The 2nd Symposium on the

Hydrogeology of Washington State

ABSTRACTS

August 25, 26, & 27th, 1997
The Evergreen State College

Sponsored By: The Washington State Department of Ecology
The Washington Hydrological Society

Supported By: The U.S. Geological Survey
The Washington State Department of Natural Resources

WASHINGTON STATE DEPARTMENT OF ECOLOGY

WHS

Abstracts from the 2nd Symposium on the Hydrogeology of Washington State

August 25-27, 1997
The Evergreen State College
Olympia, Washington

Presented By:
The Washington State Department of Ecology
The Washington Hydrologic Society

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Keynote Speaker

Water, Microbes, and Rocks: The Geochemical Ecology of Contaminated Groundwater

Dr. Philip C. Bennett

When an organic substance, either natural or anthropogenic, infiltrates into an aquifer it becomes a component of a dynamic biogeochemical system. From the perspective of the subsurface microbe, these compounds may be benign, toxic, or in most cases a rich source of carbon in an otherwise carbon-poor environment. Microbes consume this carbon, producing energy, cell mass, and geochemically reactive byproducts. The transformation of organic toxicants by native microorganisms, sometimes known as intrinsic bioremediation, is considered one of the most promising remediation approaches for contaminated ground water. From a geologic perspective, however, rapid metabolic transformation of organic substances also results in dramatic changes in the geochemical ecology of that aquifer, changing the native microbial consortia, aquifer mineralogy and permeability, vadose-zone gas composition, and water chemistry. This lecture will examine the geology and geochemistry of microbial transformation of hydrocarbons using laboratory experiments, geochemical modeling, and field observations of contaminated aquifers, including results from the collaborative U.S. Geological Survey's Bemidji research program. Hydrocarbon degradation produces bicarbonate, acidity, and organic waste products, potentially changing the bulk geochemistry of the aquifer over wide areas, or more subtly, producing reactive microenvironments near attached microbes. How does oil degrade in ground water, what are the degradation byproducts, and what is the nature of the microenvironment created around an attached microbe? Are these biogeochemical reactions a significant contribution to subsurface mineral diagenesis? Is mineral weathering enhanced only by surface colonizing microbes, or do microbes affect equilibria by altering "bulk" pore-water chemistry? Do microbes colonize mineral surfaces in order to leach necessary nutrients, or is colonization controlled by surface charge and surface roughness? The goal of this lecture is to examine the geochemical consequences of subsurface microbial processes.

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Over the past year, Dr. Bennett has assumed the honorable role of Henry Darcy Distinguished Lecturer for the National Ground Water Association. Dr. Bennett holds a B.S. from The Evergreen State College (1981), an M.S. in Environmental Sciences from the State University of New York, College of Environmental Science and Forestry in Syracuse (1985), and a Ph.D. in Geology from Syracuse University (1989). Some of his current research interests include the transport of contaminants in karst aquifers by colloids and sediments, silicate surface chemistry and weathering kinetics, and the geochemical fate of high-explosive compounds in wetland environments, including vapor-phase contaminant transport in the vadose zone.

Water Resources Aquifer Studies

Analysis of Artificial Recharge of the Highline Aquifer System

Richard J. Martin

To determine the impacts of groundwater withdrawals on the Highline Aquifer System in King County, Washington, a groundwater flow model was constructed using the United States Geological Survey code MODFLOW. The Highline aquifer supplements surface water resources for the Seattle Public Utilities during summer peak period use. With continuing growth in the region, additional groundwater supplies are needed beyond the current maximum capacity of the aquifer. Previous model studies indicated that at current usage, baseline water levels in the aquifer would decline by 1 to 2 feet per year. To offset this decline, the Seattle Public Utilities embarked upon a study to evaluate the effectiveness of artificially recharging the aquifer with excess surface water supplies during the winter and spring. After calibration of the model to pilot recharge tests, the model was used to assess long term impacts of artificial recharge on water levels. The results indicate that performing artificial recharge may allow an additional 1 to 2 million gallons per day to be pumped from the aquifer over a period of 3 to 4 months during the summer peak period, while maintaining baseline water levels. This case study suggests that performing artificial recharge of aquifers during the winter and spring with excess water from surface water reservoirs, may be a viable option to minimize local groundwater decline in Western Washington.

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Oral

An Overview of the Major Aquifer Systems in Washington

J.J. Vaccaro[1]

There are four major aquifer systems in the State of Washington, the Spokane aquifer (SA), the Columbia Plateau aquifer system (CPAS), the Puget Sound aquifer system (PSAS), and the part of the Willamette Lowland aquifer system (WLAS) that underlies Clark County, Washington. These systems underlie some 33,000 square miles, about 50 percent of the State. More than 90 percent of the State's population reside within their boundaries. Most of the ground-water withdrawn for domestic, municipal, commercial, industrial, and agricultural uses in Washington is from these systems.

The systems are composed of a diverse assemblage of rock materials due to their respective geologic histories. The SA was formed by the scouring and back-filling from repeated glacial out-burst floods originating from ice-dammed Lake Missoula. As a result, a large part of the SA is composed of gravel-to-boulder size rock materials, and its hydraulic conductivities are very large.

The CPAS was formed by repeated eruptions of basaltic lava of the Columbia River Basalt Group (CBRG) during Miocene time. Concurrent with the eruptions was basin subsidence resulting in accordantly layered basalt flows that thicken toward the center of the Plateau. Thick unconsolidated deposits overly the basalts in the basinal areas of the Plateau, mainly in the western part, and are considered part of the CPAS.

The PSAS and WLAS are large Neogene-age structural basins filled with sediments that compose the aquifer systems. The PSAS is mainly composed of large thicknesses of alternating sequences of coarse-grained glacial outwash aquifers separated by glacial till and fine-grained interglacial sediments that form semiconfining-to-confining units. The Holocene interglacial sediments consist predominantly of coarse-grained alluvium in the large river valleys. The WLAS is composed of a wide range of rock materials—including Pliocene-age semi-consolidated to consolidated sediments, Pleistocene-age glacial outwash, and Holocene-age alluvial deposits. These basin-filling sediments overly the CBRG throughout much of the area; this part of the CBRG is considered part of the WLAS. Overall, the sediments are finer-grained with depth.

Together, about 1,935 cubic feet per second (ft^3/s) or 1,250 million gallons per day (Mgal/d) is pumped from these four major systems: about 320 ft^3/s (175 Mgal/d) from the SA, 945 ft^3/s (610 Mgal) from the CPAS, 545 ft^3/s (350 Mgal/d) from the PSAS, and 125 ft^3/s (80 Mgal/d) from the WLAS in Washington. This pumpage supports agricultural, commercial, and industrial economic activities in the State. The effects of pumping have been profound for the CPAS, resulting in water-level declines as much as 300 feet. The effects of the pumping of the other systems has not been as large, except in local areas. Together, these systems receive about 55,815 ft^3/s (22.9 inches per year) of precipitation. Total ground-water recharge to these systems is estimated to be about 23,560 ft^3/s (9.7 inches per year). Recharge varies spatially from nearly 0 to more than 45 inches per year. Most of the recharge ultimately discharges to streams.

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Poster

Buried Forests and Sand Deposits Containing Mount Rainier Andesite and Pumice Show Evidence for Extensive Laharic Flooding from Mount Rainier in the Lower Duwamish Valley, Washington

Patrick T. Pringle[1], Judith A. Boughner[2], James W. Vallance[3], Stephen P. Palmer[1]

In Auburn, Washington, wood from the outer part of a stump that was buried by a laharic flood from Mount Rainier (Pringle and Vallance, 1996) has been dated at 1,100 yr B.P. The pumiceous Auburn sand layer has been correlated with a moderately explosive eruption at Mount Rainier that generated a large sandy lahar or lahars in the White River valley.

More than 40 additional buried trees, possibly correlative with the Auburn trees, have been recovered from a sandy deposit at Kent, Washington, 10 km farther downstream. In addition, a 1.5-m-thick layer of bedded, medium-to-coarse sand, predominantly consisting of crystal and volcanic fragments of Mount Rainier andesite and pumice, can be found as far north as Port of Seattle Terminal 107 in the lower Duwamish Valley (about 3 km from Elliott Bay), more than 120 km flow distance from Mount Rainier. The base of this distal deposit sits about 4 m above mean low low water on a shelly mud deposit.

