., Richland, WA 99354
[1]*Phone (509) 372-7909; E-mail ahuc461@ecy.wa.gov*
[2]*Phone (509) 372-7915; E-mail jcag461@ecy.wa.gov*

Applications of an Electromagnetic Borehole Flowmeter for Hydrologic Characterization

Darrell Newcomer[1] and Vince Vermeul[2]

Electromagnetic borehole flowmeter (EBF) surveys are effective for accurately measuring the vertical groundwater-flow distribution in wells under ambient (static) and dynamic (e.g., pumping-induced) test conditions. Ambient EBF surveys are useful for determining the representativeness of well water samples for hydrochemical characterization, while dynamic EBF surveys are commonly used for determining the vertical distribution of relative hydraulic conductivity within the well-screen section. EBF surveys used in most hydrologic characterization investigations have reported a measurement resolution of vertical flow rates within the range of 0.04 to 40 L/min.

Monitoring wells with very low or no ambient vertical flow conditions are generally assumed to be more viable (less bias) for the detection and monitoring of groundwater contaminants. To demonstrate this type of application, an EBF ambient survey was conducted at a well site within a well network used for monitoring a technetium-99 contaminant plume within the upper part of the unconfined aquifer at the Hanford Site. The observed technetium-99 concentration for this well (41 pCi/L) is two to three orders-of–magnitude lower than observed concentrations at surrounding monitoring well facilities. An EBF ambient well survey conducted within the 8-m saturated well-screen interval at this well location indicated an upward, in-well vertical flow rate ranging up to 0.35 L/min. This observed upward flow supports a conceptual model where deeper relatively uncontaminated groundwater is flowing upward within the well and discharging to more shallow, overlying contaminated groundwater near the top of the well-screen section. The observed low technetium-99 concentrations at this well site are believed attributable to the bias imposed by the ambient in-well vertical flow condition.

Dynamic EBF surveys determine the lateral in-flow distribution within the well-screen section during pumping. From this lateral in-flow distribution, the vertical distribution of relative horizontal hydraulic conductivity within the surrounding aquifer can be inferred. This type of characterization information is important for the design and deployment of in situ treatment technologies within heterogeneous aquifer systems. At several treatability test sites, dynamic EBF vertical flow profiles have been used to evaluate formation heterogeneities and assess their potential impact on testing and deployment of the planned technology demonstrations. These data, along with standard hydraulic testing results, depth discrete contaminant profile information, and physical core data were used to develop a detailed site specific conceptual model of site hydrogeologic conditions.

[1] *Pacific Northwest National Laboratory, P.O. Box 999, Richland, Washington, (509) 376-1054*
[2] *Pacific Northwest National Laboratory, P.O. Box 999, Richland, Washington, (509) 376-8316*

Measurement of Contaminant Discharge into the Columbia River along the Hanford Reach using a Passive Flux Chamber

Donny Mendoza[1], Brad Fritz, Greg Patton

Past operations at the 300 Area of the Hanford Site have resulted in the release of contaminants, primarily uranium, to the soil column. These contaminants have migrated to the groundwater and ultimately to the Columbia River shoreline. To date, the total mass of uranium being discharged into the river is not well understood. River stage plays a significant role in regulating groundwater discharge to the Columbia River. The dynamic nature of the river fluctuations causes changes in hydraulic gradient, which complicates groundwater discharge estimates and contaminant flux measurements.

A passive flux chamber was installed in the hyporheic zone along the 300 Area of the Columbia River to gain a better understanding of both groundwater discharge and uranium flux. The flux chamber consisted of a 91.4 cm diameter galvanized dome that was outfitted with a bidirectional flow meter and was placed along the shoreline. The flux chamber was left in the river for months at a time under the dynamic conditions of the river. The unit proved to be rugged and provide quality data for the direction and magnitude of groundwater flow. Initial results demonstrated that groundwater flow measured in the flux chamber was consistent with calculated estimates using hydraulic gradient measurements. Parallel with the flux chamber, a passive water sampler using solid phase adsorbents was developed. Future work will deploy the passive water samplers coupled with the flux chamber, thus providing an estimate of uranium flux into the Columbia River.

[1] *Pacific Northwest National Laboratory, Richland, Washington 99352, (509) 372-3507, FAX (509) 376-5368, E-mail Donald.Mendoza@pnl.gov*

Comparison of Percussion vs. Resonant-Sonic Coring Methods for Suprabasalt Sediments at the Hanford Site

Bruce A. Williams,[1] Bruce N. Bjornstad,[2] and David C. Lanigan[3]

Subsurface investigations of groundwater and vadose systems are being conducted at the Hanford Site in southeastern Washington State to support remedial action decisions. Detailed subsurface characterization data is necessary to understand complex contaminant distributions, develop hydrogeologic conceptual models, and conduct contaminant treatability tests. These data all require intact, representative subsurface samples, and more precise, continuous, and intact recovery techniques for mud- to cobble-size sediments.

