5th Washington Hydrogeology Symposium

PROGRAM

APRIL 12-14, 2005

Sheraton Tacoma Convention Center, Tacoma, Washington

Organized by:

Pacific Northwest National Laboratory

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Washington State Department of Ecology

USGS science for a changing world

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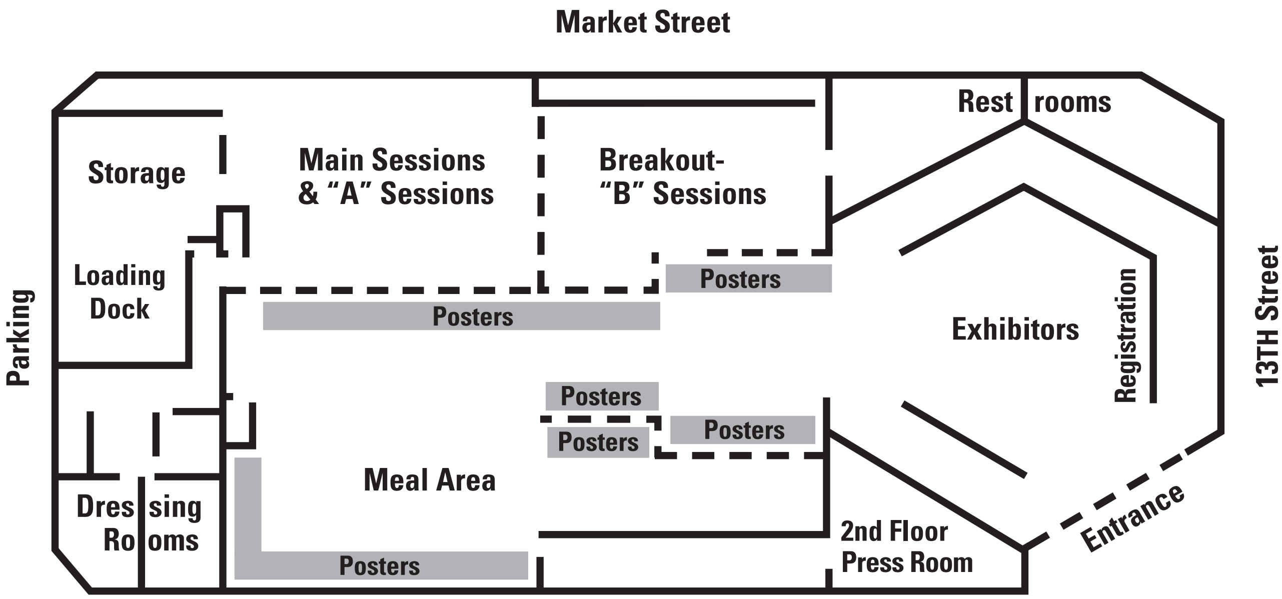

Table of Contents

Contents	Page

Welcome

The 5th Washington Hydrogeology Symposium provides a unique opportunity to connect with other professional hydrogeologists and geologists from throughout the Pacific Northwest. More than 400 participants will come together to experience presentations on a wide range of current topics, partake in some excellent field trips, and interact in thought-provoking workshops and panel discussions. The Symposium Steering Committee has been hard at work over the past few months putting together an exceptional program. For 2005, we have more poster presentations, keynote speakers, workshops, and field trips than ever before.

The Symposium Steering Committee

Top (L-R): Gary Turney, Bob Miller, Phil Long, Brian Drost, Steve Foster. Bottom (L-R): Sandy Williamson, Donna Freier, Laurie Morgan, Mark Freshley. Not pictured: Steve Cox, Duncan Foley, Marcia Knadle, Jon Lindberg, Chris Neumiller, and Bob Peterson.

The Symposium is hosting four enlightening and diverse Keynote Speakers this year, including: Dr. Bill Woessner, 2005 GSA Birdsall-Dreiss Lecturer from University of Montana, Missoula; Dr. Graham Fogg, an expert in heterogeneity from the University of California at Davis; Dr. Ileana Rhodes of Shell Global Solutions, international lecturer on hydrocarbon contamination forensics, and Dr. Philip Mote, Washington State Climatologist. In conjunction with the Symposium, the American Water Resources Association, Washington Chapter will also be holding a Policy Dialogue Scoping Session where former Governor Gary Locke's Water Policy Advisor, Jim Waldo will be the Keynote Speaker.

The foundation of the Symposium has always been the technical Talks and Posters. We have over 100 this year! In addition, please join us on one or more of five terrific Field Trips throughout Washington, ranging from a Coastal Cliff Geology Dinner Cruise in the Commencement Bay area to the Hydrogeology of Mount St. Helens. We also have eight career-enhancing Workshops from which to choose - a record number. These Workshops provide excellent opportunities to expand your horizons. Take full advantage of this opportunity and learn from top-notch leaders in the field of Hydrogeology.

We have a number of Special Events planned this year. Our traditional dinner will be at the Washington State History Museum for a refreshing change of pace. There are also several Harbor Dinner Cruises from which to choose - bring along a spouse or friend!

Thank you for joining us at the 5th Washington Hydrogeology Symposium!

General Symposium Schedule

8:00 AM | 8 AM to Noon | Noon-1 PM Break | 1:00 PM | 1:30 PM | 2:00 PM | 2:30 PM | 3:00 PM | 3:30 PM | 4:00 PM | 4:30 PM | 5 to 6 PM Break | 6:00 PM | 6:30 PM | 7:00 PM | 7:30 PM | 8:00 PM | 8:30 PM | 9:00 PM

Sunday, April 10, 2005

- F1-Hanford - Day 1 - CANCELLED

Monday, April 11, 2005

- F1-Hanford - Day 2
- F2-Mount St. Helens
- AWRA Policy Scoping Session
- W2-Ecology EIM Database Import

Tuesday, April 12, 2005

Symposium Registration

- Symposium Day 1 - See Detailed Schedule - Lunch Included
- Dinner at the WA History Museum - Included

Wednesday, April 13, 2005

- Symposium Day 2 - See Detailed Schedule - Lunch Included
- F3-Coastal Geology Dinner Cruise
- W3-Seawater Intrusion Panel
- W4-Geochemistry - Evaluate Sources

Thursday, April 14, 2005

- Symposium Day 3 - See Detailed Schedule
- F4-Fort Lewis GW and Source Remediation - Includes Box Lunch
- W5-NW Geo DB & Lunch
- W6-Excel for Hydrologic Calcs
- W8-Subsurface Heterogeneity
- W7-Seawater Intrusion Modeling
- Harbor Dinner Cruise
- F5-Geohistory of Columbia Gorge Floods - Day 1

Friday, April 15, 2005

- F5-Geohistory of Columbia Gorge Floods - Day 2

7:30 AM	TUESDAY APRIL 12, 2005 - REGISTRATION	
8:15 AM	Welcome & Keynote 1: Bill Woessner, University of Montana — Viruses & Pharmaceuticals in Groundwater	
9:30 AM	Break	
9:45 AM	1A: GROUNDWATER-SURFACE WATER INTERACTIONS: CHEMISTRY, MODELS, AND REGULATIONS	1B: AQUIFER STORAGE AND RECOVERY
SESSION 1	**Logistic Regression Used to Relate Ground Water Quality to Man-Made and Natural Causes:** *Sandy K. Williamson, U.S. Geological Survey* **Development and Applications of Groundwater Flow Model for the Dungeness River Area, Sequim, WA:** *Thomas C. Goodlin, Tetra Tech EC, Inc.* **Using Numerical Models to Assess Storm-Water Infiltration Basins in Shallow Groundwater Settings:** *Dawn M. Chapel, Pacific Groundwater Group* **Hydrogeology and Critical Aquifer Recharge Areas:** *Laurie Morgan, WA Department of Ecology*	**Groundwater Storage Assessment and Beneficial Use of Class A Reclaimed Water in WRIA 14:** *Steve Nelson, SLR International Corporation* **City of Walla Walla Aquifer Storage and Recovery Development:** *Michael P. Klisch, Golder Associates Inc.* **Evaluating ASR Using Columbia River Water, Kennewick, Washington:** *Steve J. Germiat, Aspect Consulting, LLC* **ASR and Buildout Applications of the Dungeness Groundwater Flow Model, Sequim, WA :** *Ann C. Soule, Clallam County Environmental Health Services*
11:15 AM	Poster Session 1 - Groundwater Contamination and Remediation	
12:00 PM	LUNCH (provided) - Phil Mote, University of Washington, State Climatologist — Pacific Northwest Climate: Past, Present & Future	
1:30 PM	2A: POINT SOURCE CONTAMINANTS IN THE SUBSURFACE	2B: CHANGING CLIMATE, RETREATING GLACIERS, AND GROUNDWATER AVAILABILITY
SESSION 2	**Investigation of Casing Corrosion in Wells from the Hanford Nuclear Reservation, Richland, Washington:** *Christopher F. Brown, Pacific Northwest National Laboratory* **Contaminant Ratios as a Key to Contaminant Sources and Histories in the Hanford 200 West Area:** *Floyd N. Hodges, WA Department of Ecology* **Field Measurement of NAPL Volumes in the Vadose Zone by Partitioning Interwell Tracer Testing:** *Richard E. Jackson, INTERA Inc.* **A Refined Conceptual Model for Dense Non-Aqueous Phase Liquids (DNAPL) in the Subsurface at the 200 West Area, Department of Energy Hanford Site:** *Dawn Kaback, Geomatrix Consultants, Inc.*	**On the Continuing Retreat of South Cascade Glacier, Washington:** *Edward G. Josberger, U.S. Geological Survey* **Implications of Global Warming on Water Availability:** *Chris V. Pitre, Golder Associates Inc.* **Development of the Abbotsford-Sumas Aquifer Groundwater Flow Model for a Climate Change Impacts Study:** *Diana Allen, Department of Earth Sciences, Simon Fraser University* **Glacier Shrinkage and Hydrological Effects: Diminishing Returns:** *Andrew G. Fountain, Departments of Geology and Geography, Portland State University*
3:00 PM	Break	
3:30 PM	3A: REMEDIATION - I	3B: NON-POINT SOURCE CONTAMINATION
SESSION 3	**Pilot Testing of Permanganate Injection at Low Concentration to Restore a Solvent-Impacted Drinking Water Aquifer:** *Dave Heffner, Aspect Consulting, LLC* **Use of Enhanced In-situ Reductive Dechlorination to Replace Pump and Treat at an Aerospace Manufacturing Facility in Tukwilla, Washington:** *Clinton L. Jacob, Landau Associates* **A Tale of Two Barrier Walls: A Performance Comparison of Groundwater Containment Walls near Seattle, Washington:** *John D. Long, Geomatrix Consultants, Inc.* **Steam-Enhanced Remediation of a Former Wood-Treating Facility at the Port of Ridgefield Lake River Industrial Site; Effects of Hydrostratigraphy on the Distribution of Heat and Mass Removal of Contaminants:** *Eric Roth, Maul Foster & Alongi, Inc.* **Laboratory and Field Studies of Cr-Bioimmobilization in Groundwater at Hanford:** *Terry C. Hazen, Lawrence Berkeley National Laboratory*	**Vadose Zone Nitrate Contamination, Malheur County, Oregon:** *Paul F. Pedone, Natural Resources Conservation Service, USDA* **Pesticides in Surface Waters of the Pacific Northwest-Overview of USGS Regional Findings:** *Sandy K. Williamson, U.S. Geological Survey* **Ground Water Nitrate Distributions and Denitrification in a Portion of the Abbotsford-Sumas Aquifer, Northwest Washington:** *Robert Mitchell, Western Washington University, Geology Department* **Trace Metals Levels in Puget Sound Glacial Materials:** *Lori J. Herman, Aspect Consulting, LLC* **Does Bacterial and Nitrate Contamination in Streams in Whatcom County, Washington, Come from Ground Water?:** *Stephen E. Cox, U.S. Geological Survey*
5:20 PM	Break - Visit the Exhibitors	
6 - 9 PM	DINNER (provided) and Cash Bar at the Washington State History Museum	

7:30 AM	WEDNESDAY APRIL 13, 2005 - REGISTRATION	
8:00 AM	**Keynote 2: Ileana Rhodes, Shell Global Solutions — Overview of Petroleum Hydrocarbon Chemistry and Environmental Forensics**	
9:00 AM	**Break**	
9:30 AM	**4A: DATA ANALYSIS AND EXCHANGE**	**4B: EFFECTS OF HETEROGENEITY**
SESSION 4	**Pacific Northwest Water Quality Data Exchange:** *John Tooley, GIS Supervisor, WA Department of Ecology* **An International Perspective on Maintaining Optimum Well Performance:** *Jim S. Bailey, Golder Associates Inc.* **Trends in Uranium Plume Parameters, 300 Area, Hanford Site, Washington:** *Christopher J. Murray, Pacific Northwest National Laboratory* **Groundwater Evaluation Methodology and Development of Concentration Limits for Landfills near Surface Water Bodies:** *Bryan Graham, Tetra Tech EC, Inc.*	**Groundwater Flow Direction Anomaly Near Seattle's Union Station After the Nisqually Earthquake:** *Brian Butler, Landau and Associates* **Layered Heterogeneity and its Effect on Technetium-99 Behavior in Variably Saturated Sediments: A Case Study of Hanford's 216-B-26 Trench:** *Anderson L. Ward, Hydrology Technical Group, Pacific Northwest Laboratories* **Effect of Geology and Groundwater-Surface Water Interaction on Groundwater Flow and a Dissolved Chlorinated Solvent Plume in the Esperance Sand, Everett, Washington:** *Mark P. Molinari, URS Corporation* **Effective Leak Detection — A Needed Component During Retrieval of High-Level Mixed Waste from Single Shell Tanks at the Hanford Site:** *Joseph A. Caggiano, WA Department of Ecology*
11:00 AM	**Poster Session 2 — Geohydrology and Watersheds**	
12:00 PM	**LUNCH (provided)**	
1:30 PM	**5A: CONTAMINANT FATE AND TRANSPORT STUDIES**	**5B: HYDROSTRATIGRAPHY**
SESSION 5	**Ground Water Discharges of High pH and Chlorinated Hydrocarbons into the Hylebos Waterway, Tacoma, Washington:** *Roy Jensen, Weston Solutions, Inc.* **The Impact of Stratigraphy and Geochemistry on Contaminant Fate Transport at the Boomsnub/Airco Superfund Site, Hazel Dell, Washington:** *Glenn A. Hayman, EA Engineering, Science and Technology, Inc.* **Stable Isotopes of Strontium as Tracers of Seawater Intrusion and TCE: Case Studies from the Dominguez Gap (CA) and a Fractured Limestone Terrane (MO):** *Richard W. Hurst, Hurst & Associates, Inc.* **Trace-Element Concentrations and Occurrence of Metallurgical Slag Particles in Bed Sediment Cores from Lake Roosevelt, Washington:** *Stephen E. Cox, U.S. Geological Survey*	**Evaluation of the Nature of the Boundary between the Northern and Central Quito Aquifers, Quito, Ecuador:** *Mark P. Ausburn, KOMEX* **Investigating Vertical Contaminant Distribution Using Innovative Methods:** *Susan M. Narbutovskih, Pacific Northwest National Laboratory* **Identification of Leakage Effects During Site Characterization Investigations at the Potential Black Rock Reservoir Site:** *Frank A. Spane, Pacific Northwest National Laboratory* **Three-Dimensional Geologic Model for the Washington Portion of the Spokane Valley-Rathdrum Prairie Aquifer:** *James L. Poelstra, WA Department of Natural Resources, Geology & Earth Resources Division*
3:00 PM	**Break**	
3:30 PM	**6A: WATERSHED MANAGEMENT PROBLEMS AND PLANS**	**6B: GROUNDWATER/SURFACE WATER - I**
SESSION 6	**Oregon's Water Woes: Past and Present:** *William N. Orr, University of Oregon* **Klamath Basin Rangeland Trust and the Irrigation Hydrology of Wood River Valley:** *Charles T. Ellingson, Pacific Ground Water Group* **Des Moines Creek Basin — A Holistic Restoration Approach:** *Zahid Khan, Des Moines Creek Basin Restoration Projects, King County Department of Natural Resources & Parks* **The Role of Ground-Water Hydrology in Resolving Water-Supply Issues in the Upper Klamath Basin, Oregon and California:** *Marshall W. Gannett, U.S. Geological Survey*	**North Creek Stream Flow Enhancement:** *Charles S. Lindsay, Associated Earth Sciences, Inc.* **Shallow Aquifer Response to Modifications in Columbia River Hydroelectric Management:** *Fred Wurster, U.S. Fish and Wildlife Service, Division of Engineering/Water Resources* **Hydrogeologic Framework of Eastern Jefferson County, Washington: Implications For Surface Water-Ground Water Interactions:** *F. William Simonds, U.S. Geological Survey* **Groundwater Contaminants Entering the Columbia River at the Hanford Site's 300 Area:** *Gregory W. Patton, Pacific Northwest National Laboratory*
5:00 PM	**Break**	
5:30 - 8:30 PM	**Dinner Cruise and Workshops**	

7:30 AM	THURSDAY APRIL 14, 2005 - REGISTRATION	
8:00 AM	Keynote 3: Graham Fogg, UC Davis — Groundwater Vulnerability and the Meaning of Age Dates	
9:00 AM	7A: REMEDIATION - II	7B: GROUNDWATER/SURFACE WATER - II
SESSION 7	**Understanding and Treating a TCE Plume that Defies Conventional Wisdom:** *Thomas C. Goodlin, Tetra Tech EC, Inc.* **Challenges in the Remediation of Groundwater Contaminated with Sr-90 in N-Area, Hanford Site, Washington:** *Dibakar Goswami, WA Department of Ecology* **Environmental Tracer Investigation of Ground-Water Flow and TCE Migration beneath Fort Lewis, Washington:** *Richard S. Dinicola, U.S. Geological Survey*	**Thermal Profiling of Long River Reaches to Characterize Ground-Water Discharge and Preferred Salmonid Habitat:** *J.J. Vaccaro, U.S. Geological Survey* **Monitoring Groundwater Quality Along the Columbia River, Hanford Site, Washington:** *Robert E. Peterson, Field Hygrology and Chemistry, Pacific Northwest National Laboratory* **A Decade of Regulatory Process to Reach Active Remediation, The Boeing Plant 2 Chlorinated Solvent Interim Action, Seattle, Washington:** *Hideo Fujita, WA Department of Ecology*
10:25 AM	Break	
10:45 AM	8A: EMERGING CONTAMINANTS AND PUBLIC EXPOSURE	8B: GROUNDWATER MODELING
SESSION 8	**Mercury Emissions and Lake Deposition: A Qualitative Model and its Application to Lake Whatcom, Washington:** *A. Paulson, U.S. Geological Survey* **Ground Water Investigations for Perchlorate in Washington and Oregon:** *Kevin Broom, Weston Solutions, Inc.* **Volatile Organic Compounds in Soil Gas above a Ground Water Contaminant Plume at Fort Lewis, Washington:** *Gregory W. Patton, Pacific Northwest National Laboratory*	**Linking ArcGIS to the SQL Server Database to Merge and Analyse Spacial and Tabular Datasets for Water-Quality Studies:** *Frank Voss, U.S. Geological Survey* **Upland Basin Groundwater Models for Predicting Septic System Impacts and Land Use Planning:** *Gary E. Andres, Land and Water Consulting, Inc.* **Impact of Climate Change and Drought on Groundwater Management in the Yakima Basin:** *Lance Vail, Rajiv Prasad, Scott Waichler, Mark Wigmosta, Pacific Northwest National Laboratory*
11:45 AM	Closing Remarks and Door Prize Drawing	
12:00 PM	END OF SYMPOSIUM (Lunch provided with some workshops and field trips)	

Occurrence, Transport, and Fate of Viruses and Pharmaceuticals in Groundwater Impacted by Septic System Effluent: The Hydrogeologists and Human Health

Dr. William W. Woessner
2005 GSA Hydrogeology Division's Birdsall-Dreiss Distinguished Lecturer
University of Montana, Missoula

Over the last 20 plus years Dr. Woessner has studied how the disposal of sewage from households, and larger multiple user facilities in unsewered areas has impacted the underlying groundwater. When the densities of dwellings using septic systems increase, concern is often raised by adjacent homeowners, and/or local and state governments that potable groundwater will be impacted. Though individual household wells are usually not regularly tested, groundwater serving multiple households, communities, or the public must be free of fecal coliform bacteria and contain nitrate-nitrogen below 10 mg/l. However, recently, federal regulators have suggested groundwater supplies should be tested for viruses. In addition, the discovery of trace quantities of pharmaceuticals in surface water impacted by sewage and sewage treatment plant waste has raised concerns that groundwater degraded by septic system effluent may also contain low levels of pharmaceuticals.

This presentation will focus on the occurrence of a select group of viruses and pharmaceuticals in septic systems, and the processes controlling the transport and fate of these constituents in the underlying shallow aquifers. Dr. Woessner will present the results of sampling sewage impacted groundwater associated with a high school drain field and virus tracer experiments used to assess transport processes in shallow sand and gravel dominated aquifers. The results of a survey level study that chronicled the occurrence of 20 pharmaceutical compounds in a large number of individual septic tanks, and the prevalence and fate of these compounds in the associated groundwater will also be discussed. Both prescription and non-prescription drugs were detected. The presentation will conclude with a discussion how hydrogeological data may or may not be used to examine related risks to human health.

Dr. Woessner is a professor of hydrogeology at the University of Montana-Missoula, where he was recently named a Regents' Professor. He is also Director of the Center for Riverine Science and Stream Re-naturalization. He holds a PhD in Hydrogeology and an MS in Water Resources Management from the University of Wisconsin-Madison and an MS in Geology from the University of Florida-Gainesville. He has authored numerous articles and books, mostly about groundwater modeling and floodplain aquifers, including the renowned "Applied Groundwater Modeling" (1993), written with Mary P. Anderson.

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Logistic Regression Used to Relate Ground Water Quality to Man-Made and Natural Causes

Jim Tesoriero, Michael G. Rupert, Lonna M. Frans, and Alex K. (Sandy) Williamson[1]

Ground-water vulnerability typically has been assessed using qualitative methods and expressed as relative measures of risk, like DRASTIC. The logistic regression approach has the advantage of having both model variables and coefficient values determined on the basis of existing water-quality information. Unlike DRASTIC-type methods, the logistic regression approach does not depend on the somewhat arbitrary assignment of variables and weighting factors based on qualitative criteria. Logistic regression is a great way to rigorously relate man-made and natural factors to ground-water quality. It usually produces more statistical confidence than regular multiple regression because logistical regression tries to answer a simple yes-or-no question (contaminant exceeds threshold) rather than the multiple regression question relating a wide range of concentration values to contributing factors. Logistic regression can be used to assess ground-water susceptibility (relative ease with which contaminants can reach aquifer) and ground-water vulnerability (relative ease with which contaminants will reach aquifer for a given set of land-use practices). In three USGS studies in Washington and Colorado, the variables that best explain the occurrence of high nitrate or pesticides included the (1) well and/or casing depth, (2) percentage of urban and agricultural land or the amount of fertilizer applied within a radius of 3.2 kilometers of the well, (3) surficial geology, and (4) mean soil hydrologic group, which is a measure of soil-infiltration rate. Maps can be made of the predicted depth to which wells would need to be cased in order to have an X-percentage probability of drawing water with high nitrate or pesticides or the predicted probability of high nitrate or pesticides for wells cased to median casing depth.

References:

http://water.usgs.gov/pubs/wri/wri02-4269/pdf/WRIR02-4269.pdf
http://wa.water.usgs.gov/pubs/misc/ps.gw.vol35.no.6.html
http://www.ecy.wa.gov/events/hg/abstracts2000.pdf page 10 & 77 http://webserver.cr.usgs.gov/midconherb/html/texas.html
http://water.usgs.gov/pubs/wri/wri004110

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Development and Applications of Groundwater Flow Model for the Dungeness River Area, Sequim, WA

Thomas C. Goodlin[1], Elizabeth W. Roy[2], Suzanne L. Burnell[3]

A regional groundwater flow model of the Sequim-Dungeness area was developed for the Washington Department of Ecology and the Dungeness River Water Users Association to better define the groundwater system and to provide an analytical tool for assessing the impacts of irrigation conservation alternatives in the Conservation Plan EIS. Simulations applied via the groundwater model also supported planners in answering questions related to the impact of human activities on groundwater, streamflows, wetlands, and well development for this eastern half of WRIA 18. The MODFLOW code was applied to generate both steady state and transient (monthly) models based on data gathered by the USGS and others from December 1995 through September 1997. The 14.5-mile by 9.5-mile model area centers about the Dungeness River and extends from the mountains to the sea. The project team assembled a detailed hydrogeologic information base, including hydrogeologic reports, recharge data, river/stream flow rates, pumping wells, and boring logs to support the construction of a seven-layer model. Model construction represents the Dungeness River surface-water/groundwater interchange via the MODFLOW stream package, and applies drain cells to create groundwater discharge via creeks and to marine waters. Calibration of both the steady-state and transient models was conducted to match observations for hydraulic head elevations, groundwater flow volumes, and river/aquifer water exchange. The models incorporate nine other streams, irrigation ditches, river diversions, and over 4,000 pumping wells.

Varied degrees of lining irrigation ditches simulated the four EIS alternatives to measure relative differences in computed aquifer response. Separate simulations also were completed for: aquifer storage and recovery (ASR) and evaluation of impacts from future development per the 2514 Watershed Planning Act. The ASR simulations demonstrated the ability to divert river flow at times when optimum instream flow is exceeded to make additional storage available for later recovery during the dry season. For 2514 watershed planning, complete development of current zoning was simulated for additional groundwater withdrawals and changes to aquifer recharge that would result. The simulation results indicate relative differences to current conditions in aquifer drawdowns and river flow loss.

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Using Numerical Models to Assess Storm-Water Infiltration Basins in Shallow Groundwater Settings

Dawn M. Chapel[1] and Charles T. Ellingson[2]

Shallow groundwater can cause surface flooding as water tables rise in response to recharge. Susceptible settings occur in many areas of the Puget Sound Lowland and Spokane, Washington. The years 1996 and 1999 were particularly wet years that caused historical high water tables in some locations, with surface flooding lasting up to months. As communities continue to develop, high water table settings are increasingly creating a challenge both for storm-water disposal designers and land-use regulators who administer critical areas, respond to public emergencies, and who are required to assess development proposals before issuing permits.

