7th Washington Hydrogeology Symposium

POSTERS

April 28, 4:00 – 5:30 PM

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Data Access via Web Services; The New Alphabet Soup of Data Sharing

John E. Tooley[1]

The National Environmental Information Exchange Network, a joint venture of the Environmental Council of States and the U.S. Environmental Protection Agency, has provided a set of data-sharing standards and services which allow data exchange across boundaries, both geographic and institutional. The 'Exchange Network' is a standards-based collection of internet protocols such as eXtensible Markup Language (XML), Hypertext Transport Protocol (HTTP), web services, and Simple Object Access Protocol (SOAP). This alphabet soup of technologies provides a vendor-agnostic approach to share data and allows these data to be mixed in a number of imaginative ways.

The USGS has recently joined the Exchange Network party by adding Web Services to publish data from the National Water Information System (NWIS). Water-Quality data are now available using the same data standards and parameter vocabulary as EPA. At last we can access data from USGS, EPA, and several state and tribal governments using the same protocols, vocabulary, and access technology.

Consumers of these data are free to construct interfaces, analytical tools, and models based on these services, and are encouraged to be innovative. This poster illustrates how the services connect together, and shows how data users will be able to take advantage of these innovations.

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Modifications to DPM—A Deep Percolation Model for Estimating Ground-Water Recharge

John J. Vaccaro[1] and Marijke van Heeswijk[2]

The Deep Percolation Model (DPM) is a daily water-budget model developed by the U.S. Geological Survey for estimating ground-water recharge from precipitation and irrigation. Recharge is defined as the amount of water leaving either the active root zone (deep percolation) or, in the case of bare soils such as sand dunes, the mapped depth of the soil column. DPM is designed to create independent estimates of ground-water recharge for ground-water flow models and can be used at scales ranging from field plots to large regions with variations in climatic, soil, land-use, and land-cover conditions.

DPM Version 1 was released in 1987 and Version 2 was released in 1997. Version 2 eliminated the requirement for a quadrilateral model-grid system and allowed for soils in the root or soil zone to saturate. In addition, the method used to calculate surface runoff was changed to a combination of an approximation of Darcy flow for saturated soils and saturation excess, and the Priestly-Taylor potential evapotranspiration method was added for non-agricultural land-use/land-cover options. Agricultural land-use/land-cover options continued to use the original Jensen-Haise method of DPM Version 1. A revision to DPM Version 2 incorporated after 1997 included the option of specifying time-varying saturated vertical hydraulic conductivities—the limiting infiltration rate below the root zone.

DPM Version 3.0 was released in 2008 and enhances Version 2 by making it consistent with a modularized version of DPM released in 2007 that is included in the U.S. Geological Survey's Modular Modeling System (MMS). Revisions include the addition of new land-use/land-cover options, the simulation of snowmelt during rain-on-snow conditions as a function of wind speed, the estimation of incoming solar radiation if no solar radiation data are available, the option of applying irrigation above or below the vegetation canopy, the option of distributing precipitation areally using monthly instead of annual weighting factors, reading input and output file names externally to the program, and sizing arrays so it is less likely that users will need to recompile the program. DPM Version 3.0 is backward compatible with datasets created for Version 2. DPM Version 3.0 may be downloaded from *http://wa.water.usgs.gov/dpm* and the equivalent MMS version of DPM may be downloaded from links provided in *http://pubs.usgs.gov/sir/2006/5318/pdf/sir20065318.pdf.*

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Hydrologic and Thermal Conditions of the Eastbank Aquifer System near Rocky Reach Dam, Douglas County, Washington

Marijke van Heeswijk[1] *and Stephen E. Cox*[2]

The Lower and Combined Aquifers of the Eastbank Aquifer system, located in a river-terrace deposit along the Columbia River near Rocky Reach Dam, Washington are primarily recharged by the Columbia River and provide water to a salmonids hatchery and a regional water system servicing the cities of Wenatchee, East Wenatchee, and parts of unincorporated Chelan and Douglas Counties. In 2006, mean annual pumpage by the hatchery and regional water system was about 43 and 16 cubic feet per second, respectively. Successful hatchery fish production needs cool water and concerns over possibly increasing ground-water temperatures prompted an analysis of hourly ground-water and river temperatures measured by the Chelan County PUD from January 1991 through August 2007. The results indicate increasing interannual trends in temperatures in most of the Lower and Combined Aquifers from 1999 through 2006 that correspond to increasing trends in the annual mean and annual maximum river temperatures during the same period of 0.07 and 0.17°C per year, respectively, which are within the natural variability of the river temperatures. There were no trends in the annual minimum river temperatures during the same period, and there were no trends in the annual minimum, mean, and maximum river temperatures from 1991 through 1998 and from 1991 through 2007. Because most of the Lower and Combined Aquifers reached thermal equilibrium—defined by constant time lags between changes in river temperatures and subsequent changes in ground-water temperatures—prior to 1999 and seasonal pumpage patterns were relatively stable from 1999 through 2006, increasing interannual trends in ground-water temperatures are most likely explained by increasing trends in river temperatures.