Presently, percussion and resonant-sonic drilling methods are used at Hanford. Percussion drilling methods employ traditional cable-tool, split-spoon or percussion-hammer coring techniques. These methods rarely provide adequate characterization samples from the coarse-grained sediments found at the Hanford Site, because they tend to skew grain-size distributions, disturb sedimentary structure, and alter the geochemical reactivity of the core. Further, column treatability studies and flow-through experiments in such materials may not be representative of the reactive and hydraulic properties of the geologic formation. In contrast, the resonant-sonic drilling method is much less destructive and more effective at obtaining relatively intact, continuous core within coarse-grained facies of the Hanford and Ringold formations. Recent resonant-sonic continuous core sampling at Hanford's 300 Area produced a higher recovery rate and more representative core samples than percussion methods. The quality of the core sediment (i.e., the preservation of texture, stratification, and grain fabric) for all but the coarsest material was very high. The overall quality of the resonant-sonic coring was greatly improved from conventional split-spoon coring by using larger diameter core liners and a longer core barrel. The larger diameter core facilitated a more complete recovery of the predominantly pebble to cobble gravel sections without plugging, breaking, pulverizing, or moving the larger clasts. The longer core allowed a more continuous recovery process with less depth interval disruption, e.g., sloughing and measurement error, between core runs.

Recovery of continuous, intact core samples, that are representative of subsurface conditions, is greatly improving our understanding of contaminant distribution and the hydrogeology of the aquifer system and vadose zone within which the contamination moves. In addition to providing superior characterization samples, the resonant-sonic coring method is typically faster when compared to the other methods.

Pacific Northwest National Laboratory, PO Box 999, Richland, WA, 99352;
[1]Phone (509) 372-3799; Fax (509) 376-2210; E-mail ba.williams@pnl.gov
[2] Phone (509) 373-6948; Fax (509) 376-5368; E-mail bruce.bjonstad@pnl.gov
[3] Phone (509) 376-9308; Fax (509) 376-5368; E-mail david.lanigan@pnl.gov

Automated Water Level Monitoring and three-point problems at the Hanford Site

Robert S. Edrington[1]

The availability of high-frequency, high-quality water level data enables Fluor Hanford's (FH) Groundwater Remediation Project (GRP) to more thoroughly characterize, model and analyze the effectiveness of Groundwater remediation efforts at the Department of Energy's Hanford Site. MS Excel spreadsheets are a commonly used tool in the analysis of data. The combination of frequency water level data and formatted spreadsheets has lead to an easy analysis of the gradient (slope) of the water table or potentiometric surface in an affected aquifer which is the driving force in determining the speed and direction of movement of contaminates in groundwater. This spreadsheet-based analysis tool can give a quick picture of flow directions and patterns for a given area of interest. This analysis gives scientists and regulators one more piece of information to evaluate the reliability of more complex models used to simulate contaminant transport. Only with realistic models can effective remedial design be performed. Water level data combined with three-point analysis aid in the numerical analyzes and modeling used for the evaluation of the effectiveness of remediation efforts (e.g. pump-and-treat, In-Situ barriers, natural attenuation, etc).

FH's GRP uses an automated water level monitoring network (AWLN) to collect and process water level data that provides low cost high-quality data for monitoring, modeling, and analysis of remediation efforts at the Hanford Site's 5 Operable Units. Currently, approximately 207 square kilometers (80 square miles) of groundwater have contamination levels that exceed drinking water standards.

The GRP's AWLN is comprised of over 80 remote stations that record head readings at over 100 monitoring wells throughout the 560 square mile Hanford site. Each station collects hourly readings from in-well pressure transducers on a solar panel/battery powered datalogger. Each station in the network downloads its data weekly via radio modem to a central desktop computer. The downloaded data is uploaded through a custom desktop application into a SQL-server database. This database contains both the raw head data along with the field verification data and processed data that can be either viewed on-screen or exported to a spreadsheet. The data are processed from raw head measurements to water elevation in meters (datum NAVD 88) and used in producing regulatory mandated reports, water table maps, hydrographs, and numerical analysis tools such as capture zone analysis and contaminant modeling.

[1] *Fluor Hanford, Groundwater Remediation Project, 1200 Jadwin Ave., MSIN E6-36, Richland, WA 99352; Telephone (509) 373-3909; E-mail Robert_S_Edrington@rl.gov*

Macroscopic Investigation of Different Sorption Mechanisms between Selenite and Selenate on Hanford Sediments

Michelle Valenta[1], Wooyong Um[2], and R. Jeffrey Serne[3]

Low activity radioactive waste is slated to be vitrified and disposed of in the Integrated Disposal Facility (IDF) located in the 200 East area of the Hanford Site. Radioactive selenium (^{79}Se) has been identified as one of the key radionuclides of concern (in addition to ^{99}Tc, ^{129}I, and ^{90}Sr). Weathering of the glass may result in the release of selenium (Se) that would cause contamination of the soil and groundwater. To better understand the migration of Se in the environment, an understanding of sorption mechanisms for two common Se oxyanions, selenite and selenate, is required.