The Terminal 107 sand unit contains pumice granules that resemble those found in the massive laharic sand at Auburn. The flood that buried trees in Kent and that may have left the sand deposit at Terminal 107 evidently inundated the lowermost 10 km of the Duwamish Valley from valley wall to valley wall. This flood may represent a pulse of sedimentation that followed the 1,100 yr B.P. laharic flood at Auburn by hours, days, or weeks.

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Oral

Columbia River Influence on Groundwater, Hanford Site, Washington

Robert E. Peterson

The interaction between Hanford Site groundwater and the Columbia River is being investigated as part of remedial investigations to support environmental restoration decisions. Sampling objectives include tracking groundwater contamination from hazardous waste sites to locations of potential human and ecological exposure in the river environment. Methods include collecting samples from monitoring wells; polyethylene sampling tubes driven into the aquifer near the shoreline; riverbank seepage during low river stage; and riverbed substrate pore water. Pressure transducers, specific conductance probes, and data loggers are used to collect hourly data at locations where conditions change rapidly.

Previous work along the retired reactor areas on the Hanford Site has demonstrated the highly variable characteristics of groundwater near the Columbia River. Daily and seasonal river stage fluctuations exert a strong influence on water quality, as observed in sampling locations near the shoreline. Because groundwater remediation activities regard protection of the Columbia River and its ecosystem as a high priority, an understanding of the interaction between contaminated groundwater and river water is essential if informed environmental restoration decisions are to be made.

The unusually high Columbia River discharge that occurred during Winter 1995/1996 increased bank storage significantly. Increased bank storage changes the water quality observed at monitoring locations near the river. The effects may include a reduction in contaminant concentrations because of dilution by river water. An increase in contamination may also result from a higher water table in areas where residual contamination held on the normally unsaturated soil column is now remobilized by the saturated conditions. The time period for recovery from the effects of unusually high river discharge conditions is a key parameter in designing monitoring schedules. Repetitive sampling at selected shoreline locations suggests that recovery occurs relatively quickly, and within the seasonal cycle.

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Evidence of a Buried Channel of the Green River within the Covington Upland: A Linear Aquifer?

Brian R. Beaman, P.E.[1] and Kathy S. Killman[2]

A detailed hydrogeologic investigation of the southeastern portion of the Covington upland (Black Diamond area) in south King County resulted in the drilling of a water well that provides evidence of a buried channel of the ancient Green River. Preliminary testing of the well suggests an available resource and pumping capability of at least 1,000 gallons per minute (gpm).

Leading up to the drilling of the new well, data including over 600 water well logs and nine coal exploration drillholes were reviewed. Detailed geologic mapping was conducted of the subject property including an area within a one-mile radius of the property.

The vast majority of the water wells in the Black Diamond area yield less than 20 gpm. However, review of the water well logs indicated that over 70 percent of these wells are less than 120 feet deep and completed within Vashon age recessional outwash and till. The pre-Vashon glacial and interglacial soils in this area are several hundreds of feet thick. Review of the few "deep" wells in the Black Diamond area suggested a potential productive aquifer zone at a depth within the pre-Vashon sediments. In addition, deep coal exploration drillholes and mapping of the Green River gorge south of Black Diamond revealed a "trough" in the bedrock, further suggesting an ancient path of the Green River. The deep trough in the bedrock in this area has been recognized since the mid-1960s.

A water well was sited and drilled in August 1996 about one mile north of the Green River and about one mile southwest of Black Diamond. The upper 120 feet of the well penetrated two layers of till separated by moist, but not saturated, consolidated sediments. At 120 feet, gravel with sand was encountered that extended to 238 feet, where silt was encountered. The well was terminated at a depth of 240 feet. Ground water was encountered at 120 feet immediately upon penetration of the second till layer. The static ground water level stabilized at a depth of about 100 feet.

The thick sequence of gravel in an area where gravel layers are usually less than ten feet thick suggested an infilled channel of an ancient course of the Green River. Based on further review of the water well logs, there is a strong inference the channel extends in a west-northwest direction toward the Kent area. It appears that a few wells may have penetrated the top of this aquifer, but were not drilled any deeper. This "linear aquifer" may be an important water resource for the Black Diamond/Covington upland area.

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Poster

Geohydrology of the Cedar River Ground-water Basin, King County, Washington

Stephen H. Evans[1], Roy E. Jensen[2]

The Cedar River ground-water basin lies east and south of the City of Renton, Washington and is a potential deep ground-water reservoir located close to population centers. Several water districts either have water rights in the basin, or are interested in developing supplies. Domestic wells have explored the uppermost aquifers in the area, but with a total package of up to 1,000 feet of glacial and interglacial sediments, much of the strata are unexplored.

Wells logs from the files of the Washington State Department of Ecology and various unpublished reports were used to develop preliminary interpretation of the geohydrologic conditions of the basin. Few borings have penetrated the deeper portions of the basin. These data were used to synthesize an interpretation of the structural and sedimentary limits of the basin, and to tentatively correlate the identified aquifers with those outlined by the USGS beneath the Covington area located just west of the study area.

Several conceptual models were developed for the basin. The preferred model divides the basin into two hydrologically separate portions. The available data suggest that a buried bedrock ridge runs eastward from the former mining town of Cedar Mountain, beneath the Cedar Hills Landfill to the Hobart area. If this ridge in fact exists, then the deeper portion of the basin between Renton and Cedar Hills is isolated from the strata around Maple Valley.

Problems associated with the present data base will be identified and a program of further investigations to address some of the basic interpretation issues will be presented. Such a program should include a combination of geophysical and drilling elements and baseline water quality sampling in the deep aquifers to complement the recently established sampling network developed for King County.

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Groundwater Development in Complex Geologic Terrain Lewis County, Washington

William C. B. Gates, Ph.D., P.E., P.G. [1]

Groundwater development in the upland bedrock units of Lewis County, Washington has historically presented difficult problems because of the complex geologic terrain. This paper focuses on groundwater development in the Eocene Lincoln Creek and Ohanapecosh Formations. The primary problems have included location and development of usable quantities of good quality groundwater. Fracture systems in these rock units are generally tight and dirty. Small quantities of groundwater occur in zones of secondary porosity along fractures and at bedding contacts. The highest producing wells occur where multiple fracture zones intersect. Typical yields for these fracture flow wells are low and range from 1 to 10 gpm with attendant low specific capacities.

To locate wells within the bedrock units, the author blends three exploration techniques: terrain and fracture trace analysis, ground truth and geologic structural mapping, and analysis of the hydro-potential value (HP-Value) of the fractures. The hydro-potential value is a rock-mass classification, semi-quantitative technique employed to evaluate the potential for developing groundwater in bedrock. Previous research by the author has demonstrated an inverse exponential relationship between well yields, attendant specific capacities and the HP-Value. Low HP-Values (<1) predict the potential for high-yield wells and attendant specific capacities. By coupling these techniques, the author has successfully located concentrations of open fractures that convey groundwater through the bedrock units. In addition, using the HP-Value technique, the author accurately predicted yields and specific capacities for wells targeting these fractures.

The Lincoln Creek Formation near Galvin, Washington comprises bedded, tightly fractured, fossiliferous marine silty sandstones. Primary porosity is very low and groundwater occurs essentially along fractures and bedding planes. Two intersecting primary fracture sets (striking north and northeast) were observed on the fracture trace analysis and during the structural mapping. Test wells installed at the intersections of these primary fracture sets produced 2 to 4 gpm. Low well yields were expected, considering the HP-Values averaged 3 for the fractures.

The Ohanapecosh Formation comprises interbedded andesitic basalts and volcaniclastic flows. Similarly, primary porosity is very low and groundwater is limited to fractures and contacts between the flows. Two intersecting primary fracture sets (striking northeast and northwest) were observed on the fracture trace analysis and during the structural mapping. Predicted well yields based on an average HP-Value of 2.48 were 4 to 5 gpm. Observed well yields from pumping tests ranged from 5 to 8 gpm as expected and predicted from the HP-Value analysis.