Analyses of water-level data collected on July 18, 2007 and dissolved-constituent and bacterial concentrations in samples collected August 20–22, 2007 showed that most of the water pumped by the hatchery recharges along the river at the generally shortest distance between the hatchery well field and the river. In addition, analyses of the historical ground-water temperature data showed that at historical pumping rates, water pumped by the hatchery recharged about two months prior to the time it was pumped from the aquifer.

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The Effects of Timber Harvest on Watershed Hydrology Near Kalaloch, Olympic Peninsula, WA

Casey Hanell[1] and Robert Mitchell[2]

The effects of timber harvesting on canopy interception and evapotranspiration and hence soil and groundwater levels continue to be the subject of research throughout the Pacific Northwest because of their influence on slope stability. We used a combination of field measurements and numerical modeling to explore the affect of timber harvesting on runoff and groundwater levels in a moderately steep watershed (2 sq-km) located 6 km southeast of Kalaloch, WA on the coast of the Olympic peninsula.

Hourly water-levels were monitored with data loggers in 10 shallow piezometers for two years. Water-levels were correlated to precipitation data collected at three on-site rain gauges positioned under the tree canopy and open air precipitation measurements recorded at the Black Knob weather station 25 km south of the research site. In all 10 bores, rapid water level rise is observed and the strongest correlation between peak water levels and precipitation occurs within several hours after the onset of the event. The rapid water level rise may be the result of the capillary fringe extending to the ground surface. During a precipitation event, water held in tension becomes groundwater, rapidly saturating the soil column.

The Distributed Hydrology Soils Vegetation Model (DHSVM) predicts clear-cut timber harvest will result in a 10 percent reduction in evapotranspiration over the two year period from February 2005 through February 2007. The DHSVM predicts this 10 percent reduction in evapotranspiration will result in a 6 percent increase in streamflow and a 4 percent increase in soil moisture and groundwater recharge. These field and modeling results suggest that timber harvesting at this site will influence shallow soils to a higher degree than deeper aquifer systems that control the stability of deep-seated landslides.

Timber harvest at the research site began in the summer of 2008 and is still occurring at the time of this abstract submission. Following timber harvest, data collection will continue and will be compared to pre-harvest data and model predicted responses.

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Modeling the Effects of Land Use Practices on the Hydrology of Ebey's Prairie, Whidbey Island, Washington

Michael Larrabee[1] and Robert Mitchell[2]

Ebey's Prairie is a broad low terrace, approximately 6 km^2 in size, located within the Ebey's Landing National Historical Reserve on Whidbey Island, WA. The prairie, which is underlain by a complex sequence of glacial marine deposits, is primarily used for agricultural. In the mid-1900s, agricultural drainage tiles, drainage ditches and fill were installed by local landowners to increase tillable acreage. It is believed that these activities may have altered the runoff on the prairie, and subsequently aquifer recharge.

Little is known of the original surface and shallow groundwater movement within Ebey's Prairie. It is thought that the prairie was once bisected by a broad riparian corridor consisting of waterlogged soils, swampy areas, seasonal ponds, and intermittent flows, which likely contributed to aquifer recharge. However, modern surface water on the prairie is limited to a small marsh and seasonal creek. Although the local aquifer recharge is dependent on precipitation, the region receives less than 530 mm (21 in) of rain annually. Over-pumping of groundwater has resulted in salt water intrusion into coastal wells. As a result, there has been an increased interest in the historic hydrology of the prairie and its relationship to aquifer recharge.

Our research is using the Distributed Hydrology-Soil-Vegetation Model (DHSVM) to simulate the modern and historic surface hydrology of Ebey's Prairie and to quantify the effect of land-use practices on surface hydrologic conditions and aquifer recharge. A hydrologic model for the modern conditions is being created and calibrated to discharge measurements taken from a seasonal creek located in the prairie. We are using a combination of remote sensing imagery, soils data, oral interviews, historic photos, and geophysical techniques to develop a conceptual picture of the historic water features. These features will then be simulated in the calibrated DHSVM model and comparatively analyzed with simulations of the modern hydrology.

This project was initiated by the National Park Service in order to improve the understanding of the local water resources and subsequently assist with the management of the resource. Additionally, information learned from this project may be useful to the City of Coupeville, which is considering several storm-water management actions, including water impoundments in Ebey's Prairie.