Batch sorption experiments were conducted to better understand the sorption mechanisms of selenite and selenate on several different sorbents, including Hanford soils, quartz, and a synthetic aluminum oxide, under natural conditions and varying geochemical parameters. Solution pH was varied between 2 and 10 and ionic strength was varied between 0.01M and 1.0M (controlled by the addition of $NaNO_3$). The batch sorption results for both selenite and selenate indicate an increase in sorption at lower pHs (<5) on the natural Hanford soils and aluminum oxide. The sorption increase at lower pHs was more obvious on the aluminum oxide. Both selenite and selenate decreased in sorption uptake at higher pHs (greater than 6 for selenate and greater than 8 for selenite) on the aluminum oxide as surface sorption sites became more deprotonated with increasing pH. The quartz displayed a slight increase in sorption uptake at a pH<5 only for the selenite; the quartz did not display any sorption uptake for the selenate. A decrease in ionic strength caused only a slight increase in sorption for both selenite and selenate on the natural soils. As with the pH, the lowest ionic strength showed some sorption of selenite on quartz, and no sorption of selenate. Selenite sorption on the aluminum oxide was very high for all three ionic strengths. Selenate, however, showed an increase in sorption with decreasing ionic strength. The ionic strength dependant sorption behavior shown in the selenate and the independent sorption behavior of the selenite suggests that selenite sorption is an inner-sphere surface complex and selenate displays an outer-sphere surface complex.

In addition to the macroscopic batch studies, two saturated column experiments packed with natural Hanford soil and groundwater were conducted to help evaluate the mobility of selenite and selenate. In support of the batch results, the column results show that the mobility of selenite is more retarded than selenate.

Pacific Northwest National Laboratory, PO Box 999, MS P7-22, Richland, WA 99352;
[1] Phone (509) 372-2485; Fax (509) 376-4890; E-mail michelle.valenta@pnl.gov
[2] Phone (509) 376-4627; Fax (509) 376-4890; E-mail wooyong.um@pnl.gov
[3] Phone (509) 376-8429; Fax (509) 376-4890; E-mail jeff.serne@pnl.gov

Discrimination between Manmade and Natural Uranium with High-Resolution Spectral Gamma Logging

Rick McCain[1], Paul Henwood[2], and Carl Koizumi[3]

Uranium is ubiquitous in the geologic environment as a trace element. It is also the primary component of nuclear reactor fuel and a major contaminant at Hanford. Conventional spectral gamma logs based on scintillator detectors report values for ^{40}K, ^{232}Th and ^{238}U, which represent the most common naturally occurring radionuclides in geologic materials. However, the standard data processing methods for conventional logs will likely produce misleading assay values in environments where anthropogenic radionuclides are present, particularly where anthropogenic uranium is a factor. The gamma rays normally used to assay naturally occurring ^{238}U will not be detectable in anthropogenic uranium. This presentation provides a summary of how anthropogenic and natural uranium can be detected and quantified using high resolution spectral gamma logging.

[1] *Hanford Geophysical Logging Project, S M Stoller Corp, 1100 Jadwin Ave, Suite 300, Richland, WA 99352; 509-376-6435; fax 509-376-6460; rmccain@stoller.com*
[2] *Hanford Geophysical Logging Project, S M Stoller Corp, 1100 Jadwin Ave, Suite 300, Richland, WA 99352; 509-376-6429; fax 509-376-6460; phenwood@stoller.com*
[3] *Hanford Geophysical Logging Project, S M Stoller Corp, 2597 B 3/4 Road, Grand Junction, CO 81503; 970-248-7797; fax 970-248-8512; ckoizumi@stoller.com*

Application of Surface Complexation Modeling to Uranium(VI) Sorption on Hanford Sediments

Wooyong Um[1], R. Jeffrey Serne[2], and Christopher F. Brown[3]

A series of U(VI) sorption experiments with varying pH, ionic strength (dominated by dissolved sodium concentration), dissolved U(VI) concentrations, and alkalinity was conducted to provide a more realistic database for U(VI) sorption onto near-field vadose zone sediments at the proposed Integrated Disposal Facility (IDF) on the Hanford Site, Washington, USA. Uranium(VI) sorption onto Hanford formation sediments under variable geochemical conditions showed varying U(VI) K_ds depending on different conditions. Decreasing U(VI) sorption uptake with increasing ionic strength and pH was observed due to the formation of U(VI)-carbonate complexes at high pHs and enhanced competition from high concentrations of electrolytes (primarily Na^+) for the surface sorption sites with increasing ionic strength. The distribution coefficient (K_d) for U(VI) in a synthetic glass leachate that is predicted to result from the weathering of vitrified wastes disposed in the IDF is 0 mL/g due to the high sodium and carbonate concentrations and high pH of the synthetic glass leachate. However, when the pH and alkalinity increase in the IDF porewater to simulate the mixing scenario between the glass leachate and the existing IDF porewater, varying U(VI) sorption affinity is observed and the value of the U(VI) apparent K_d rises up to 4.3 mL/g, because of U(VI) coprecipitation with calcite.

To predict U(VI) sorption when the solution conditions vary, a non-electrostatic general composite approach of surface complexation model was applied and fit to experimentally measured U(VI) sorption data. A combination of two U(VI) surface species, monodentate ($SOUO_2^+$) and bidentate ($(SO_2UO_2(CO_3))^{2-}$), simulated the measured U(VI) sorption data well, and the determined U(VI) surface reaction constants could be used in future IDF performance assessments to predict U(VI) sorption as the near-field vadose zone pore fluids and leachates change over time and with increasing distance from the IDF.