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Oral

Groundwater Supply and Water Rights: Blaine, Washington.

Mark Birch[1], David Banton[1], William Duffy[2]

The city of Blaine is faced with a limited water supply to serve its growing population. Options available to enhance the water supply were recently reviewed, including interies, water reuse and conservation, rehabilitation of existing wells, and additional groundwater development. Results indicate that interie options are presently not feasible, due to limited neighboring supplies. Water reuse, conservation measures, and well rehabilitation will reduce overall short-term demands. However, additional sources of water are required to meet future demands.

Studies suggest that additional groundwater is available from a shallow aquifer where six of the city's eight wells have been completed. The shallow aquifer is in hydraulic continuity with Dakota Creek, but down stream of the tidally influenced stream reach terminus. As such, additional groundwater development is possible under a tidal-influence exemption clause for Dakota Creek. An alternative is further development of a 750 ft deep aquifer recently estimated to have a potential yield of between 2,000 and 3,000 gpm. The deep aquifer is separated from the overlying shallow aquifer and Dakota Creek by 400 to 500 ft of low permeability clay and silt, and it appears to extend westward to Drayton Harbor about 2 miles away.

A study of the shallow and deep aquifers is currently underway, including an evaluation of U.S/Canadian and Native American water rights issues. Results will be presented in a report to be presented to Ecology describing the feasibility, advantages, and disadvantages of further developing each aquifer. Preliminary results suggest that a transfer of shallow aquifer water rights to the deep aquifer may be possible. This could reduce the contamination susceptibility of the city's water supply, enhance local spring and tributary flow by taking shallow wells off-line; and reduce the overall impacts to Dakota Creek by utilizing groundwater from the deep aquifer that may otherwise discharge into Drayton Harbor.

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oral

Hydrogeologic Setting of the Pullman-Moscow Basin Eastern Washington and Northern Idaho

Dr. Dale R. Ralston and Dr. John H. Bush[1]

The geologic setting of the aquifers within the Columbia River Basalt Group is distinctly different along the eastern margin than in the center of the basin. This paper describes the hydrogeologic features that are important in the Pullman-Moscow area near the contact between the Columbia River Basalts and the basement rocks. The dominant aquifers along the eastern margin of the Columbia Plateau occur in the Wanapum and Grande Ronde Formations of the Columbia River Basalt Group. The upper aquifer, typically present in the Wanapum Formation, supplies most domestic wells; the dominant municipal water supply source is the lower aquifer which occurs in the Grande Ronde Formation.

The key geologic factors in controlling the basalt aquifers are: 1) the pre-basalt, basement topography, 2) the relation between marginal associated sediments and basalt units, 3) the thinning and post emplacement deformation of basalt units over subsurface basement highs, 4) the onlap and offlap of Wanapum and Grande Ronde Formations near the basement contact and 5) the character of the contact zone between the Priest Rapids Member of the Wanapum Formation and the underlying Grande Ronde Formation. Basement rock highs, both those exposed and those covered by one or more basalt flows, form the boundaries to the Pullman-Moscow ground water system. A buried bedrock high may form the southwestern "boundary" of the Pullman-Moscow aquifer as represented in published ground water models. Another bedrock high may have forced the ancestral Palouse River to flow south through the Pullman area rather than its present course to the west.

The characteristics of associated marginal sediments of the Latah Formation vary from site to site and with depth. The uppermost unit of the Latah Formation, referred to as the Sediments of Bovill, vary in grain size and thus hydraulic conductivity. Significant recharge to the basalt aquifers probably occurs where the sediments are coarse-grained near small streams emanating from the bedrock highs.

Both onlap and offlap relations exist between the Grande Ronde and Wanapum Formations as the flows approach the edge of the plateau. Direct recharge to the Grande Ronde Formation is more likely in the offlap areas. In onlap areas, the thickness and hydraulic properties of interbeds and/or saprolite zones play a role in regional ground water flow patterns.

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Hydrogeology of the Crown Jewel Mine, Okanogan County, Washington

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The Crown Jewel mine is a proposed open pit gold mine by Battle Mountain Gold that will be located near Chesaw in Okanogan County, Washington. The mine is located on Buckhorn Mountain just to the east of the topographic divide between Toroda and Myers Creeks, part of the Kettle River basin. The pit will be mined to a depth of about 450 feet below the local water table and cover an area of 130 acres. The hydrogeology and hydrology of the mine site area has been intensely investigated since 1992 in support of the Environmental Impact Statement prepared by the Washington Department of Ecology and US Forest Service.

The mine site hydrology has been characterized by numerous methods including stream gauging, drilling of mineral exploration holes, piezometers, monitoring wells, packer tests, and pumping tests. Pumping tests and packer tests were used to investigate the hydraulic behavior of the groundwater flow system and in particular the behavior of the North Lookout Fault zone, a prominent structural feature that crosses the site. Pump testing and chemical characterization of surface and groundwater were used to evaluate the interaction between surface and groundwater. The overall conceptual model of the hydrogeology of the site was investigated through numerical modeling. Two dimensional cross-sectional modeling and two-dimensional plan view modeling using a depth-dependent transmissivity function was used to evaluate the effect of pit dewatering on groundwater and surface water conditions. Based upon the modeling work, and subsequent water balance analysis, a streamflow mitigation and augmentation program was developed to prevent impairment to surface water resources in the basin from development of the mine.

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oral

Hydrostratigraphic Study of Arsenic Distribution in Groundwater in the Granite Falls Area, Washington

Kathy Goetz Troost

A limited hydrostratigraphic study was conducted to evaluate the distribution of arsenic in groundwater in the Granite Falls area. The specific objectives of the study were to determine the aquifers present in the area and determine the arsenic distribution within each aquifer. In order to address these objectives, arsenic and well data were obtained from the Snohomish Health District and the US EPA. Well logs were interpreted to determine a simplified hydrostratigraphy and develop cross sections. A total of 284 data points were obtained and plotted. Of these, depth data were available for only 158 wells, and only 76 of the data points had drillers' logs.

In general the data are sufficient to draw strong conclusions about the association of arsenic and specific hydrostratigraphic units. Five hydrostratigraphic units were identified: alluvium, recessional/surficial deposits, glacial/interglacial deposits, basal gravel/residuum, and bedrock. The high and intermediate arsenic concentrations (>0.050 and 0.010 to 0.050 mg/L, respectively) are predominantly limited to wells screened in or withdrawing from bedrock or the basal aquifers. The highest arsenic concentrations to date are associated with wells screened in fractured bedrock. According to the draft environmental impact statement, which was prepared for the Associated Gravel site northeast of Iron Mountain, much higher arsenic concentrations were found in the bedrock than in the glacial till. For that study, arsenic concentrations were obtained from crushed rock and soil. What control the bedrock has over the arsenic concentrations is unknown. The data are too biased to determine spatial trends in the bedrock. The bias comes from the predominance of shallow wells and number of wells drilled in the valleys where the highest population density occurs. Arsenic in the groundwater does not appear to be inherent or ubiquitous with glacial deposits. Otherwise, the intermediate and high arsenic concentrations would be more randomly distributed than in this data set.

In areas with high well density, such as small residential neighborhoods, higher arsenic concentrations were noted in the shallow wells completed above bedrock in the recessional/surficial and/or glacial/interglacial units. In these high density areas, there is a mixture of shallow hand dug wells (generally less than 65 feet deep) and deeper drilled wells, sometimes several wells on the same lot. Groundwater from the different units could be mixing naturally via less permeable layers; groundwater could be discharging from the bedrock into the overlying units via an upward hydraulic head, fracturing, or direct connections; or there might be an interconnection of the aquifers due to the well boreholes. The aquifer in the basal hydrostratigraphic unit is under hydrostatic pressure southwest of Granite Falls. High arsenic concentrations were observed in the shallow wells in this area. The elevated arsenic could be reflective of the nearby bedrock high (just to the north) or mixing of aquifer water given, the artesian pressure on the basal aquifer in this area.