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Ground Water Controls on Surface Water in Horseshoe Lake, King County, Washington

Jennifer Hilden Saltonstall[1], Curtis J. Koger[2], and Bridget August[3]

Horseshoe Lake is a small lake formed in a closed depression located in southeast King County with a history of dramatic surface water level fluctuation. Surface water flooding of surrounding residential property has occurred in 1991 and 1996, and most recently threatened in early 2007. Recent geologic and hydrogeologic subsurface exploration information, Horseshoe Lake surface water elevation data, and ground water elevation data from shallow and deeper aquifer intervals have been integrated to develop a conceptual hydrogeologic model of ground water – surface water interactions in the Horseshoe Lake subbasin. The Horseshoe Lake topographic depression was formed by meltwater erosion through low-permeability Vashon lodgement till deposits that separate overlying shallow Vashon recessional outwash ground water from deeper pre-Olympia ground water. The Horseshoe Lake depression is essentially a window into the underlying pre-Olympia aquifer. This conceptual hydrogeologic model is fundamentally different than previous ground water studies of the lake system, which modeled the lake system as perched above low-permeability Vashon lodgement till.

Water level monitoring data demonstrate Horseshoe Lake is not formed in a till-bottomed depression. Since the till is missing there is a direct hydraulic connection between Horseshoe Lake and deeper ground water, with Horseshoe Lake providing a source of recharge to the pre-Olympia aquifer. The surface water level in Horseshoe Lake generally mirrors the ground water levels in the deeper pre-Olympia aquifer; however, the Horseshoe Lake elevations are higher, indicating vertical flow from the lake into the pre-Olympia aquifer.

Based on ground water elevation data from multiple monitoring wells, ground water flow in the pre-Olympia aquifer interval is primarily toward the southwest, and flows to springs within Crisp Creek and along the northern wall of the Green River Valley.

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Determining Changes in Land Use and Land Cover in the Chamokane Creek Basin, Washington, Using Remote Sensing

Sonja Lin[1] and Sue Kahle[2]

Residential development in the Chamokane Creek basin, Stevens County, Washington, is expected to increase ground-water use and potentially affect streamflow in the basin. The U.S. Geological Survey is conducting a study in cooperation with the Bureau of Indian Affairs, the Spokane Tribe, and the Washington Department of Ecology to describe the ground- and surface-water system of the basin and to examine the potential effects of increased ground-water use on water resources in the basin.

Ground water that is exempt from State water-right permitting requirements is difficult to quantify. Remote sensing techniques can help identify and estimate current and historical exempt uses. Furthermore, changes in land use and land cover need to be incorporated into the conceptual model of the basin's ground- and surface-water system to accurately describe historical and current hydrologic conditions. Land use and land cover can influence components of the hydrologic system, such as recharge and evapotranspiration rates. Remote sensing and spatial statistics can be used to determine and analyze general land use patterns and land cover changes, as well as help estimate changes in exempt water use in the basin.

Water rights in the basin were adjudicated in 1979; therefore, we will use imagery from the late 1970s (exact year will depend on availability) as a benchmark to assess changes in land use and land cover from pre-adjudication to present. The basic components of this analysis include (1) data preparation, (2) data analysis, and (3) accuracy assessment.

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Estimated Crop Irrigation Water Use in the Pacific Northwest, 2005

Ron Lane[1]

Water use in the Pacific Northwest 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. Since 1950, the U.S. Geological Survey has, at five-year intervals, compiled and published estimates of the amount of water used for various purposes throughout the United States. In addition, water use reports for some individual states have been routinely published. However, because water-use and management decisions made in one state may affect water resources in adjacent states we must begin to examine and analyze water use at the regional level and not just at the state level. This poster presents the Crop Irrigation Water Use in the Pacific Northwest using data compiled and published by the States of Washington, Oregon, and Idaho for 2005. This single-water use category accounted for 80 percent of the total reported fresh water use in the Pacific Northwest during 2005.

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Hydrogeologic Framework in Tributary Subbasins of the Lower Skagit River, Skagit and Snohomish Counties, Washington

Mark Savoca[1] and Theresa Olsen [2]

Recent population growth along the Interstate Highway 5 corridor near Mt. Vernon, Washington has led to increased domestic water use, with many new wells serving residents concentrated in four tributary subbasins of the Skagit River. These subbasins include the East Fork and mainstem of Nookachamps Creek, Carpenter Creek, and Fisher Creek. Planning for future development in these subbasins requires an understanding of their ground-water resources and, in particular, how future ground-water use likely will affect streamflow in the tributaries. In June 2006, the U.S. Geological Survey (USGS) Washington Water Science Center, in cooperation with Skagit County and the Washington Department of Ecology (Ecology), began a project to characterize the ground- and surface-water flow system in the tributary subbasins, and to integrate this and other information into a numerical flow model. A hydrogeologic framework of the area was constructed as part of this study.

Geologic units in the study area record a complex history of accretion along the continental margin, mountain building, deposition of terrestrial and marine sediments, igneous intrusion, and the repeated advance and retreat of continental glaciers. Defining the extents and thicknesses of aquifers and confining beds within these geologic units was essential to understanding ground-water flow and movement of water between aquifers and nearby streams. Construction of the hydrogeologic framework began with the merging of existing 1:100,000 and 1:24,000 digital surficial geologic maps. A dataset of more than 300 well logs was assembled from USGS and Ecology databases. Geologic and hydrogeologic unit assignments were made based on lithologic interpretations of those logs and guided by stratigraphic interpretations from previous investigations by the Washington Department of Natural resources. Maps of hydrogeologic unit extents and the interpolated elevations of unit tops were constructed using a Geographical Information System.