In response, many communities are developing tools and guidelines to help manage growth in areas with shallow groundwater. Such tools and guidelines have included construction of regional high-water table maps; identification of critical areas; setting standard minimum depths-to-water for development approval; developing alternative options for storm-water disposal; and developing groundwater monitoring programs. On a more site-specific scale, evaluations may include the use of numerical models to predict groundwater responses to proposed developments and storm water infiltration system. The use of numerical models as a predictive tool for site-specific assessments can be valuable but are complex and many model design parameters need to be considered that can affect the simulation results.

This paper focuses on the use of transient finite-difference groundwater flow models as a predictive tool for assessing groundwater mounding in high-water table settings. In particular we focus on designing models for simulating groundwater mounding in response to focused recharge beneath storm-water infiltration basins. Important model design considerations include the choice of an appropriate time-step size; model grid spacing; and three-dimensional layering. Also important are the input parameters such as aquifer characteristics; boundary conditions; and the appropriate storm-event to simulate. We demonstrate the importance of these model design considerations by presenting two studies in the Puget Sound Lowland area where we have developed three-dimensional transient finite-difference models to assess groundwater mounding beneath storm-water infiltration basins.

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Hydrogeology and Critical Aquifer Recharge Areas

Laurie Morgan

The State of Washington passed the Growth Management Act (GMA) in 1990. The GMA includes provisions for critical areas, which include wetlands, fish and wildlife habitat, critical aquifer recharge areas, frequently flooded areas, and geologically hazardous areas. Critical Aquifer Recharge Areas are areas that have a critical recharging effect on aquifers used for potable water. The goal is to protect public drinking water supply aquifers from contamination and depletion.

Counties and cities adopt Critical Aquifer Recharge Areas and use best available science, planning, zoning, ordinances, and public outreach programs to protect these areas. This process involves many people, including planners, council members, commissioners, citizens, government staff, and hydrogeologists.

While cities and counties are taking steps to adopt and update planning and ordinances for their Critical Aquifer Recharge Areas, they also have to address a myriad of natural resource issues, most of which involve water. Groundwater is intertwined with practically all aspects of natural resource management. Natural resource subject areas where groundwater is a key factor include streams, lakes, wetlands, flooding, channel migration, erosion, landslides, water supply, stormwater management, water re-use, saltwater intrusion, endangered fish, and others. Each of these subject areas has their own regulatory origins and funding sources that has tended towards the separation of these issues. There is a strong move afoot globally to integrate the management of these various topics under the heading of “integrated water resources management” or other ways of expressing the same goal.

This talk will focus on the actual on-the-ground hydrogeology of Critical Aquifer Recharge Areas, using examples of how these areas have been delineated, characterized, and designated. The place of Critical Aquifer Recharge Areas in the overall scheme of natural resource and water planning will also be discussed.

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Groundwater Storage Assessment and Beneficial Use of Class A Reclaimed Water in WRIA 14

Steve Nelson[1], LHG and James D'Aboy[2], PE

Mason County regional planners will manage Class A reclaimed water derived from treated municipal effluent for multiple use benefits in WRIA 14 (Kennedy-Goldsborough Creek). The storage assessment plan for WRIA 14 will provide planners and stakeholders a tool to understand the natural conditions and land use policies that will constrain temporary storage of reclaimed water in the watershed. We evaluated the hydrogeologic conditions of infiltration materials, the hydrostratigraphy that directs groundwater discharge, and seasonal water levels in groundwater and surface water receptors. We identified the range and location of beneficial uses of reclaimed water including stream augmentation through groundwater recharge, industrial processes, and irrigation. Potential impacts to existing water uses and regulatory constraints on water discharge near sensitive areas will limit the locations and timing of reclaimed water discharge. Using GIS to compile and display hydrogeologic and hydrologic conditions, land uses, and sensitive areas facilitated the identification of optimal sites in WRIA for temporary storage and reuse of reclaimed water.

Following the assessment phase of work, we performed infiltration tests and monitored water levels at optimal sites to evaluate the feasibility of temporary storage of reclaimed water and the hydrogeologic conditions that will govern the location, rate, and timing of water discharge.

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City of Walla Walla Aquifer Storage and Recovery Development

Michael P. Klisch[1] and David Banton[2]

The City of Walla Walla uses surface water from Mill Creek and groundwater from deep basalt wells to meet the city's water demand. Walla Walla began to investigate Aquifer Storage and Recovery (ASR) in the late 1990's as a means of augmenting the water system capacity to meet peak demands or when the city's surface water source cannot be used because of high turbidity. ASR was first evaluated in Walla Walla in the 1950's as a means of halting observed groundwater level declines in the basalt aquifer.

The basalt aquifer in the vicinity of Walla Walla is moderately to highly permeable and is separated into discreet blocks by faulting. Adjacent blocks are separated by low-permeability fault gouge or by offset of permeable interflow ones against low-permeability flow interiors. These fault-bounded blocks are favorable for storage of treated drinking water. The city converted Well No. 1 to an ASR well and completed ASR pilot tests in 2000.

The success of the Well No. 1 pilot testing led the city to convert Well No. 6 to an ASR well. ASR pilot testing was completed in Well No. 6 in 2003. About 77 Mgal of water were recharged into the basalt aquifer over 49 days, and stored for 43 days. About 140 Mgal of water was recovered over a 43-day period. During the recharge period, water levels in the basalt aquifer rose, resulting in restoration of flowing artesian conditions at Well No. 4.

The pilot testing completed in both wells indicated that ASR is feasible, and the city has started full-scale implementation of ASR using both wells. Well No. 1 has been used as an ASR well since 2001, and started using Well No. 6 as an ASR well since the fall of 2003. The City is also evaluating expanding ASR to some of their other wells

A three-dimensional groundwater flow model of the Walla Walla area is being developed to evaluate whether the basalt aquifer can meet the city's water supply needs in the event their surface water source is lost because of fire in the watershed, the overall capacity of the basalt aquifer to store water and ASR operational scenarios to maximize aquifer storage capacity, and to provide the framework for future groundwater management area evaluations.

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Evaluating ASR using Columbia River Water, Kennewick, Washington

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Watershed planning efforts for WRIA 31 (Rock-Glade watershed) indicate that water storage will be an important water management strategy to meet future water demand in the watershed. Approximately 90 percent of the WRIA 31 population resides within the City of Kennewick, which projects a 140% increase in water demand by the year 2021. Water required to meet Kennewick's summer peak demand is currently drawn from the Columbia River at the time that flows are naturally lowest and of greatest importance for in-stream resources. Water storage can help alleviate this timing problem between seasonal water supply availability and demand in this arid watershed, as well as provide a cost effective means to address short term peak demands.

Aquifer storage and recovery (ASR) is a promising water storage option since the Columbia River Basalt aquifers are highly productive, yet have seen substantial long-term water level decline from large irrigation withdrawals in parts of the WRIA. This overdraft represents a minimum available aquifer storage capacity. All streams in WRIA 31 are ephemeral, thus the Columbia River is the only feasible source of excess water for a storage project of any size there. Diverting peak winter Columbia River flows, storing that water in the subsurface, and subsequently recovering it for summer use could reduce direct diversions from the river in the summer. This project, funded by a Washington State Department of Ecology (Ecology) watershed planning grant, provides a feasibility-level assessment of applying ASR to meet Kennewick's municipal (multipurpose) needs.

Candidate ASR sites are located near Kennewick's existing and planned water supply infrastructure. The hydrogeologic conceptual model for each site is focused toward local geologic structural controls on groundwater flow and quality. The environmental assessment estimates potential impacts associated with applying ASR in the candidate areas. Outcomes of the feasibility project include an ASR pilot testing plan, and system characterization which will provide the supporting documentation if the City pursues submittal of an ASR application to Ecology.

ASR using Columbia River source water, particularly where water treatment capacity currently exists, can be a technically viable means of managing the available water resource to support community and economic growth. Because of seasonal timing advantages afforded by water storage, it also helps make additional in-stream water available during critical flow periods. Because of hydrologic similarities across WRIA 31, knowledge gained through this project in Kennewick provides a starting point for evaluating ASR opportunities elsewhere in the WRIA.

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ASR and Buildout Applications of the Dungeness Groundwater Flow Model, Sequim, WA

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Watershed planning in the Elwha-Dungeness (WRIA 18) under RCW 90.82 prompted questions about the availability of groundwater for future supply in the overappropriated Dungeness basin. The Planning Unit employed the regional flow model developed for the Wash. Dept. of Ecology and the Dungeness River Water Users Assn. by Tetra Tech FW, Inc., for two specific questions: (1) would aquifer storage of Dungeness high flows benefit the shallow aquifer and/or surface water systems during low-flow season, and (2) how are the aquifers, small streams, and the Dungeness River affected by various scenarios of potential future groundwater withdrawals. A separate paper describes construction and calibration of the seven-layer, regional model.

Model-simulated aquifer storage and recovery (ASR) involved diverting 5 cfs from the Dungeness River to shallow aquifer recharge for any day in which the river flow exceeded 580 cfs (i.e., April and June). The amount of recharge varied in three runs conducted—one each for high-, intermediate-, and low-flow years. Transient model results showed that sustained mounding of 1 to 5 feet can persist through the dry season. However, beneficial effects during the low-flow season (August-October) in low-flow years are small to negligible, while they are significant in medium- and high-flow years. Because of these results, the Elwha-Dungeness Watershed Plan (now under County legislative review) recommends ASR as a potential tool for compensating impacts of future groundwater withdrawals in the basin.

Continued rapid development forces the question of meeting future water demands in this watershed that has a high degree of hydraulic continuity between aquifers. Potential future groundwater withdrawals at “full buildout” were estimated by applying assumed rates of withdrawal to all undeveloped parcels within existing land use zones in the study area. Modelers simulated three scenarios for withdrawals outside municipalities and Urban Growth Areas (UGAs): (1) all are from individual wells tapping the shallow aquifer, (2) all are from individual wells tapping the middle aquifer, and (3) most are from one of four wellfields tapping the lower aquifer. Recharge was decreased within UGAs to reflect increased impervious surfaces, as well as across the study area to reflect decreased irrigated agriculture. Recharge from septic systems was 70% of residential withdrawals outside UGAs. Results for all three scenarios show decreased streamflows and aquifer levels at full buildout; the third scenario showed the least impact. Impacts from the first and second scenarios were found to be fairly similar. Because these results indicate relative differences depending on the arrangement of withdrawals, the Watershed Plan recommends utilizing strategically-located community wells in the lower aquifer as one management strategy for minimizing impacts to surface water.

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Pacific Northwest Climate: Past, Present & Future

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Dr. Philip W. Mote is an affiliate faculty member with the Department of Atmospheric Sciences, University of Washington, where he earned his PhD. He is the Washington State Climatologist. He is also a consultant with Northwest Research Associates, where he specializes in studies of clouds, water vapor, and radiation in the tropical upper troposphere and lower stratosphere. He will explain why some surprising climatic changes are being forecast for the Pacific Northwest.

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Investigation of Casing Corrosion in Wells from the Hanford Nuclear Reservation, Richland, Washington

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The Hanford Nuclear Reservation (HNR), located in Southeastern Washington, was once home to weapons grade plutonium production. Over the last fifteen years, the HNR has shifted from production and operation to clean up and decontamination. Numerous Resource Conservation and Recovery Act (RCRA) wells have been installed throughout the HNR to characterize and define trends in the physical, chemical, and biological conditions of the environment, as well as to identify and quantify new or existing environmental quality problems. In 2003, it was determined that two RCRA monitoring wells in the A/AX Waste Management Area (WMA), 299-E24-19 and 299-E25-46, failed due to rapid corrosion of the stainless steel casing (type 304L) over a significant length of the well. Complete casing corrosion occurred between 276.6 and 277.7 feet below ground surface (bgs) in well 299-E24-19 and from 274.4 to 278.6 feet bgs in well 299-E25-46.

Samples from the "zone of interest" were retrieved and subjected to a series of laboratory tests in an attempt to identify the cause of corrosion. Analysis of the sidewall core samples (collected at the time of well decommissioning) yielded a clear relationship between chloride concentration and well casing corrosion. The sidewall core samples containing the greatest amount of chloride, 3000 µg/g of sediment, came from the well that experienced the longest length of casing failure (4.2 feet in well 299-E25-46). The highest calculated porewater chloride concentration from these samples was in excess of 10,000 mg/L, which is two orders of magnitude above the corrosion threshold value (100 mg/L) for pitting/crevice corrosion of type 304L stainless steel at this pH (7-8). Furthermore, both of the failed wells were reported to have been subjected to compressive force at the time of installation, which likely resulted in deformation of the casing. Therefore, it appears that chloride enhanced stress corrosion cracking was the primary mechanism responsible for failure of the stainless steel casing in these two wells. Testing is currently underway to investigate the source of chloride in the sidewall core samples. Preliminary results indicate chloride could have been present as a trace constituent in the bentonite material; however, additional data will be required, and is currently being collected, to fully evaluate/confirm this hypothesis.

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Contaminant Ratios as a Key to Contaminant Sources and Histories in the Hanford 200 West Area

Floyd N. Hodges

A half century of nuclear weapons production has left a legacy of highly contaminated groundwater under much of Hanford's 200 West Area. Major contaminant plumes of tritium, technetium-99, iodine-129, chromium, uranium, nitrate, and carbon tetrachloride are present. In many cases these plumes are overlapping, adding a degree of complexity. The overlapping of contaminant plumes is a result of temporal variations in groundwater flow directions resulting from changes in effluent disposal locations during the operational history of the site.

This contaminant background has made it difficult to distinguish more recent groundwater impacts from contamination resulting from past practice waste disposal. Hanford's high-level waste tanks and related equipment have historically been sources of large quantities of vadose zone contamination and it is important to be able to detect this contamination when it reaches groundwater

Experience at the T and TX-TY Tank Farms, located in the northern portion of the 200 West Area indicates that the use of ratios of groundwater contaminant species provides a means for distinguishing different contaminant sources and can provide significant information about the history of contaminant sources.

Ratios involving technetium-99, tritium, and nitrate clearly define mixing lines for past practice contamination and indicate that high concentrations of technetium-99 and other contaminants detected in wells at the T and TX-TY Tank Farms area are a result of leaks of tank waste within these waste management units. Ratio analysis of groundwater from a contaminant plume located at the northeast corner of the T Tank Farm shows the affects of a water line leak on contaminant concentrations observed in the monitoring well at that location. It also indicates that the contaminant plume at that location is located in a zone of relatively low permeability near the top of the aquifer. Current groundwater monitoring, using wells with 10.6 m well screens, draws a disproportionate quantity of water from higher-permeability zones deeper within the screened intervals. The result is a large underestimation of contaminant levels present within the tank farm contaminant plume.

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Field Measurement of NAPL Volumes in the Vadose Zone by Partitioning Interwell Tracer Testing

Richard E. Jackson[1], Minquan Jin, John Londergan and Jeff Silva

Gas tracers have been used to measure the average interwell volumes of non-aqueous phase liquids (NAPLs) beneath field sites in Utah, Texas and New Mexico. The tracers are typically perfluorinated hydrocarbons and the NAPLs measured have been predominantly trichloroethylene (TCE) and toluene.

The tracers are selected and tested in laboratory soil columns first to determine if there is any tracer sorption to clean soil and then to measure the tracer partition coefficients in columns containing known amounts of NAPL and water. UTCHEM multi-phase simulations are used to estimate the mass of each tracer required and the duration of the partitioning interwell tracer test (PITT). These simulations optimize the design of the PITT through the efficient placement of injection, extraction, monitoring and control wells so that the tracer penetrates and 'samples' the NAPL zone that was earlier approximated by soil coring.

The first vadose-zone PITT was undertaken in 1995 at the Chemical Waste Landfill at Sandia National Laboratories in New Mexico (Mariner et al., 1999, *Environmental Science & Technology* 33:2825-2828). It predicted that TCE DNAPL had penetrated to approximately 10 m below ground surface (bgs). This prediction, which was subsequently confirmed during site excavation, demonstrated that vadose-zone PITTs could reliably be used to guide remedial planning. The volume of TCE DNAPL predicted to be present beneath this site was 680 ± 120 L in a swept pore volume of 620 m^3.

Subsequently, vadose-zone PITTs were used in year 2000 at both Hill AFB, Utah to measure the TCE DNAPL volume beneath a former solvent disposal area and at DOE Pantex, Texas to measure the toluene LNAPL volume beneath a similar site. At Hill AFB, only 125 ± 26 L of DNAPL was measured in a swept pore volume of 275 m^3, despite some 200,000 L having been recovered from the alluvial aquifer beneath the site. At DOE Pantex, 3200 ± 420 L of LNAPL were measured at 15-30 m bgs in a swept pore volume of 2,000 m^3, apparently trapped above a caliche layer that inhibited its downward migration. A soil vapor extraction system was then installed to remove this LNAPL source that threatened to contaminate the underlying Ogallala aquifer. Based upon these successes, it is clear that vadose-zone PITTs can be used to detect and quantify the large volume (~750 tons) of carbon tetrachloride released at 200 Area West, DOE Hanford during the Cold War years.

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A Refined Conceptual Model for Dense Non-Aqueous Phase Liquids (DNAPL) in the Subsurface at the 200 West Area, Department of Energy Hanford Site

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The challenge of locating dense non-aqueous phase liquid (DNAPL) source terms in the subsurface to make remedial-action decisions is daunting. One of the largest solvent plumes in the United States is located in the 200 West Area of the U.S. Department of Energy Hanford Site. The goal of this work was to identify high-probability locations and extent of the carbon tetrachloride (CCl_4) source term at this site. Information from many previous investigations at the 200-West Area, site operations, waste characteristics, and disposal practices, was utilized to create a Refined Conceptual Model that highlights subsurface locations where DNAPL is believed to exist. The Refined Conceptual Model describes the present-day situation through a series of seven discrete subsurface sub-domains, each with unique physical and/or chemical features likely to affect where CCl_4-related DNAPL contamination may be present. The sub-domains extend from the near-surface vadose zone to the Ringold Lower Mud Unit at the base of the unconfined aquifer. Four of the seven sub-domains are targeted as high-probability sites for DNAPL.

Utilizing the Refined Conceptual Model, a number of investigative techniques and innovative approaches capable of detecting CCl_4-related contamination were evaluated for validation of the conceptual model. A cost-effective phased strategy directed at investigating the most likely locations was recommended. Because the location of DNAPL is believed to be strongly controlled by significant subsurface heterogeneities, the recommended investigation program targets enhancing our understanding of the location and extent of these heterogeneities. The strategy begins through use of non-invasive methods, including surface geophysics, passive and active soil gas monitoring, and progresses to invasive methods where borehole locations are selected based upon the results of the non-invasive activities. Invasive methods build upon new drilling, sampling, and testing technologies, such as the Enhanced Access Penetration System and the Borehole Flow Meter, to refine the hydrogeologic DNAPL model.

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On the Continuing Retreat of South Cascade Glacier, Washington

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The South Cascade Glacier in the northern Cascades Range of Washington State is responding quickly and dramatically to observed climate warming in the Pacific Northwest. The U.S. Geological Survey monitoring program of South Cascade Glacier has measured the winter and summer mass balances since 1959, the longest such record in North America. From 1976 to 1995, the record shows almost continuously negative annual net mass balances; from 1995 to present, there are four years (1997, 1999, 2000, and 2002) when the annual net balance has been slightly positive as a result of increases in the winter accumulation. However, this period is marked by some of the most negative summer balances on record, which has resulted in a continued shrinking of the glacier. The mass balance fluctuations are the result of fluctuations in the atmospheric circulation in the Northeast Pacific, as characterized by standard climate indices (the Southern Oscillation Index and the Pacific Decadal Oscillation, for example). Furthermore, there exists a strong relation between the winter and summer balances and the regional atmospheric conditions, as characterized in the NOAA National Center for Environmental Prediction atmospheric re-analysis data. Under currently accepted climate change scenarios, the glacier will continue its retreat, possibly at an accelerated rate. To examine current and possible future roles of North Cascades glaciers in providing late summer stream flows, the USGS is applying a new glacier melt and runoff model capable of simulating the dynamic response of runoff from glaciers of changing size. Initially, the model will be applied at South Cascade Glacier, where ample benchmarking data are available. In the future, the USGS plans to apply the model to additional glacierized basins to describe watershed-scale response to climate and glacier changes.

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Implications of Global Warming on Water Availability

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Predicted increases in both precipitation and temperature (Climate Impacts Group [CIG], University of Washington) raise the question of how water availability will be affected. Will there be more water available for streamflow and recharge to aquifers, or will higher temperatures result in higher rates of evapotranspiration and a net water loss? Water balance analyses were conducted on the Kitsap and the Little Spokane watersheds to answer this question. There is currently seasonal snowpack accumulation in the Little Spokane watershed, and none in the Kitsap watershed. Both watersheds have precipitation as the only input (i.e., there are no upgradient basins).

A monthly spreadsheet water balance was developed for the Kitsap watershed. The amount of "terrestrial water" (the difference between precipitation and actual evapotranspiration) is the water available for maintenance of instream flows and groundwater recharge. Increase in precipitation is almost entirely offset by increased evapotranspiration in 40 years. However, the seasonal fluctuations in terrestrial water will be amplified, and the wet season shortened by approximately two months. The concentration of terrestrial water into a shorter season is expected to result in greater runoff rates, and less groundwater recharge. Stormwater management is expected to become more critical in this urbanizing watershed under global warming conditions. Less recharge will be important in this watershed where groundwater is expected to provide all of the future water supply, and supports summer stream baseflows.

An integrated climate/surface runoff/groundwater model (MIKE SHE) was used to simulate the hydrology of the Little Spokane watershed with and without climate change effects. Slightly less than half of the snow was produced under global warming conditions than currently occur. The current streamflow hydrograph often peaks during the fall rains and a spring freshet, separated by an intervening period of winter snow accumulation. Under future conditions, the double peak is less distinct with streamflows being higher during the fall and winter, and lower during the spring freshet and summer low flow period.

In the watersheds evaluated, groundwater recharge and summer streamflows are predicted to be lower. Seasonal extremes are predicted for the Kitsap watershed. Less extreme winter and spring flows are expected for the Little Spokane watershed. This, combined with the prediction that climate variability will increase and predictability will decrease (Tsonis, 2004), will make water resources management increasingly more difficult, even without the current difficulties of managing water resources. Establishing regulatory minimum instream flows based on historical or current conditions may be less defendable in the future without considering climate change conditions.

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Development of the Abbotsford-Sumas Aquifer Groundwater Flow Model for a Climate Change Impacts Study

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A three dimensional groundwater flow model was developed for the Abbotsford-Sumas unconfined aquifer in the central Fraser Valley along the boundary of British Columbia and Washington State. The study involved linking climate models and the groundwater model to investigate future impacts of climate change on groundwater resources. The aquifer system is 160 km^2 in area and consists of unconfined and semi-confined units comprised of heterogeneous glaciofluvial/glaciolacustrine sediments, which infill depressions in glaciomarine sediments that overlie Tertiary bedrock. The valley shape was modeled using geostatistical methods from existing bedrock contours (seismic studies), deep exploration well lithologs, shallow wells intercepting bedrock outcrops, off-shore bathymetric surveys, valley wall slopes and extrapolated profiles. After extensive review of geologic and hydrogeologic information for the Fraser Valley, the hydrostratigraphy was modeled in 3D using 2500 standardized, reclassified, and interpreted well borehole lithologs from both sides of the border. In contrast to the traditional approach of generating layers for a model via the construction of cross sections, definition of layer contacts, and subsequent export of model layers, hydrostratigraphic units were mapped directly into Modflow from the bottom up, considering slices of the aquifer and the aquifer media represented in a 3D grid. This approach was necessary due to the extreme heterogeneity of the aquifer and the inability to define layers at a fine enough resolution. Spatial trends in hydraulic properties were interpolated and mapped onto the model layers. All known surface water features (including all rivers, streams, ditches, canals, lakes) in central Fraser Valley were included as boundary conditions. Spatially-distributed and temporally-varying recharge zonation was mapped for the surficial aquifer. The method involved using GIS linked to the one-dimensional HELP (USEPA) hydrologic model that estimates aquifer recharge. The recharge model accounts for soil distribution, vadose zone depth and hydraulic conductivity, the extent of impermeable areas, surficial geology, as well as strong precipitation gradients across the aquifer extent. Although recharge was computed as monthly averages per climate scenario, it is driven by physically-based daily weather inputs generated by a stochastic weather generator and calibrated to local observed climate. Four year long climate scenarios were run, each representing one typical year in the present and future (2020s, 2050s, and 2080s), by perturbing the historical weather according to the downscaled CGCM1 general circulation model results (Environment Canada). The calibrated transient model was used for all climate scenarios.

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Glacier Shrinkage and Hydrological Effects: Diminishing Returns

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Over 1200 alpine glaciers exist in Washington and cover an area of about 417 square kilometers. With few exceptions, all glaciers have been shrinking over the past century and the rate of shrinkage has accelerated over the past few decades. Overall, smaller glaciers exhibit greatest shrinkage, relative to their size, compared to larger glaciers. Preliminary results from studies of glacier change in several national parks reveal the spatial pattern of glacier change. Glacier shrinkage, while contributing to global sea level change, has two important local effects. First, the net release of water from its storage in the frozen state enhances overall stream discharge. Second, the shrinking area of glaciers reduces their moderating effect on stream flow, particularly during late-summer and drought periods, and shifts peak runoff towards early summer. Consequently these alpine basins become more susceptible to future drought. From an ecological perspective, the greatest effects are in the high alpine regions where glacier recession opens new areas for biological expansion, and where the hydrological dependence on glaciers is greatest. Lesser effects, related to suspended sediment loads, are felt well downstream (10's km) from glaciers.

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Pilot Testing of Permanganate Injection at Low Concentration to Restore a Solvent-Impacted Drinking Water Aquifer

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Routine testing in 1998 of a water supply well at a maintenance facility in Lewis County, Washington, indicated the presence of chlorinated hydrocarbons, primarily tetrachloroethene (PCE) and trichloroethene (TCE), at concentrations above federal Maximum Contaminant Levels (MCLs) in drinking water. The subsequent remedial investigation identified a plume of affected groundwater extending nearly 2,000 feet northward from the site, and comprehensive testing of water supply wells detected chlorinated hydrocarbons in five off-site drinking water wells. An area of soil in the central portion of the facility was identified as the primary source of chlorinated hydrocarbons in groundwater, and 700 tons of affected soil were excavated and removed as an interim action in 2002. Although the interim action is expected to have eliminated the source of chlorinated hydrocarbons, numerical transport modeling predicts that it may take 60 years for concentrations of TCE within the entire plume to attenuate below MCLs. In addition to the lengthy post-interim action restoration time frame, groundwater modeling indicates that migration of affected groundwater may result in future surface water concentrations exceeding standards at a nearby river, and could also impact additional off-site drinking water wells.