There are several data quality issues for this study: uncertainty in the locations of wells, uncertainty in the drillers' interpretation of geology, a limited data set, and incomplete records. There are several possible biases of this study: poor or no well seals, allowing communication between aquifers; few bedrock wells; incomplete tracking of high arsenic concentrations in the last six years; spatial distribution of wells; and seasonal fluctuations affecting arsenic concentrations. Even with these uncertainties, high arsenic concentrations in groundwater are apparently associated with the bedrock aquifer or aquifers in close contact with bedrock.

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Oral

Interpretation of a 60-day Pumping Test of the Seabeck Aquifer System

Joel W. Purdy[1] *and Martin B. Sebren*[2]

A 60-day pumping test was conducted to better understand the long-term capabilities and regional characteristics of aquifers located in west Kitsap County near Seabeck, Washington. Considering that existing and further ground water withdrawals could exceed 3,000 gpm, the available water system infrastructure of Public Utility District No.1 of Kitsap County was used to help evaluate the potential of the aquifer system. Kitsap PUD's Seabeck Well 3 was pumped at an average of 584 gpm for 60 days. Seven other wells were monitored before, during, and after the pumping period. Based on the evaluation of the pumping test, coupled with compilation of other hydrogeologic data, the capacity and extent of the aquifer system was estimated.

The description of the aquifers in the Seabeck area has evolved over the years. Previous fisheries studies identified and named four productive, water-bearing zones as separate aquifers. The 60-day test and associated hydrogeologic characterization of the aquifer system demonstrated that, regionally, there was no basis for the separation of the aquifers. Consequently, previously identified aquifers in the area have been combined and referred to as the Seabeck Aquifer System.

The 60-day test of KPUD's Seabeck Well 3 has provided valuable information on the Seabeck Aquifer System. The test demonstrated drawdown interference in all wells monitored up to a distance of 1 ½ miles. Drawdown and recovery data showed that the aquifer system can maintain a production level of 600 gpm for an extended period with no apparent residual affect on the system's water levels. The recovery trend shows that interference observed during the test was temporary, and that aquifer water levels returned to the expected non-stressed levels. Water chemistry was stable and of excellent quality throughout the pumping period; there was no evidence of saltwater intrusion.

The work has culminated in an aquifer protection study, in which a conservative production rate of 1,400 gpm over current ground water withdrawals was suggested for future planning purposes. The testing has provided important information for production wells in the Seabeck area and the county resource planning efforts of KPUD.

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Oral

Long Term Performance of a Highly Productive Aquifer

Kim de Rubertis[1] and Catherine Kraeger-Rovey[2]

The Eastbank Aquifer derives its name from the east bank of the Columbia River where the aquifer is located immediately upstream from Rocky Reach Dam. Although small in area, the aquifer is highly productive, yielding as much as 30,000 gpm to meet the demands of a regional water system and a hatchery.

The aquifer was first recognized during design and construction of Rocky Reach Dam. A number of exploratory wells were drilled into the aquifer prior to and during dam construction. The wells revealed a potential seepage path from the reservoir through highly pervious gravel. A cutoff wall was constructed in the left abutment of the dam to prevent uncontrolled seepage.

The City of Wenatchee first exploited the aquifer in 1977 with the construction and testing of one well. Three additional production wells were drilled and tested in 1979. Since 1985, peak regional water system demand has been about 7,000 gpm. Future demand is likely to increase.

Public Utility District No. 1 of Chelan County in 1987 conducted an extensive exploratory program and constructed four additional wells in the aquifer to supply up to 23,000 gpm to the Eastbank Hatchery. Cool water (~12°C) was desired for the hatchery. Initial testing involved installing pressure transducers and thermistors in 12 wells and the Columbia River, pumping the hatchery wells, and monitoring aquifer response. Hydraulic and thermal models, calibrated to observed aquifer response, were developed to predict long term aquifer performance at initial, temperature-managed, and increased demands.

An evaluation of ten years monitoring of the aquifer's hydraulic and thermal performance reveals changes in aquifer heads and temperatures that provide important clues for managing the aquifer to continue to supply cool water for the hatchery and to meet increased regional demand. Predicted and actual performances are compared, and a management strategy is developed.

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Murray Creek, Pierce County, Washington: An Example of Hydraulic Continuity

Robert Palmquist[1], Thomas Meyer[2], Edward McCarthy[3]

Murray Creek is a 3-mile long, perennial stream on the Fort Lewis Military Reservation near Tacoma, Washington. The stream originates in Kinsey Marsh and flows south and west across a broad upland past the Madigan Army Medical Center (MAMC), First Special Forces Facility (FSFF), and Logistics Center and under Interstate Highway #5 (I-5) before descending 30 feet into American Lake. During the summers of 1994 and 1995, the reaches downstream of MAMC went dry. Murray Creek hosts native cutthroat trout and is used by a kokanee run for spawning. Concern for the kokanee run led to a 1996 watershed assessment to evaluate potential causes of the low flows.

The assessment found that flow reductions resulting from increased impervious surface, evapotranspiration from invasive plants, and increased leakage through disturbed channel reaches were insignificant to minor. The data suggested below average seasonal precipitation may have contributed to the low 1994 baseflow. However, the principal cause of the reduced baseflows was probably increased seepage from Murray Creek resulting from increased ground water withdrawals. Investigations were conducted to evaluate the relationship between Murray Creek baseflows and ground water in the underlying aquifer. This work included a survey of channel sediments and form as well as installation of ten shallow piezometers completed in sand or gravel three to five feet below the silt and sand of the channel floor. Water levels were monitored to determine vertical hydraulic gradient. Four reaches with different gradients were identified:

- A perennially losing reach where the piezometers were dry. This reach, located downstream from MAMC, went dry in 1993 and 94.
- A mixed reach, which varied from gaining to losing seasonally, located near the FSFF.
- A perennially gaining reach immediately located upstream from the FSFF. This reach is adjacent to a high terrace with numerous small springs and seeps.
- A second mixed reach downstream from Kinsey Marsh.

The only large ground water withdrawals near Murray Creek during the summers of 1994 and 1995 were the cooling wells at MAMC. They withdrew between 1,100 and 2,000 gpm from the shallow aquifer. A distance-drawdown analysis indicated their cones of depression extend 600 feet northeast to Murray Creek and 1,100 feet northwest and northeast away from the creek. The cones likely intercepted Murray Creek at the FSFF mixed reach. MAMC withdrawals appear to have drawn down the water table beneath this reach, which in turn increased the vertical hydraulic gradient and infiltration from the creek. Baseflows in Murray Creek are in a delicate balance. Without large ground water withdrawals, ground water inflow sustains baseflow, as demonstrated by the summers preceding 1994. With increasing ground water withdrawals, however, ground water inflow during years with average to below average winter recharge is insufficient to maintain summer baseflows.

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Oral

Prioritization of Potential Artificial Recharge Sites using a Spreadsheet Methodology in Thurston County, Washington

Joseph E. Becker

The LOTT (Lacey, Olympia, Tumwater and Thurston County) Wastewater Management Partnership is preparing a long-term plan for management of wastewater in northern Thurston County. One of the program directions being considered by LOTT is to use highly treated wastewater to replenish ground water supplies. As part of the consultant team working for LOTT, Robinson & Noble was asked to prioritize, without the benefit of field work, areas within the County that would be potentially favorable for artificial recharge of highly treated wastewater at rates of one to five million gallons per day. We examined over 500 square miles of the County and identified 32 regional areas, ranging in size from 0.75 to 25.5 square miles each, which might be favorable for artificial recharge by surface spreading or shallow subsurface applications.

A two-step process was used to determine where regional sites capable of receiving the required recharge rates existed in the County. The first step characterized the hydrogeologic parameters necessary for artificial recharge. The second step selected potentially suitable areas based upon the parameter characterization. Six parameters were determined to be of interest: surface geology, surficial unit thickness, soil permeability, depth to water table, and slope. The study area was divided into 2037 quarter sections. For each quarter section, the six parameters were characterized using available sources of information.