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Unique Geochemistry of Gravelly Lake, Tacoma, WA: Evidence for a Deep Groundwater Component

B.M. SHAPIRO[1], *and J.H. TEPPER*[1]

Gravelly Lake (GL) is one of numerous kettle lakes in Pierce County. The substrate in the area is composed of several glacial outwash and till units. This lake covers an area of ~65 hectares and has no surface water inputs; the main water source is groundwater. American Lake (AL) lies up gradient from GL suggesting transport of groundwater in the shallow aquifer from AL to GL. Compared to AL, GL exhibits more stratification, greater clarity (Secchi depths to 9.5m), and higher SiO_2, Ca, Mg, and alkalinity. Another unique feature is a color change from steel-blue to aquamarine during summer months. The primary goals of the project are to characterize the composition of water at different depths and seasons, establish processes responsible for chemical variation, and identify factors responsible for unique chemical characteristics of GL.

Over an eight-month period 80 samples were collected and analyzed. Levels of major cations (Si = 5.6 ppm, Ca = 13.4 ppm, Mg = 5.2 ppm) are notably higher (up to 390% for Si) in GL than AL. GL showed more variation with depth than in AL. Month-to-month variations in GL spring chemistry track variations in AL water chemistry, indicating rapid (< 1 month) groundwater flow from AL to GL springs. However, the compositions of the groundwater springs reflect more than one end-member. Spring compositions vary (from one to another and month to month), consistent with mixing between AL water and an additional groundwater component. The elevated Si levels are the result of deep groundwater. The chemistry of GL is most similar to the deep groundwater component; whereas the springs mostly resemble AL. Seasonal trends in whole lake element loading (Si increased 2.5 fold from June-Jan.) reflect changes in relative contribution of shallow versus deep groundwater. A recent USGS study has identified a localized linear disruption of the confining layer between the shallow aquifer and deeper aquifers that may provide a window for deep groundwater transport. We conclude that deep groundwater is the dominate source of water at GL during summer months when lower rainfall results in diminished flow from AL. Diatoms were also recognized in sediment collected from GL. We attribute the aquamarine color of GL water in summer months to precipitation of calcite driven by diatom photosynthesis when Si is high.

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Hydrogeologic Framework for the Chambers-Clover Creek Watershed, Pierce County, Washington

Wendy Welch[1] and Burt Clothier[2]

The Chambers-Clover Creek Watershed (CCCW) covers about 180 square miles in the southern Puget Sound Lowland of Pierce County in western Washington. The watershed is underlain by as much as 2,000 feet of unconsolidated sediments that are the result of multiple Pleistocene glacial and interglacial periods. Defining extents and thicknesses of the aquifers and confining units within these unconsolidated sediments is essential to understanding ground-water flow and interactions with surface water features.

In April 2006, the U.S. Geological Survey (USGS) Washington Water Science Center began a project to characterize the water resources and create a numerical ground-water flow model of the CCCW. As part of that project, a more detailed hydrogeologic framework of the area was needed.

Four major elements were completed to construct the hydrogeologic framework. A digital surficial geology map was compiled by merging existing 1:100,000 digital data with scanned and digitized 1:24,000 geologic maps. A dataset of more than 450 wells was assembled from the USGS National Water Information System database and hydrogeologic unit assignments were made incorporating surficial geology, drillers' logs, and previous investigations. Eight cross-sections were created to illustrate the likely correlations between hydrogeologic units across the entire study area. Finally, maps were created to show the extents of the hydrogeologic units and the interpolated elevations of the unit tops.

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Ground-Water Flow Model of Lower Skagit River Valley, Skagit and Snohomish Counties, Washington

Ken Johnson[1] *and Lisl Fasser*[2]

The U.S. Geological Survey (USGS) Washington Water Science Center, in cooperation with the Washington State Department of Ecology (Ecology) and Skagit County, is developing a numerical model of ground-water flow for parts of the lower Skagit River valley area of Skagit and Snohomish Counties. Local stakeholders had raised concerns that residential development and increased domestic water usage could affect stream baseflows. This project focuses on the potential effects of ground-water withdrawals on several tributaries of the lower Skagit River, including Carpenter Creek (also Hill Ditch) and Fischer Creek, and the mainstem and East Fork of Nookachamps Creek.

Data collection for the project included drilling exploratory borings and wells and establishing a ground-water and surface-water monitoring network. Many environmental conditions were monitored including baseflows for determining gaining and losing reaches, year-round streamflows at gaging stations, monthly or continuous water levels in domestic and dedicated wells, and seasonal ground-water levels and gradients in the Skagit River delta west of the study area. A new digital elevation model of the area was prepared using LiDAR methodology. Drillers' log data from USGS and Ecology databases were interpreted, in conjunction with previous geologic interpretations by the Washington State Department of Natural Resources, to provide a hydrogeologic framework for the numerical model.