In situ chemical oxidation of dissolved PCE/TCE using permanganate was pilot tested as a potential means of reducing the aquifer restoration timeframe and assuring that unacceptable impacts to surface water and additional drinking water wells will not occur. Permanganate-amended groundwater was circulated between an extraction well and a reintroduction well at a flow rate of approximately 10 gallons per minute. Additional wells installed between and downgradient of the extraction/reintroduction well pair were monitored to assess contaminant destruction, permanganate persistence, and effects on subsurface conditions. The pilot test was notable for the relatively large well spacing and low permanganate injection concentration being tested. Both of these test parameters (large well spacing and low chemical usage) must be successfully demonstrated in order for full-scale application of this technology to be economically viable at this site.

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Use of Enhanced In-Situ Reductive Dechlorination to Replace Pump and Treat at an Aerospace Manufacturing Facility in Tukwila, Washington

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Electron donor substrates were injected in June 2004 at the Boeing Developmental Center to enhance reductive dechlorination (RD) of perchloroethene (PCE) and trichloroethene (TCE) released from a former vapor degreaser. Boeing is conducting cleanup under Washington State Department of Ecology's Voluntary Cleanup Program (VCP). The vapor degreaser was removed in 1984 following 28 years of operation, and 1,400 tons of accessible source zone soil was removed in 1989. A groundwater pump and treat (P&T) system was operated nearly 8 years (1994-2001), providing effective containment of the dissolved phase plume and reducing volatile organic compound (VOC) concentrations to below site screening levels at nearly all affected monitoring wells. The P&T system was shutdown in December 2001 to evaluate both potential rebound of VOCs and natural attenuation as a remedy for residual contamination. Complete RD (through vinyl chloride to ethene and ethane) occurs at the site under reduced aquifer conditions caused by naturally occurring organic carbon. However, two years after system shutdown (November 2003), groundwater concentrations of PCE, TCE, and breakdown products rebounded significantly near the former degreaser, indicating that additional source zone treatment was required.

During the initial injection in June 2004, approximately 10,000 gallons of extracted groundwater was mixed with 550 gallons of sodium lactate, 260 gallons of vegetable oil emulsion, and 1 kg of yeast extract for injection to six monitoring wells near the former degreaser. Insoluble vegetable oil and soluble sodium lactate were injected together to take advantage of their respective slow-release and fast-release of hydrogen (the electron donor utilized for RD). Yeast extract provides trace nutrients.

Quarterly groundwater samples will be collected during the first year to evaluate the progress of remediation and the frequency of subsequent injection; injection events are expected to occur approximately every 6 months. Initial data collected 3 months following injection, demonstrates enhanced RD, elevated organic carbon concentrations, more highly reduced aquifer redox conditions, and the production of fermentation byproducts 2-butanone (MEK) and acetone that provide short-lived co-solvency benefits. RD results in complete destruction of contaminants, which is preferred over contaminant transfer to another medium (e.g. air) as occurred with P&T. The annual cost of semiannual donor injection is less than for P&T operation.

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A Tale of Two Barrier Walls: A Performance Comparison of Groundwater Containment Walls near Seattle, Washington

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Two hydraulic containment barrier walls were installed around two multi-acre contaminated sites located near Seattle, Washington. The walls were installed using the same construction techniques and share similar stratigraphy but have markedly different hydraulics based on tidal influences, the locations of these sites relative to the discharge area, differences in aquitard properties, and infiltration.

The general hydrogeology consists of an upper aquifer zone of higher permeability sands at approximately 65 in depth above lower permeability clayey silts averaging 20 feet thick. Both barrier walls were installed using vibrated-beam technology with a cement fly ash and attapulgite clay slurry. The barrier walls are four to six inches in thickness with a measured hydraulic conductivity of 1.0×10^{-8} cm/sec. Groundwater is pumped from within the barrier walls to maintain inwardly-directed hydraulic gradients. Performance monitoring of these barrier walls uses clusters of groundwater monitoring wells located inside and outside of the barrier wall. Water level changes in these wells were monitored over one to two months using a network of transducer/loggers.

One wall was installed in Seattle's Georgetown neighborhood near Beacon Hill. Groundwater levels in the area fluctuate in response to seasonal precipitation. The wall performance was measured by observing changes in water levels in response to start of pumping inside the wall. Water levels inside the wall fell uniformly during pumping, compared to water levels outside the wall. This wall and aquitard behaved ideally, with the water levels dropping at a constant rate. The pumping rates required to maintain the inward gradient are similar to those anticipated prior to wall installation.

The other wall was installed in Tukwila, next to the Duwamish Waterway. Groundwater levels on the outside of the wall vary due to changes in tides and river stage. The wall performance was measured by observing water level changes inside and outside the wall due to tidal fluctuations before groundwater extraction began. The barrier wall limited tidal variation inside the wall to between 2% to 18% of the overall tidal range. Groundwater pumping inside the wall to maintain the inward gradient exceeded expected pumping rates by over ten times due to the combined effects of infiltration and leakage through the low permeability aquitard. The higher leakage rate through the aquitard layer was unanticipated based on borings completed prior to wall construction, and may be caused by an unidentified area of higher conductivity within the aquitard.

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Steam-Enhanced Remediation of a Former Wood-Treating Facility at the Port of Ridgefield Lake River Industrial Site; Effects of Hydrostratigraphy on the Distribution of Heat and Mass Removal of Contaminants

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Steam-enhanced remediation (SER) is a technology whereby steam is delivered into the subsurface through injection wells, and contaminated fluids and vapor are removed by extraction wells for on-site treatment. Heating the subsurface to steam temperatures has been shown to increase the removal of wood-treating chemicals by increasing their vapor pressures and reducing their viscosities. However, delivery of heat to the subsurface can be highly dependent on the properties of the porous media.

In 1993, Pacific Wood Treating Corporation abandoned its 41-acre Port of Ridgefield Lake River Industrial Site, leaving a 30-year footprint of recalcitrant wood-treating chemicals on soil and groundwater. The site overlies a regional aquifer and adjoins the Ridgefield National Wildlife Refuge and Lake River, all of which maybe threatened by these impacts. To prevent further migration of light and dense nonaqueous-phase liquid (NAPL), the Washington State Department of Ecology determined that an emergency source removal, using SER, was warranted. The SER will be completed in two phases. The purposes of Phase I are to begin removal of light- and dense-phase nonaqueous wood-treating chemicals, which act as a continued source of groundwater contamination, and to hydraulically control the plume's migration. The purpose of phase 2 is to completely remove NAPL, eliminating the source of contamination.

Four hydrostratigraphic units are interpreted to occur at the site. Based on site characterization work, each of these units has distinct hydraulic properties, which were used to form a conceptual site hydrostratigraphic model and perform a capture zone analysis of the well field. Temperature, pressure, and water quality data collected during startup suggest that heterogeneities within these units play an important part in contaminant mass recovery, SER system design, and evaluating hydraulic containment.

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Laboratory and Field Studies of Cr-Bioimmobilization in Groundwater at Hanford

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To demonstrate the feasibility of a cost-effective remediation technology for bioimmobilization of Cr(VI) in contaminated groundwater, we have conducted a series of bench-scale and field-scale integrated treatability studies. In these studies, we have investigated coupled hydraulic, geochemical, and microbial conditions, which are necessary to maximize the extent of Cr(VI) bioreduction and minimize the Cr(III) reoxidation in groundwater.

Using bench-scale studies, we have shown the presence of several types of bacteria in the sediments from the Hanford 100H site, including *Bacillus/Arthrobacter* and *Geobacter* species, which are known to reduce or sorb hexavalent chromium. Under background conditions, the total microbial population in Hanford sediments is $<10^5$ cells g^{-1}, which is likely insufficient for direct enzymatic Cr(VI) reduction. We have shown that different types of HRC and metal remediation compounds (MRC™) products could stimulate an increase in biomass to $>10^8$ cells g^{-1}, generate highly reducing conditions, and enhance Cr(VI) removal from the pore solution.

At the Hanford 100H field site, we drilled and equipped two new wells—injection Well 699-96-45, located 15 ft downgradient from the existing monitoring well 699-96-43, and a monitoring and pumping Well 699-96-44, located 15 ft downgradient from the injection well. To assess the background hydraulic properties of the Hanford formation and to design the HRC injection test, three Br-tracer injection tests and two pumping tests (concurrently with the Br-tracer tests) were performed before the HRC injection. We also performed a series of geophysical (seismic and radar) cross-borehole measurements.

Pilot field-scale biostimulation of the groundwater was conducted, using injection of 40 lbs of ^{13}C-labeled HRC into the injection Well 699-96-45, followed by Br-tracer injection into the Hanford formation, over the depth interval from 44 ft to 50 ft. Pumping from the monitoring well 699-96-44 started immediately after the injection on 8/3/2004, and continued for 27 days. Microbial cell counts reached the maximum of 2×10^7 cells g^{-1} 13-17 days after the injection. The HRC injection generated highly reducing conditions: DO dropped from 8.2 to 0.35 mg/l, Redox Potential—from 240 to -130 mV, and pH—from 8.9 to 6.5. Geophysical cross-borehole tomography confirmed the distribution of the HRC plume in the subsurface between the injection and the pumping wells. After pumping was ceased, background microbial conditions began to recover under conditions of natural groundwater flow.

Directions of future research include the determination of whether dissolved oxygen and manganese oxides could reoxidize Cr(III) to Cr(VI), and the development of a 3D reactive transport code, TOUGHREACT-BIO, to simulate coupled biological and geochemical processes.

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Vadose Zone Nitrate Contamination, Malheur County, Oregon

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The purposes of this study were to sample the vadose zone materials in the Ontario Hydrologic Unit Area (HUA) and to measure specific physical and chemical properties of these alluvial sediments. Such properties as grain-size distribution; content of organic matter, nitrate, ammonium, and total nitrogen (Kjeldahl); cation exchange capacity, pH, and others were measured. Sampling of the vadose zone was performed during the fall of 1990 and 1991 after crops were harvested and irrigation was finished. Results show that nitrate concentrations in the vadose zone materials range from 0 to 36.3 ppm (parts per million parts soil) with an average concentration of 5.45 ppm. With an average bulk density of 1.59 g/cm3 for vadose zone materials, this represents an estimated average nitrate mass of 700 kg/ha (632 lbs/ac). Ammonium concentrations range from 0.09 to 13.30 ppm with an average of 3.98 ppm. Total nitrogen (Kjeldahl) ranges from 0.0 to 0.230 percent with an average of 0.027 percent

The Ontario HUA is located in northeastern Malheur County, in eastern Oregon, near the Snake, Owyhee, and Malheur Rivers. The river valleys and terraces comprise 62,400 hectares (156,000 acres) of irrigated farmland growing crops that include onions, potatoes, sugar beets, sweet corn, and others. A shallow alluvial aquifer of sand and gravel ranges in thickness from 3 to 9 meters (10 to 30 feet) and underlies most of the HUA. During the irrigation season, the water table is at a depth between 1.5 and 6 meters (5 and 20 feet). This shallow aquifer is the main source of drinking water in the area. Groundwater sampling has identified nitrate levels that exceed the EPA drinking water standard of 10 milligrams per liter (mg/l) of nitrate-nitrogen. The area was declared Oregon's first groundwater management area under the Groundwater Quality Protection Act of 1989. Based upon surface and groundwater sampling, agricultural practices were identified as the main source of the contamination. The Oregon Department of Environmental Quality (DEQ) required the county to develop a groundwater management plan for reducing the nitrate-nitrogen levels. The *Northern Malheur County Groundwater Management Action Plan* was developed in which a list of recommended Best Management Practices (BMPs) for irrigated cropland was developed. Implementation of this BMP's by agriculturalists has been voluntary. The cost of implementing the BMP's has been shared with landowners through various USDA programs as well as some State funding. The primary purpose of many BMP's is to reduce the amount of nitrates that leach from the vadose zone into the aquifer. Continued monitoring is necessary to understand the dynamic relationship between agricultural management, the vadose zone, and the groundwater, and to determine if nitrate levels in the aquifer can be reduced within the time frame set by the Action Plan.

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Pesticides in Surface Waters of the Pacific Northwest— Overview of USGS Regional Findings

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Over the last decade, studies across the Pacific Northwest revealed widespread occurrences of many different pesticides and their metabolites, often in complex mixtures. Three herbicides (atrazine, simazine, and metolachlor) plus one insecticide (diazinon) are typically found in 40 to 99% of samples from both urban and agricultural settings across the Northwest, and over 50 compounds are often found in most non-forested watersheds. Concentrations usually are low, but mixtures or high concentrations during spates may be harmful to aquatic communities. Aquatic-life criteria or drinking water standards are occasionally exceeded, mostly by current-use insecticides or legacy organochlorine compounds; however, the lack of water-quality guidelines for most current-use pesticides or their mixtures hampers assessments of risk. Depending on local hydrologic controls, pesticide concentrations in streams are usually highest shortly after application and during irrigation or storm runoff. However, some compounds are routinely detected at relatively uniform concentrations during non-runoff periods, perhaps due to ground water inputs. Pesticide-use data, especially for urban settings, also are rare, further limiting understanding of controls on fate and transport. Pesticide occurrence in streams is broadly related to urban and agricultural land use and local surface and ground water hydrology. Comparison of loading from urban and agricultural areas is problematic, but urban sources clearly are important, especially for insecticides. Controls on sediment erosion can help reduce transport to streams for the most insoluble (generally legacy) pesticides, but may do little to control movement of the more soluble pesticides. Time series data from geographically diverse sites indicate some changes over time, including the appearance of new compounds. Local hydrologic patterns, pesticide use, land use practices in urban and agricultural areas, and pesticide properties must be evaluated together for their combined effects on pesticide fate and transport in order to effectively reduce and manage risks to humans and aquatic life.

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Ground Water Nitrate Distributions and Denitrification in a Portion of the Abbotsford-Sumas Aquifer, Northwest Washington

Robert Mitchell[1], Leslie McKee[2], Scott Babcock[3]

The Abbotsford-Sumas aquifer is a shallow, predominately unconfined aquifer located in southwestern British Columbia, Canada and northwestern Whatcom County, WA. The shallow glacial outwash aquifer has a history of nitrate contamination because of the agricultural activities that take place on the well drain soils that mantle its surface. As such, best management strategies are being employed to improve water quality in the region. However, denitrification processes within the aquifer complicate the assessment of these strategies. We monitored a variety of ground water parameters in a 10 sq-km study area adjacent to the international boundary in northern Whatcom County to evaluate nitrate distributions and to examine the denitrification potential of a peat deposit that bisects the study area.

Monthly sampling of 26 domestic wells in the study area occurred between July 2002 and June 2004. The majority of the wells (21) yielded median-nitrate concentrations above 3 mg-N/L, which is typical of non-point agricultural sources. Median-nitrate concentrations above the regulatory MCL of 10 mg-N/L were observed in 14 of the wells. And, in general, shallow wells had higher nitrate values than deeper wells. Nitrogen isotope data ($\delta^{15}N$) indicated that nitrate sources included a mix of manure and inorganic commercial fertilizers. Nitrate concentrations south of the peat deposit were significantly lower than the concentrations to the north, and nitrate levels within the peat were negligible. Nitrogen gas and a combination of nitrogen ($\delta^{15}N$ on nitrate) and oxygen ($\delta^{18}O$ on water) isotopes measured on samples from select wells confirmed that denitrification occurs in the peat. In addition, water-chemistry data from a few wells north of the peat deposit suggest that denitrification was responsible for the anomalously low nitrate concentrations measured at these wells—possibly due to buried, unmapped peat deposits.

The implication of these findings is that a natural mechanism for nitrate reduction exists in this region. Glacial-stratigraphic data suggest that peat occurs throughout this region at various unmapped depths. Identifying these peat deposits and their influence on nitrate concentrations may help facilitate nutrient management in the region.

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Trace Metals Levels in Puget Sound Glacial Materials

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In order for the Port of Seattle to continue construction of the 3rd Runway following a very stringent ruling in the summer of 2002 by the Washington Pollution Control Hearings Board (PCHB), it was necessary to develop a program to demonstrate that imported fill could meet unprecedented requirements for soil metals levels testing. Obtaining approvals for the fill was crucial to continuing the runway project, and legal appeals of the PCHB ruling had been filed by both sides that were unlikely to be settled before the next construction contracting period.

The challenge was to develop a work plan for implementation by third parties that could meet the stringent PCHB requirements, allow development of biddable construction documents, meet many legal challenges imposed by the opponents to the project, and produce results that satisfied Ecology review. In addition, given the PCHB's technical basis for fill criteria, there was doubt as to whether the specific fill criteria defined by the PCHB could even be met by natural geologic deposits.

This presentation describes the criteria that were imposed on imported fill to the runway, the considerations used to develop a program work plan for qualifying the fill, and the results of the testing of 9 fill sources. The data obtained from the fill source testing adds to our understanding of natural background metals levels in Puget Sound and identifies some interesting relationships between metal levels and geologic units and their provenance. The data also establish background levels for metals such as selenium and antimony for which none are currently published.

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Does Bacterial and Nitrate Contamination in Streams in Whatcom County, Washington Come from Ground Water?

Stephen E. Cox[1], F. William Simonds[1], Rose F. Defawe[1] and Llyn Doremus[2]

The streams of Whatcom County have high concentrations of fecal bacterial and nitrate during seasonal low water periods. A study was conducted to determine if field application of cow manure was contributing to the contamination through a ground water pathway. This study included three primary components: (1) identification and monitoring of reaches of streams in the Nooksack Lowland that are gaining water through ground water inputs; (2) assessment of the flux of bacteria and nitrate in discharging ground water; and (3) evaluation of the extent of denitrification occurring at the ground-water/surface water interface.

Discharging ground water was identified and monitored at four study sites, including a reach of the Nooksack River near Everson; multiple reaches on Fishtrap Creek; and reaches of Fourmile Creek and a tributary of Bertrand Creek. The potentiometric gradient between ground water and surface water was continuously monitored for 8 to 18 months at single stations on each of the four streams. Water-level gradients that indicated discharging ground water were observed throughout the monitoring periods except during periods of maximum streamflow. Samples of discharging ground water rarely contained measurable concentrations of the fecal bacteria Escherichia coli or nitrate. In addition, large concentrations of ferrous iron were common at most sites along Fishtrap, Fourmile, and Bertrand Creeks, confirming that ground water in these reaches was not a substantial source of these contaminants to the stream and that redox geochemical conditions within the ground-water system were strongly conducive to denitrification. Evidence of the extent of denitrification is currently being evaluated through the measurement of dissolved nitrogen gas, which is an end product of microbial denitrification.

A laboratory microcosm experiment was conducted to determine the longevity of fecal coliform bacteria in stream sediment from Fishtrap Creek. While the initial rate of bacterial mortality in stream sediments after contamination was high, fecal coliform bacteria were present at a concentration greater than 300 viable cells per gram of sediment after 102 days. These results indicate that once fecal coliform bacteria have been deposited in stream sediments, they can survive for many weeks and are potentially available for re-suspension and transport with increased streamflow.

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Overview of Petroleum Hydrocarbon Chemistry and Environmental Forensics

Ileana Rhodes, Ph.D.,
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This presentation will provide a brief description of petroleum hydrocarbon chemistry and some of the techniques used to identify petroleum and petroleum products in environmental media. Actual environmental forensic case studies will illustrate the capabilities and limitations of the different techniques and approaches.

Dr. Ileana A.L. Rhodes is a Principal Consultant at Shell Global Solutions (US). Her areas of expertise include sampling and analysis of soil, sediments, water and groundwater for environmentally significant compounds; characterization and fingerprinting of petroleum and petroleum products in free phase and in environmental samples; sampling and analysis of hazardous air pollutants in process streams; field methods to expedite site assessment and remediation; regulatory consulting on analytical issues and litigation support. She has a Ph.D. in Analytical Chemistry from Louisiana State University (1980) and a B.S. in Chemistry from the University of New Orleans (1975).

Dr. Rhodes is a frequent lecturer at technical workshops in the US and Europe on a variety of issues including environmental forensics, oxygenates and TPH. She was part of the US EPA delegation of speakers at "Field Screening Europe 2001" conference in Germany. In 1998, she gave eight lectures in six Asia Pacific countries on solving environmental challenges. She is a member of the environmental monitoring workgroup of the American Petroleum Institute.

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Pacific Northwest Water Quality Data Exchange

John Tooley

Water quality and water related issues (such as Total Maximum Daily Load or the Endangered Species Act listing of several salmonid populations) are the most critical environmental issues in the Pacific Northwest. There is an unprecedented need for sharing of watershed data across jurisdictional boundaries. The major obstacles to such sharing are:

- A reliable mechanism does not exist to catalog available data, and to discover what is available.
- Data is of highly variable quality.
- There is significant professional disagreement about the inclusion of poor quality data in any collection.

The environmental agencies of Alaska, Idaho, Oregon, and Washington and EPA Region 10 created the Pacific Northwest (PNW) Water Quality Data Exchange (the Exchange) to enhance the ability of the PNW scientific community to discover and gain access to data which may suit their purposes. The Exchange will develop a consortium of sources of water-related data throughout the PNW to include the traditional regulatory community as well as agencies in closely related mission areas (e.g. Fish and Wildlife Management agencies). Data may be made available on the network, regardless of quality, provided that the supplier agrees to document what is known of data quality. The technological “bar” for participation will be set as low as possible, which is crucial to developing broad participation. The Exchange has developed a location-based front end for data access. This data access tool will be demonstrated and project background, goals, and progress will be discussed.

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An International Perspective on Maintaining Optimum Well Performance

Jim S. Bailey

Operation of any ground water supply well requires constant monitoring and occasional rehabilitation in order to optimize long term performance and yield. Naturally occurring bioactivity and natural water chemistry in the well and surrounding aquifer is impacted by the operation of the well and the frequency of regular maintenance activities. Failure to carefully monitor well performance often results in declining yield and reduced well capacity.

The well rehabilitation technologies available for water supply wells in the Northwest include chemical, mechanical and impulse generation. Since ground water chemistry is a critical factor in the operation of most water supply systems, it is often the choice of well owners to avoid the use chemical rehabilitation technologies if possible. If chemical treatment is required, limit it to only those chemicals that minimize changes in water chemistry and are tailored to the specific biofouling problem. Recent university research on well rehabilitation technologies has provided additional understanding to which technologies are most effective.

In Germany, strict environmental laws related to ground water quality have resulted in the development and enhancement of non-chemical well rehabilitation technologies. The City of Berlin's water supply comes exclusively from 900 wells. The City has developed and maintained a very aggressive research and development program on well performance monitoring, operation, and maintenance over the past 50 years.

Some of the most effective non-chemical rehabilitation technologies used to maintain the Berlin well system includes impulse generation devices in conjunction with other traditional mechanical methods. These technologies are similar to some used in the United States but with some significant differences and improvements based on the experience with the large Berlin well field. The key differences involve the careful documentation of long term performance to allow early identification of declining well yield and detailed rehabilitation processes designed specifically for each well. The application of the Berlin well field experience to northwest supply wells offers an excellent approach to optimizing long term performance of these systems.

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Trends in Uranium Plume Parameters, 300 Area, Hanford Site, Washington

Christopher J. Murray[1], Yi-Ju Chien[2], and Robert E. Peterson[3]

Determining the trend in contamination levels is a key element in selecting Monitored Natural Attenuation as a remedial action alternative. Geostatistical methods were used to evaluate the trends in the uranium plume beneath the 300 Area of the Hanford Site, including trends in concentration, the mass of dissolved uranium in the plume, the area and volume of the plume, and the length of the Columbia River shoreline impacted by the plume.

To generate representative uranium concentration values for the analysis, trend charts for each well in the plume and surrounding area were reviewed. Data that were deemed to be non-representative of long-term conditions (i.e., outliers) were not used in subsequent calculations of statistical summary values. The minimum, maximum, and average values were calculated for two-year time intervals for each well. If no data existed for a well within a particular time interval, no representative value was assigned. The representative values used for geostatistical analysis cover 4 time periods: 1996-1998, 1998-2000, 2000-2002, and 2002-2004. Analysis of the concentration data indicated that the maximum and average uranium concentration decreased over each of the 4 time periods; however, the median concentration increased slightly for the last time period after decreasing over the previous time periods.

Variogram analysis was used to model the spatial variability of the uranium concentration data and sequential Gaussian simulation was used to generate 600 simulations of the uranium concentration on a regular grid for each of the 4 time periods. The concentration simulations were transformed through a Monte Carlo process into simulations of the mass of uranium in each grid cell. Integration of those grids provided estimates for the total mass of uranium in the plume over time, as well as the uncertainty in those estimates. The mass estimates indicate substantial decreases in the mass of uranium from 1997 through 2001 (from 108 kg to 52 kg), with the estimated mass remaining about the same in 2003 (50 kg) as it was in 2001. The concentration simulations were also analyzed to estimate the trends in concentration, area and volume of the plume, and length of the shoreline impacted by the plume. We conclude that geostatistical methods provide a useful approach for analysis of trends in the 300 Area uranium plume.

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Groundwater Evaluation Methodology And Development of Concentration Limits for Landfills Near Surface Water Bodies

Bryan Graham1, Stan Peterson2, Dennis Goldman3

An innovative Integrated Groundwater Evaluation Methodology (IGEM) was developed to comply with regulations regarding groundwater monitoring at a municipal solid waste (MSW) landfill adjacent to a surface water body located near south San Francisco Bay, California. The IGEM approach developed was approved by the regulators and set a precedent that can serve as a blueprint for other near-shore sites facing similar compliance requirements.