The general composite approach, using a surface complexation model without the electrical double layer terms, can predict the mobility of U(VI) more accurately under the varying geochemical conditions expected to affect the mobility of U(VI) that might leach from Low Activity Waste (LAW) glass at the IDF in the Hanford Site than the traditional constant or single-valued K_d model.

Pacific Northwest National Laboratory, Applied Geology and Geochemistry, PO Box 999, P7-22, Richland, WA 99352; Fax (509) 376-4890
[1] *Phone (509) 376-4627; E-mail wooyong.um@pnl.gov*
[2] *Phone (509) 376-8429; E-mail jeff.serne@pnl.gov*
[3] *Phone (509) 376-8389; E-mail christopher.brown@pnl.gov*

Updated Carbon Tetrachloride Contamination Model in the 200 West Area, Hanford Site, Washington

Ken Moser[1], Wes Bratton[2], Virginia Rohay[3], Mark Byrnes[4], Tom DiFebbo[5]

An estimated 363,000 to 580,000 L of carbon tetrachloride was discharged to three primary disposal sites from 1955 to 1973. Much of the carbon tetrachloride was mixed with surfactants such as lard, tributyl phosphate, and dibutyl butyl phosphonate. The resulting groundwater solvent plume is one of the largest in the United States (~11 km^2).

Characterization and interim remediation (vadose zone soil vapor extraction and groundwater pump-and-treat) have been ongoing since the early 1990s. The completion of two remedial investigations, including focused DNAPL investigations, in 2006 has led to an updated carbon tetrachloride contamination model. Key updated model aspects include:

- Significant amounts of carbon tetrachloride likely evaporated during disposal, and refinement of the remaining mass of carbon tetrachloride in the vadose zone and groundwater is in progress for use in feasibility studies during 2007.
- Over 3,400 vadose zone soil vapor and soil sample results show that the highest concentrations are located within 75 to 150 m of the three primary disposal sites; no other significant vadose zone sources overlie the groundwater plume.
- The vadose zone is contaminated by dissolved phase, free-phase, sorbed phase, and vapor phase carbon tetrachloride with most of the remaining mass held in fine-grained layers.
- The liquids from the three primary disposal sites, other nearby sites, and natural recharge contacted vadose zone contamination and created dissolved phase liquids that migrated, along with vapor and free-phase (?), into the groundwater.
- The groundwater contamination is now predominantly dissolved phase, although testing is ongoing to investigate if DNAPL is present near the base of the aquifer.
- Depth-discrete groundwater samples indicate that the groundwater plume extends vertically through the entire ~61 m of the unconfined aquifer. Away from the source areas, the highest concentrations in most cases are located in mid-aquifer and deeper due to natural and artificial recharge.

Vista Engineering Technologies, LLC, 8203 W. Quinault Ave., Bldg. C, Suite 200, Kennewick, WA 99336; Telephone (509) 737-1377; Fax (509) 737-1383
[1]E-mail moser@vistaengr.com
[2]E-mail bratton@vistaengr.com
Fluor Hanford, Inc., MSIN E6-35, P.O. Box 1000, Richland, WA 99352; Fax (509) 373-3974
[3]Telephone (509) 373-3803; E-mail Virginia_J_Rohay@rl.gov
[4]Telephone (509) 373-3996; E-mail Mark_E_Byrnes@rl.gov
[5]Environmental Quality Management, Inc., 1777 Terminal Dr., Richland, WA 99352; Telephone (509) 946-4985 ext. 22; Fax (509) 946-4595; E-mail TomD@eqminc.com

Technetium-99 Contamination in the Northern Part of the 200 West Area, Hanford Site, Washington

Virginia Rohay[1] and Duane Horton[2]

Technetium-99 was measured at a maximum concentration of 181,900 pCi/L in a groundwater sample collected 10 m below the water table during drilling of a well northeast of Waste Management Area T in 2005. Waste Management Area T is in the northern part of the 200 West Area at the Hanford Site. Before this well was drilled, a water table plume of technetium-99 had been mapped in this area showing concentrations up to 27,400 pCi/L. The maximum technetium-99 concentration measured in a second well drilled approximately 80 m to the east (downgradient) was 15,600 pCi/L at the same approximate depth below the water table. Elevated technetium-99 was not detected at depth in a third well drilled to the south, although technetium-99 concentrations at the water table in this area have been as high as 8,000 pCi/L within the past year. Understanding the lateral and vertical distribution of the high-concentration technetium-99 plume in groundwater is needed to support selection of a remedial alternative for groundwater cleanup.

Sources of the technetium-99 contamination may include tank leaks, direct discharges to the soil column through engineered waste sites, and/or leaks during transfer of contaminated liquids (e.g., pipe leaks). Drivers for contaminant migration to the aquifer may include artificial recharge and/or natural recharge.

Significant changes in the groundwater flow rate, flow direction, and elevation in this area over the past 50 years have impacted the migration pathways of contaminants within the aquifer. The vertical and horizontal distribution of technetium-99 probably also is influenced by varying aquifer permeability, vertical hydraulic gradients, and distance from contaminant source. Preliminary evaluation of groundwater chemistry suggests the presence of two different major ion compositions; the spatial and temporal changes in the groundwater chemistry may be indicative of different contaminant sources or releases and transient groundwater flow patterns.