The ground-water flow model includes well withdrawals by public water systems and individual residences; a representation of the complex hydrogeologic framework using the Hydrologic-Unit Flow (HUF) package; recharge based on a precipitation distribution augmented by septic system return flows; stream and lake boundary conditions; fluxes across the Skagit River delta; and submarine ground-water discharges to Skagit Bay. The model initially was calibrated using average monthly water levels and baseflow seepages to simulate steady-state conditions, and then was expanded to include seasonal transient conditions. This model currently is being used to estimate potential effects from implementation of several management alternatives.

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The Contaminated Groundwater to Surface Water (GW-SW) Pathway: Some Case Studies at Contaminated Sites and Regulatory Implications in Washington State

Jerome Cruz[1], Charles San Juan[2], Hun Seak Park[3]

Identifying and evaluating contaminated groundwater plumes that discharge to a surface water body have important implications for successful cleanup and compliance in contaminated sites that are near surface water. During site characterization, the elements of the conceptual model would include hydraulic evidence for continuous or periodic discharge into surface water (baseflow, submarine discharge, preferential pathways, seeps, etc.), presence of a product or dissolved plume and plume source, source mass loading, biological/chemical transformations at the groundwater-surface water interface, exposure pathways or impacts to sediments and water, and appropriate cleanup levels at the point of compliance. Especially at many small shoreline contaminated sites in western Washington, it is common to find that little is done to properly characterize this pathway. The following subjects are examined in the context of this pathway under the MTCA cleanup regulation:

- Some examples of submarine discharge and plume discharge of contaminated groundwater or product in Washington state are presented;
- Existing MTCA rule language on the subject of the groundwater–surface water interface are revisited along with some implications in regulatory compliance;
- Discussion of the groundwater-surface water interface and points of compliance at sites near surface water are presented;
- Problematic issues and recommendations are presented in demonstrating compliance at sites with tidal influence, institutionally-controlled sites with persistent contaminant sources, or sites seeking to use natural attenuation as the single preferred remedial alternative.

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Geochemical Analysis of Surface and Groundwaters Around Cle Elum, WA; Implications for the Proposed Exempt Well Moratorium

David Hickey[1],Ryan Opitz[2], Travis Hammond[3], Clayton Larkins[4], and Carey Gazis[5]

The Yakima River drainage is one of the most heavily irrigated regions in the state and water use has been much contested and litigated. It is important to understand the relationship between groundwater and surface water because all of the surface water in the Yakima drainage is appropriated and many water rights holders depend on this water for their livelihood. Due to this water demand in the drainage and the increase in drilling of domestic wells, a moratorium on exempt well drilling was proposed in 2007. In particular, residents were concerned about groundwater supplies in the uppermost Yakima River watershed, the area around the towns of Cle Elum and Roslyn, and the impact of continued development there on surface water supplies. The hydrogeology of this area is poorly understood due to the complex stratigraphy where the valley floor meets the bedrock of the Cascade Range

In this study geochemical data is used to evaluate the surface-groundwater interaction in the area around Cle Elum, WA. The study was begun as a class project for an Environmental Geochemistry class at Central Washington University. Students collected samples from over 30 domestic wells and nearby surface water sources in the Cle Elum/Roslyn area. Trace element and major ion data will be presented for these samples and will be used along with statistical analysis to draw conclusions regarding the different sub-surface water bearing units as well as the relationship between the surface and ground waters.

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Estimating the Probability of Elevated Nitrate Concentrations in Ground Water in Washington State

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Logistic regression was used to relate anthropogenic (manmade) and natural variables to the occurrence of elevated nitrate concentrations in ground water in Washington State. Variables that were analyzed included well depth, ground-water recharge rate, precipitation, population density, fertilizer application amounts, soil characteristics, hydrogeomorphic regions, and land-use types. The variables that best explained the occurrence of elevated nitrate concentrations (defined as concentrations of nitrite plus nitrate as nitrogen greater than 2 milligrams per liter) were the percentage of agricultural land use in a 4-kilometer radius of a well, population density, precipitation, soil drainage class, and well depth. Based on the relations between these variables and measured nitrate concentrations, logistic regression models were developed to estimate the probability of nitrate concentrations in ground water exceeding 2 milligrams per liter. Maps of Washington State were produced that illustrate these estimated probabilities for wells drilled to 145 feet below land surface (median well depth) and the estimated depth to which wells would need to be drilled to have a 90-percent probability of drawing water with a nitrate concentration less than 2 milligrams per liter. Maps showing the estimated probability of elevated nitrate concentrations indicated that the agricultural regions are most at risk followed by urban areas. The estimated depths to which wells would need to be drilled to have a 90-percent probability of obtaining water with nitrate concentrations less than 2 milligrams per liter exceeded 1,000 feet in the agricultural regions; whereas, wells in urban areas generally would need to be drilled to depths in excess of 400 feet.