The 12-acre MSW landfill, operational from 1965 to the late 1970's, is bordered on the north by a storm water retention pond, on the northeast by a salt evaporation pond, and to the east and southeast by a brackish slough. As a result of the influence of permanent regional dewatering, the groundwater gradient is reversed from the normal gradient that otherwise would have groundwater discharging to the water bodies. However, a component the groundwater flow could enter the water body to the southeast at a distance of 65 feet from the landfill. The groundwater is not considered of beneficial use due to high total dissolved solids and low yield. Therefore, comparison of groundwater to maximum concentration limits (MCLs), designed to protect drinking water is not applicable. A direct comparison of groundwater concentrations in site monitoring wells directly to Ambient Water Quality Criteria (AWQCs), designed to protect sensitive receptors in surface water, is not applicable due to natural attenuation processes that take place in the distance between the downgradient monitoring wells and the potential surface discharge. A primary objective of the IGEM was to develop appropriate concentration limits for groundwater constituents from samples collected from monitoring wells, based on sensitive receptors at the nearest point of exposure, taking into consideration physical and chemical changes that occur to groundwater constituents between the monitoring point and the nearest point of exposure.

Calculated concentration limits (CCLs) for groundwater were developed for the COCs by employing available screening values including US Environmental Protection Agency (EPA) and State chronic saltwater AWQCs for each compound. Since screening values were not available for all COCs, a protocol was developed for deriving surrogate chronic saltwater screening values. An EPA-approved model then was used to calculate attenuation factors (AFs) for each COC. A CCL in groundwater for each COC was then established by taking the appropriate surface water screening value and multiplying it by the respective AF; resulting in a site-specific, chemical-specific CCL.

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Groundwater Flow Direction Anomaly Near Seattle's Union Station After the Nisqually Earthquake

Kris Hendrickson, P.E. 1, Stacy Pischer, L.G. 2, and Brian Butler, L.G. 3

The Union Station property in Seattle was the site of industrial activity beginning in the late 19th century. Industrial activities at the property included a manufactured gas plant and a metal foundry constructed on the shore and on pilings over the mudflats of Duwamish Bay. In the early 20th century, the manufactured gas plant and foundry were demolished; 20 to 25 ft of fill material was placed on the tideflat surface; and Union Station, a railroad passenger terminal, was constructed. The terminal ceased operation in 1971. The southern terminus of the downtown Seattle transit project bus tunnel was subsequently completed along 5th Avenue at the property. Union Station Associates completed renovation of the Union Station building and construction of two parking garages and four new buildings in 2001.

Soil and groundwater conditions at the Union Station property were evaluated in a series of investigations. These investigations showed that contaminants related to former industrial activities were present near and above the former tideflat surface. There also appeared to be petroleum hydrocarbons in groundwater from a source or sources upgradient of the property. Remediation, except for groundwater monitoring, was completed as part of property redevelopment. Groundwater monitoring at the property began in 1997.

Elevation contours of the water table aquifer, based on monitoring well water level measurements, were consistent from 1997 through 2000. Groundwater elevations significantly changed in one upgradient well beginning in March 2001, resulting in groundwater flow directions changing from westerly toward Elliott Bay, consistent with the regional flow direction, to easterly in the vicinity of that well. Contaminant distribution patterns in the well also changed. The cause of these changes is hypothesized to be a physical change in the subsurface, as a result of the February 28, 2001 Nisqually earthquake, that provides a new preferential pathway for groundwater, such as a broken pipeline or pumping related to foundation cracking.

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Layered Heterogeneity and its Effect on Technetium-99 Behavior in Variably Saturated Sediments: A Case Study of Hanford's 216-B-26 Trench

Andy Ward[1]

Waste discharges to the 200 TW 1 Operable Unit, which includes the 216-B-26 trench, are believed to have contributed the largest liquid fraction of contaminants and 99Tc to the vadose zone in Hanford's 200 Areas. Owing to the potential risk, remediation is being accelerated at this site but because of the abs4ence of contaminants in the groundwater, there was some uncertainty about the inventory and the fate of the discharged contaminants. The objectives of this study were to (1) develop a conceptual model for contaminant fate and transport at the 216-B-26 Trench site and (2) evaluate remedial alternatives including no-action and on-site capping. The conceptual model included the effects of small-scale stratigraphy; site-specific changes in hydrogeologic properties; and lateral spreading along sloped strata with contrasting physical properties. Model parameters were derived from pedotransfer functions which were used with high-resolution neutron moisture logs to define the heterogeneity on a scale of 7.6 cm in the vertical direction. Longitudinal and transverse horizontal heterogeneity was inferred from the spatial correlation structure of a nearby experimental test site. Transport simulations with STOMP show that small-scale layered heterogeneity and natural capillary breaks caused extensive lateral movement of water and contaminants. Simulations predict a vadose zone contaminant plume between 25 and 55 m below the surface with peak ^{99}Tc concentrations on the order of $2 \cdot 10^6$ pCi/L. Compared to the no-action alternative, a 0.5 mm/yr surface barrier delayed arrival of the ^{99}Tc peak at the water table beyond the year 6500 and reduced the concentrations reaching a hypothetical receptor well to values below the maximum contaminant levels. The Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RL01830.

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Effect of Geology and Groundwater-Surface Water Interaction on Groundwater Flow and a Dissolved Chlorinated Solvent Plume in the Esperance Sand, Everett, Washington

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A detailed hydrogeologic investigation of the Esperance Sand aquifer and surface geology was conducted within upper Powder Mill Gulch as part of the facility-wide Remedial Investigation (RI) of the Boeing Everett Plant. The purpose of the investigation was to assess the source area and extent of chlorinated volatile organic compounds, primarily trichloroethene (TCE), in Esperance Sand groundwater. There was no known source or release of TCE in the Powder Mill Gulch area. TCE was originally detected in perennial stream flow at the head of Powder Mill Creek. The results of the subsequent RI show that the geology and hydrology within the gulch have a significant affect on local groundwater flow and the lateral extent of the TCE plume in Esperance Sand groundwater. The presence of a thin (< 5-foot thick), hard silt interbed within the relatively homogenous Esperance Sand has a significant local effect on vertical groundwater gradient and contaminant migration within the aquifer.

The Boeing Everett Plant is situated on the northern portion of the Intercity Plateau, the upland bounded by Puget Sound, Possession Sound, and the Snohomish River Valley. Like most of the uplands within the Puget Lowland, Vashon glacial till caps the plateau and there are localized deposits of post-glacial outwash, peat and alluvium on the surface. The Vashon till is greater than 100 feet thick beneath the Everett Plant, and unconfined groundwater occurs within the underlying Esperance Sand at a depth of approximately 200 feet below ground surface. The Esperance Sand is 60 feet to greater than 130 feet thick beneath upper Powder Mill Gulch and is underlain by glaciolacustrine silt and clay (Lawton clay or equivalent) which is a regional aquitard. Powder Mill Gulch drains to the north and is incised into the upland and coastal terrace that flanks the north margin of the upland. Boeing's two large stormwater detention basins, a peat filter stormwater treatment system, and engineered wetlands occupy the current head of the gulch. Perennial flow within the creek occurs approximately 500 feet downstream of the stormwater detention basin outfall as a result of the incised creek channel intercepting the groundwater surface in the Esperance Sand.

Groundwater flow within the Esperance Sand beneath the northern portion of the Intercity Plateau is north-northwest. The horizontal gradient is 0.002 beneath the Everett Plant. Within uppermost Powder Mill Gulch, the flow is toward the creek with local horizontal gradients of 0.04 to 0.055. A hard silt bed is locally present within the Esperance Sand. Where it is absent there is a slight downward vertical gradient. However, where it is present, it inhibits downward groundwater flow. Groundwater levels in wells screened above the silt are up to 12 to 13 feet higher than adjacent wells screened below the silt. Detailed geologic mapping downstream within the gulch identified multiple springs on top of the silt outcrops in the side slopes. The local groundwater flow conditions have a significant control on the lateral and vertical extent of TCE and other volatile organic constituents in the plume.

We conclude that similar lateral flow conditions should be expected in other Puget Sound upland drainage channels incised through Vashon till into the Esperance Sand, and that internal stratigraphy within the sand can have significant local affects. Furthermore, there is value in geologic mapping (and the associated "bushwacking") within drainages to better understand subsurface conditions upstream and adjacent upland areas.

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Effective Leak Detection—A Needed Component During Retrieval of High-Level Mixed Waste from Single Shell Tanks at the Hanford Site

Joseph A. Caggiano

Beginning in 1944, high-level mixed radioactive and dangerous waste was discharged to 149 large underground single-shell storage tanks (SSTs), with only a single liner of carbon steel in a reinforced concrete tank, at the Hanford Site. These tanks are actively storing the residual waste. Pumpable liquids have been removed, but saltcake and sludge will be retrieved to feed a vitrification plant under construction. Adequate leak detection technologies are necessary during tank waste retrieval operations to monitor the retrieval process for releases to the vadose zone, to protect groundwater from further contamination and to support final risk assessments.

The 149 SSTs, in 7 Waste Management Areas (WMAs), are scattered throughout the Central Plateau of the Hanford Site. Waste releases, assumed for 67 of the 149 unfit-for-use SSTs, have reached groundwater at depths greater than 75 meters in five of seven WMAs. Groundwater is monitored under assessment/compliance status at the 5 WMAs that have impacted groundwater. Boreholes surrounding tanks in the vadose zone have been logged using neutron and gross- and spectral-gamma logging tools. Borehole logging reveals gamma-emitting constituents in many drywells indicating a waste contaminant inventory in the shallow vadose zone. Deep vadose zone contamination is not monitored, but is the source for continued contaminant transport to groundwater.

Liquids are used for waste retrieval in these tanks of suspect integrity to dissolve or mobilize the waste. Detecting leaks during waste retrieval is essential to quantify releases and to track the movement of releases. Leak loss inventory is 1 (of 4) components of the source term inventory used for fate and transport modeling and ultimately supports risk assessments needed for closure of SST WMAs.

Technology tests at a scale model SST and drywell logging experience provided the basis for selecting and implementing leak detection systems. The U.S. Department of Energy has proposed to use in-tank monitoring and mass balance to assess leaks during retrieval, supplemented with drywell logging. These methods have proved highly uncertain. High-Resolution Resistivity (HRR) is being tested during a SST retrieval as a better means of ex-tank leak detection and to determine leak rate and volume. If successful, HRR will become the ex-tank leak detection method used to monitor retrieval leaks and to provide needed vadose zone contaminant inventory data for risk assessment.

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Ground Water Discharges of High pH and Chlorinated Hydrocarbons into the Hylebos Waterway, Tacoma, Washington

Roy E. Jensen[1], Jonathan Williams[2]

Ground water contaminated with high pH and chlorinated hydrocarbons is discharging into the Hylebos Waterway from site located in the Commencement Bay area, Tacoma, Washington. The source of contamination was generated from a facility used to manufacture caustic soda, trichloroethylene and tetrachloroethene. Investigations ongoing since the 1980s give insight into the geological, chemical and hydraulic factors controlling discharges of groundwater into a tidal fluctuating marine surface water body.

The site is located on the narrow peninsula surrounded by the Hylebos and Blair Waterways. Ground water occurs in a 300-feet plus thick heterogeneous complex of silt and sands deposited by the ancestral Puyallup River. Two general groundwater flow systems have been identified beneath the site. A shallow system recharged locally by precipitation composed of freshwater water flows towards northwest and discharges into the Hylebos Waterway. An intermediate system composed of brackish to saline water flows southwest beneath the site. The transition between the shallow and intermediate flow system occurs at depths between 50 and 100 feet. Groundwater flow patterns are complicated by the tidal action, density, and variations in permeability.

Elevated pH (11-13) is present in groundwater to depths of 100 feet beneath the site. No discharges of high pH water have been documented in seeps samples from the intertidal zone suggesting that these intertidal seep discharges are composed primarily of bank storage rather than discharging groundwater. High pH discharges into the subtidal zone are identified by the presence of milky seeps and white encrustations caused by precipitation of high dissolved load as groundwater comes into contact with surface water.

Defining the factors controlling the discharges of chlorinated hydrocarbon contaminated groundwater is complicated by the presence of DNAPLs in sediment beneath the waterway. The available evidence suggests that the primary point of discharge for contaminated groundwater occurs in the subtidal zone. The presence of vinyl chloride in sediment and groundwater indicates conditions favorable for dechlorination are present.

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The Impact of Stratigraphy and Geochemistry on Contaminant Fate Transport at the Boomsnub/Airco Superfund Site, Hazel Dell, Washington

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The Boomsnub/Airco site has been studied extensively over the last 12 years and plumes of hexavalent chromium and trichloroethene (TCE) up to 4,000 feet long have been identified. Geologic units of concern in the area include the alluvial aquifer, the aquitard, and the Upper Troutdale aquifer. The alluvial aquifer is a major water-bearing unit and contains the majority of the groundwater impacted by TCE and chromium. The base of the alluvial aquifer consists of 10 to 20 ft of silt that grades into the aquitard. The Troutdale Formation underlies the aquitard. The contaminant plumes migrate downward in the alluvial aquifer with increasing distance from the source areas. Little if any breakdown of the site contaminants has been found in this aquifer. Wells that monitor water quality in the Troutdale aquifer indicate minor amounts of contaminants are present in a very limited area, suggesting the contaminants are attenuating with vertical migration. Mass balance calculations point to the possibility of chromium attenuating in the alluvial aquifer. Other evidence suggests that TCE may be attenuating in the silt and clay below the alluvial aquifer. A field investigation is planned for November and December 2004 to further define the stratigraphy, hydrogeology and geochemistry at the site with emphasis being placed on characterizing the silt and clay layers and gathering evidence of natural attenuation of the contaminants. Parameters to be evaluated include chromium species, TCE and daughter products, dissolved oxygen, redox, and hydrogen. The conceptual model for the site will be presented and the results of the investigation will be summarized.

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Stable Isotopes of Strontium as Tracers of Seawater Intrusion and TCE: Case Studies from the Dominguez Gap (CA) and a Fractured Limestone Terrane (MO)

Richard W. Hurst

Stable, naturally-occurring isotopes of the element strontium (Sr; $^{87}Sr/^{86}Sr$ ratio) are not routinely employed in groundwater investigations. Although, for obvious reasons, oxygen and hydrogen isotopes tend to be the "isotopes of choice" in hydrogeology, high precision $^{87}Sr/^{86}Sr$ ratio analyses provide a different perspective given: (1) Sr isotopes do not fractionate; and (2) their presence in contaminants of concern (nitrate/perchlorate salts, saline water). In this presentation, I will address the application of Sr isotopes to issues involving seawater intrusion into a series of aquifers in the Dominguez Gap (Long Beach, California) and as a surrogate tracer of TCE-impacted groundwater through a fractured limestone terrane in Lee's Summit, Missouri.

The Dominguez Gap Barrier Well System is an E-W trending series of injection wells designed to mitigate the intrusion of seawater into local aquifers, one of which provides potable water to the Los Angeles area. Questions arose regarding the barrier's effectiveness, given that aquitards separating the aquifers may be "leaky" and the possibility that oilfield brines may, in addition to seawater, be contributing to groundwater salinity. Analyses of $^{87}Sr/^{86}Sr$ ratios and Sr concentrations ([Sr]) of ~ 40 groundwaters were performed given the Sr geochemistry of seawater, injection well water, and oilfield brines differ significantly (seawater, $^{87}Sr/^{86}Sr \sim 0.7092$, Sr ~ 8 ppm; injection water, $^{87}Sr/^{86}Sr \sim 0.7102$, Sr ~ 1 ppm; oilfield brine, $^{87}Sr/^{86}Sr \sim 0.7082$, Sr > 1,000 ppm). Resultant plots of groundwater data ($^{87}Sr/^{86}Sr$ versus [Sr]) yielded statistically significant hyperbolic mixing curves ($R^2 \sim 0.95$), indicating that aquifer waters were commingling, not only with each other because of leaky aquitards, but also with seawater and injection well water---no evidence for contributions to salinity by oilfield brines was observed. The Sr data were used by the LA Department of Public Works in planning extensions of the Dominguez Gap Barrier Well System.

The interpretation of hydrologic and groundwater trichloroethene/dichloroethene (TCE/DCE) data at an industrial facility in Lee's Summit, MO was complicated by questions concerning hydrologic continuity given the presence of primary and secondary fracturing of limestone in this karst terrane. Sr isotopic analyses, having been shown to be an effective surrogate tracer of volatile organic carbons, were performed on TCE-impacted groundwaters. The results, again via mixing relationships, identified groundwater flow paths due to hydrologic continuity between fractures, as well as potential sources of TCE that were later verified via soil borings. Results were used to plan locations of groundwater remediation wells.

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Trace-Element Concentrations and Occurrence Of Metallurgical Slag Particles In Bed Sediment Cores From Lake Roosevelt, Washington

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Vertical distributions of trace-element concentrations in bed sediments of Lake Roosevelt were determined from 6 sediment cores collected in 2002. Concentrations of trace elements varied greatly in the sediment core profiles. Trace-element concentrations in sediment core profiles for arsenic, cadmium, copper, lead, mercury, and zinc exceeded sediment-quality guidelines in one or more intervals of all sampled cores. The largest concentrations occurred below surficial sediments, typically in the lower one-half of each profile. For many trace elements, concentrations decreased in the more recently deposited sediments of the upper 20 to 30 percent of the sediment core profiles such that surficial concentrations of arsenic, lead, and mercury in some cores were less than the sediment-quality guidelines. The trace-element profiles of the five cores collected along the pre-reservoir Columbia River channel exhibited many similarities that were not apparent in the core collected from the Spokane River arm of the reservoir. These differences are likely due to the greater influence of sediment inflow from the Coeur d'Alene Basin in that portion of the reservoir.

Particles of slag, a trace element-rich byproduct of metals smelting processes, were found in selected intervals from three cores. Based on their distinctive physical characteristics, appearance (smooth, glassy, black in color, and being both angular and rounded in shape), and chemical composition (measured using a scanning electron microscope equipped with an energy dispersive spectrometer (SEM/EDS)), the source of the slag was determined to be the smelter located in Trail, British Columbia, which has discharged slag to the Columbia River for nearly 100 years. SEM/EDS examination of the morphology and chemistry of the surface of the slag particles from the core sediments showed the development of exfoliation flakes and leaching of zinc and other elements, suggesting that the glassy slag particles were undergoing hydration and chemical weathering.

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Evaluation of the Nature of the Boundary between the Northern and Central Quito Aquifers, Quito, Ecuador

Mark P. Ausburn[1], Christian Zarn[2] and Graeme E. Smith[3]

Until 1991, the Quito Aquifer, located in the Central Inter-Andean Valley in northern Ecuador, provided approximately 30% of the drinking water for the City of Quito, Ecuador. Because of projected water shortages, exploitation of the Quito Aquifer is anticipated in the near future.

The Quito Aquifer occurs within a narrow north-south trending graben on the eastern flank of the Volcano Pichincha. The Quito Aquifer has been divided into the Southern, Central and Northern Quito Aquifers. Of these, the Central Quito Aquifer (CQA) and the Northern Quito Aquifer (NQA) are the best understood and the most important from the standpoint of production potential of good quality water.

Groundwater in the CQA and the NQA occurs in upper Pleistocene to Holocene age volcanic and volcano-sedimentary deposits derived principally from the Volcano Pichincha. These deposits overlay lower Pleistocene age volcanic and volcano-sedimentary deposits, which in turn unconformably overlay Cretaceous age lavas and volcanic breccias (basement).

In October of 2002 and May of 2004, Komex installed ten groundwater monitoring wells into the Quito Aquifer beneath the Mariscal Sucre Airport, which straddles the boundary between the CQA and the NQA. Though the purpose of the wells was to evaluate contaminant conditions in the groundwater beneath the Airport, they also provided a significant amount of new information on the hydrogeology and hydrogeochemistry on the boundary between the CQA and the NQA.

The NQA/CQA hydrogeologic divide appears to be located one km south of its 1983 location, and corresponds approximately to the northernmost extent of a Holocene age lacustrian tuff deposit (La Carolina Formation), and a sudden and significant change in the depth to basement. The genesis of the Quito groundwater basin and the CQA/NQA boundary is related to east-west oriented extension (late Pliocene or early Pleistocene) followed by east-west oriented compression (middle Pleistocene to Holocene), which controlled in turn: faulting, basement movement and geometry, depositional patterns, orientation of hydro-stratigraphic units, formation and locations of recharge/discharge areas, and groundwater flow gradients and directions.

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Investigating Vertical Contaminant Distribution Using Innovative Methods

Susan M. Narbutovskih[1] and Ronald Schalla[2]

Source determination of groundwater contamination is complicated by heterogeneous and anisotropic hydraulic properties related to complexly stratified sediments. Not only is it difficult to understand contaminated flow paths in the vadose zone, but spatial changes in hydraulic conductivity related to complex depositional patterns can results in groundwater monitoring that does not provide representative samples of the contaminant plume.

In general, samples collected from monitoring wells provide "average" contaminant concentrations within an aquifer over the screened interval. Various properties affect whether the sample collected with conventional method is adequate to determine the location and concentration of a contaminant plume. Circulation within the well and heterogeneities/anisotropy of permeability in the surrounding aquifer along with sampling method can significantly impact how well samples actual represent conditions at various depths within the surrounding aquifer. This paper identifies the need for technically meaningful groundwater-monitoring results and provides an innovative approach to obtain these cost-effective samples.

Understanding the vertical and horizontal distribution in the aquifer must be done through the well screen and filter pack in conventionally screened monitoring wells. Proper design, construction, and development of the well screen interval are essential. An accurate understanding of ambient, static flow conditions within the monitoring well is critical for determining the vertical contaminant distribution within an aquifer before discrete interval sampling is conducted. Once the in-well flow conditions are understood, effective discrete vertical sampling can be conducted to obtain representative samples for specific depth zones of interest.

The question of sample representativeness is also important as low flow purging techniques gain popularity to combat the increasing cost of well purging at many hazardous waste sites. Several technical approaches (e.g., well tracer techniques and flowmeter surveys) can be used to determine in-well flow conditions, each having merits and limitations. Proper fluid extraction methods using low volume or no purge sampling methods can be used to obtain representative samples of aquifer conditions at various depths in the well screen and aquifer. A case history is presented with results indicating a highly stratified chemical plume.

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Identification of Leakage Effects During Site Characterization Investigations at the Potential Black Rock Reservoir Site

F. A Spane and Kayti Didricksen

To assess the possible hydrologic impact of the potential Black Rock Reservoir on local and surrounding areas, detailed hydrogeologic characterization of geologic units underlying the site is required. Relevant hydrogeologic parameters for assessing the impact of the Black Rock Reservoir include: hydraulic and storage properties of vadose zone and groundwater systems, vertical leakage between hydrogeologic units and the presence of hydrologic barriers (e.g., faults) to groundwater flow. Of particular importance is the potential leakage of surface water stored within the reservoir, which may alter existing local groundwater systems and adversely impact adjacent surface and groundwater-basin hydrologic conditions (e.g., Hanford Site). To assess the potential for leakage and impact on existing, groundwater-flow systems, a borehole field-testing program has been designed by the U.S. Bureau of Reclamation to characterize selected hydrogeologic units underlying the potential reservoir location. Inherent in the leakage characterization assessment is utilization of a site piezometer for observing formation pressure measurements during the drilling, testing and subsequent monitoring of nearby hydrologic test wells. Techniques and assessment methods specifically designed for identifying leakage and vertical hydraulic communication include:

- cross-formational responses occurring during drilling and testing of nearby test wells
- diagnostic leakage responses associated with formational single or multi-well hydrologic tests
- barometric response pattern analysis
- extended baseline monitoring (groundwater dynamics assessment), and
- groundwater hydrochemistry/isotopic content comparison.

Results obtained from the initial borehole field testing program indicate a consistent pattern for the presence of leakage between several of the hydrogeologic units underlying the potential site. Leakage was corroborated by cross-formational responses, diagnostic hydrologic test results and barometric response pattern analysis. Although leakage was detected by a number of identified characterization techniques, detailed analysis of controlled hydrologic tests utilizing analytical and numerical methods provided the best approach for quantifying in-situ leakage properties. Additional refinement of the leakage detection techniques is planned at future Black Rock reservoir field testing sites.

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Three-Dimensional Geologic Model for the Washington Portion of the Spokane Valley-Rathdrum Prairie Aquifer

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The Quaternary sedimentary deposits in the Spokane and Little Spokane River Valleys and surrounding areas are predominantly composed of catastrophic Pleistocene flood deposits from glacial Lake Missoula and Pleistocene lacustrine deposits from glacial Lake Columbia. These deposits can be divided into flood gravels, sublacustrine sand, and lacustrine deposits, recognizing that deposits can be interbedded with layers of varying grain texture.

We developed a digital thickness model of the Quaternary sedimentary deposits of the Washington portion of the Spokane Valley-Rathdrum Prairie aquifer using surface geology maps, geologic cross sections, and water well logs. The digital model captures both the thickness and textural variation of flood gravels, sublacustrine sands, and lacustrine deposits throughout the project area, and defines the aquifer boundary at its bedrock contact.

Published and unpublished 1:24,000-scale and 1:100,000-scale geologic mapping was used to define the Quaternary stratigraphic units used in the subsurface model and to delineate the areal extent of these deposits. Thirty-eight geologic cross sections developed by interpretation of water well logs and seismic reflection imaging were used to generate point data for 860 'vertical measuring sites'. An additional 61 water well logs were interpreted and included in the point dataset for areas where the subsurface conditions were not adequately defined by the cross sections. The point data was then contoured using heads-up digitizing, and interpolated into raster files with a cell dimension of 50 feet. These raster files can be stacked to yield a three-dimensional model of Quaternary sedimentary deposits for the Washington portion of the Spokane Valley-Rathdrum Prairie aquifer.

While we developed this three-dimensional model to evaluate the ground-motion amplification effects of soft soils in the upper 100 feet of the soil-rock column, there are other uses for this model. The thickness and textural variation of aquifer sediments represented in the model are transferable to other investigations such as liquefaction hazard assessment or groundwater flow modeling.

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Oregon's Water Woes: Past and Present

Elizabeth Orr and William Orr (University of Oregon)

It is an open secret that Oregon is running out of both ground and surface water, and much of the remaining flow is badly contaminated. How did this crisis come about? A look at the environmental history of the state's water use reveals a pattern of continual reckless consumption rather than of conservation. Wasteful practices, which began with the first settlers, when water was plentiful, continue even today, leading the state further down a disastrous route.

Before the 1950s water allocations primarily went toward agricultural production, but today demand has drastically changed, and agriculture must compete for a supply with municipalities, industry, fish and recreation. The search is on for the mythical limitless streams flowing underground as new water rights permits are passed out, new management ideas are drawn up, and incredibly complex schemes juggle water from place to place, from season to season, and from user to user. In the Deschutes region, water mitigation gives credits in exchange for water rights. In the Klamath basin the buying and selling of water is the currently suggested solution, and in the Willamette Valley the aid is to reserve millions of gallons of water for uncertain needs years into the future. All of these propositions are based on the hope that each will be the one to refill the rivers and aquifers.