Additional characterization activities have been initiated to better understand the source(s) and the 3-dimensional distribution of the technetium-99 contamination. Two new wells will be drilled to refine the contaminant distribution models for technetium-99 in the aquifer. One new well will be drilled to the north of the high technetium-99 contamination, and one will be drilled to the southwest.

[1]*Fluor Hanford, Inc., MSIN E6-35, P.O. Box 1000, Richland, WA 99352; Telephone (509) 373-3803; Fax (509) 373-3974; E-mail Virginia_J_Rohay@rl.gov*
[2]*Pacific Northwest National Laboratory, MSIN K6-75, P.O. Box 999, Richland, WA 99352; Telephone (509) 376-6868; FAX (509) 376-5368; E-mail DG.Horton@pnl.gov*

Workshops

Some Workshops may become space-limited (first come, first served), and some may be canceled if minimum pre-registration targets are not met. Registrants will be notified by e-mail of Workshop details. Fees will be refunded if cancellations occur. All workshops will be held at the Greater Tacoma Convention Center after symposium.

WORKSHOP #1

Geochemical Modeling of Hydrocarbons and Invasive Waters on Groundwater Systems

TIME: Thursday, May 3, 1:30-4:30 PM, Rm 315

This evening workshop will stress the use of geochemical and stable isotopic techniques to monitor the fate of hydrocarbons and invasive waters (e.g. storm and reclaimed water) in groundwater systems. Participants will first be provided with background information on a variety of stable isotopes (C, H, O, N, Sr, Pb), then, via series of case studies, participants will be shown how high precision isotopic techniques can be incorporated with other site specific data to:

- Estimate the age and fate of hydrocarbon releases in groundwater,
- Discriminate invasive (storm and reclaimed) water from local groundwater using comparative isotope geochemistry, and
- Assess hydrologic continuity between hydrostratigraphic units in the subsurface.

Examples of specific case studies include:

- Storm water runoff from the Mohave Generating Station (coal-fired power plant) in eastern California,
- Impact of smelter versus gasoline-derived lead on groundwater in Tacoma,
- Impact of oxygenated gasoline on groundwater in Connecticut,
- Nitrate contamination of groundwater related to agricultural and naturally-occurring hydrocarbons in southern California, and
- Historic leaded gasoline release impacts on local groundwater via infiltration and surface runoff.

Each participant will be provided with course notes that include the figures presented in the workshop as well as a reference list for further self-study.

COST PER PERSON: $50. MAXIMUM SIZE: 35 participants; minimum: 18. LEADERS & CONTACT: Leader: *Richard W. Hurst*, Ph.D., Hurst & Associates, Inc. Contact: Bob Miller, rdminc@cybcon.com (503) 650-7726.

WORKSHOP #2

Groundwater in Tidally Influenced Aquifers

TIME: Thursday, May 3, 1:30 to 4:30 PM, Rm 316

This workshop will present practical tools that are used by groundwater professionals in interpreting data from tidally influenced aquifers. The workshop is structured as a combination of formal lectures, practical examples, and discussion, with an emphasis on case studies. A rigorous, yet practical approach is taken towards the design and implementation of a reliable data collection program, following with the diagnosis of aquifer response and the estimation of representative aquifer properties in tidal settings. Focus will be on hydraulic response rather than chemical processes. Topics covered during the workshop will include:

- Hydraulic gradients in tidally fluctuating groundwater,
- Aquifer properties from tidal response,
- Strategies for designing successful aquifer tests in tidal influenced groundwater,
- Physical processes present at the groundwater / surface water interface, and
- Designing groundwater monitoring programs.

COST PER PERSON: $50. MAXIMUM SIZE: 35 participants; minimum: 18. LEADER & CONTACT: *Roy E. Jensen*, LHG, is the lead instructor for the workshop. Mr. Jensen is a Senior Hydrogeologist with Hart Crowser, Inc. in Seattle, Washington. He has eighteen years of experience in hydrogeology specializing in the interpretation of hydrologic data and the analysis of groundwater problems in tidal influenced aquifers. CONTACT: *Charles San Juan*, Ecology (360) 407-7191, csan461@ecy.wa.gov

WORKSHOP #3

Want to Know How Do Get Data into That Ecology EIM Data Base? Come to this Workshop!

TIME: Thursday, May 3, 1:30 to 4:30 PM, Rm 317

This workshop will include a demonstration and Q&A session on how to submit data to Ecology's Environmental Information Management (EIM) database. EIM is Ecology's main database for environmental monitoring data, containing over 4 million records on physical, chemical, and biological analyses and measurements. Data submittal is now a requirement for cleanup sites and water quality grant and loan recipients.