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Nitrate in Manure, Groundwater, Soil, and Grass Crop at a Dairy Field Overlying the Sumas-Blaine Aquifer

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Nitrate concentrations in the Sumas-Blaine Aquifer near the Canadian border have been impacted by agricultural sources including dairy and raspberry farming on both sides of the border. The Sumas-Blaine Aquifer is the main drinking water source for rural residents in north-central Whatcom County. The purpose of the study was to observe nitrogen dynamics in a typical grass field receiving dairy manure. For four years we have intensively monitored nitrate and related parameters in groundwater, soil, manure, and grass crop on a 22-acre field. Seven monitoring wells were installed in the field, six near the top of the aquifer (13 feet) and one at the bottom (38 feet). The field is located near the western edge of the aquifer, where depth to water is shallower (0-11 feet), and the substrate is finer than the eastern half of the aquifer.

The field was re-seeded in spring 2004, just prior to the start of the study. Tillage that occurred during re-seeding resulted in rapid mineralization of accumulated soil organic nitrogen. Mean nitrate+nitrite-N concentrations in groundwater near the top of the water table reached 30 mg/L the winter following re-seeding, while mean 2004 fall soil nitrate concentration was 31 mg/kg (weekly samples September-October). For three years following tillage, manure application ranged from 360-645 lb/acre total N (37-64% as ammonia-N) resulted in decreasing groundwater nitrate+nitrite-N concentratons. Monthly mean nitrate+nitrite-N concentrations in groundwater have been less than 10 mg/L, the maximum contaminant level for drinking water, for 15 months. Mean fall soil nitrate concentrations during 2005 to 2007 were 16 to 21 mg/kg, and crop yields ranged from 5.3 to 7.2 tons/acre dry matter (340-450 lb/acre N).

The combination of low dissolved oxygen and adequate organic carbon in this part of the aquifer provided conditions suitable for denitrification in over half of the shallow monitoring wells.

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Naturally Occurring Aqueous Arsenic and Seawater Intrusion on Lummi Island, Washington

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Lummi Island is an 8.8 mi^2 elongated island located in the Puget Sound six miles west of Bellingham, Washington. Lummi Island has a relatively small population of approximately 900 permanent and 1,500 seasonal residents. Freshwater on northern Lummi Island is primarily stored in fractured sandstone bedrock (Chuckanut formation) and unconsolidated glacial sediments. Two different types of groundwater contamination are present in these aquifers: naturally occurring arsenic and seawater intrusion. The naturally occurring arsenic varies spatially throughout the island, and the concentrations fluctuate seasonally. Additionally, seawater ions are intruding into the groundwater supply, which is the primary source of drinking water for the residents of the island. The process of mobilization of the naturally occurring arsenic and the extent of the seawater intrusion has not been fully explored. The purpose of this study is to determine the geochemical, physical, and seasonal influences on both arsenic concentrations and seawater ions on Lummi Island.

We have collected water samples and *in situ* measurements from about 40 wells distributed throughout northern Lummi Island for geochemical analysis in April and September, 2006. The relationship between aquifer materials, arsenic, and seasonality are being explored using a combination of statistical analyses, redox chemistry, rock element analysis, and Scanning Electron Microscopy. The extent of the seawater intrusion is being examined using major ion plots on Piper and Stiff diagrams.

Preliminary findings indicate no correlation between iron or manganese and arsenic concentrations. However, a positive correlation was found between major seawater ions and arsenic occurrence. This correlation will be used to predict arsenic concentrations with major ion values. Water samples and rock element analysis both indicate that arsenic occurrence is most prominent within the sandstone bedrock layer.

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An Evaluation of Extraction Techniques for QuantifyingTc-99 in Contaminated Sediments

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Technetium-99 (Tc-99) is a contaminant of interest at the U.S. Department of Energy's Hanford Site, located in southeastern Washington State, due to its long half life (2.2 x 10^5 years) and mobility in subsurface environments. Under oxidizing, neutral conditions, technetium has a valence state of +7 and forms the highly mobile pertechnetate anion (TcO_4^-). Therefore, K_d values of 0 mL/g are generally used to describe the partitioning of Tc-99 under these conditions. With a K_d of 0 ml/g, it has been assumed that the addition of water to a sediment contaminated with Tc-99 will result in total extraction of the Tc-99. However, previous results have shown a quantifiable difference between water-extractable and acid-leachable Tc-99 activities in sediments from several boreholes emplaced on the Hanford Site. A study to test different extraction techniques for their ability to fully extract Tc-99 from contaminated sediments was conducted using 25 Hanford Site sediments containing Tc-99 at activities ranging from 1 to greater than 1000 pCi/g. Water extraction (WE), acid digestion (AD) and microwave-assisted digestion (MD) were performed on each sample. Half of the filtrate from each extraction was immediately analyzed for Tc-99 (using ICP-MS), and the other half was treated using TEVA® resin prior to Tc-99 analysis. A laboratory control sample (LCS) was prepared and taken through the same extractions as the sediments. The LCS consisted of an uncontaminated sediment that was put into a ball mill for several seconds to further homogenize the sample. After grinding, a known activity of Tc-99 was added to the sediment. The non-resin treated samples resulted in 70% recovery of Tc-99 in the LCS from WE, 90% recovery from AD, and 120% recovery from MD. For the resin-treated samples, the MD results became more accurate, resulting in 102% recovery of Tc-99 from the LCS. Recovery for the WE and AD remained approximately the same post-resin treatment. An additional LCS was created that excluded grinding of the sediment prior to the addition of the Tc-99 spike. The WE for this LCS resulted in an average recovery of 104% vs. 82% recovery in the AD and 116% recovery in the MD. While the MD results were comparable to the previous LCS experiment, the WE resulted in a much higher recovery, and the AD resulted in a slightly lower recovery. The lower recovery of Tc-99 in the water extracts of the LCS that was ground in the ball mill suggests that some of the Tc-99 in the spike may have been reduced by fresh ferrous iron surfaces exposed during grinding of the sediment. These results imply than a technique more robust that water extraction may be required to quantify total Tc-99 concentrations in contaminated sediments obtained using split-spoon sampling or drive barrel techniques where disaggregation of Hanford gravel and coarse sand particles may expose fresh iron-bearing minerals that might lead to technetium reduction.