In the process of research on past environmental water uses, the authors have come upon many astonishing activities and trends, most of which continue today. If Oregonians are to find a way out of their water dilemma, an historic perspective may help to avoid and correct past practices that led to this situation.

Klamath Basin Rangeland Trust and the Irrigation Hydrology of Wood River Valley

Charles T. Ellingson[1], Chrysten Lambert[2], Shannon Peterson[3]

The mission of the Klamath Basin Rangeland Trust is to restore the quality and quantity of water in Oregon's Wood River Valley and the upper Klamath Basin to enhance the natural ecosystem and supply water for downstream agriculture, ranching, native fish and wildlife. KBRT cooperates with property owners and agencies to increase the flow of water to Upper Klamath Lake; improve cattle management to protect water quality; and reestablish wetlands to increase water storage capacity and produce wetland-related environmental benefits.

In order to increase instream flows, KBRT negotiates with water right holders to forebear irrigation, and rehabilitates wetland and fish habitats on participating properties. Compensation of water right holders is primarily funded through the U.S. Bureau of Reclamation's water bank program. Irrigators are compensated based on the volume of water saved by cessation of irrigation on their property. As a result, knowledge of water diversions, evapotranspiration rates, and surface and groundwater return flows are paramount.

In order to evaluate the effectiveness of KBRT's land management strategies at improving the upper Klamath ecosystem, KBRT supports research and monitoring of valley surface water, groundwater, water quality, and fish and wildlife habitat.

The Wood River Valley is a deep, flat bottomed, alluvium-filled graben of the basin and range province, at an elevation of about 5500 feet above sea level. Influent streams are either snow-melt, or groundwater (spring) dominated. Irrigation diversions from streams abruptly and significantly reduce water flows. Return flows occur overland and through a shallow aquifer. The ambient water table lies within 10 feet of land surface in an aquifer composed of Mazama ash.

The water table is maintained by irrigators within the depth of shallow roots in flood-irrigated properties, and falls to below typical rooting depths under unirrigated fields. Bowen ratio stations were deployed on both irrigated and non-irrigated pastures to assess the volume of water saved by the cessation of flood irrigation. A network of shallow groundwater piezometers and water level recorders reveal diurnal groundwater fluctuations that reflect groundwater use by pasture vegetation. Further evaluations of the interactions between vegetation and the surface water and groundwater systems are on-going.

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Des Moines Creek Basin – A Holistic Restoration Approach

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Effective watershed restoration in highly urbanized basins is challenging for many reasons, including limited land, the high cost of appropriately scaled solutions, differing political priorities, and the lack of holistic restoration and adaptive management approach. To restore the health of the watershed in a holistic manner, a number of public agencies are collaborating on a suite of projects in the Des Moines Creek Basin. An adaptive watershed management approach will be applied to further enhance the stream habitat by implementing additional projects once the initial projects have demonstrated their effectiveness.

The Des Moines Creek Basin is approximately 5.8 square miles of highly urbanized areas located within the cities of Sea-Tac and Des Moines. Increased impervious surface (nearly 40 percent) within the basin contributes to a “flashy” flow regime, significantly increasing channel erosion, causing loss of spawning gravel and large woody debris. The loss of these habitat elements significantly reduces the ability of the system to support salmon, resident trout, and other aquatic organisms. The increased development within the watershed has reduced the infiltration of stormwater, causing low baseflow, high temperature, and poor dissolved oxygen during summer months.

Although regulatory approaches are critical to effective stormwater management, they are not very effective in resolving longstanding problems created by inadequate flow control standards applied to past development. Recognizing the difficulty in dealing with these problems independently, the cities of Sea-Tac and Des Moines, Port of Seattle, Washington State Department of Transportation, and King County formed a Basin Committee as a way to jointly plan and fund a holistic watershed restoration effort. A basin plan was developed to address the watershed problems holistically by implementing a suite of restoration projects. A regional stormwater detention pond coupled with a high-flow bypass system has been designed to reduce instream channel erosion. Once the flow regime is stable, a series of projects is planned to enhance fish habitat, water quality, and channel stability. A low flow augmentation project is also planned to maintain a fish-friendly baseflow during dry summer periods. These integrated projects are planned to address a diverse range of problems and to restore a flow regime that will help recreate a stable stream system. The project performance will be measured by monitoring channel erosion, stream flows, and several biological indicators. Based on the monitoring results, adaptive management measures will be implemented. These projects are currently under construction with an anticipated completion date of 2007.

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The Role of Ground-Water Hydrology in Resolving Water-Supply Issues in the Upper Klamath Basin, Oregon and California

Marshall W. Gannett[1] and Kenneth E. Lite Jr.[2]

The upper Klamath Basin is the center of one of the most contentious water-management dilemmas in the western United States. Although the controversy centers on the competition for surface water between agricultural users and endangered fish, ground-water hydrology is proving to be an important element in developing a management strategy for the basin in two principal ways.

First is the potential to use ground water as an alternative source of water during drought. Ground-water pumping has increased markedly in response to recent water shortages. The increased pumping, however, has been accompanied by year-to-year water-level declines. There is a growing consensus that present levels of pumping cannot be maintained on a continuous basis. Although it is likely that ground water can be used to augment surface water during dry periods, considerable work remains in finding the optimal balance between the rates, distribution, and timing of pumping, and acceptable impacts. This is an area of active research.

The second way in which ground-water hydrology affects the management strategy is in water-supply forecasting. The management of Upper Klamath Lake, reservoirs, river flows, and agriculture are highly dependent on early season water-supply forecasts. Different forecasts can result in very different operational criteria in the basin with consequences for water users and aquatic wildlife. Forecasting for the upper Klamath Basin, however, has been problematic in comparison to most other basins in the west.

Recent work suggests that a quantitative understanding of the basin's ground-water hydrology is important for forecasting due to the predominance of spring-fed streams in the upper basin and the importance of regional spring complexes to the overall water supply. The regional ground-water system tends to integrate the climate signal over multiple years. Spring flow, and consequently late-season stream flow, is strongly influenced by conditions in previous years. Historically, forecasting methodologies incorporated parameters reflecting only present water-year conditions. Hydrologists and forecasters are presently working to incorporate ground-water information into forecasting models.

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North Creek Stream Flow Enhancement
Snohomish County, Washington

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North Creek is a small perennial stream that begins in southwestern Snohomish County and flows south into King County where it eventually joins the Sammamish River near Bothell. The North Creek Watershed Management Committee has ranked fisheries habitat as the most important beneficial use of North Creek and the Muckleshoot Tribe has identified the stream as providing valuable spawning habitat for salmonids. North Creek is currently listed as a section 303d water body under the Federal Clean Water Act for low dissolved oxygen and fecal coliform, and seasonal low flow has been identified as a limiting factor for salmonids in the upper reaches of the stream. Furthermore, the Washington State Department of Ecology has closed the North Creek drainage basin to additional surface and ground water right allocations since 1987.

The City of Everett is currently completing a stream flow augmentation project that is designed to improve water quality and quantity in North Creek. The project involves pumping ground water from a deep aquifer (Intercity Aquifer) during the summer and early fall months of the year into upper reaches of North Creek. The current ground water withdrawal is from a production well located on a parcel of property owned by the City near 124th Street in southwestern Snohomish County. Recently completed production and monitoring wells at the site indicate that the Intercity Aquifer may be capable of supplying several cubic feet per second (cfs) of high quality water for stream flow augmentation. Ground water levels in the Intercity Aquifer are monitored during the winter and spring months to confirm that the aquifer is totally recharged by natural precipitation. Furthermore, stream flow is monitored below the discharge point into the creek to evaluate the effect of pumping on flow in the creek. Additional production wells may be installed in the future and up to a total of four cfs of high quality water will be put into North Creek if the long-term monitoring data indicates that the winter water levels in the aquifer continue to return to typical pre-pumping levels during the winter/spring months.

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Shallow Aquifer Response to Modifications in Columbia River Hydroelectric Management

Frederic C. Wurster

Since its establishment in the early 1960's, the Umatilla National Wildlife Refuge (Umatilla) has protected important riparian habitat on the Columbia River in Washington and Oregon. In the last 6 years there has been extensive mortality in the cottonwood forests on the refuge accompanied by little or no cottonwood recruitment. These riparian forests provide crucial habitat for migrating songbirds and waterfowl in addition to acting as important refugia for local wildlife.

Historic air photograph analyses show that in addition to losing riparian habitat the areal extent of McCormack Slough, a large open water wetland on the refuge, has declined. Hydrologic data from a network of shallow ground water monitoring wells and staff gages indicate surface water flows from the Columbia River into McCormack Slough. Additionally, water table fluctuations in the riparian forest adjacent to the slough are tightly coupled with the slough's water surface elevations. Historic data from the U.S. Army Corps of Engineers (USACE) indicates a fundamental change in John Day Dam operation beginning in 1993. That year, USACE began spilling more water over the dam, for the benefit of migrating juvenile salmon. This operational change reduced maximum water surface elevations on the Columbia at Umatilla by 2 ft. Because water table fluctuations are closely associated with water levels in McCormack Slough, we believe changes in dam operation have indirectly caused the observed mortality in the riparian forests at Umatilla.

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Hydrogeologic Framework of Eastern Jefferson County, Washington: Implications for Surface Water–Ground Water Interactions

F. William Simonds

The hydrogeologic framework and preliminary interactions between surface water and ground water were determined as part of a study of the water resources in the Chimacum Creek Watershed and other significant drainages within eastern Jefferson County. The study will assist local watershed planners in assessing the status of water resources and the potential impacts of groundwater development on surface water systems.

The surficial geology of the Chimacum Basin was compiled from existing sources, modified using LIDAR imagery, and used along with drillers' logs from more than 110 wells to define the hydrogeology. Quaternary glacial deposits, which overlie bedrock, form four hydrogeologic units: the recessional outwash aquifer, the till confining unit, the advance outwash aquifer, and the older glacial sequence. The advance outwash aquifer is the most productive source of groundwater in the area, although ground water is found throughout the glacial deposits in discontinuous lenses of sand and gravel.

Seepage runs made in June and October 2002 were used to quantify gains and losses to the groundwater system along Tarboo Creek, Chimacum Creek, and the lower reaches of the Big and Little Quilcene Rivers. Vertical hydraulic and thermal gradients measured with in-stream mini-piezometers and piezometers with nested temperature sensors were used to refine the boundaries between gaining and losing reaches and define seasonal variations in surface water–ground water exchanges. Each of the creeks examined had a unique pattern of gaining and losing reaches that reflect changes in the geology underlying the streambed. Significant surface water losses were found at transitions between Quaternary, valley-filling peat deposits and recessional outwash on Chimacum Creek and on the alluvial plain near the mouths of the Big and Little Quilcene Rivers.

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Groundwater Contaminants Entering the Columbia River at the Hanford Site's 300 Area

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Past operations at the Hanford Site resulted in the release of radiological and chemical contaminants to the soil column. These contaminants have migrated to groundwater which is discharging to the Columbia River along the shoreline. Groundwater levels in the 300 Area are heavily influenced by river stage changes, with significant changes occurring in daily, weekly, and seasonal cycles. River stage along the 300 Area shoreline may change by up to 2 m within a few hours. As the river stage rises, river water flows into the aquifer (bank storage). When the river stage falls, water flows out of the aquifer via riverbank springs. Riverbank spring water discharged immediately following a drop in river stage is composed of a mixture of bank storage river water and groundwater. With continued low river stage, the percentage of groundwater discharging from the river bank springs increases.

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 uS/cm) with groundwater (>400 uS/cm) provides an indicator of the influence of bank storage. This study characterized the radiological and chemical contaminants existing in the near shore environment by analyzing river and riverbank spring water, and shallow groundwater collected from piezometer-style tubes. In addition, at selected locations hourly measurements of river stage and specific conductivity were obtained.

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Groundwater Vulnerability and the Meaning of Age Dates

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Understanding and Treating a TCE Plume that Defies Conventional Wisdom

Thomas C. Goodlin

A stable trichloroethene (TCE) plume in a coarse-grained glacial outwash aquifer presents challenges both for defining a conceptual model that explains the observed transport behavior and for developing a remedial approach that addresses the persistent, low-concentration contaminant. A 1,500-ft TCE plume at McChord AFB Site SS-34N extends off-Base at roughly 100 μg/L in the shallow, unconfined aquifer formed within coarse Steilacoom Gravels and Vashon Recessional Outwash. An aquitard formed by the Vashon Till underlies the shallow aquifer with an irregular contact. In the site vicinity, the thin (about 20-foot), unconfined aquifer features rapid groundwater flow (10 to 20 ft/day). No residual vadose zone contamination is documented, nor is there evidence of dense non-aqueous phase liquid (DNAPL) in the aquifer. Negligible biodegradation occurs in the aerobic, relatively carbon-free, coarse glacial outwash. These conditions suggest that TCE released some 30 years ago should have been flushed from the system. Indeed, the initial groundwater flow and transport modeling with these assumptions struggled to reproduce a short, stable plume.

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Challenges in the Remediation of Groundwater Contaminated with Sr-90 in N-Area, Hanford Site, Washington

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The Hanford Site, managed by the United States Department of Energy, is a 560 square-mile former reactor-fuel-grade plutonium production site. The current mission is environmental remediation and cleanup of the waste from these activities. The remaining waste, most now stored in underground tanks and capsules, includes radioactive Strontium-90 (Sr-90) from the reprocessing of the fuel cladding. Some Sr-90 has leaked to the soil from the underground tanks and from fuel cladding failures.

Strontium-90 has a half-life of 28.8 years. It moves slowly through the vadose zone and in groundwater. The Sr-90 plume can currently be measured along the Columbia River, at the 100 N Area, at up to 9,000 pCi/l. This contamination represents the largest potential risk to human health and the environment due to its direct flux and the associated exposure. The groundwater velocity fluctuates and influences the Sr-90 concentration within this near-river environment due to the highly variable Columbia River stage resulting from electricity generation upstream at the Priest Rapids Dam.

The distribution of the Sr-90 plume has changed very little over the past 10 years despite active groundwater remediation through pump and treat designed primarily to reduce the flux of Sr-90 to the Columbia River. Realizing the fact that the pump and treat would take about 250 years to remediate the groundwater below drinking water standards, the application of more effective innovative technologies were considered and evaluated. Technologies such as the application of a permeable barrier using clinoptilolite, impermeable barriers, sequestration technology and phytoremediation were expected to have the potential to reduce the risk to human health and the environment.

Ecology is taking appropriate and immediate steps to further evaluate the effectiveness of immobilization of Sr-90 through the injection of sequestering agents such as calcium citrate or sodium phosphate in a zone adjacent to the Columbia River. This is expected to reduce the flux of Sr-90 to the hyporheic and riparian zones. Additionally, a thorough evaluation of phytoremediation in the riparian/near shore areas is being conducted as a part of the treatment train. The evaluations of these technologies are expected to lead to better and more efficient remediation of Sr-90 and reduced risks along the Columbia River.

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Environmental Tracer Investigation of Ground-water Flow and TCE Migration beneath Fort Lewis, Washington

Richard S. Dinicola

The U.S. Geological Survey (USGS) used environmental tracer and other data to develop a refined conceptual model for ground-water flow and trichloroethene (TCE) migration in the sea-level aquifer beneath Fort Lewis, Washington. Past disposal practices have led to a three-mile-long plume of TCE-contaminated ground water from beneath the Logistics Center on Fort Lewis. The site is underlain by a complex and heterogeneous sequence of glacial and nonglacial deposits that have been broadly categorized into an upper aquifer, a mostly continuous confining unit, and a lower "sea-level" aquifer. TCE contamination is found in both aquifers.

The environmental tracers sampled included common ions and selected general ground-water chemistry analytes: TCE; stable isotopes of oxygen (^{18}O), hydrogen (^{2}H), and carbon (^{13}C); tritium (^{3}H); chlorofluorocarbons; and sulfur hexafluoride. Tracer concentrations were determined for ground-water samples collected during 1999-2000 from wells screened in the upper aquifer and the sea-level aquifer, and for surface-water samples collected from American Lake (located approximately two miles northwest and down-gradient from the TCE source area.)

Three localized ground-water flow features were identified that are of particular relevance to TCE migration. A "mound" of ground-water beneath American Lake diverts the flow of TCE-contaminated ground water in the sea-level aquifer to the west around the southern end of the lake. Stable isotope (^{18}O and ^{2}H) data in particular provided clear evidence that American Lake is a significant source of recharge to the sea-level aquifer and is responsible for the mound of ground water. Higher ground-water altitudes to the north of Fort Lewis, combined with the mound beneath American Lake, prevent TCE-contaminated ground water from migrating toward the City of Lakewood's water-supply wells.

Stable isotope and other environmental tracer data confirmed that TCE migrates into the sea-level aquifer primarily through a "window" in the overlying confining layer. Within the sea-level aquifer, TCE migrates westward in the flow field influenced by ground-water recharge from American Lake. Tracer data indicated that attenuation of TCE concentrations in the sea-level aquifer is most rapid near the confining-layer window due to dispersion, but attenuation slows substantially in the down-gradient part of the contaminant plume due to less dispersion.

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Thermal Profiling of Long River Reaches to Characterize Ground-Water Discharge and Preferred Salmonid Habitat

J.J. Vaccaro[1] and K.J. Maloy[2]

The thermal regime of riverine systems strongly influences the species composition, trophic structure, and population dynamics of aquatic ecosystems. Ground-water discharge is an important component of the thermal regime, providing preferred thermal structure for fish with different life histories, such as salmonids, and refugia during seasonal extremes of water temperature. In large, diverse river basins, documenting the thermal regime and locating the areas of ground-water discharge has been difficult. A method was developed to profile the thermal structure of long (on the order of 8 to 25 kilometers) river reaches by towing thermistors from a boat that sample near-surface and near-bed temperatures at 1- to 3-second intervals, while a Geographic Positioning System records spatial coordinates. This method was developed, tested, and applied to the Yakima River Basin, Washington. Seven reaches were profiled in the summer of 2001 during low flows of an extreme drought year. A total of 146 kilometers of river was profiled over 7 days. The thermal profile provided valuable information on the spatial and temporal variation in habitat and, notably, indicated areas of ground-water discharge. The areas of ground-water discharge were typified by a temperature decrease in summer and an increase in winter. The spatial distribution of the river's temperature structure determined using this method cannot be captured by fixed-station or synoptic data. The profiles exhibit inter- and intra-reach diversity that reflects the many factors controlling the temperature of water as it moves downstream. These profiles provide a new perspective on the temperature regime of a riverine systems that represents part of the aquatic habitat template for lotic community patterns, including a logical progression of the longitudinal gradient of fish assemblages.

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Monitoring Groundwater Quality Along the Columbia River, Hanford Site, Washington

R. E. Peterson

Groundwater from the aquifer underlying the Hanford Site discharges to the Columbia River. In some areas of the Site, that groundwater is contaminated as the result of past operational practices involving disposal of liquid wastes. The contaminated areas have been grouped into CERCLA operable units and have been extensively characterized during remedial investigation activities, followed by long-term monitoring. For contaminant plumes that are near the river, monitoring using samples from traditional wells has been supplemented by collecting samples from small diameter polyethylene tubes implanted in the aquifer along the river shoreline. These "aquifer sampling tubes" provide much more extensive geographic coverage than what could be economically attained using traditional drilling methods.

Aquifer sampling tubes (tubes) are installed near the low river stage shoreline by driving temporary steel casing to a maximum depth of ~10 meters, using a hand-held air hammer or truck-mounted hydraulic ram. Tubing, with a six-inch stainless steel screen at the lower end, is then inserted into the casing and affixed to a detachable drive point at the lower end, and the temporary casing withdrawn using hydraulic jacks. Typically, a site is equipped with three tubes, with screens positioned near the top and bottom of the uppermost hydrologic unit, and a third at mid-depth in the unit. The portion of the tube above ground is protected using polyvinyl chloride conduit, to provide shielding from sunlight and browsing animals. The site is covered with cobbles to protect it during high river stage, and to make it blend in with the surroundings.

The Hanford Site currently has 133 shoreline sites equipped with 339 individual tubes. The spacing between sites is ~600 meters, with more closely-spaced sites in areas where detailed observations are warranted. Analytical results for tube samples contribute to a variety of groundwater-related information needs, including (a) concentrations of contaminants at locations close to sensitive aquatic habitat, (b) dilution of contaminants by river water in the bank storage zone, (c) performance evaluation of groundwater remedial actions, and (d) long-term trends in contaminant concentrations near the river.

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A Decade of Regulatory Process to Reach Active Remediation, The Boeing Plant 2 Chlorinated Solvent Interim Action, Seattle, Washington

Hideo Fujita

Investigating, characterizing and remediating large, complex facilities with long histories of industrial usage can be challenging for both the owners of the facility and the regulatory agencies charged with their oversight. This is especially true when the regulations are not designed to efficiently address site investigation and cleanup in a holistic manner. A long, regulatory process is created in these instances. The Resource Conservation & Recovery Act (RCRA) Interim Measure (IM) at The Boeing Company's (Boeing) Plant 2 Facility (Plant 2) involved a regulatory process interwoven with complex technical issues.

Plant 2 is situated in the Seattle/Tukwila area of Washington along the central portion of the Duwamish Waterway, a constructed navigation channel. Historically, industrial degreasers were used to remove oils and grease from metal parts during machining and fabrication operations. At Plant 2, Boeing achieved hydraulic stabilization to contain and isolate solvent-contaminated soil and groundwater associated with former degreasing operations and/or leakage from a TCE tank with interlocking sealable (Waterloo BarrierTM) sheet pile containment structures. Boeing installed the Waterloo sheet pile containment structures in 1993. The summer of 2004 brought the first active remediation within these containment structures.

Timely action to prevent the groundwater solvent plume from discharging into the Duwamish Waterway was a critical and a high-priority issue at Plant 2. Analytical data from groundwater monitoring, over the past ten years, demonstrate that the containment structure is competently and effectively containing the contaminated soil and groundwater at Plant 2. Thousands of analytical data points, numerical analysis, site specific geochemistry and hydrogeology were integral elements funneled through the RCRA regulatory process for the contaminant fate and transport analysis and the implementation of the IM in the saturated and vadose zones. As demonstrated at Plant 2, an IM can be a good regulatory vehicle to use when a long regulatory process is anticipated. In this instance, it helped promote implementation of containment technology in a timely manner to stop contaminated groundwater from reaching the Duwamish Waterway.

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Mercury Emissions and Lake Deposition: A Qualitative Model and its Application to Lake Whatcom, Washington

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A simple atmospheric deposition model was developed that allowed comparisons of the deposition of mercury (Hg) to the surfaces of lakes in Whatcom County, Washington. The model required wind data, Hg emission rates from each source, an estimate of the speciation of Hg in the emissions (particulate, reactive or vaporous Hg) of each type of Hg source, and the atmospheric residence time of each Hg species. Of all the lakes examined, basin 1 of Lake Whatcom would have been most affected by the Hg emissions from the chlor-alkali plant that operated in the City of Bellingham until 2000. The down-lake decrease in estimated atmospheric deposition to Lake Whatcom was not reflected in the enrichment of Hg in the sediments above pre-industrial concentrations. The enrichment ratios of 2 to 3 in the sediment from throughout Lake Whatcom were on the lower end of values of enrichment ratios found across the U.S. The length-adjusted concentrations of Hg in largemouth and smallmouth bass were not related to estimated deposition rates of Hg to the lakes from local atmospheric sources. Estimates of Hg deposition derived from the model indicated that the most significant deposition of Hg attributed to local sources would have occurred to the lakes north of the City of Bellingham. These lakes are in the primary wind pattern of two municipal waste incinerators that closed in 1997.

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Ground Water Investigations for Perchlorate in Washington and Oregon

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The Environmental Protection Agency (EPA) in coordination with state and local agencies has completed studies or is in the process of investigating various sites in Washington and Oregon for the presence of perchlorate in ground water. Perchlorate is an emerging contaminant and has been discovered in drinking water supplies located in proximity to military operations or sites used in the manufacture and production of solid rocket propellants, flares, explosives and various pyrotechnics.

In 2002, perchlorate was detected in ground water samples collected from drinking water wells in the Lakewood Water District (LWD) at concentrations ranging from 4 to 6 µg/L. Additional water samples were collected in 2004 from seven LWD drinking water supply wells, monitoring wells, and Chambers and Clover Creeks. Because of their proximity to the water supply wells, samples were collected from 12 monitoring wells located on the McChord Air Force Base. Low levels of perchlorate were detected in 16 of the 19 wells and both surface water samples. The maximum reported concentration of perchlorate was 1.3 µg/L. Perchlorate was present in multiple producing horizons to a depth of 562 feet.

Perchlorate has been detected in ground water in the Lower Umatilla Basin, in Morrow and Umatilla Counties, Oregon. As part of an ongoing study of nitrate contamination, initial sampling for perchlorate was conducted in 2003. Perchlorate concentrations ranged from 1 to 20.7 µg/L and were detected in half of the 133 wells sampled. The EPA and ODEQ have begun testing for perchlorate in additional wells and surface water in order to determine the extent of the contamination and identify any potential sources.

Analysis for perchlorate was conducted using two laboratory methods, Method 314.0 (method detection limit [MDL] 1.0 µg/L) and Method 8321A-mod (MDL 0.2 µg/L). Method 314.0 was developed for analysis of drinking water samples, whereas, Method 8321A-mod is an analytical method targeted for samples with relatively high turbidity. A comparison of the results indicated that although perchlorate concentrations detected using Method 8321A-mod are comparable to the results generated by Method 314.0, the concentrations reported by Method 8321A-mod are generally lower.

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Volatile Organic Compounds in Soil Gas above a Ground Water Plume at Fort Lewis, Washington

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Remediation of a groundwater plume containing volatile organic compounds, primarily trichloroethene (TCE), is ongoing at a waste site at Fort Lewis Washington. A study of the vertical migration of organic vapors through the vadose zone was undertaken to evaluate potential health impacts to residents of a housing unit in the vicinity of the plume. Previous work to determine potential health risks to residents of the housing area from vapor intrusion into indoor air used estimated groundwater concentrations. This approach resulted in an estimated cancer risk from vapor intrusion of 7×10^{-5}. While this is within the U.S. Environmental Protection Agency guidelines for cancer risk (10^{-4} to 10^{-6}), the assumptions inherent in the model result in the potential for actual cancer risk to exceed 10^{-4}. In order to reduce the uncertainties in the modeled cancer risk, a soil gas monitoring study was conducted over a portion of the groundwater plume in the vicinity of a housing unit and at a background location.