A spreadsheet workbook was constructed with each cell representing a quarter section and a separate worksheet made for each parameter characterization. Additional worksheets were constructed to rate each quarter section as suitable, possibly suitable, or unsuitable for artificial recharge based solely on a single parameter. The suitability codes were multiplied together to give each quarter section a total score. A score of greater than zero indicated the area was potentially suitable, with the lower the number, the higher the probability of it being suitable.

Quarter sections with the lowest positive scores were divided into 32 regional sites such that th' general hydrogeologic setting was consistent over each site. It was evident that some of the sites selected by this spreadsheet methodology were more suitable for recharge than others. Therefore, the sites were further scored and ranked, using a regional perspective rather than a small-scale (quarter section) perspective, on the probability of each site being able to accept reclaimed water and route it to a regional ground or surface water system. Ongoing work, including field work, is being completed to further prioritize potential recharge sites.

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Quaternary geologic mapping and stratigraphy in the Deming and Kendall 7.5-minute quadrangles, Whatcom County, Washington--Implications for valley hydrostratigraphy in the foothills of the North Cascades

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Our geologic mapping (Dragovich and others, 1997, DGER OFR, in press) and examination of lithologic logs from about 1,100 water well and six geotechnical borings reveal complex Quaternary stratigraphy in the Kendall and Deming quadrangles. In this investigation, we combined outcrop examinations with subsurface data to produce a series of fence diagrams (Dragovich and others, 1997, DGER OFR, in press). The fence diagrams show a stratigraphy that generally conforms with the previous Puget Sound-Fraser River lowland studies directly to the west and northwest (Armstrong and others, 1965, GSA Bull., v. 76, p. 321-330; Easterbrook, 1974, USGS Misc. Inv. Series Map I-854-B, respectively). Lithostratigraphic units include (1) Vashon Stade advance outwash(?) and till, (2) Everson Interstade glaciomarine drift and facies equivalents, (3) Sumas Stade outwash and till, and (4) alluvium. A mid-Holocene Nooksack Middle Fork lahar (NMFL) separates alluvium into younger and older units. We have traced the NMFL in the subsurface from its exposures along the Middle Fork to the Puget Lowlands about 10 km downstream where it is identified in new geotechnical borings at Nugents Corner bridge. Mass-wastage and volcanogenic deposits, restricted marine environments, and glacial ice-dammed lakes contribute to the complex facies changes observed in the subsurface. Thick sequences of Everson-age glaciomarine diamicton and glaciomarine (Everson Interstade) or glaciolacustrine (Sumas Stade) clays and locally varved silts and clays locally underlie alluvium. Lateral facies changes between diamicton and fine sediments may reflect proximal-to-distal glaciomarine ice-marginal environments. An apparent lack of macrofossils in these deposits may reflect the rapid accumulation of sediments in a restricted and dynamic glacial-estuarine environment.

Geohydrologic implications of the study include first-order depositional facies analyses of the lithostratigraphy and thus identification of confining units controlling valley subsurface hydrology. Static water well levels illustrate the local ground-water perching capabilities of the NMFL, glaciomarine drift, and glacial lake sediments given the proper local conditions. At least one geotechnical boring contains saturated alluvium above NMFL and glaciomarine drift confining units. Nonsaturated alluvium occurs between the perched water table and below the NMFL.

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South Tacoma Wellfield and the Sea Level Aquifer Test

Doug Dow[1], James Carr[1], Robert Palmquist[1], and Jane Evancho[2]

The City of Tacoma (City) has 14 production wells in the South Tacoma Wellfield (wellfield). These wells are located within the South Tacoma meltwater channel created during the last glacial retreat. Initial hydrogeologic interpretation concluded that these wells were completed in a single, unconfined aquifer. Drilling of new test wells and closer inspection of the older well logs have identified two aquifers -- an upper, Shallow Aquifer (SA) and a lower, Sea Level Aquifer (SLA) -- separated by 10 to over 50 feet of low permeability sediments. The validity of this reinterpretation was assessed by Tacoma's SLA test (test). The test is perhaps the longest and most intensively monitored pumping test in the State. Between June 14 and September 18, 1995, five City wells in the SLA were pumped at a combined rate of 12,000 gpm. During and after the test, water levels were measured in 93 wells in the 100-square-mile study area with the cooperation of eight water utilities and two military installations.

The test was designed to determine (1) the ability of the SLA to sustain ground water withdrawals at or near the City's water right and (2) the impact of these withdrawals on water levels in other municipal production wells. During the test, over 1.65 billion gallons (5,064 acre feet) of ground water were withdrawn, creating a cone of depression 75 feet deep in the SLA with a mean radius of 4 miles. Drawdown in the SLA reached equilibrium within two weeks. A double cone of depression was created in the overlying SA with a maximum drawdown of 10 feet and a composite zone of influence with a mean radius of 2 miles. The SA cone of depression indicated potential leakage through the aquitard at old Airlift Well 7, which is open to both aquifers near the center of the wellfield, and along Flett Creek, where the aquitard may be locally absent. Upon cessation of pumping, water levels recovered within two weeks.

On November 16, 1995, static ground water levels were simultaneously measured in all production and monitoring wells on November 16, 1995. To achieve static conditions, 95 percent of the municipal production wells were not pumped for at least 24 hours. The resulting potentiometric map indicated the wellfield's recharge area extends southeastward into eastern Fort Lewis. Water balance calculations indicate this area receives 7.25 inches or 19,000 acre feet per year (af/yr) of recharge from the SA during normal years.

The test determined the SLA was capable of producing large quantities of water without significant impacts to other municipal production wells. Interference in the municipal production wells within the zone of influence was insignificant outside the South Tacoma channel. Comparison of the City's SA water rights (9,682 af/yr) to the estimated recharge of 19,000 af/yr indicates the SLA is capable of sustaining the City's withdrawals. Water budget calculations for the study area indicate a sufficient supply of ground water is available for all its existing SLA water rights.

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Oral

Stratigraphy and Sedimentology of Late Neogene Suprabasalt Sedimentary Units in the Yakima Fold Belt: Some Geologic Constraints on Ground Water Flow in Suprabasalt Aquifers in the Mid-Columbia Region, or Debunking Misconceptions about Sediments Overlying the Columbia River Basalt Group

Kevin A. Lindsey[1] and Terry L. Tolan[2]

Late Neogene sedimentary units, including the Ringold Formation, Snipes Mountain Conglomerate, Alkali Canyon Formation, Dalles/Chenoweth Formation, and the Ellensburg Formation overlie the Columbia River basalt in structural basins throughout the Yakima Fold Belt. Typically these units form significant parts of the vadose zone as well as the majority of the unconfined suprabasalt aquifers in these basins. Consequently, understanding stratigraphic and sedimentologic facies relationships within these units is important for accurately interpreting ground water flow through them. Four basic facies types are common to all of the suprabasalt sedimentary units in the region, fluvial gravel, fluvial sand, paleosols, and lacustrine deposits.

Fluvial facies generally are characterized as relatively homogeneous accumulations of poorly consolidated sand and gravel showing little or no variation in ground water flow characteristics. Paleosol and lacustrine facies typically are portrayed as thick, laterally extensive, homogenous silt and clay deposits forming significant barriers to ground water movement. Where facies occur together, layer cake stratigraphies are commonly assumed.

Field observations however, generally indicate fluvial facies are well stratified and highly variable, containing intercalated finer grained lithologies, cemented intervals, and matrix mud which where present exert significant local control on ground water movement. On a larger scale, the distribution of channel bodies (e.g., laterally extensive sheets to narrow elongate ribbons) and erosion surfaces influence flow and transport characteristics. Paleosol facies typically contain intercalated fluvial facies. In such cases preserved channel tracts can produce preferred flow pathways through deposits that are otherwise relatively impermeable. Additional ground water flow complexities occur in suprabasalt sediments near interbasinal and intrabasinal structural highs. In these cases, stratigraphic units, like those dominated by lacustrine facies, which can form barriers to flow may be short circuited.

An understanding of the interplay between depositional systems and basin structure and tectonics is needed to guide the development of practical three-dimensional facies architecture from which actual ground water pathways and barriers can be delineated. Such facies models provide a superior basis upon which to base monitoring system design and numerical flow and transport modeling.