COST PER PERSON: No charge. MAXIMUM SIZE: 50 LEADER & CONTACT: *Chris Neumiller*, Ecology (360) 407-6258, cneu461@ecy.wa.gov

WORKSHOP #4

Subsurface Heterogeneity: *Why It Is Important, Why We Usually Ignore It, and What to Do About It*

TIME: Thursday, May 3, 1:30 to 4:30 PM, Rm 318

Inadequacies of transport models are most commonly attributed to insufficient representation of heterogeneity and its control of scale-dependent dispersion, early breakthrough due to referential flow, and long-term (decades to centuries) tailing. This is often seen by the nearly ubiquitous ineffectiveness of pump-and-treat remediation. Moreover, recent studies have shown that interpretation of so-called groundwater age data can be dubious or misleading unless one has a transport model with good representation of subsurface heterogeneity. We've also seen that something as "simple" as a pumping test may be misinterpreted without a good understanding of subsurface complexities. How can we do a better job? This workshop will show examples of how the lack of geologic characterization of heterogeneity in flow and transport models can diminish the reliability and utility of groundwater models, especially transport models. We will then ask ourselves the question: "If we know heterogeneity is so

WORKSHOP #4 (Cont.)

important, why do we usually ignore it?” The ensuing discussion will help lead us to insights regarding how the philosophy and science of hydrogeology might evolve so as to resolve this problem. The last portion of the workshop will be devoted to presentation of one approach to modeling subsurface heterogeneity – the transition probability approach. This approach allows relatively easy infusion of geologic and geophysical information into quantitative models of geologic heterogeneity.

COST PER PERSON: $35. MAXIMUM SIZE: 50 participants; minimum: 18. LEADER & CONTACT: Leader: *Dr. Gary Weissmann*, Associate Professor - Hydrogeology, Stratigraphy, Sedimentology; Unv. New Mexico (weissman@unm.edu). Contact: Charles San Juan, Ecology (360) 407-7191, csan461@ecy.wa.gov

FIELD TRIPS

Some Field Trips may become space limited (first come, first served), and some may be canceled if minimum pre-registration targets are not met or if access to field trip areas is closed due to road, safety, or security conditions. Registrants will be notified by e-mail of Field Trip details. Fees will be refunded if cancellations occur. Unless indicated otherwise, all Field Trips will start and end at the Greater Tacoma Convention and Trade Center.

FIELD TRIP #1

Hydrogeology of the Walla Walla Basin

TIME: Saturday April 28, 7 AM to Sunday April 29, 7 PM

The Walla Walla Basin of southeastern Washington and northeastern Oregon is a structural and topographic basin. The Walla Walla River, flowing out of the adjacent Blue Mountains, and shallow aquifer-fed spring creeks historically provided a reliable source of water for seasonal salmonid migrations, the native American inhabitants of the Basin, later settlers who came to farm and ranch, and more recently the burgeoning wine grape industry. To the Native American inhabitants of the Basin, Walla Walla meant Many Waters. However, as is common throughout the arid to semi-arid American west, the abundant water which drew people in is now under stress. This field trip will explore the many aspects of water in the Walla Walla Basin, from its historic extent to current conditions. During this two-day trip we will feature:

(1) hands on stops where we will look at Columbia River basalt, alluvial sediments, and geologic structural features which influence groundwater occurrence and movement, (2) overview stops where we can discuss current and past conditions in the Basin as a whole, and (3) several of the ongoing projects designed to test ways to reverse declining groundwater water levels, rejuvenate spring creeks, and enhance baseflow to the Walla Walla River during hot summer months.

COST PER PERSON: $170 (double occupancy), $220 (single occupancy), includes overnight stay with continental breakfast in Walla Walla, WA (double occupancy), box lunches (2), morning and afternoon refreshments, and guide book. Participants will be on their own for dinner Saturday night. Transportation is by van. On Saturday, the trip will depart from the Greater Tacoma Convention and Trade Center in Tacoma and will rendezvous with field-trip leaders at about 11:00 am in Kennewick at the offices of Groundwater Solutions. Eastern Washington attendees are welcome to join the trip at the Kennewick location at 11:00 am. On Sunday, the trip will end at about 3:00 pm in Kennewick to allow for a 7:00 pm return to Tacoma. MAXIMUM SIZE: 20 participants; minimum: 8. LEADERS & CONTACT: Leaders: *Kevin*

Lindsey, Groundwater Solutions Inc., KLindsey@ groundwatersolutions.com, (509) 735-7135; *Bob Derkey*, Washington Department of Natural Resources, Division of Geology and Earth Resources, robert.derkey@wadnr.gov, (509) 339-7857; *Terry Tolan*, Groundwater Solutions, Inc., ttolan@ groundwatersolutions.com, (509) 735-7135; and *Bob Bower*, Walla Walla Basin Watershed Council, bob.bower@wwbwc.org, (541) 938-2170.

FIELD TRIP #2

Hydrogeology of Mount Rainier

TIME: Sunday April 29, 8 AM to 6 PM

Mount Rainier, the highest peak (14,410 ft) in the Cascade Range, is a dormant volcano whose load of glacier ice exceeds that of any other mountain in the conterminous United States. This tremendous load of ice, in combination with great topographic relief, poses a variety of geologic hazards, both during inevitable future eruptions and during intervening periods of repose (*http://vulcan.wr.usgs.gov/Volcanoes/Rainier/Hazards/OFR98-428/framework.html*). This trip to scenic Mount Rainier will offer a host of topics including the geologic origins of this northwest volcanic beauty, on-going monitoring at the mountain, the geologic hazards faced by the multitudes that live downstream from the volcano and the recent geomorphic changes to the mountain resulting from recent record-setting rainfall. On November 6 and 7, 2006, Mount Rainier National Park received 18 inches of rain in 36 hours http://www.nps.gov/mora/parknews/upload/floodPP.pdf. Extensive flood damage resulted from this event that offers many examples of the erosive power of water on both natural and man-made features. This trip will be coordinated closely with National Park Service personnel on duty at Mount Rainier National Park and the final itinerary will depend on road reconstruction and access issues. Transportation will be by van.