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Use of Narrow-Diameter, Direct-Push Wells to Characterize and Remediate Carbon Tetrachloride in the 200 West Area, Hanford Site, Washington

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Carbon tetrachloride was discharged to three liquid waste disposal sites in the 200 West Area of the Hanford Site from 1955 to 1973. The sites received carbon tetrachloride in mixtures with other organics (e.g., tributyl phosphate) and also entrained/dissolved in aqueous phase liquids. Soil vapor extraction (SVE) through perforated or screened wells was initiated in 1992 to remediate the vadose zone underlying these waste sites. A soil sample collected in 2003 from approximately 19.4 to 20.1 m depth in well 299-W15-46, which was being drilled near the 216-Z-9 Trench waste site, was found to contain a relatively high concentration of carbon tetrachloride (380 mg/kg). This high concentration is believed to be associated with a silt layer that is present from 19.8 to 20.4 m depth and had not been remediated by the existing SVE wells. The high concentration suggests that the carbon tetrachloride is present as a DNAPL. In 2006, a comprehensive field study culminated with direct-push technology to investigate the extent of this silt layer and associated carbon tetrachloride soil concentrations in the vicinity of this waste site. Similar carbon tetrachloride concentrations (390 mg/kg) were detected in a soil sample from 19.5 to 20.1 m depth at P66, the push location ~3.1 m east of well 299-W15-46. Carbon tetrachloride was not detected in samples from this depth at the other nearby push locations: P69 (~6.3 m west of well 299-W15-46), P68 (~12.1 m east of well 299-W15-46) and P67 (~3.9 m south of well 299-W15-46).

Narrow-diameter SVE wells were installed at push locations P66 (well C4937), P68 (well C5340), and P69 (well C4938). The wells are screened from 18 m to 19.7 m and have outside diameters of 3.6 cm. The wells were added on-line to the 14.2 m^3/min (500 ft^3/min) SVE system in June 2007 and produced flows of approximately 0.3 m^3/min (9 ft^3/min). During SVE, the carbon tetrachloride soil vapor concentrations were significantly higher in well C4937, the location with the DNAPL soil sample. During monitoring following SVE, concentrations at C4937 and C4938 have been comparable.

Pressure testing was conducted at these three narrow-diameter wells in October 2008 to evaluate the zone of influence of these wells. If analysis of the data indicates that the wells have adequate zones of influence to support shallow (less than 30 m deep) SVE, a direct-push technology will be considered in the future for SVE well installation as part of the remedial action for carbon tetrachloride in the vadose zone.

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Final Remedy for Treating 200 West Area Groundwater, Hanford Site, Washington

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The 200-ZP-1 Groundwater Operable Unit (OU) is one of two groundwater OUs located within the 200 West Area groundwater aggregate areas of the Hanford Site. An interim pump-and-treat system for this OU was implemented in 1995 to control the 2,000-µg/L contour of a 5-mi^2 carbon tetrachloride plume associated with the Plutonium Finishing Plant. Fourteen extraction wells and five injection wells are currently operating at a combined rate of approximately 320 gal/min. The primary contaminants of concern include carbon tetrachloride, trichloroethylene, technetium-99, iodine-129, hexavalent chromium, tritium, and nitrate.

The *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* remedial investigation/feasibility study process was recently completed for the 200-ZP-1 OU with the signing of the final Record of Decision in September 2008. The selected remedy requires the installation of a full-scale pump-and-treat system, combined with flow-path control, monitored natural attenuation, and institutional controls.