Gas samples were collected at three vertical locations: ambient air, shallow soil gas, and deep soil gas. Sampling locations were arranged in a linear array perpendicular to groundwater concentration profile contours. This provided concentration gradient information to evaluate the relative impact the groundwater concentration has on soil gas concentrations. Co-located shallow and deep soil gas measurements were collected to account for any attenuation between the surface and deeper soil gas sampling depth. Sampling was conducted during the wet winter season, and then repeated during the drier late summer season. Ambient air and soil gas samples were collected in evacuated 6-liter Summa® canisters.

Preliminary results indicated that there was not a significant health risk from vapor migration. Observed deep soil gas concentrations of TCE exceeded desired indoor air concentrations at some locations. However, all shallow soil gas concentrations were below the detection limits. Using the highest measured soil gas concentrations as input to the Johnson-Ettinger model, and using the most conservative input parameters for vapor migration, resulted in a worst case estimated cancer risk of 5×10^{-5}. The use of measured soil properties as input to the Johnson-Ettinger model resulted in estimated cancer risks of 1.5×10^{-5}.

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Linking ArcGIS to the SQL Server database to merge and analyze spatial and tabular datasets for water-quality studies

Frank Voss

Linking the ArcGIS geographic information system to the SQL Server database can provide capabilities that can be used to lower the cost of managing and analyzing data for water-quality studies. These capabilities include: the ability to import spatial and tabular data from a variety of formats (coverages, spreadsheets, text files, images, databases) into a single relational database; the ability to perform complex data queries using easy to learn SQL statements; and the ability to perform calculations and processing using a single mainstream programming language (Visual Basic). Examples are given on how ArcGIS and SQL Server can be used to increase the efficiency of performing logistic regression to generate maps showing areas of aquifers that are vulnerable to nitrate contamination and how ArcGIS and SQL Server can be used to automate unsaturated-zone model simulations for a large number of sites.

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Upland Basin Groundwater Models for Predicting Septic System Impacts and Land Use Planning

Gary E. Andres

Increasing development in upland basins adjacent to the Spokane Valley-Rathdrum Prairie Aquifer (SVRP) has led to concerns about groundwater quality impacts from septic systems. The SVRP is a sole source aquifer that straddles Washington and Idaho, and supplies water for 800,000 people. The upland basins in Idaho provide a significant amount of recharge to the SVRP, which flows westward and discharges primarily into surface water in Washington. The concern about groundwater quality has prompted state agencies to create models to aid land use planning in the upland basins.

Two groundwater flow/solute transport models were developed for Kootenai County, Idaho to be used as tools in predicting potential nitrate impacts on groundwater from proposed septic systems. These models cover areas to the south (Spokane River Uplands Basin) and north (Hidden Valley/ Lost Creek Basin) of the SVRP. The basins cover large areas and are characterized by a wide range in relief, with the primary groundwater resource lying in fractured metamorphic rock.

Although a significant number of wells, mainly for domestic purposes, tap the upland basin aquifers, little data was available regarding water levels and nitrate concentrations. As a result, a field data collection program was completed for both areas by visiting a subset of the existing wells in locations chosen to provide an adequate distribution through the basins.

The models were created using the codes MODFLOW and MT3D with the model parameters housed in the user interface GWVistas. Development was assisted through the import of GIS coverages, and was based on a conceptual model derived from well logs, groundwater elevation data, and USGS gaging station information. Existing septic system locations were based on building structure coverages. The models were calibrated to the field data and user manuals were developed outlining the process for adding potential septic systems. Output can be viewed in GWVistas or exported to GIS.

The models are currently being used by the Kootenai County Planning Department to evaluate proposals for developments in the upland basins and to identify areas of concern where nitrate levels are high. For the evaluations, septic systems are added to the model and the output used to assess if nitrate concentrations would rise above acceptable levels. Developers are already aware of this tool and are working with the county early in the process to configure developments in an acceptable manner before they get too far along in the design process thereby reducing cost and agency time.

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Impact of Climate Change on Management of Groundwater in the Yakima Basin for Drought Management

Lance Vail, Scott Waichler, Rajiv Prasad, Mark Wigmosta

Replacement for withdrawn presentation.

Pacific Northwest National Laboratory

5th Washington Hydrogeology Symposium

POSTERS

POSTER SESSION 1 — GROUNDWATER CONTAMINATION AND REMEDIATION		POSTER SESSION 2 — GEOHYDROLOGY AND WATERSHEDS	
1.	**The Role of Hydrogeology in Remedy Selection at the Fort Lewis Logistics Center Superfund Site:** *Troy D. Bussey, Jr., Fort Lewis Public Works/ Anteon Corp. ENRD, and Marcia E. Knadle*	21.	**Determine the Optimal Location of Observation Wells in an Heterogeneous Unconfined Aquifer by Evaluation of Pumping Test after Dupuit Formel to Get a Best Effective Hydraulic Conductivity:** *Ayman Abdulralman, Department of Water Resource, Department of Irrigation and Drainage, Aleppo University*
2.	**Development of an Integrated Borehole Geologic Information System for the Hanford Site:** *George V. Last, Pacific Northwest National Laboratory , and V.R. Saripalli, D.A. Rush, R.D. Mackley*	22.	**Pilot Study for a State-based Ambient Groundwater Monitoring Program — Centralia-Chehalis Valley, WA:** *Charles F. Pitz, WA Department of Ecology, and Kirk Sinclair, Adam Oestreich*
3.	**Does Bacterial and Nitrate Contamination in Streams in Whatcom County, Washington come from Ground Water?:** *Stephen E. Cox, U.S. Geological Survey, and F. William Simonds, Rose F. Defawe, Llyn Doremus - Correction: this paper will be given as an oral presentation in Session 3B Non-point Source Contamination.*	23.	**Measurement and Use of Stream-bed Temperatures to Quantify Stream/Groundwater Exchanges and Associated Nutrient Fluxes Within the Deschutes River and Percival Creek Watersheds, Thurston County, WA.:** *Kirk Sinclair, WA Department of Ecology, and Mindy Roberts, Dustin Bilhimer*
4.	**Sustainability for Appropriate Potable Water Supply Contexts and Prospects in the Remote Coastal Communities of Bangladesh:** *Md. Salequzzaman, Environmental Science Discipline, Khulna University, Bangladesh, and Research Fellow, Institute for Sustainablitiy and Technology Policy (ISTP) Murdock University, Australia, and Md. Bayzidur Rahman, Md. Arif Chowdhury, Md. Zahidul Murad*	24.	**Evaluating Recharge Parameter Sensitivities in the Precipitation-Runoff Modeling System:** *D. Matthew Ely, U.S. Geological Survey*
5.	**Use of River Tubes to Delineate and Characterize Groundwater Discharge Into the Columbia River along the Hanford Reach:** *Donny Mendoza, Pacific Northwest National Laboratory, and Brad Fritz, Tyler Gilmore, Greg Patton, Nancy Kohn*	25.	**Estimated Domestic, Irrigation, and Industrial Water Use in Washington, 1985, 1990, 1995, and 2000:** *R.C. Lane, U.S. Geological Survey*
6.	**Hydraulic Analysis of Landfill Leachate Collection System at Unlined Closed Landfill:** *Arnie Sugar, HWA GeoScience, Inc.*	26.	**Quaternary Geology of the Lower Elwha River Valley, Clallum County, Washington:** *Vance Atkins, URS Corporation, and Mark Molinari, Bob Burk*
7.	**A Degrading TCE Plume in the Deep Hyporheic Zone: A Candidate for Monitored Natural Attenuation?:** *James G.D. Peale, Maul Foster & Alongi, Inc., and James J. Maul*	27.	**Using Emerging GIS and Database Technologies to Develop and Manage Large Datasets and Geographic Information for a National-Scale Ground-Water Quality Study:** *Frank D. Voss, U.S. Geological Survey*
8.	**Evaluating Regional Trends in Ground-water Nitrate Concentrations of the Columbia Basin Groundwater Management Area, Washington:** *Lonna M. Frans, U.S. Geological Survey.*	28.	**Hydrologic Investigation and Ground-Water Flow Model of the Rathdrum-Spokane Aquifer, Kootenai County, Idaho and Spokane County, WA:** *Sue C. Kahle, U.S. Geological Survey, and Helen Harrington, Guy Gregory*
9.	**Using New Media to Remove Hexavalent Chromium (Cr+6) from Groundwater Extracted:** *Mark Byrnes, Fluor Hanford, and Jared D. Isaacs*	29.	**Forecasting Runoff in Watersheds with Seasonally Frozen Soils:** *Mark C. Mastin, U.S. Geological Survey, and Marijke van Heeswijk, Roger P. Sonnichsen*

10.	**Bedrock Heterogeneity and Shallow Occurrence of Saline Groundwater, Josephine County, Oregon:** *Tom Wiley, Oregon Department of Geology and Mineral Industries, and I.K.Gall, E.J. Schaafsma*	30.	**Use of Calibration Curves to Improve Low Velocity Measurements with the Swoffer Current Meter:** *Joseph Lubischer, Aspect Consulting, LLC, and Erick W. Miller*
11.	**Monitoring the Health of an Urban Watershed:** *Joel Zylstra, Department of Geosciences and Environmental Studies Program, Pacific Lutheran University , and Beth Stone, Michelle Stark, Nicole St. Amand, Bryce Robbert, Stephanie Puhl, Susan McPartland, Kit McGurn, Julie Locke, Sarah Larson, Jewel Koury, Aaron Highlands, Erika Helm, Mandy Heimbuch, Jennifer Halaas, Somer Goulet, Jennifer Catlett*	31.	**Investigations into the Cause of a Sinkhole in Jubilee Lake:** *Bryce E. Cole, Walla Walla College, and Michelina S. Oms, Ebigalle L. Voigt*
12.	**Automated Water Level Monitoring at the Hanford Site:** *Robert S. Edrington, Fluor Hanford*	32.	**Simulating Runoff in Two Basins in the Lake Whatcom Watershed, Whatcom County, Washington Using a Distributed Hydrology Model:** *Katherine Kelleher, Western Washington University, Geology Department, and Robert Mitchell*
13.	**Occurrence and Distribution of Trace Elements in Lake Roosevelt Beach, Bed Sediments, and Air:** *Michael S. Majewski, U.S. Geological Survey, and Sue Kahle*	33.	**Investigation of Mine-Related Impacts at an Abandoned Lode Mine in Western Oregon:** *Catherine M. Bohlke, EA Engineering, Science and Technology, Inc., and Glenn A. Hayman*
14.	~~**Calibration and Improvement of the System Assessment Capability:** *William E. Nichols, Pacific Northwest National Laboratory, and C. Arimescu, R.W. Bryce, D.W. Engel, P.W. Eslinger, C.T. Kincaid, T.B. Miley, S.K. Wurstner*~~ ***- Withdrawn***	34.	**Applicability of the NLOS Model for Predictions of Soil Water Movement and Nitrogen Transport in an Agricultural Soil, Agassiz, BC:** *Heather Hirsch, Western Washington University, Geology Department, and Robert Mitchell, Shabtai Bittman*
15.	~~**Hanford Site Composite Analysis 2004 Results Using the System Assessment Capability:** *P.W. Eslinger, Pacific Northwest National Laboratory, and C. Arimescu, R.W. Bryce, D.W. Engel, P.W. Eslinger, C.T. Kincaid, T.B. Miley, W.E. Nichols, S.K. Wurstner*~~ ***- Withdrawn***	35.	**Use of Automated Downhole Groundwater Monitoring to Characterize Post-Redevelopment Conditions in a Tidally Influenced Aquifer System, Port of Seattle Southwest Harbor Project:** *Peter Bannister, Aspect Consulting, LLC, and William Goodhue, Kathy Bahnick*
16.	**Isotopic Ratios Used to Distinguish Contaminant Sources in Single Shell Tank Waste Management Area S-SX***: Joseph A. Caggaino , WA Department of Ecology, and Floyd N. Hodges, Vernon G. Johnson*	36.	**Dye Trace Study Results Used for Estimating Hydraulic Conductivity and Rock Avalanche Debris Stability Along Washington SR 20:** *Jamie Schick, URS Corporation, and Bob Burk, Selene Fisher, Jim Flynn, Steve Lowell, Martin McCabe, Balin Strickler*
17.	**Characterization of the Vertical Distribution of Carbon Tetrachloride Contamination in Hanford Site Groundwater:** *Bruce A. Williams, Pacific Northwest National Laboratory, and F.A. Spane, V.J. Rohay, D.B. Erb*	37.	**A Clear View of How Ground Water and Surface Water Are Linked - A Bench-Scale Model:** *Laurie Morgan, WA Department of Ecology, and Suzan Porter*
18.	**Edge of Field Nitrate Loss in a Dryland Agricultural Setting:** *Caroline N. Wannamaker, Washington State University, Department of Geology, and C.K. Keller, Richelle Allen-King, Jeffery L. Smith*	38.	**Update on the Use of Buried and Submerged Forests to Date and Characterize Geologically Recent Landscape Disturbances in Washington:** *Patrick T. Pringle, WA Department of Natural Resources, Division of Geology and Earth Resources.*
19.	**The Impact of Radiological Groundwater Contaminants on Drinking Water at the U.S Department of Energy's Hanford Site in Southeastern Washington :** *R.W. Hanf, Battelle, Pacific Northwest National Laboratory, Enivironmental Characterization and Risk Assessment Group, and L.M. Kelly*	39.	**Simulation of the Saltwater Interface Along Southern Puget Sound Shorelines, Pierce Co, WA:** *Linton Wildrick, Pacific Groundwater Group, and Russ Prior*
20.	**Three-Dimensional Modeling of DNAPL in the Subsurface of the 216-Z-9 Trench at the Hanford Site:** *Martinus Oostrom, Environmental Technology Division, Pacific Northwest National Laboratory, and M.L. Rockhold, P.D. Thorne, G.V. Last, M.J. Truex*	40.	**Aquifer Susceptibility Mapping of Vashon - Maury Island, King Co., WA:** *Kathy G. Troost, University of Washington, Dept. of Earth and Space Sciences, and Kenneth H. Johnson, Derek B. Booth, Sarah Ogier, Aaron P. Wisher*
		41.	**Is New, Detailed, 1:12,000-Scale Geologic Mapping Worth the Cost? Hydrogeologic Applications of a Geologic Database of the Seattle Area, Washington:** *Kathy G. Troost, University of Washington, Dept. of Earth and Space Sciences, and D.B. Booth, S.A. Shimel, A.P. Wisher, M.A. O'Neal*

The Role of Hydrogeology in Remedy Selection at the Fort Lewis Logistics Center Superfund Site

Troy D. Bussey, Jr.[1] *and Marcia E. Knadle*[2]

The Fort Lewis Logistics Center National Priority List site is located south of Tacoma, Washington on the Fort Lewis military installation. Disposal of industrial wastes in the East Gate Disposal Yard (EGDY) between the 1940s and 1970s has resulted in trichloroethylene (TCE) plumes in the upper Vashon Aquifer and the lower Sea Level Aquifer (SLA). The Vashon Aquifer TCE plume extends for a total distance of approximately 2.5 miles downgradient from the EGDY source area while the SLA TCE plume extends for approximately 3.2 miles downgradient of a higher-permeability “window” that enables enhanced contaminant transport from the Vashon Aquifer to the SLA. A 1990 Record of Decision (ROD) selected a remedy that included installation and operation of 2 Vashon Aquifer pump-and-treat (P&T) systems: one in EGDY and one near the installation boundary at Interstate 5. It also included a contingency for the Army to install a SLA P&T system if an extensive TCE plume was confirmed in the SLA.

Fort Lewis Public Works is in the process of formally modifying the remedy in a pending ROD Amendment. The proposed modified remedy includes the ongoing operation of the I-5 P&T system as well as installation and operation of an optimized EGDY P&T system and a SLA P&T system, completion of source treatment actions (i.e., near-surface drum removal and in-situ thermal treatment of TCE hot spots in soils), and implementation of institutional controls within the on-base plume boundaries. While factors such as life-cycle costs, P&T performance, engineering assessments, regulatory negotiations, and imposed deadlines all contributed to the need for a modified remedy, an improved understanding of site hydrogeology laid the critical groundwork for developing the modified remedy. The conceptual site model (CSM) has been greatly refined via post-ROD characterization in the source area and distal edges of the plumes, an isotopic tracer study, and iterative development and application of a detailed flow-and-transport model. Several agencies and contractors have cooperatively conducted these hydrogeology-based projects over several years; together, they have greatly improved the understanding of the TCE source areas, the complex hydrostratigraphy, localized and semi-regional groundwater flow directions, TCE transport within and between aquifers, boundary conditions, and groundwater/surface water interactions. The refinements to the CSM have focused source treatment and SLA treatment actions, predicated non-intuitive modifications to the EGDY P&T system as well as a non-intuitive use of a P&T system for the SLA plume, and are projected to decrease remedy operation-and-maintenance life-cycle costs.

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Development of an Integrated Borehole Geologic Information System for the Hanford Site

G. V. Last[1], V. R. Saripalli[2], D. A. Bush[3], R. D. Mackley[4]

Borehole data are the cornerstone of subsurface characterization, monitoring, and performance assessment programs. These data often take great effort and expense to generate. Yet, historically they have been managed in an ad hoc fashion, using a wide variety of formats (generally non-digital) and scattered across individual project records. Additionally, data collection procedures have varied over time and are often poorly documented, making it difficult to evaluate, integrate, and apply the data.

A number of database, borehole log, and mapping tools are commercially available to help manage and interpret borehole data. However, none of these tools can take advantage of existing databases that contain data collected over the last 60 years at the Hanford Site. Thus, the Groundwater Remediation Project is developing an integrated borehole geology data management and interpretation system to maximize the value of these data.

HBGIS (Hanford Borehole Geologic Information System) is a secure online web application supported by Microsoft SQL Server® as a back end database. It is designed to support the Hanford community with a user friendly GUI (graphical user interface) that will provide a comprehensive information management system for archival, retrieval, and interpretation of data from over 4000 boreholes. HBGIS's unique feature is its ability to connect directly to different databases to get the relevant borehole information rather than storing duplicate data available in other Hanford databases. HBGIS data transformation option allows exporting data into graphical data processing software such as LogPlot™ and SoilVision[5].

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Sustainability for Appropriate Potable Water Supply Contexts and Prospects in the Remote Coastal Communities of Bangladesh

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The paper converses about the contexts of appropriate potable water supply situations in the Remote Coastal Bangladesh and its prospects to introduce the alternative sources as the sustainable water supply solutions. Until now, most of the remote areas of Coastal Bangladesh are less privileged in amenities being predominated by scarcity of potable water supply for their daily livelihoods. Recently the high salinity intrusion induced by climate change coupled with unplanned agricultural practices such as shrimp aquaculture has jeopardized both the ground and surface water sources. This situation becomes alarming by the recently discovered arsenic contamination of ground water, not only for coastal communities but all over the country. Lack of proper sanitary knowledge also aggravates the scenarios and has brought out a virtual water calamity to the coastal peoples. The study analyzed several interventional projects that already adapted in this area to solve the persisting problems and revealed several appropriate technologies and alternate water supply sources by considering the locally available and low cost raw materials and technological options. For example protected ponds, different types of rain water harvesters, pond sand filters, Kalshi-filters, and other such options are being proven as the successful interventions. The study find out that all the options are not suitable for all the areas rather the selection criteria by using GIS (Geographic Information System) applications along with the local climatic conditions and socio-economic status of the community people. Thus the paper suggests a comprehensive policy framework of selecting appropriate places for appropriate technological options by using already applied GIS based analysis considering relevant socioeconomic and environmental aspects of the coastal communities in Bangladesh.

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Use of River Tubes to Delineate and Characterize Groundwater Discharge into the Columbia River Along the Hanford Reach

Donny Mendoza[1], Brad Fritz[1], Tyler Gilmore[1], Greg Patton[1], Nancy Kohn[2]

Hanford Site Facilities were used in the production of special nuclear materials for over 40 years. These past operations resulted in the release of radiological and chemical contaminants along the Hanford Reach. Over time, the contaminants have migrated to the groundwater and have been detected along particular stretches of the Columbia River shoreline. There is a net discharge of groundwater to the river, but discharge rates are affected by fluctuations in the river level and the geology.

River tubes (piezometer style sampling tubes) were driven into the streambed of the Columbia River to investigate the dynamics of groundwater discharge in this large river system. An array of river tubes was installed along the shoreline to delineate groundwater discharge areas. The River tubes were installed using a gasoline powered jackhammer operated by one or two people which allowed installation in areas inaccessible by vehicles. The tubes are also used for groundwater sample collection and many were also instrumented with data loggers for measuring specific conductance, river level, and temperature.

The conductivity measurements from the river tubes correlate well with other sampling techniques currently being used along the shoreline. Groundwater samples have also been obtained at the lowest, intermediate, and highest river levels observed this year for radiological and chemical analysis. River tube sampling data also correlate well with other more traditional sampling techniques along the river. The methods employed for the installation of this monitoring network have been shown to provide data that is critical in understanding the complex dynamics of groundwater discharge into the Columbia River along the Hanford Reach.

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Hydraulic Analysis of Landfill Leachate Collection System at Unlined Closed Landfill

Arnie Sugar, L.G., L.H.G.

Hydraulic analysis of a leachate collection system at a closed landfill was performed to evaluate the effectiveness of the collection system and the relationship between shallow ground water, surface water, and leachate. The leachate collection system was installed along the downgradient edge of the unlined landfill, where leachate seeps formerly discharged to surface water, including a tidally influenced river. The system includes a geomembrane cover on the downgradient sideslopes of the landfill, 4000 feet of lined leachate collection trench, pump stations, and a sanitary sewer force main conveying collected liquids to a wastewater treatment plant.

Operational pumping data suggested inflow of water into the system from outside the landfill. The hydraulic analysis included ground water and surface water level monitoring during periods of pumping and recovery of the collection system, at 24 shallow piezometers, drainage ditches, river, and leachate wet wells/pumping stations. The study evaluated the performance of the collection system, contribution of leachate vs. clean water, degree of hydraulic gradient control, and surface water (including tidal) interactions.

Analysis of the data collected indicated the leachate collection system was capturing leachate and shallow ground water from the landfill, preventing migration of leachate or ground water off the landfill and into adjacent surface water, as well as capturing some ground water from the other (non-landfill) side of the trench.

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A Degrading TCE Plume in the Deep Hyporheic Zone: A Candidate for Monitored Natural Attenuation?

James G. D. Peale[1], James J. Maul[2]

During a Remedial Investigation, a dissolved-phase TCE plume was identified with a source located about 500 feet upland from the Portland Harbor portion of the Willamette River (about River Mile 6). The Portland Harbor is listed on the National Priorities list by the USEPA and considered to fall into the category of a “mega site” because of its size and the number of potentially responsible parties that could have contributed to the contamination.

TCE concentrations in the source area were greater than 10% of the solubility limit. The site is located on fill and alluvial sediments overlying the Columbia River Basalt (CRB), which is a regional aquifer. The CRB was encountered at depths ranging from about 100 to 230 feet bgs. Sonic drilling technology and discrete reconnaissance groundwater sampling techniques were applied to characterize the nature and extent of the plume. The vertical extent of the TCE plume is between about 20 and 100 feet below ground surface (bgs) in the source area, and between about 80 and 140 feet bgs in downgradient wells.

The upland portion of the remedial investigation (RI) confirmed that site soil and groundwater are also heavily impacted by manufactured gas plant (MGP) waste, including light and dense non-aqueous phase liquids (NAPL). MGP-related DNAPL was found in downgradient wells screened between 110 and 125 feet bgs. A third, low-level plume of off-site contaminants was found below the TCE plume, in coarser alluvium overlying the CRB.

Local groundwater is typically expected to discharge to the river. Vertical gradients calculated at wells located along the river bank were inconclusive with respect to deep groundwater discharge conditions, requiring characterization of sediment and groundwater below the river. In-river work was accomplished using a direct-push drilling rig deployed on a barge, and reconnaissance groundwater sampling and hydrology measurements to assess possible plume discharge and exposure endpoints.

The initial results were unexpected, showing that the depth of the plume continues to increase (to as deep as 185 feet bgs) with distance from the source, and may flow underneath the river. The vertical thickness of the TCE plume appears to decrease with distance as well. The analytical data suggest that a substantial zone of groundwater flow beneath the river (hyporheic zone) is present. Furthermore, the analytical data show that TCE is anaerobically degrading, suggesting that monitored natural attenuation combined with limited, in-situ source treatment may be a remedial alternative.

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Evaluating Regional Trends in Ground-Water Nitrate Concentrations of the Columbia Basin Groundwater Management Area, Washington

Lonna M. Frans

Trends in nitrate concentrations in water from 474 wells in 17 subregions in the Columbia Basin Groundwater Management Area (GWMA) in three counties in eastern Washington were evaluated using a variety of statistical techniques, including the Friedman test and the Kendall test. The Kendall test was modified from its typical 'seasonal' version into a 'regional' version by using well locations in place of seasons. No statistically significant trends in nitrate concentrations were identified in samples from wells in the GWMA, the three counties, or the 17 subregions from 1998 to 2002 when all of the data were included in the analysis. For wells in which nitrate concentrations were greater than 10 mg/L, however, a significant downward trend of -0.4 milligrams per liter (mg/L) per year was observed between 1998 and 2002 for the GWMA as a whole, as well as for Adams County (-0.35 mg/L per year) and for Franklin County (-0.46 mg/L per year). Trend analysis for a smaller but longer-term 51-well dataset in Franklin County found a statistically significant upward trend in nitrate concentrations of 0.1 mg/L per year between 1986 and 2003. The largest increase of nitrate concentrations occurred between 1986 and 1991. No statistically significant differences were observed in this dataset between 1998 and 2003 indicating that the increase in nitrate concentrations has leveled off.