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Oral

The Hydrogeology of the Colfax area, Whitman County

K. Scott King[1]

The Colfax area includes the primarily agricultural district surrounding the City of Colfax in central Whitman county, eastern Washington. The area is in a semi-arid region of smooth rolling hills formed from loess deposits which overly Miocene basalts of the Columbia River Basalt Group. Groundwater has been an important resource in the area since the late 1800's. The City of Colfax, and virtually all of Whitman County, obtains all of its water needs from groundwater.

The area is within the eastern portion of the Columbia Plateau aquifer system. Two fractured basalt units comprise the most productive aquifers in the area - the Wanapum and the Grande Ronde units. Only limited quantities of groundwater have been exploited within the loess (Palouse formation) or other overburden units. The hydraulic conductivity of the basalt aquifers is variable, ranging from an average of about 2 ft/d to several thousand ft/day, and is controlled by secondary porosity. Groundwater flow is generally from the eastern basin margins westward toward the central Columbia basin. The Palouse loess exists in thicknesses of up to 300 feet, and the Wanapum varies in thickness up to about 250 ft thick. The underlying Grande Ronde outcrops in the Palouse River valley and is likely several thousand feet thick. Recharge occurs primarily through two mechanisms: broad areal infiltration of precipitation, and interaction with surface water.

The City of Colfax is located at the confluence of the north and south forks of the Palouse River in a canyon that is about 200 feet deep. Four municipal wells annually produce about 335 MG from the Grande Ronde unit. The Palouse river canyon and lateral canyons exert strong hydraulic influence on groundwater in the Wanapum basalt causing groundwater flow and discharge toward the Palouse River. Measurements in a municipal well, completed within the Grande Ronde 300 feet below the valley floor, indicate water levels 180 feet below the level of the river and demonstrate the confined nature of the Grande Ronde at depth. Artesian pressures also exits in the Grande Ronde unit at municipal wells 5 miles up the north fork valley where free flowing wells only 110 feet deep have provided the majority of Colfax's water supply for more than 80 years. At that location, a linear geologic feature transverse to regional flow is thought to enhance the wellfield productivity.

Management steps have been implemented in order to protect groundwater quality in the area, including a wellhead protection plan for the Colfax municipal wells and a critical recharge areas ordinance proposed by the county.

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Oral

The Origin of Saline Ground Water in the Duwamish Valley, King County, Washington.

Roy E. Jensen[1], K. Scott King[2], Keith A. Pine[3]

Saline ground water was discovered during a recent groundwater investigation of a site located in the Duwamish Valley near Seattle, Washington. The site is located adjacent to the Duwamish Waterway, which was straightened and deepened during the early 1900's. Ground water is present beneath the site in an unconfined aquifer consisting of a coarsing upward sequence of interbedded sand and silt with an average thickness of 80 feet. These sediment were deposited in a prograding deltaic-fluvial system deposited into a marine embayment. Underlying the aquifer is a marine silt and glacial till unit which acts as a confining layer with laboratory permeabilities of 10^{-6} cm/sec.

The upper portion of the aquifer consists of 50 feet of freshwater (<500 mg/L TDS) overlying 20 to 30 feet of saline water (10,000 to 20,000 mg/L TDS). The contact between the freshwater and saline layers is sharp. Groundwater flow in both layers is southwest towards the waterway. Tritium was not detected in the saline water (<0.8 T.U.) but was detected in the freshwater zone (5 T.U.). The absence of detectable tritium in the deep saline ground water indicates that the deeper ground water is significantly older than the freshwater layer. Deep saline water has been found at another site more than 1 mile from the waterway.

The saline stratification of the aquifer is not likely due to intrusion of saltwater from the "saltwater wedge" present in the Duwamish Waterway, because the position of the salt/freshwater interface would be much deeper and closer to the waterway. The hydrogeologic setting and data favor the hypothesis that the saline groundwater found at depth is ancient marine water trapped during sedimentation and has remained stabilized by the density contrast in the lower permeability zones of the aquifer. Upward diffusion of dissolved ions into the more actively flowing upper aquifer may have caused the lower dissolved concentrations compared to sea water. The occurrence of fresh water in what appears to be an equivalent deep aquifer suggests that the distribution of saline water may be controlled by a combination of stratigraphic conditions and hydraulic factors.

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Water Resources Policy and Management

Assessment and Protection of Sequim-Dungeness Aquifers

Ann Soule[1]

The Sequim-Dungeness area on the North Olympic Peninsula has been the focus of Clallam County's groundwater quality and hydrogeologic investigations for over seven years. This poster presents the history and status of groundwater quality and quantity protection in Eastern Clallam County, where aquifer resources provide essential drinking water, habitat, and agricultural benefits.

Much of the "Sequim prairie" has characteristically coarse soil, making underlying aquifers particularly susceptible to contamination from activities at the land surface. Monitoring data shows that certain localized areas have experienced increases in nitrate concentrations from 2.5 to over 10 mg/L since 1980. In addition, it is widely known that water is a critical resource in the area, playing a part in the decline of fish stocks in the Dungeness River. A multi-disciplinary advisory committee was established to develop a plan for preventing contamination and protecting regional aquifer resources. The Sequim-Dungeness Groundwater Protection Strategy, adopted by Clallam County in 1994, recommends actions directed to virtually every segment of the community. Significant recommendations include initiating inspection programs for water well construction and existing on-site sewage disposal systems; establishing "areas of special concern" where nitrate concentrations are documented to exceed 3 mg/L; studying the hydrogeology of the area to determine patterns of flow and availability; and establishing the County as the central data repository.

In a substantial effort to implement the Groundwater Protection Strategy, a comprehensive assessment of the hydrogeology is currently being conducted by the USGS in cooperation with Clallam County, Washington Department of Ecology, and the Jamestown S'Klallam Tribe. The assessment is scheduled to conclude in 1998. Many other recommendations of the Strategy involve additions or adjustments to current programs and regulations (including the Critical Aquifer Recharge Area ordinance), and ongoing support of key services.

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Oral

Causes, Recurrence Frequency, and Duration of Flooding Observed Near 192nd Street East and Canyon Road, Frederickson, Washington

Dan Matthews[1], Lori Herman[2]

The Frederickson industrial area experienced significant flooding this winter that covered major roadways, flooded water supply wells, and disrupted many businesses. Many large industrial facilities rely on the roads for access to this area which is Pierce County's largest industrial area outside of the Tacoma Tideflats. The nature and cause of the flooding, estimated recurrence frequency and potential flooding duration were studied as the first step in assisting the Port of Tacoma and the County with potential solutions. The uniqueness of this flood assessment is that the flooding was determined to be primarily a groundwater issue. This presentation will discuss the distinct hydrogeologic environment that lends itself to recurrent flooding and the precipitation correlation analyses which were used to assess the recurrence interval.

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Oral

Development of New Groundwater Supplies : Issues and Approaches to Mitigation of Streamflow Impacts

Robert H. Anderson[1], *David Banton*[2]

Water resource development in Washington has reached an impasse in recent years because surface waters are, in many cases, fully appropriated, particularly during the summer months when demand is high and streamflows low. Pressure to develop new groundwater resources continues to increase, but permitting of new groundwater sources is hampered by the interconnection of groundwater with surface water, or hydraulic continuity. Discussions continue on the definition of hydraulic continuity and approaches to demonstrating the degree of hydraulic continuity, but an adequate resolution, compatible with a prescribed regulatory framework, remains elusive. While recent basin assessments are a first step in the basin approach to water resource allocation, data are still lacking in most basins to allow a defensible final allocation or adjudication of water resources. Mitigation of streamflows remains a viable approach to developing new groundwater supplies in the near term, while broader issues of basin management continue to develop.

This paper addresses a number of issues and approaches in developing new groundwater supplies while maintaining adequate streamflows using mitigation. Broader issues are addressed including:

- How groundwater withdrawals can affect streamflows
- Streamflow regimes in the Pacific Northwest and their relationship to groundwater
- Permitting issues for approval of new groundwater withdrawals with mitigation
- Operation and management issues for groundwater supplies that utilize streamflow mitigation

Three specific mitigation approaches are described :

1. Direct augmentation of streamflows using groundwater
2. Direct augmentation of streamflows using surface water
3. Indirect augmentation of streamflows using artificial groundwater recharge

Discussion of these approaches includes examples of how these mitigation approaches have been applied in other areas and possible applications for various water supply scenarios in Washington.