COST PER PERSON: $65, includes lunch, refreshments and guide book. MAXIMUM SIZE: 20 participants; minimum: 8. LEADERS & CONTACT: *Carolyn Driedger*, U.S. Geological Survey, Cascades Volcano Observatory, driedger@usgs.gov, (360) 993-8907 and *Paul Kennard*, Mt. Rainier National Park, Paul_Kennard@nps.gov, (360) 569-2211 Ext. 3394.

FIELD TRIP #3

Low Dissolved Oxygen Problem in Washington's Hood Canal

TIME: Monday April 30, 8 AM to 5 PM (including transit times).

This trip will feature the spectacular scenery and geology of Washington's Hood Canal and the complex problems that threaten marine wildlife. The field trip begins Monday morning in Tacoma, traveling by van to Twanoh State Park on the Lynch Cove arm of Hood Canal. Participants will have the opportunity to participate in two half-day demonstrations. In one demonstration, 11 participants will be taken out onto Lynch Cove in a boat to conduct a continuous-temperature-depth (CTD) sounding of the water column, collect water-quality samples, and to measure currents across Lynch Cove with an acoustic Doppler current profiler (ADCP). In the afternoon, a second

FIELD TRIP #3 (Cont.)

Low Dissolved Oxygen Problem in Washington's Hood Canal

demonstration will be conducted at the shoreline to show participants how ground-water discharge is measured using piezometers, seepage meters, and electrical resistivity surveys and how various citizen groups monitor Hood Canal to protect against further degradation. Each demonstration will be repeated in the morning and afternoon to double the capacity of the trip, if necessary.

COST PER PERSON: $105, includes transportation by van, morning and afternoon refreshments and lunch at Twanoh State Park. MAXIMUM SIZE: 22 participants; minimum: 8. LEADERS & CONTACT: *Tony Paulson*, U.S. Geological Survey, apaulson@usgs.gov, (253) 552-1681 and Bill Simonds, U.S. Geological Survey, wsimonds@ usgs.gov, (503) 251-3262

FIELD TRIP #4

Coastal Cliff Geology Dinner Cruise

TIME: Wednesday evening, May 2, 5:30 to 9 PM

This field trip features a unique opportunity to enjoy great geology from a different perspective as well as an opportunity to network with colleagues in the delightful surrounding of an evening buffet dinner cruise. Kathy Troost, Brian Sherrod and friends will lead an evening boat cruise departing from Thea Foss Waterway and traveling along the bluffs of Point Defiance and the Tacoma Narrows to the site of the new Tacoma Narrows Bridge. Along the way, trip leaders will describe the geology, the Tacoma fault zone, coastlines and shoreline processes, landslides, the foundation for the Tacoma Narrows Bridge, culture and history, the Port of Tacoma fill and Puyallup River delta, habitats and environmental conditions, and Puget Sound. Exposures of well-dated Quaternary sediments will be visible, including at measured sections where Olympia, Whidbey, Possession, and Double Bluff-aged deposits have been identified with absolute age dating techniques. Participants will receive a guidebook with color maps, images, and a fold out geologic strip map with measured sections. This trip will include a buffet dinner and choice of beverage on board the charter vessel.

COST PER PERSON: $75 MAXIMUM SIZE: 70 participants; minimum: 50. LEADERS & CONTACT: *Kathy Troost*, University of Washington, Dept. of Geological Sciences ktroost@u.washington.edu, (206) 616-9769.

FIELD TRIP #4
Coastal Cliff Geology Dinner Cruise (Cont.)

THE BOAT: "My Girl" is a 69 ft long Coast Guard certified vessel with a professional, licensed crew. The boat has inside seating for 75, a sun deck, enclosed aft deck, rest rooms, and much more. We will have sunlight until about 8 PM. The boat is docked within walking distance of the Greater Tacoma Convention and Trade Center and will depart from the dock promptly at 5:30 PM.

http://www.mygirltheboat.com

FIELD TRIP #5
Characterizing Submarine Groundwater Discharge

TIME: Thursday May 3, 1:30 PM to 4:30 PM

Scientists from the Water-Resources and Geologic Disciplines of USGS will demonstrate and discuss recent techniques for characterizing submarine ground-water discharge. The demonstration will take place along Ruston Way in Tacoma and will include geochemical (radon and radium isotopes), geophysical (2-d resistivity), seepage meter (barrel and electro-magnetic), and subsurface-sampling methods. Many of these techniques were originally developed for East Coast application, but have recently been applied with success in Hood Canal and Puget Sound.

COST PER PERSON: $15, includes transportation and afternoon refreshments.
MAXMUM SIZE: 20 participants; minimum: 8.
LEADER & CONTACT: *Rick Dinicola*, U.S. Geological Survey, dinicola@usgs.gov (253) 552-1603; *Peter Swarzenski*, pswarzen@usgs.gov, (727) 803-8747 ext 3072; and *Bill Simonds*, wsimonds@usgs.gov, (360) 993-8985.