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Using New Media to Remove Hexavalent Chromium (Cr+6) From Groundwater Extracted in the 100-D Area, Hanford Site, Washington

Mark E. Byrnes[1], Jared D. Isaacs[2]

A plume of dissolved hexavalent chromium (Cr+6) was discovered in groundwater in 1995 along the Columbia River shoreline, in the 100 D Area of the Hanford Site. The source of the Cr+6 contamination is believed to be sodium dichromate-dihydrate ($Na_2Cr_2O_7 \bullet 2H_2O$) which was historically used for corrosion control in reactor cooling water.

An interim Record of Decision (ROD) issued in 1996 identified pump-and-treat as the selected remedial action for the 100-D Area groundwater. Groundwater extracted from four wells is treated onsite by passing water through a series of filters containing DOWEX resin (Dow Chemical Company); the filtered water is then re-injected upgradient of the 100-H Area. These DOWEX resins are exchanged every few weeks when they become loaded with Cr+6 and are later shipped offsite at great expense for regeneration, or are disposed if uranium concentrations are too high for shipment. In the latter case additional resin material must be purchased.

Additional groundwater characterization showed the 100-D Cr+6 plume to be much larger than previously understood and was outside the capture zone of the existing pump-and-treat system. Treatability tests performed in 1997 and 1998 proved In-Situ Redox Manipulation (ISRM) to be a viable remedial option. The ISRM technology creates a chemically reduced permeable treatment zone that reduces Cr+6 to less mobile and less toxic trivalent chromium. The interim ROD was amended in 1999 to identify ISRM as the selected remedial alternative for the 100-D Area groundwater.

More recently, the lead regulatory agency expressed concern over an area between the ISRM barrier and the pump-and-treat system where Cr+6 contaminated groundwater was not being captured or treated. The decision makers agreed to expand the pump-and-treat system to the west. However, in an effort to reduce the high cost of offsite DOWEX resin regeneration, the expanded system utilizes an MR3 Systems treatment train that contains a patented MR3 Systems media that can be regenerated onsite. Preliminary analytical results have shown that the MR3 Systems media is successfully reducing Cr+6 concentrations of over 1,100 ppb in the influent to below detection (5 ppb). If treatability tests of the onsite regeneration process prove to be successful, other treatment trains onsite may be evaluated for potential replacement with the MR3 Systems media.

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Bedrock Heterogeneity and Shallow Occurrence of Saline Groundwater, Josephine County, Oregon

By T.J. Wiley[1], I.K. Gall[2], and E.J. Schaafsma[3]

Geologic mapping in the vicinity of Grants Pass, Oregon, shows that the distribution of fresh and saline (>80ppm) groundwater is locally controlled by steeply dipping bedrock features. Bedrock in this area consists of Mesozoic meta-sedimentary, meta-volcanic, and intrusive rocks. The Rogue River and its tributaries—the regional groundwater discharge areas—are incised into the bedrock but locally flow across Quaternary alluvium. Comparing new geologic maps to a map showing areas with saline ground water suggests that the down-gradient limits of many saline anomalies correspond to changes in bedrock. Types of geologic anomalies bounding saline groundwater zones include: 1.) Structural features such as faults and/or up-thrown fault blocks, 2.) Intrusive features such as dikes and intrusive contact zones, 3.) Depositional contrasts such as steeply dipping contacts between volcanic rock and phyllite, and 4.) Erosional features such as bedrock highs in alluvium. Each appears to segment near-surface fresh-water aquifers and an underlying saline aquifer. Longer groundwater residence time and longer, generally deeper flow paths are suggested for the saline groundwater.

Many saline groundwater anomalies are associated with adjacent topographic highs, topographic breaks, or buried bedrock highs. These topographic features lead us to infer that bedrock is less permeable at the down gradient edge of the anomalies. At intrusive contacts and dikes, the relative ages of emplacement, contact metamorphism, and cooling suggest mechanisms that would locally truncate or anneal fractures, reducing local aquifer permeability, and forcing deeper saline groundwater into shallow flow systems sampled by wells. Within the Grants Pass pluton, local bedrock highs are often associated with dry wells, which also suggests that zones of low permeability correspond to these features. In outcrop, rocks from these zones appear to be less fractured than surrounding rock.

Saline water is most commonly encountered in wells drilled upgradient from bedrock anomalies that cross the bottoms of major valleys. Saline water is less common in upland wells. This suggests that shallow groundwater in the uplands is dominated by fresh water recharge from local rainfall.

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Monitoring the Health of an Urban Watershed

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This study was conducted to monitor the health of Clover Creek watershed. Clover Creek, a sub-basin of WRIA 12, is a small, rapidly urbanizing, lowland Puget Sound watershed. We identified indicators of health for the watershed, using stakeholders' goals as well as environmental and economic sustainability of watershed health as a guide. These indicators allow the community to evaluate its progress toward achieving these goals. We characterized the watershed using chemical, biological and physical data gathered in the field during spring 2004, as well as available socioeconomic data. These data were used to evaluate the current health of the watershed. In addition we used data gathered in past years to characterize changes in watershed health through time. Results indicate that with respect to water quality the watershed is generally healthy. However water quantity, salmon habitat quality and accessibility, and development, continue to cause concerns.

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Automated Water Level Monitoring 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. The modeling and analysis of contaminates in an aquifer is central to remediation work at any Hazardous waste cleanup site. Water level data are a key component to the full characterization, modeling, analysis and decision making in the remediation of groundwater contamination. The gradient (slope) of the water table or potentiometric surface in an affected aquifer is the driving force in determining the speed and direction of movement of contaminates in groundwater. Computer-based solute-transport models are used as a primary tool in understanding the subsurface migration and behavior of groundwater contaminants. Water level data of sufficient duration and frequency of measurement are needed to calibrate and evaluate the reliability of these models before simulations of contaminant transport can be made. Only with realistic models can effective remedial design be performed. Water level data are also needed for numerical analyzes (stream-flow, capture-zone, etc) 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 75 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.

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Occurrence and Distribution of Trace Elements in Lake Roosevelt Beach, Bed Sediments, and Air

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The upper Columbia River in northeastern Washington State has received metals discharged from a lead/zinc smelter in Canada for over 100 years, much of it as slag. Although the amount of discharge has recently been dramatically reduced, the bed sediments in the river remain heavily contaminated with trace metals. High concentrations of trace metals have also been detected in the water, fish, and benthic invertebrate communities. Lake Roosevelt is a large reservoir on the Upper Columbia River that extends for 217 kilometers from the Grand Coulee Dam to within 24 kilometers of the Canadian border. During the spring, the reservoir water level is lowered to make room for the winter snow melt, and it is lowered again in the fall for fish management. During the spring drawdown the reservoir pool depth can drop more than 20 meters, exposing many thousands of hectares of contaminated beach and bed sediments. Once dry, the bed sediment materials have a high potential for entrainment into the lower atmosphere by wind gusts, and can be carried downwind throughout the Lake Roosevelt airshed, exposing humans to potentially high levels of trace metals.

This study determined the occurrence, concentrations, and distribution of trace elements in the fine-grained fraction of exposed beach, bed, and bank sediments, and in the air along the length of Lake Roosevelt. Trace element concentrations in the surficial bed sediments varied, but the major slag components of arsenic, cadmium, copper, lead, and zinc showed pronounced decreasing concentration gradients from the Canadian border to Grand Coulee Dam. Concentrations of Cu, Pb, and Zn exceeded the Canadian trace metal probable-effect level guidelines for adverse biological affects in aquatic systems at several sites in the upper reach of the reservoir.

Air sampling is conducted at three sites on a regular schedule from January through June, and for one month in the fall. Extra samples are taken during high wind events. The air samples collect particles of a mean diameter of 10 micrometers or less (PM10). The results showed that many of the same trace metals found in the bed sediments were also present in the air at nanogram-per-square-meter concentrations. The mean PM10 concentrations at the sampling sites ranged from <10 $\mu g/m^3$ to 50 $\mu g/m^3$, and were below the current USEPA PM10 air quality standards. Trace metal concentrations in air were also usually one or more orders of magnitude below any established air quality standard or reference level. These low levels may be due to the high water levels in recent years and the resulting minimization of exposed beach sediment.

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Calibration and Improvement of the System Assessment Capability

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Hanford Site Composite Anaylysis 2004 Results Using the System Assessment Capability

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Isotopic Ratios Used to Distinguish Contaminant Sources in Single Shell Tank Waste Management Area S-SX

Joseph A. Caggiano[1], Floyd N. Hodges[2], Vernon G. Johnson[3]

High-level, mixed radioactive and dangerous waste was discharged to 177 underground storage tanks at the Hanford Site during operations. 149 of these are Single-shell tanks (SSTs) constructed of a single liner of carbon steel inside a reinforced concrete tank. Releases are assumed at 67 of these SSTs. Eleven of the assumed leaking tanks (of 27 total) are at Waste Management Area (WMA) S-SX. At least two of these "assumed" leakers at WMA S-SX have impacted groundwater. SSTs in WMA S-SX operated in a self-boiling mode, with condensate collected and routed to adjoining cribs. High temperatures within the tanks apparently contributed to rapid deterioration of carbon steel tank liners.

Numerous cribs located on the hydraulically up-and downgradient sides surround WMA S-SX and received high-volume liquid waste discharges that have infiltrated to groundwater, making discrimination of contaminants resulting from tank leaks difficult. However, because of different process histories, analysis of ratios of groundwater contaminants (technetium-99, uranium, tritium, and nitrate) allows the distinction of crib vs. tank releases and demonstrates that releases from tanks in WMA S-SX have affected groundwater. The distinction of crib vs. tank sources is significant because the tanks will close under RCRA, while the past-practice cribs will close under CERCLA.

Groundwater at WMA S-SX is monitored by 16 monitoring wells at this RCRA TSD unit under a groundwater assessment plan. At least two major technetium-99 plumes are present. One plume apparently has its source at the S-104 Tank. The second plume apparently has its source at one of several tanks in the southwest corner of the SX Tank Farm. Drilling near the SX-115 Tank has found groundwater concentrations of technetium-99 as high as188,000 pCi/L; however, concentrations of this magnitude have not been detected in downgradient wells at this time. The plume arising from this source has crossed the WMA boundary and is migrating downgradient.

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Characterization of the Vertical Distribution of Carbon Tetrachloride Contamination in Hanford Site Groundwater

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Carbon tetrachloride was used at the Hanford Site in southeastern Washington as part of the plutonium recovery process. Liquid waste containing carbon tetrachloride was discharged to the soil column in the central portion of the 200 West Area from 1955 through 1973. By 2003, the groundwater plume of dissolved carbon tetrachloride exceeding the 5 μg/L maximum contaminant level extended laterally over 10.6 km^2. Wells used for monitoring the plume typically are screened in the upper 15 m of the unconfined aquifer, which is up to 60 m thick. Although carbon tetrachloride has been detected throughout the unconfined aquifer, the vertical distribution of the plume is not well known.

The unconfined aquifer is composed of semi-consolidated, poorly stratified, fluvial sand and gravel (Ringold Unit 5). A low-permeability lacustrine silt/clay (Ringold Lower Mud) occurring ~60 m beneath the water table forms a semi-confining base for the unconfined aquifer in this region. Past discharges of wastewater throughout the 200 West Area created an areally extensive groundwater mound that has declined 12 m since 1984. Regional groundwater flow is easterly toward the Columbia River. Hydraulic conductivities for the upper 10 m of the unconfined aquifer range between 0.02 and 64 m/day, with a geometric mean of 2.6 m/day. Limited test data suggests that the upper portion of the unconfined aquifer is generally more permeable than the middle and lower portions of the unconfined aquifer.

Hydrochemical depth sampling results from new characterization boreholes suggest that the maximum concentration of carbon tetrachloride typically occurs 20 to 30 m below the water table at locations downgradient from the original liquid discharge sources. At some locations, the lateral extent of the deeper carbon tetrachloride contamination exceeds that of the plume mapped at the water table. At locations near the original liquid discharges, the maximum concentration of carbon tetrachloride occurs near the water table. The increased depth of the maximum carbon tetrachloride concentrations with distance from the source is believed to result, in part, from the predominantly downward vertical gradient that was imposed by the artificially produced groundwater mound, and from the existing hydrogeologic heterogeneities within the unconfined aquifer. New wells are planned to help refine the conceptual model of the carbon tetrachloride distribution and support remedial action decisions.

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Edge of Field Nitrate Loss in a Dryland Agricultural Setting

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Four complete water years of nitrate concentrations have been monitored in soil water samplers, a tile drain and surface waters beneath and near a dryland, agricultural field in the Palouse Region of Washington State, USA. Undulating hills and basins of wind blown loess dominate this region with the main soil type characterized as silt-loam Mollisols. The field in our study area is subjected to typical farming practices and crop rotations, receiving ammonia fertilizer during fall and spring plantings at a rate of ~170 kg of nitrogen per hectare. Precipitation is strongly seasonal with most of the mean annual 480 mm occurring between January and April. Nitrate concentrations exhibit a distinctive seasonal pattern. Concentrations in surface waters range from less than 1 mg NO_3-N /L in late September/October and increase with the onset of flow, differing from a typical dilution effect, to 15-40 mg /L in late February/March. Soil water is similar in timing and behavior to surface waters, with lowest average concentrations of ~10 mg /L in June, up to average concentrations ~120 mg /L in late February/March. We hypothesize that varying fertilization rates and timing contribute to the year-to-year variations in amplitude of nitrate concentration fluctuations. Either of two processes could explain the rapid winter increases in NO_3 concentrations. The first process is rapid transport of water over and through our soils, on a timescale of weeks to months, so that NO_3 in winter surface water is fertilizer from the most recent application. A second possible process is rapid activation of flow paths in communication with high - NO_3 pore water, coinciding with saturation of the soil profile; these flow paths then gradually deactivate as the profile drains and dries out. Research using stable oxygen isotopes is currently being conducted to help better understand residence times of water in our system and to help identify the NO_3 transport processes.

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The Impact of Radiological Groundwater Contaminants on Drinking Water at the U.S Department of Energy's Hanford Site in Southeastern Washington

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For decades, many millions of gallons of radiologically contaminated liquid waste from nuclear materials production were discharged to ground disposal facilities at the U.S. Department of Energy's (DOE) Hanford Site in southeastern Washington State. Production activities at the site have ended, but persistent contaminants are still present, and there is concern about potential health impacts to site workers and members of the public who may be exposed to those contaminants. An area of concern is the possibility for remaining waste to adversely impact onsite drinking water. DOE drinking water sources on the Hanford Site include a small number of groundwater wells, but surface water systems supplied by pumping facilities located along the Columbia River shoreline provide most of the site's drinking water. Hanford-produced contaminants are known to exist in groundwater beneath the site and contaminated groundwater is discharging to the Columbia River in the vicinity of active shoreline drinking water intakes. Data from drinking water monitoring indicate that some Hanford Site groundwater contaminants are present in onsite drinking water, but that concentrations are generally well below state and federal drinking water limits. These data should provide assurance to consumers that radiological contaminants in Hanford Site groundwater are not significantly impacting the health of workers and the public through the onsite drinking water pathway.

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Three-Dimensional Modeling of DNAPL in the Subsurface of the 216-Z-9 Trench at the Hanford Site

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Three-dimensional modeling was conducted to enhance the conceptual model of carbon tetrachloride (CT) distribution in the vertical and lateral direction beneath the 216-Z-9 trench at the Hanford Site. Simulations targeted migration of dense, nonaqueous phase liquid (DNAPL) consisting of CT and co-disposed organics in the subsurface beneath the 216-Z-9 trench as a function of the properties and distribution of subsurface sediments and of the properties and disposal history of the waste. The geological representation of the computational domain was extracted from a larger Earthvision™ geologic model of the 200 West Area subsurface. Simulations of CT migration were conducted using the STOMP simulator, a multi-fluid flow and transport code developed by Pacific Northwest National Laboratory. The simulations consisted of one Base Case simulation and 22 sensitivity analysis simulations. The sensitivity simu¬lations investigated the effects of variations in 1) fluid composition; 2) disposal rate, area, and volume; 3) fluid retention; 4) permeability; 5) anisotropy; 6) sorption; 7) porosity; and 8) residual saturation formation on the movement and redistribution of DNAPL. Additional simulations were conducted to investigate the effect of soil-vapor extraction (SVE) on the distribution of CT in the subsurface of the 216-Z-9 trench. The simulation results indicate that the Cold Creek unit accumulated CT and has a large impact on DNAPL movement and the resulting distribution of CT in the subsurface. The Cold Creek unit is a relatively thin, laterally continuous unit comprised of a silt layer and a cemented carbonaceous layer located about 40 m below ground surface and about 50 m above the water table. The simulations also show that the lateral extent of the vapor-phase plume in the vadose zone was much more extensive than the lateral extent of the DNAPL. Density-driven vapor flow caused the CT vapor to move downward until the plume contacted relatively impermeable units (e.g., the Cold Creek unit) or the water table. At these interfaces, the vapor plume moved laterally. The vapor plume also partitioned into the water and onto the solid phase as it moved. The CT present in the Cold Creek unit can continue to volatilize over time and move downward to layers where it could be removed by SVE or deeper where groundwater contamination could take place.

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Determine the Optimal Location of Observation Wells in an Heterogeneous Unconfined Aquifer by Evaluation of Pumping Test After Dupuit Formel to Get a Best Effective Hydraulic Conductivity

Dr. Ayman Abdulrahman

In a pumping test the drawdown of the groundwater table has to be measured through observation wells determine the hydraulics conductivity of the field. In a homogenous isotropy Aquifer two observation wells in one line might be enough to determine the K-Value of the Aquifer. In this case, the contour lines of the groundwater table are circulars and the well lies in the center of these circles. In the nature, the actual draw down of groundwater table is not circular. That means that the assumed Model of the homogenous Aquifer is practically non-existent.

The aim of this Research is to determine the best locations of observation wells in an heterogeneous unconfined Aquifer. We assumed different areas around the pumping well to search and understand the effective hydraulic conductivity (keff) in an heterogeneous unconfined Aquifer and to know what the keff means for any configuration of observation wells, the area impacted, and ways to minimize estimation error. By change the location or increasing the number of observation wells, the influence of the heterogeneity on evaluation of pumping test will be first studied. The geostatistical methods will be used to generate the spatial distribution of K-value in the field .The spatial distribution of k-values is generally log-normal distribution The most important parameters of the variogram are the sill and range. These two parameters will be varied to investigate their influence on the evaluation on pumping test.

The investigated field is divided to cells (with rows and columns). The K-values in the field are generated by using the program HYDRO-GEN for different variances and integral scales. There are 999 Realizations for each case of variance (sill) and integral scale (range). The Modflow program is used to simulate the groundwater table after pumping for some pumping rate Q from the well and for some H. The results of drawdown for each realization are used to determine the K-Value through Dupuit-Equation by assuming different distribution of observation wells. This K-value is compared with the real K-value for some areas around the well and the standard deviation of the ratio (the calculated of K-value with Dupuit-Equation to generate K-value) for the 999 Realisations will calculated for each case and its distribution will be considered as error distribution.

The following questions will be investigated. What is the error distribution in every case? How can the accuracy of the evaluation of pumping test be improved upon with the distribution of observation wells (by increasing its number and their locations around the well)? How does the error distribution change when the investigated area is bigger than the area covered by the observation wells? To answer these questions in a heterogeneous aquifer, different configurations of observation wells around the pumping well will be considered and investigated. Finally the best location of observation wells which have the lowest error distribution will be selected for use. The influence of the variance (sill) and the integral scale (range) will be researched and analysed to all possible locations of observation wells.

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Pilot Study for a State-Based Ambient Groundwater Monitoring Program – Centralia-Chehalis Valley, Washington

Charles F. Pitz[1], Kirk Sinclair[2], Adam Oestreich[3]

In response to concerns regarding the absence of a state-level program to measure and describe ambient groundwater conditions, a pilot test of an assessment approach has been initiated in the Centralia-Chehalis area of Washington State. The program design being tested is intended to provide systematic, comparable procedures for the collection of baseline information about groundwater and hydrogeologic conditions at a basin or sub-basin scale. Conducting a pilot test will help evaluate and refine technical methods, and provide better estimates of the schedule, staff, and budget requirements of the approach.

The main objectives for the pilot study include:

- Characterization and description of the study area hydrogeologic setting through the assembly of existing and new information
- Monitoring and description of ambient groundwater water-level conditions
- Monitoring and description of ambient groundwater water-quality conditions
- Monitoring and description of groundwater/surface water interactions along the mainstem Chehalis River.

The assessment approach is focused on description (versus explanation) of current conditions. Since many of the most pressing groundwater related environmental or public drinking water health issues occur or begin near land-surface, monitoring and characterization efforts are concentrated primarily in the uppermost principal aquifer of the study area.

Field tasks undertaken to date include a dry-season seepage run and installation and monitoring of in-stream piezometers in the Chehalis River, inventory and monitoring of selected supply wells and upgradient facility monitoring wells, installation of a water-level transducer network, and installation and monitoring of new monitoring wells in key areas.

If successful, the assessment approach could be applied to study areas in other parts of the state where baseline groundwater data is missing and in high demand. The lessons learned during the pilot study will be instrumental in the state's decision whether or not to pursue and dedicate resources to a longer-term program.

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Measurement and Use of Streambed Temperatures to Quantify Stream/Groundwater Exchanges and Associated Nutrient Fluxes Within the Deschutes River and Percival Creek Watersheds, Thurston County, WA

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Section 303(d) of the federal Clean Water Act requires Washington to identify and list all surface waters in the State whose beneficial use(s) are impaired by pollutants. Water bodies on the "303(d) list" require the preparation of Total Maximum Daily Loads (TMDLs) to identify and quantify impairment sources and to recommend strategies for reducing point and non-point source loads. The Deschutes River and Percival Creek were included on the 1996 and 1998 303(d) lists for temperature and other parameters. This study was undertaken, as part of a larger TMDL investigation of the Deschutes River watershed, to gain a better understanding of the role(s) that groundwater and hyporheic exchange processes play in mitigating and/or exacerbating the impairment of listed surface waters.

Twenty three in-stream piezometers were deployed for this study of which eighteen were installed along the main-stem Deschutes River and five along Percival Creek. Each piezometer was instrumented with recording thermistors for twice-hourly monitoring of groundwater temperatures at three different depths up to 1.5 meters below the stream bed. The piezometers were accessed monthly, from July 2003 and September 2004, to measure vertical hydraulic gradients between the stream and near-surface groundwater. Piezometers located in areas of groundwater discharge were sampled monthly during summer 2004 to evaluate near-stream-groundwater nutrient concentrations.

The thermal profile and vertical hydraulic gradient data for each piezometer were subsequently input to VS2DH (USGS public domain software), to derive surface water/groundwater flux estimates via one-dimensional fluid flow and energy-transport modeling. The simulated fluxes from VS2DH were then combined with the measured nutrient concentrations from sampled piezometers to estimate nutrient mass loads to surface water from groundwater at each piezometer site. These discrete point flux and mass load estimates will serve as inputs to the broader TMDL effort which seeks to develop one-dimensional (QUAL2K) water quality models for the Deschutes River and Percival Creek.

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Evaluating Recharge Parameter Sensitivities in the Precipitation-Runoff Modeling System

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Ground-water recharge estimation methods vary from extremely complex to relatively simple. Results from the most commonly used methods, however, are limited by the scale of application. The methods either measure recharge at a point or site scale and must be extrapolated to a larger area, or they measure a large area without an effective means to scale down to a local area. Another method to estimate ground-water recharge is to use process-based models that compute distributed water budgets on a watershed scale. To date, these models have not been evaluated to determine which model parameters are the dominant controls in determining ground-water recharge.

The Precipitation-Runoff Modeling System (PRMS) is a process-based, deterministic, distributed-parameter modeling system designed to analyze the effects of precipitation, climate, and land use on streamflow and general basin hydrology. PRMS computes water movement through a series of reservoirs, including a ground-water recharge zone. Estimated recharge from PRMS reflects the net effect of precipitation, surface runoff, evapotranspiration, and ground water released from storage and can be considered an “effective” recharge rate. An understanding of the watershed-model parameters that control recharge estimates will help hydrologists focus on the compilation of the most relevant data in studies of regional ground-water recharge.

Existing watershed models from Washington State were examined for this study. Parameter sensitivities were determined using a nonlinear regression computer program to generate a suite of diagnostic statistics. Those statistics measure the amount of information provided by the data. This evaluation identified the model parameters that were most important for determining ground-water recharge and examined the appropriateness of watershed-model-derived recharge estimates for incorporation into a regional ground-water model.

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Estimated Domestic, Irrigation, and Industrial Water Use in Washington, 1985, 1990, 1995, and 2000

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Water use in the State of Washington has evolved in the past century from meager domestic and stock water needs to the current complex requirements for public-water supplies, large irrigation projects, industrial plants and numerous other uses. Water-use data are of considerable importance in determining water availability, allocating irrigation water, locating sources of pollution, and numerous other resource-management decisions. This series of four posters presents state and regional estimates of the amount of ground water and surface water used for public supply, domestic, irrigation, and industrial purposes in the State of Washington during the years 1985, 1990, 1995, and 2000.

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Quaternary Geology of the Lower Elwha River Valley, Clallum County, Washington

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The U.S. Bureau of Reclamation's Elwha River Ecosystem and Fisheries Restoration Project includes the removal of the Elwha and Glines Canyon Dams from the Elwha River near Port Angeles, Washington. As part of this project, URS completed a groundwater resource evaluation of the lower Elwha River to investigate the quantity of groundwater available as part of an assessment of water supply alternatives to mitigate water quality and quantity impacts associated with removal of the dams.

The Elwha River is currently a water source for the City of Port Angeles municipal water system, the Lower Elwha Klallam Tribe Fish Hatchery, the Washington State Department of Fish and Wildlife Rearing Channel, and the Daishowa Paper Manufacturing Company. Maximum water demand for these users is approximately 90 cubic feet per second. The hydrogeologic data obtained by this study was used to evaluate the availability of groundwater to provide this water demand and alternative groundwater intake structures as potential components of a modified water supply system for the users.

The initial study consisted of existing data compilation and evaluation, geologic mapping, and an electrical resistivity imaging survey to identify potential target areas for subsurface exploration. Based on the initial study, exploratory borings and observation wells were installed to further assess the subsurface stratigraphy. Aquifer test wells and piezometers were installed based on the surface and subsurface exploration results, and aquifer pumping tests were conducted. The data was analyzed and interpreted with respect to the project objectives.