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Oral

Erosion Control and Stormwater Management During Construction of a Large Semiconductor Chip Manufacturing Facility in Camas, Washington

Robert C. Leet[1] and Eli M. Caudill[2]

Erosion control and stormwater management are receiving increased attention due to the potential detrimental impacts of turbidity, siltation, and chemical discharges to surface waters. These impacts are typically mitigated at construction sites through the use of Best Management Practices (BMPs) such as slope stabilization, seeding, straw mulch, straw bale barriers, plastic sheeting, silt fencing, rock protection/stabilization, and stormwater detention ponds. Proper design, installation, and maintenance of these BMPs are critical to their effectiveness.

At the 70-acre WaferTech construction site in Camas, Washington (silicon chip fabrication plant), erosion control efforts have been complicated by several factors. These include fine-grained silt and clay soils, delayed construction of surface drainage features, and record rainfall amounts during winter 1996. As a result, the stormwater drainage system became overwhelmed and an adjacent creek and wetlands were impacted by turbid runoff and siltation. Corrective measures to prevent further impacts included repairs to existing BMPs, installation of new BMPs, and regular maintenance of the BMPs. Additional steps taken or evaluated to improve performance of the stormwater drainage system have included field tests of alternate erosion control matting and silt fence materials, field tests of mechanical filtration equipment, modifications to the stormwater detention ponds, and chemical (coagulant) treatment.

Analyses of stormwater samples from the site suggest that the turbidity of the runoff is caused by high concentrations of very small (non-settleable) sediment particles. Results of monthly water quality testing begun in November 1996 indicate that the turbidity of the adjacent creek and stormwater discharges from the site improved significantly from mid-December 1996 through April 1997. This improvement is presumably due to: 1) decreased rainfall; 2) decreased suspended sediment loads as the sediments introduced to the drainage system in November and December have settled out or been flushed from the system; and 3) decreased erosion as building and road construction progresses, earthwork is reduced, and erosion control BMPs continue to be implemented. Factors 1) and 3) should lead to continued improvement of stormwater quality as summer approaches and construction nears completion, hence no further impacts to surface waters are anticipated.

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Poster

Establishment and Documentation of the Port Madison Water Resources Basin, the Suquamish Tribe's First Step to a Pro-Active Water Resources Protection Strategy

David R. Fuller and Cherrie L. Crowell

The Suquamish Tribe has developed a pro-active water resource management strategy for the protection of the Port Madison Indian Reservation. The initial phase of this strategy was the documentation of a basin contributing waters to the Reservation and Grovers Creek Hatchery. Hence, the Port Madison Water Resources Basin is defined as an area, within which any impact to water poses a direct potential threat to the quality and/or quantity of waters flowing over, under or through the Port Madison Indian Reservation.

The establishment of the basin has been facilitated through integration of GIS, real-time GPS, and hydrogeologic software to gather, manage, interpret and display key elements of the basin. The initial elements of the basin documentation include mapping water well locations, aquifers, recharge areas, wetlands, springs and streams. Monitoring and analysis of water quality, flows, water level fluctuations in wetlands, precipitation, development of water budgets and numeric groundwater models have been underway for several years and are expanding. The expectation of this Basin approach, is that the Suquamish Tribe will be regularly included in the review and planning of activities being permitted within the Basin to pro-actively avoid significant impacts to Tribal and treaty-protected resources.

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CANCELLED

Oral

Identifying Ground-Water Threats from Improperly Abandoned Deep Boreholes

William P. Iverson[1], *and Robert F. Kubichek*[2]

Proper well abandonment procedures require complete sealing of the borehole to achieve protection of subsurface aquifers from shallow pollutants and deep contaminants such as saline waters or organic petroleum fluids. Ideally, for shallow wells, the casing is removed, and the well filled with plugging material. In the case of deep wells, however, the casing cannot be removed, and isolation of aquifers becomes difficult as both the annulus and the casing must be plugged. Without isolation, fresh water sources are in danger of slow and permanent contamination.

Cased wells over 1000 feet deep form the focus for this technology. In Washington State, thousands of abandoned boreholes exist, but most are shallow. Across the nation, the problem is even worse, especially in regions of former oil and gas production. Two general categories of problem wells are documented. First, old wells with little or no record of procedures used during abandonment. And second, decommissioned wells where records do exist, but suspect due to cost cutting economics at the time of abandonment, or simply the presence of local ongoing contamination. In any case, wells suspected of improper abandonment are normally found welded shut. Even when the cap is removed, a shallow cement plug often blocks access for wireline equipment that could definitively test the subsurface configuration. When suspicions are sufficiently high, the decision must eventually be made whether or not to drill out the surface plug and re-enter the well. The cost of such procedures unfortunately sways the decision, especially when numerous wells are involved and remediation results cannot be guaranteed. The need exists for accurate identification of improperly abandoned wells, without removing the welded cap or surface plug.

In our approach, a downgoing acoustic pulse is generated at the surface. The pulse propagates down the well casing and produces reflections at discontinuities (plugs) in the well. Upgoing reflected energy is detected by acoustic sensors at the surface and used to estimate plug size and location. To test the procedure, a dedicated borehole was constructed to evaluate acoustic sensors, data acquisition techniques, signal processing methods, and modes of wave propagation. Recorded signals are very complex, comprising both reflections and secondary reverberations. Computer simulations verify the propagation modes and data processing algorithms used to interpret these data. Seven field tests (to date of writing) on various abandoned wells have been completed, demonstrating that data acquisition procedures are the most crucial for producing interpretable results. Boreholes with no cement are easily identified with such acoustic pulses. Work continues on partially plugged wells.

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Poster

Proposed Guidelines for Sanitary Control Area Determination for New Public Water System Wells

John Littler[1], Curtis Koger[2], Derek Sandison[3], and David Jennings[4]

Current Washington State Department of Health (WDOH) Sanitary Control Area (SCA) guidelines require a minimum radius of 100 feet around wellheads. The purveyor controls the land use and access to the wells within this radius so that the integrity of the source can be maintained. This is assured through the provision of protective covenants. Source vulnerability differs from site to site and a set radius of 100 feet may not be applicable in all cases. Draft guidance is under consideration by WDOH to implement changes to the existing SCA requirements in an effort to take source vulnerability into account during the source approval process for new public water supply wells.

The SCA around wellheads has two components, physical protection and contaminant risk reduction. Physical protection needs are defined by the minimum area necessary to protect the well from physical damage. Contaminant risk reduction is based on an assessment of vulnerability. The results of a susceptibility assessment are combined with a contaminant risk assessment to determine the vulnerability category for a well. The susceptibility analysis is based on existing guidance developed by WDOH to support wellhead protection planning efforts. Contaminant risk is quantified using an empirical method incorporating risk factors such as location of potential sources of contamination and mitigation measures available to the purveyor.

No reduction in SCA is considered appropriate for Category I (highest level of concern) settings, instead increased SCA requirements would be possible. Category 2 represents a moderate level of concern and standard default values are used in determination of the SCA. Category 3 settings have a low level of concern and the SCA may be reduced up to a maximum of 50 percent, provided mitigation measures will provide a level of public health protection equivalent to the standard SCA.

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Oral

Washington State Department of Ecology vs. Applicants to Appropriate Public Ground Waters: A Personal Perspective

John B. Noble

The allocation of the State's waters, both surface and ground, is the responsibility of the Washington State Department of Ecology. By law, before issuing a permit to an applicant who requests a right to the water, Ecology must determine that: (1) water is available, (2) its use will not impair existing rights, (3) it will be put to beneficial use, and (4) the allocation will not be detrimental to the public interest.

In January 1996, Ecology issued absolute denials to scores of applications for ground water, some of which had been awaiting approval for nearly ten years. These denials related to wells that would be drilled within hydrologic basins of certain "closed" or "controlled" streams. The rationale for denial was that existing rights would be impaired; the existing rights typically were those established for instream flows.