Author Index

AUTHOR INDEX

2007 Washington Hydrogeology Symposium Exhibitors

Exhibitors

BLAINE TECH SERVICES INC.

Kent, WA
916-925-2913
http://www.blainetech.com/

CASCADE DRILLING, INC.

Woodinville, WA
425-485-8908
http://www.cascadedrilling.com

CDM

Bellevue, WA
425-453-8383
http://www.cdm.com/

Clear Water Compliance Services
Lynnwood, WA
800-992-4202
http://www.clearwatercomplianceservices.com/home.html

ELECTRONIC DATA SOLUTIONS™

Field Data Solutions, Inc.
Jerome, ID
208-324-8006
http://www.elecdata.com/

Golder Associates

Redmond, WA
425-883-0777
http://www.golder.com/

HACH® Environmental
Be Right. The Environment is Worth it.

Featuring Hydrolab and OTT Products
Buhl, ID
208-543-6697
http://www.hachenvironmental.com/

2007 Washington Hydrogeology Symposium Exhibitors

HAI

Hurst & Associates, Inc.
Thousand Oaks, CA
805-492-7764
http://www.hurstforensics.com/

hydroGEOPHYSICS, Inc.

Geophysical Consulting and Contracting Services
Tucson, AZ
520-647-3428
http://www.hydrogeophysics.com/

ICE AGE FLOODS INSTITUTE

Richland, WA
877-789-9935
http://www.iafi.org/

INW Instrumentation Northwest, Inc.
Protecting our water resources since 1982

Water Monitoring and Sampling Equipment
Kirkland, WA
800-776-9355
http://www.inwusa.com/

LANDAU ASSOCIATES
ENVIRONMENTAL | GEOTECHNICAL | NATURAL RESOURCES

Tacoma and Edmunds, WA
253-926-2531 | 425-778-0907
http://www.landauinc.com/

Northwest Environmental Business Council
NEBC
Alaska · Idaho · Montana · Oregon · Washington

Northwest Environmental Business Council
Portland, OR
503-227-6361
http://www.nebc.org/

2007 Washington Hydrogeology Symposium Exhibitors

Olympic Environmental Equipment
Groundwater
• Remediation
• Monitoring
• Treatment

Olympic Environmental Equipment LLC.
Indianola, WA
360-297-5409
www.OlympicEnv.com

Sound Environmental Strategies

Seattle, WA; 206-306-1900
http://www.soundenvironmental.com/

TestAmerica
Analytical Testing Corporation

Analytical Laboratories
Bothell, WA
425-420-9200
http://www.testamericainc.com/

TRS Thermal Remediation services inc.

Snoqualmie, WA
425-396-4266
http://www.thermalrs.com/

USGS
science for a changing world

US Geological Survey
Washington Water Science Center
Tacoma, WA
253-428-3600
http://wa.water.usgs.gov/

Washington State Department of Ecology

Nuclear Waste Program
Washington State Department of Ecology
Richland, WA
509-372-7950
http://www.ecy.wa.gov/programs/nwp/

Washington State Department of Ecology

Employee Services
Washington State Department of Ecology
Olympia, WA
360-407-6186
http://www.ecy.wa.gov/jobs/jobs.html

2007 Washington Hydrogeology Symposium Sponsors

Sponsors

Silver $300 - $599

Parametrix

Bellevue, WA
425-458-6200
http://www.parametrix.com/

Gold $600 - $999

Aspect consulting
IN-DEPTH PERSPECTIVE

Seattle, WA
206-328-7443
http://www.aspectconsulting.com

CDM

Bellevue, WA
425-453-8383
http://www.cdm.com/

CH2MHILL
Hanford Group, Inc.

Richland, WA
509-372-2067
http://www.hanfordcleanup.info/

Silver $300 - $599

HARTCROWSER
Delivering smarter solutions

Seattle, WA
206-328-5581
http://www.hartcrowser.com/

PACIFIC groundwater GROUP
Water Resource & Environmental Consulting

Seattle, WA
206-329-0141
http://www.pgwg.com

PBS&J

PBS&J
Missoula, MT
406-532-7275
http://www.pbsj.com/

2007 Washington Hydrogeology Symposium Sponsors

Platinum $1,000 or Greater

CASCADE DRILLING, INC.

Woodinville, WA
425-485-8908
http://www.cascadedrilling.com

HAI

Hurst & Associates, Inc.
Thousand Oaks, CA
805-492-7764
http://www.hurstforensics.com/

LANDAU ASSOCIATES
ENVIRONMENTAL | GEOTECHNICAL | NATURAL RESOURCES

Tacoma and Edmunds, WA
253-926-2531 | 425-778-0907
http://www.landauinc.com/

Platinum $1,000 or Greater

TRS THERMAL REMEDIATION services inc.

Snoqualmie, WA
425-396-4266
http://www.thermalrs.com/

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Nuclear Waste Program
Washington State Department of Ecology
Richland, WA
509-372-7950
http://www.ecy.wa.gov/programs/nwp/