The geologic map of the study area was completed and geologic cross sections were based on selected existing wells, new borings and wells. Several notable features include: changes in alluvial stratigraphy across the middle sub-basin and the Lower Elwha fault suggesting Quaternary displacement on the fault, a deep paleo-channel in the middle sub-basin, and a possible paleo-shoreline in the lower sub-basin.

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Using Emerging GIS and Database Technologies to Develop and Manage Large Datasets and Geographic Information for a National-Scale Ground-Water Quality Study

Frank Voss

Emerging Geographic Information Systems (GIS) and database technologies are being implemented to develop and manage data and geographic information for the National Water Quality Assessment (NAWQA) program Ground-Water Trends project. The project's long-term goals are to describe changes in the quality of the Nation's ground-water resources over time and to provide a sound, scientific understanding of the primary natural and human factors contributing to these changes.

An object-oriented geodatabase data model was adopted for developing and merging large geographic and tabular datasets from multiple sources and in various vector, raster, and tabular formats into a single relational database. The geodatabase data model was implemented using ESRI's ArcGIS (Version 9.0) and ArcSDE software and Microsoft's Structured Query Language (SQL) Server relational database.

New capabilities for geographic data development (such as defining geographic feature relationships, setting attribute domains and default values, setting validation rules, and assigning behaviors) were implemented using geodatabase data access objects (a subset of ArcObjects) programmed with Microsoft's Visual Basic for Applications (VBA) and C#.NET programming environments.

Tabular data were manipulated using tools available in SQL Server Enterprise Manager. Tabular data were imported and exported using Microsoft's Data Transformation Services (DTS). Complex queries of data, data analysis, and report generation were done using SQL applications developed in SQL Query Analyzer.

The unified GIS/database developed for the Ground-Water Trends Project provides a flexible and dynamic system for scientific data exploration of large and complex datasets.

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Hydrologic Investigation and Ground-Water Flow Model of the Rathdrum-Spokane Aquifer, Kootenai County, Idaho and Spokane County, Washington

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The Rathdrum-Spokane aquifer is the sole source of drinking water for over 400,000 residents in Spokane County, Washington, and Kootenai County, 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 potential 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 State Department of Ecology, Idaho Department of Water Resources, and U.S. Geological Survey are conducting a joint investigation of the Rathdrum-Spokane aquifer to develop a comprehensive data set that will provide an improved scientific basis for ground- and surface-water management. The study will include the construction of a numerical ground-water model to support the conjunctive management of ground and surface water resources. Application of the numerical model to evaluate water resource management strategies will occur as a cooperative effort between Washington and Idaho water resource managers.

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Forecasting Runoff in Watersheds with Seasonally Frozen Soils

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Peak snowmelt and rainfall runoff into Potholes Reservoir in Grant County, Washington, is strongly affected by seasonally frozen soils. When soils are fully frozen, snowmelt and rainfall cannot infiltrate. In the case of partially frozen soils, infiltration is greatly reduced. The reduced field capacity and infiltration rate of fully or partially frozen soil profiles affect the volume and timing of surface runoff and ground-water recharge.

A previously developed frozen soils module that simulates heat and water transfer in soils was incorporated into a spatially distributed hydrologic model compiled with the U.S. Geological Survey's (USGS) Modular Modeling System (MMS). The module was originally developed by the USGS in 1994 to simulate frozen soils conditions in North Dakota. The module allows simulation of multiple frozen and thawed layers, tracks depths of freezing, thawing and other soil-profile characteristics, and computes surface runoff, water available for ground-water recharge, and evapotranspiration from the soil profile. Simulated runoff into Potholes Reservoir is improved with the use of the frozen soils module.

Incorporation of the frozen soils module into MMS is part of the Watershed and River System Management Program (WARSMP), a collaborative effort between the USGS and the U.S. Bureau of Reclamation (USBR). Under this program, the USGS develops hydrologic forecast tools that the USBR incorporates into river-management models to efficiently distribute water to lakes, reservoirs, and irrigators for growing crops. A calibrated version of the hydrologic model that includes the frozen soils module will be used by the USBR to forecast the unregulated flows that serve as input into a river-management model, RiverWare, used to optimize reservoir operations in the Columbia Basin Irrigation Project.

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Use of Calibration Curves to Improve Low Velocity Measurements with the Swoffer Current Meter

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The Swoffer Model 3000 Current Meter is in common use for stream flow measurements in Washington. Field-friendly instrument features include mechanical durability, ease of use, and electronic logging capability. However, the low velocity performance, especially important for measurements in low gradient streams, has been criticized. The accuracy of flow measurements at lower velocities (< 1 foot per second [fps]) may be substantially improved by use of a calibration curve.

Three propeller assemblies were tested by manual traverses through a water filled test trough at multiple velocities. The sensor output, or pitch, was recorded at each velocity. The pitch versus velocity data were found to fit exponential response curves. Pitch was linear with velocity above 1.5 fps, but about 5% low at 0.67 fps. Below 0.25 fps, pitch values dropped rapidly with only small decreases in velocity.

The observed system performance indicates (1) that individual calibration curves should be used for each specific propeller assembly in order to correct stream flow data where velocities are less than 1 fps and (2) that care should be used in interpreting data for velocities less than 0.25 fps.

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Investigations into the Cause of a Sinkhole in Jubilee Lake

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In past decades many earth-fill dams were constructed to create reservoirs for maintaining in-stream flows during dry summer months and for recreation purposes. Use of porous media in dam construction allows for seepage by design. However, excessive seepage through preferential flow channels can significantly deplete water storage, cause migration of fine-grained soils, and possibly result in dam failure.

A sinkhole was noted in July 2004 near the edge of Jubilee Lake in Union County, Oregon, approximately 800 feet above a dam built on Motet Creek. Concern from U.S. Forest Service managers led to a group of engineers and geologists assessing the structural stability of the dam. While the dam was viewed as stable, significant seepage was noted near the downstream side of the dam. As part of long term monitoring of dam stability, it was suggested that more study be put into the cause of the sinkhole.

There is a predominance of basaltic rocks in the region with potential conduits formed by trapped gas during cooling or through weathering processes. Thus, the primary hypothesis to the cause of the sinkhole was fines migration through preferential flow paths. Study of the sinkhole included characterization through visual observation from a surface diver and underwater videoing, measurement of water quality parameters, and seepage estimates for both the lake silts (using temperature) and within the sinkhole (using a dye tracer).

Visible stratigraphy in the sinkhole included a surficial, fine-sediment layer less than a foot in depth, approximately eight feet of unconsolidated sediments (silt through cobbles) with no distinct layering, underlain by weathered basalt. Initial surface diving in August suggested the sinkhole was 15 feet deep, however, further collapse of surface material rendered the sinkhole 6 to 10 feet deep by October. Water quality measurements indicated little differentiation between the lake profile and the sinkhole for temperature measurements, and pH measurements were consistently between 7.6 and 7.8. Seepage from the tracer dye injection stayed in the bottom of the sinkhole and appeared to advect out of view during videoing. Seepage rates observed for the dye were two orders of magnitude faster than through the silts, suggesting that velocities are fast enough to carry silts from the sinkhole site to another location through a preferential underground flow channel.

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Simulating Runoff in Two Basins in the Lake Whatcom Watershed, Whatcom County, Washington Using a Distributed Hydrology Model

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Lake Whatcom watershed occupies 36,270 hectares in the North Cascades foothills just east of Bellingham, WA. About 80% of the watershed is forestlands with pockets of urban development. Lake Whatcom is a 2,040 hectare lake in the watershed that provides drinking water for nearly 90,000 people. The objective of water managers is to preserve the lake as source of drinking water while the watershed continues to undergo urban development and logging. Our goal is to calibrate the Distributed Hydrology-Soils-Vegetation Model (DHSVM) to Austin and Smith Creek basins in the watershed to predict streamflow to the lake.

DHSVM is a physically based, distributed hydrologic model that simulates a water and energy balance at the scale of a digital elevation model (DEM). The inputs required by DHSVM are GIS grids of the topography, watershed area, soils, and vegetation. USGS 10 meter DEMs provided the topography of the watershed. The soil grid was created from the CONUS soil database, which is formatted specifically for climate and hydrologic modeling. The USGS National Land Cover classification grid was used to define the vegetation. Required meteorological inputs include precipitation, air temperature, humidity, wind speed, and radiation data.

The model was calibrated using two water years of streamflow data from gauged steams near the outlets of each basin, and meteorological data from a weather station near the two basins. Hydrologic conditions were simulated using one-hour time steps. We began the calibration process by first altering the precipitation lapse rates in DHSVM to adequately distribute rainfall throughout the basins, and to capture the timing of the recorded peak flows. Soil parameters were then adjusted for the basins to properly simulate measured baseflows. The error between the recorded and simulated yearly discharge volumes for the Austin and Smith Creek basins, were -8% and -3%, respectively.

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Investigation of Mine-Related Impacts at an Abandoned Lode Mine in Western Oregon

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An investigation was performed at the Champion Mine site, located in Umpqua National Forest, near Cottage Grove, Oregon. The work was performed to determine if the site poses a threat to human or ecological receptors. The site is located in the Cascade Range, on steep slopes at an average elevation of about 4,500 feet. Beginning in 1892, Champion Mine produced gold, with lesser quantities of silver, copper, lead, and zinc. The currently inactive mine site consists of two adits, two settling ponds, several large waste rock and tailings piles, a former mill location, and miscellaneous debris.

Underground workings at the mine include more than 15,000 feet of drifts and crosscuts and about 3,000 feet of raises on 9 levels. Groundwater from the flooded workings discharges through both adits. Water from the lower adit flows into the settling ponds. At the time of the field investigation, the ponds discharged primarily via seeps at the base of the pond berms. Water from the seeps, along with shallow groundwater discharges, forms several small drainages, which converge to form the headwaters of Champion Creek.

Field investigation activities included collection and analysis of soil, waste rock, tailings, surface water, stream pore water, sediment, plant tissue, and benthic macroinvertebrate samples. The pH of the mine discharge was neutral at the main adit but acidic at the upper adit and in several groundwater seeps; elevated metals concentrations were also detected in these samples. Low pH and significantly elevated metals concentrations were found in many of the waste rock and tailings samples.

Champion Creek surface water, pore water, and sediment quality, as well as benthic macroinvertebrate populations, were all significantly impacted in the mine area, as compared to similar creeks in the area. Contaminant sources included groundwater and surface water discharges, and erosion of fine-grained waste materials from the site. Downstream sampling locations were used to evaluate the extent of impacts to the creek.

Current and planned activities include performance of an Engineering Evaluation/Cost Analysis (EE/CA) to further assess risks to human and ecological receptors and to evaluate potential remediation technologies.

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Applicability of the NLOS Model for Predictions of Soil Water Movement and Nitrogen Transport in an Agricultural Soil, Agassiz, BC

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The fate and transport of nitrogen in an agricultural soil is being examined with the NLEAP on STELLA (NLOS) leaching model. NLOS is an adaptation of the Nitrogen Leaching and Economic Analysis Package (NLEAP) model. Currently, conservation managers rely on Post Harvest Soil Nitrate Tests to predict nitrate leaching potential. However, these tests provide only a limited and unreliable measure of annual nitrogen input to the aquifer. Therefore, United States and Canadian government agencies are considering NLOS as an additional tool for assessing the influence of nutrient management strategies on nitrate leaching to the Abbotsford-Sumas aquifer in northern Whatcom County, Washington and southern British Columbia, Canada.

NLOS incorporates fertilizer application events, climatic data, and soil properties, to simulate the fate of water and nitrogen. Historical and newly collected field data from a trial of silage corn located at the Pacific Agri-Foods Research Centre in Agassiz, BC are being used to calibrate the model. Current sampling (May 2004 -April 2005) includes soil, soil pore water, nitrous oxide emissions, and ground-water chemistry parameters. The field soil (a silt loam) has been subjected to a nutrient loading and crop management scenario comparable to regional farming practices. Although the model is being calibrated in Agassiz, BC, we expect that NLOS will perform similarly in the Abbotsford-Sumas aquifer due to similar soil types and climatic conditions.

NLOS will be validated against a subset of the field data excluded from the calibration dataset. The steady-state soil water sub-model's ability to predict water and nitrate transport during seasonal precipitation events will be examined by comparing simulations to monthly field data. In addition, a second model which incorporates both steady-state and transient flow and transport, the Leaching Estimation and Chemistry Model (LEACHM), will be calibrated and validated in order to evaluate the relative predictive ability of the two models. Because most nitrate leaching occurs in nearly saturated soils during the winter, we hypothesize that the steady-state flow module in NLOS will be sufficient for predictive purposes. Our results will provide insight into regional controls on the fate of water and nitrogen in an agricultural soil and the applicability of NLOS for nutrient management.

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Use of Automated Downhole Groundwater Monitoring to Characterize Post-Redevelopment Conditions in a Tidally Influenced Aquifer System Port of Seattle Southwest Harbor Project

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The Port of Seattle's Southwest Harbor Redevelopment Project (SWHP) site was historically used for landfilling, wood treatment, steel processing, and ship building. The SWHP site underwent coordinated remediation and redevelopment in the late 1990s, and is currently a state-of-the-art shipping terminal. The primary objective for remedial actions completed concurrent with the SWHP redevelopment was future protection of surface water quality in Elliott Bay. Automated downhole groundwater monitoring systems were installed at the SWHP site in order to collect sufficient water level and water quality data to confirm predicted post-redevelopment conditions in the tidally influenced Fill and Estuarine Aquifers.

The post-redevelopment SWHP monitoring program includes an initial two-year, post-redevelopment hydrologic characterization phase, followed up by a water quality compliance monitoring phase. Specific goals of hydrologic characterization phase included:

- Documenting reduced recharge to Fill and Estuarine Aquifers;
- Confirming reduction in downward vertical gradient;
- Confirming reduced discharge to Elliott Bay and the Duwamish River;
- Confirming reduced reduction in leachate production from a capped landfill; and,
- Documenting the effect of tightlining the Longfellow Creek Overflow Line (LFOL) on the Fill Aquifer groundwater flow system;

To meet the hydrologic characterization phase goals, downhole water level/water quality monitoring systems were deployed in 21 wells, and two years of continuous water level, conductivity, temperature, and pH data were collected. The downhole automated systems proved to be a very cost-effective approach to collecting the high-resolution data necessary to characterize the tidally influenced aquifer systems at the SWHP site. Major post-redevelopment changes in Fill Aquifer behavior were documented, particularly in the areas of the capped landfill and tightlined LFOL storm water line. Goals for the hydrologic characterization phase were met, and evaluation of site groundwater quality in relation to surface water standards is currently underway.

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Dye Trace Study Results Used for Estimating Hydraulic Conductivity and Rock Avalanche Debris Stability Along Washington SR 20

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On November 9, 2003 a rock slope failure along Washington SR 20 east of Newhalem at approximately Milepost 121.5 released approximately 1 million cubic yards of rock, forcing closure of the highway. The majority of the rock avalanche debris was deposited in the Afternoon Creek drainage. One of the initial concerns was the potential for remobilization of the Afternoon Creek debris, possibly blocking the Skagit River channel. A stability analysis was conducted to assess the potential for remobilization. Potential groundwater conditions required to evaluate stability included groundwater elevations within the rock avalanche debris and hydraulic conductivity of the debris and underlying alluvial fan. A dye trace study was used to estimate hydraulic conductivity of the rock avalanche debris and underlying alluvial fan.

Two different dyes were introduced into Afternoon Creek, one near the top of the debris mass and the other at a waterfall near the toe of the avalanche debris. The different dye injection points allowed for analysis of hydrologic conditions within the slide debris versus within the alluvial fan. Arrival times for the two dyes at sample locations along the Skagit River, coupled with site geometry, indicated values for hydraulic conductivity in the rock avalanche debris ranged from 1.65×10^{0} cm/sec to 4.11×10^{-1} cm/sec while the values for the alluvial deposits ranged from 1.08 10^{0} cm/sec to 6.08×10^{-1} cm/sec. These values are typical of a gravelly sand to sand deposit (Fetter, 1994). Exposures of the alluvial deposits consist of boulders in a sandy gravel to gravelly sand deposit.

The degree of saturation calculated using Darcy's Law, estimated site geometries, predicted runoff for a 100-year storm event, and the calculated hydraulic conductivities ranged from 40 to 70 percent. These values were used as part of an infinite slope model to assess global stability of the rock avalanche debris. The results of this analysis indicated that the debris was marginally stable.

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A Clear View of How Ground Water and Surface Water Are Linked - A Bench-Scale Model

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Many teachers in Washington State teach their students about streams and water quality. They take their students to streams and lakes and perform tests for pH, dissolved oxygen, turbidity, temperature and other parameters. The connection between ground water and surface water may be taught also, but it is somewhat difficult to make the connection real for students, since ground water is underground and harder to access.

Hydrogeologists have written numerous papers and materials on how ground water and surface water interact. Computer models show how surface water and ground water interrelate as a single resource. Hydrogeologists have standard methods to test for ground water/surface water interactions in the field. These resources can be difficult to access and apply in the classroom. However, some of the field tests can be replicated by a bench model.

We propose to build an inexpensive model out of clear containers that would show the interaction between water that is in the ground and water that is in streams.

The model will have two aquifers and a stream, each in see-through containers. The stream will be more linear (sawn clear pipe). We will use tubing to create a hydraulic connection between the aquifers and the stream. A platform with shelves will be built so that the “aquifers” may be moved higher or lower relative to the stream and each other.

We will dose an aquifer placed higher than the stream with an acid (vinegar) or a base (baking soda) and test the stream with a pH meter so we can see the effect on the stream. We will dose the stream with the aquifer placed lower in a similar method. We could also use salt or another non-toxic dissolved substance. The aquifer will have a “well” in it for testing. We will also demonstrate the connection between two aquifers that have different hydraulic head using the same method. We will be able to show a downward vertical gradient and an upward vertical gradient.

The bench model will be used in the classroom and for public education. We hope that this collaboration between a teacher and a hydrogeologist can provide both of us with a tool to educate the public about how groundwater and surface water work. Ground water and surface water really are a single resource.

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Update on the Use of Buried and Submerged Forests to Date and Characterize Geologically Recent Landscape Disturbances in Washington

Patrick T. Pringle

Use of radiocarbon dating and dendrochronology to study buried and submerged forests can provide valuable clues to the history and impacts of postglacial volcanism, fault movements, landslides, and flooding. Volcanic disturbances buried extensive riverine landscapes downstream of volcanoes and likely destroyed and/or severely disrupted pre-Euro-American-settlement human communities on floodplains. Lahars (volcanic debris flows) and laharic flooding that severely and repeatedly aggraded the Nisqually, Puyallup, White, Skagit, Duwamish, Stilliquamish, and Nooksack Rivers also caused delta progradation that dramatically altered the coastline of the Puget Lowland. Extremely large volcanic events triggered stream piracy in the Stillaguamish/ Skagit River, Fraser/Nooksack, and White/Puyallup River systems.

Submerged sites along coastal Washington, in Puget Sound, in the Columbia River, and in lakes (most landslide-dammed) contain subfossil snags that record the timing of geologic events including paleo-earthquakes. The ages of more than 28 landslides have been estimated by radiocarbon dating of associated subfossil wood or by tephrochronology. However, fewer than 25 percent of these allow constraint of the calendric age of tree mortality, and more sampling will be required to obtain outer wood. Additional tree-bearing lakes have been discovered but not sampled, and more than two dozen candidate sites lack reconnaissance. Many likely record paleo-earthquakes.

Studies of submerged forests in south Puget Sound (e.g. Sherrod, 2001) and in areas of northern Puget Sound by various researchers suggest multiple episodes of abrupt local tectonic subsidence related to shallow crustal faults.

Combined use of radiocarbon ‘wiggle matching’ and dendrochronology on subfossil trees can dramatically improve the quality and accuracy of radiocarbon ages, allow correlations among sites, and precisely date episodic hydrogeologic events, thus greatly improving our understanding of the character, magnitude, and frequency of the associated landscape disturbances. This emerging history of past volcanism, tectonism, and episodic mass wasting, and the inevitability of future eruptions and earthquakes, have profound implications for landscape change in Washington’s river valleys and coastal environments. While this recent geologic history carries a wide spectrum of hazards-related concerns that relate to aquifers, ecologic systems (including human), seismicity, land use, and future risk, ongoing science and communication efforts to better understand it have been hampered at many levels by budget shortfalls.

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Simulation of the Saltwater Interface along Southern Puget Sound Shorelines, Pierce County, Washington

Linton Wildrick and Russ Prior

One or more high-yield wells near the mouth of Chambers Creek and adjacent to Puget Sound, in Pierce County, Washington, will withdraw up to 1,810 gallons per minute, continuously, from a confined aquifer at depths greater than 600 feet below sea level. The resulting reduction in groundwater discharge to Puget Sound and decline in head may cause the saltwater interface to shift downward toward, or into, the deep aquifer. We used a numerical model for groundwater flow and solute transport, SEAWAT2000 (Guo and Langevin, 2002), to estimate the approximate distance of interface movement when the well field is pumped. This model is an offshoot of the well known groundwater models MODFLOW 2000 and MT3DMS. The regional-scale model domain includes the Tacoma-Fort Lewis upland, several islands, and the southern ends of the Gig Harbor and Longbranch Peninsulas, an area of approximately 1,070 square miles (29 mi by 37 mi). The model domain is bounded mostly by surface-water features, including the Puyallup and Nisqually Rivers, Ohop Creek, and Puget Sound. To make the model development feasible, within our budget limitations, we kept its contents as simple as possible. The complex of geologic units in the modeled area was simplified into three hydrogeologic units – an unconfined aquifer that extends from land surface to 200 feet below sea level, an aquitard that extends from 200 to 600 feet below sea level, and a confined aquifer (Unit G) that extends from 600 to 1,000 feet below sea level. Although the permeability and story properties of the actual units are complex, we represented only their average values. Puget Sound is represented as a saltwater-filled valley that was eroded into the unconfined aquifer and, some places, into the underlying aquitard, depending on the bathymetry. The model simulation indicates large head changes in the source aquifer, but very little change in the estimated position of the saltwater interface. The simplification appears to be adequate for large-scale approximation of the groundwater flow system and seawater intrusion assessment, although local details probably are not accurate.

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Aquifer Susceptibility Mapping of Vashon - Maury Island, King Co., Washington

Kathy G Troost.[1],Kenneth H. Johnson[2], Derek B. Booth[1], Sarah Ogier[2], and Aaron P. Wisher[1]

In an effort to protect its groundwater resources under the state Growth Management Act, King County has mapped its Critical Aquifer Recharge Areas (CARA) and has developed regulations to prevent contamination in the CARA. This mapping was based on a combination of where contamination could most easily reach the aquifer (susceptibility to groundwater contamination) and areas where the groundwater resource is of greatest concern (well head protection areas and sole source aquifers). The CARA used data and methodology for susceptibility that were originally developed in 1995, incorporating geology, depth to groundwater, and soil type in the evaluation.

In a pilot study to use new information and new technology for this susceptibility, King County teamed with the University of Washington to develop an objective scientific methodology for evaluating susceptibility. Vashon-Maury Island (VMI) was chosen as the site of this pilot effort because it is an island within King County surrounded by Puget Sound, an EPA-designated Sole Source Aquifer, and the subject of a Water Resource Evaluation by King County Department of Natural Resources and Parks.

An aquifer susceptibility map of VMI was produced based on new geologic mapping of the island and a geologic database of groundwater and subsurface data from approximately 900 water wells and borings. The new map replaces an older aquifer susceptibility map that was developed using twenty-year-old geologic mapping made with traditional methods. Queries of the database provided spatial information regarding surface and near-surface geologic materials, depth to groundwater, and whether the groundwater was confined or unconfined. Depth to water was determined using data from drillers' logs. In areas where drillers' logs were insufficient to show shallow water levels, a shallow aquifer was assumed to be present at the mapped base of the Vashon Advance Outwash (Qva) unit. This assumption was considered to be a more inclusive and conservative approach for delineating the CARA. LIDAR topography, aerial photography, old and new field mapping data, cultural features, and the geo-database were used to inform the geologic mapping.

The new aquifer susceptibility map shows substantially more detail, and has demonstrably greater accuracy, than the old map. Some changes are revealed between the new and old maps: for example, 12% more land area is now mapped as "low" or "medium" susceptibility rather than the "high" susceptibility it was rated before.

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Is New, Detailed, 1:12,000-Scale Geologic Mapping Worth the Cost? Hydrogeologic Applications of a Geologic Database of the Seattle Area, Washington

Kathy G. Troost.,Derek B.Booth, D.B.,S. A. Shimel, Aaron P. Wisher, and M. A. O'Nea

Multi-agency collaboration and funding have supported the building of a database of subsurface geologic data, the preparation of over 20 new geologic maps, and many new derivative maps. Originally built to prepare a detailed geologic map of the City of Seattle and to hold the base geologic data for evaluating geologic hazards, the database has far exceeded these original expectations, now containing details of more than 66,000 explorations and expanding in geographic coverage.

Geologic maps and borehole data are available to partners on agency intranets via interactive programs, to the public over the Internet using ArcIMS, and to visitors using our computer lab. The new maps and geo-database provide information such as regional geologic context for subsequent site-specific investigations, quick cross section construction, information about the extent of fill, thickness of geologic layers, rapid scanning for specific geologic settings, and depth to groundwater.

Derivative maps are facilitating planning, research, and outreach to a greatly expanded user population. For example, digital geologic maps can be easily recast and queries made of the geo-database to emphasize features: 1) potentially infiltrative soils and 2) the depth to glacially overridden material. The new geologic map yields twice the land area with high infiltration potential and more widely distributed, than was previously mapped in the City. This new map provides the critical base for evaluating concerns for stormwater runoff and contamination. The surface of glacially overridden materials, combined with the depth to bedrock and ground topography, allows easy creation of a simple but defensible seismic-velocity model of the Seattle area, now being used to generate earthquake ground-motion models and to evaluate liquefaction potential in greater detail than ever before. Both maps have multiple applications and users.

Through collaboration with this mapping project, hundreds of planners and engineers are being kept abreast of current research and geologic findings. Yet costs are substantial: a detailed, digital, USGS-published 7.5' geologic quadrangle map based on new field work and a subsurface database averages $250k at 1:24,000 scale and about twice that amount at 1:12,000 scale. Derivative maps are not nearly as expensive as the acquisition and interpretation of the underlying geologic data, but they too add an incremental expense; being only as good as their base maps. How can we quantify the benefits to our profession of having better geologic data and better educated clients to work with? Ultimately, are these new geologic products worth their cost?

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