The full-scale groundwater pump-and-treat system will be installed to reduce the mass of the contaminants of concern by a minimum of 95% in 25 years. The estimated pumping rate required to meet this objective is 1,600 gal/min. Recent groundwater modeling results suggest that the treatment system will be comprised of approximately 20 groundwater extraction wells and 16 injection wells. The groundwater treatment facility is currently being designed to accommodate a maximum flow rate of 2,500 gal/min to allow the flexibility of treating potentially higher pumping rates from the 200-ZP-1 OU, as well as water from the 200-UP-1 OU to the south. The contaminant removal methods that are currently proposed include (1) ion exchange (e.g., Purolite® A-530E resin) to remove the technetium-99 and iodine-129; (2) bio-reactors to address nitrate and hexavalent chromium, and to knock down the carbon tetrachloride and trichloroethylene concentrations; and (3) air stripping to remove the remaining carbon tetrachloride and trichloroethylene. While there currently are no treatment methods for tritium, the short half-life (12 years) for this contaminant will naturally reduce concentrations below drinking water standards within the timeframe of the remedy. Phase I operations are scheduled to begin by the end of 2011.

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Soil Water Influence on the Oxygen Isotope Ratio of Soil CO_2 Flux to the Atmosphere

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Soil hydrology is strongly linked to the carbon cycle in soils in a number of ways. Soil moisture and soil water movement control rates of organic matter decomposition, movement of inorganic and organic carbon, as well as the distribution and types of plants present. Soil water also acts as a major influence on the oxygen isotope composition of soil CO_2, as evolving CO_2 undergoes the following isotope exchange reaction with soil water:

$$H_2{}^{18}O_{(l)} + CO_{2(g)} \leftrightarrow H^+ + [HCO_2{}^{18}O]^-_{(aq)} \leftrightarrow H_2O_{(l)} + CO^{18}O_{(g)}$$

The rate at which this equilibration reaction occurs with respect to the rate of CO_2 diffusion from the soil dictates the degree to which soil CO_2 flux will reflect isotopic equilibrium with soil water. In this study, the $\delta^{18}O$ of soil CO_2 flux and soil CO_2 at depth is analyzed and compared to the $\delta^{18}O$ of soil water across a precipitation gradient in eastern Washington. Analysis of soil moisture content, soil moisture $\delta^{18}O$, and soil temperature measured at the time of CO_2 sampling will be used to model the influence of these environmental variables on the oxygen isotope composition of soil CO_2 flux.

Respiration from terrestrial soils to the atmosphere is a major flux of CO_2 to the atmospheric reservoir. The impacts of changing global climate on this flux are of interest as increased global temperatures could potentially induce a positive feedback resulting in increased soil CO_2 production and release. Oxygen isotopes combined with mass balance equations are useful for estimating inputs to atmospheric CO_2. For this method, the distinct $\delta^{18}O$ signature of all major CO_2 fluxes to the atmosphere must be known. The $\delta^{18}O$ of soil CO_2, however, is the least well constrained of CO_2 fluxes to the atmosphere, largely due to the difficulty involved with measuring this isotopic flux.

This field investigation is aimed at constraining the relationship between the $\delta^{18}O$ of soil water and the $\delta^{18}O$ of soil CO_2 by monitoring these two parameters with respect to changing environmental factors across a precipitation gradient. Identifying such relationships will enhance our ability to model and potentially monitor global soil carbon flux to the atmosphere.

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A Stable Isotope Study of Soil Water Budgets Along a Climate Transect in a Snowmelt Dominated System

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The soil water budget is an integral part of the overall water budget of a particular watershed and/or groundwater basin. Studies characterizing soil water residence times, and style and rates of downward flow can give insight into aquifer recharge rates and estimates of evapotranspirative losses. In this study oxygen and hydrogen stable isotope data in combination with a mass balance approach was used to track inputs, flux between soil water compartments, and outputs in order to understand climatic influence on the soil water budget in a snowmelt-dominated hydrologic system in central Washington.

Precipitation, snowmelt, and two types of soil water (total soil water and lysimeter water) were sampled at four sites along a wet to dry transect form Snoqualmie Pass to Ellensburg, WA. Preliminary isotopic data along with precipitation amounts from the driest site demonstrated that water moves through the soil column by both piston flow and by preferential flow along conduits to the lower soil water compartments. Piston flow appeared to predominate after smaller rainfall events as evidenced by deep total soil water isotope values that retain an isotopic signature from evaporative losses at a shallower level. After significant recharge events, isotope values from both shallow and deep samples of total soil water and mobile soil water (water not hygroscopically bound to soil particles) demonstrated mixing of pre-existing soil water with newly added recharge water. During these periods, rapid isotopic changes in deep soil water in response to recharge are an indication of preferential flow to the lower soil water compartment.

A previous study performed in the present study area demonstrated that non-fractionating losses (downward percolation and transpiration) were nearly zero in the late summer to fall at the driest site while at the wetter site these losses were significant (~0.8 mm/day) (Robertson and Gazis, 2006). The current study allows for a more detailed characterization of the contributions of the individual non-fractionating and fractionating components such as transpiration, downward percolation, and evaporation, to the soil water budget.

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