The denials generated many legal appeals, all of which were rejected by the State's Hearings Board. This concurrence of the denials effectively shut down further permits to use State ground water in the affected basins. If extended, the decisions may apply to many other basins where applications are still in limbo. In total, most of the State would ultimately be affected.

The denials are a result of a change of interpretation of State administrative rules from what was originally intended when the rules were adopted. Arguments presented during appeals called upon practical hydrogeologic theory --- as it pertains to ground-water/surface-water interaction, including aspects of seasonality and storage -- and were subsequently all rejected. While basic hydrogeologic analyses could show -- or also could deny -- that the applied-for ground water will not *adversely* deplete the associated surface water, Ecology has rejected such analyses. Instead of using hydrogeologic analyses, Ecology has adopted the literal position that, because of the pumping of a well, when a drop of water that *would* have entered a stream does *not*, that lost drop of water is an impairment of existing rights. Therefore, the right to use the ground water shall be denied. As a result of adopting this position and rejecting hydrogeologic analyses, Ecology now has a very easy task in water resources management; this is, simply, management by denial.

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Olympia Hydrogeology

Glacial Stratigraphy, Liquefaction, and Ground-Motion Amplification Studies in the Olympia, Washington, Area

Timothy J. Walsh[1], Wendy J. Gerstel[1], Stephen P. Palmer[1]

As part of a project to produce maps of earthquake-induced liquefaction and ground-motion amplification for the Olympia-Lacey-Tumwater urban growth area, we are updating the area's geologic mapping at a scale of 1:24,000. Much of the area is underlain by sediments previously mapped as Vashon recessional outwash sand and gravel, including a mappable unit of silt and well sorted fine-to-medium-grained sand. Outwash streams originating from the continental ice sheet would have flowed southward into the Chehalis River, but paleocurrent indicators in the sand are generally northward-directed. We suggest that, as glacial ice retreated north from the Olympia area, previously formed subglacial meltwater channels eroded into the earlier Pleistocene tills, outwash deposits, and bedrock became arms of a lake (for instance, glacial Lake Russell) that lay in present-day Puget Sound. Drainage reorganized to flow northward through the fresh outwash plain into the lake. Because the streams were lower energy than the outwash streams, only sand and silt were transported and deposited in deltas prograding northward into the arms of the lake, which are presently the southernmost inlets of Puget Sound. (For a more thorough discussion of the subglacial channel network, see Booth, D.B., 1994, Geology, v. 22, p.695-698.) The thickness of this sand varies substantially throughout the area, reaching more than 100 feet. Lacustrine silts (and rare clays and peats) commonly overlie these sands, particularly on the uplands dividing the Puget Sound inlets.

We suggest that the extent and thickness of these channel-fill sands, which are poorly consolidated and tend to have high impedance contrasts with underlying glacial deposits, are important factors in determining areas with significant shallow ground-motion amplification. Previous investigators have shown that earthquake intensities are greater in areas of Olympia underlain by this sand unit than in the area as a whole. Also, because the sands are loose to medium-dense and granular, we suspect that they may be subject to earthquake-induced liquefaction where they are saturated.

Geotechnical borings, water well logs, and geophysical data supplement field information and to develop cross sections to give a three-dimensional view of the distribution of these deposits and the configuration of the basin at the time of Vashon ice retreat. We are measuring shear wave velocities in recently-drilled borings to characterize the local stratigraphy and establish geologically constrained shear velocity profiles with which to model ground-motion amplification. We will use this information to compile seismic hazard zonation maps for the south Puget Sound region. These new maps and the three-dimensional model could also be useful in modeling ground water transport within the basin.

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The Ethnohydrology of Olympia

Nadine L. Romero[1]

The term, "ethnohydrology" was first introduced in 1981 by Bill Back with the U.S. Geological Survey in a paper entitled, "Hydromythology and Ethnohydrology in the New World."[2] It is a term used to describe how the science of hydrology, the observation and interpretation of hydrologic phenomena, was applied to solve practical problems of water use and management by ancient people. Back contends that the first peoples of the Western Hemisphere used their water resources to develop diverse civilizations and the rise of such civilizations was ***hydrologically*** influenced. Etiological (creation) myths were developed to explain natural phenomena and it was primarily through religion that water management was first practiced.

Research conducted for this paper using pioneer chronicles, newspapers and other historical accounts reveals Olympia's unique ethnohydrologic history, beginning with the first peoples of the Puget Sound, through the early pioneers, and up to present-day Olympians. Coastal tribes had a variety of etiological myths to explain the occurrence of complex hydrologic systems in the Puget Sound and they conceptualized ground water and springs as *finite* supplies which could become contaminated. Even in a region of high precipitation, more than 55 inches per year, struggles for water are pervasive in tribal folklore prior to European arrival. Clues to previous hydrologic landscapes and sea-level rise can be found in many etiological myths.

In Olympia pioneer times, the Indian Wars of 1856-1858 profoundly shaped the state's history and were due in part to conflicts at an artesian spring on 4th and Main street. The first artesian wells were drilled in Olympia in the 1870's as respite from higher water taxes, establishing Olympia's artesian legacy, and paving the way for the founding of the Olympia Brewery in 1896 ("Its the Water"). Today Olympians still marvel at the phenomena of flowing artesian wells and some marvel with the belief that the water comes from an underground stream (hydromythology) . More than any previous time in history, however, the public seeks education on the science of ground water in an effort to understand this highly controversial resource.

Although this paper may appear to center around a more anthropological approach to hydrology, the importance of understanding cultural evolution and its relationship to water is even far more important today. From a historical context we can glean much about natural systems and their response to human impacts. Most importantly we gain an informed perspective about where to go in the future.

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[2] Water Resources Research, Vol. 17, no.2, p257-287, April 1981

Oral

WELLHEAD PROTECTION FOR SMALL, URBAN, GROUP A WATER SYSTEMS - A CASE STUDY

William E. Halbert

The Spar Cafe and King Solomon's Reef Restaurant are small Group A, non-transient, non-community water systems in downtown Olympia, Washington. Located on 4th Avenue about one city block apart, both restaurants are served by small diameter, artesian water supply wells located on the premises. Both water systems are at least 60 years old, and a restaurant has been located on the Spar property since at least 1885.

Recently, both water systems entered into Agreed Orders with the Washington State Department of Health, Southwest Drinking Water Division, to evaluate the construction of the wells and source of the water, develop wellhead protection plans for both systems and bring the systems into substantial compliance with State regulations for Group A water systems.

This talk will focus on the hydrogeology of the artesian aquifer underlying downtown Olympia, the distribution and condition of other artesian wells in the downtown area, the wellhead protection plan developed by the water systems, upgrades made to the water systems to bring them into compliance and current monitoring requirements of the water systems.

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Ground Water Modeling

Oral

Evaluating the Risks of Potential Contaminants in Well Field Protection

Jack Wittman[1]

Much of the attention given to wellhead protection by hydrologists has understandably been focused on the delineation of the wellhead protection area (WHPA). While defining these areas is by no means a simple task, it is relatively straightforward when compared to designing a rational management plan. One of the problems of developing a management plan is that the degree of restriction on activities within the wellhead protection area should somehow be related to the risk these activities may pose to the water supply. There are very few methods of differentiating among the risks potential contaminant sources can pose to a well that are useful for planning teams working to guide the process.

In an attempt to frame this problem for a community planning team, three different analyses were completed. They included: 1) comparative one-dimensional transport modeling of compounds with different properties, 2) development of a chemical risk index that incorporates toxicity and mobility, 3) modeling chemical releases in a capture zone of a well. These analyses together indicated that it is possible for small quantity releases of some compounds to cause serious water quality problems for a drinking water supply well.

These three analyses provided the background for recommendations for quantity limitations of potential contaminants within the delineated 1 and 5-year time of travel capture zones of the community water supply wells. The actual risk posed by any facility is, of course, also related to the management of the facility and the hydrogeologic setting. This work was designed to determine how to assess the threat posed by different facilities in a similar hydrogeologic setting.

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Simulation of Groundwater Flow and Solute Transport Around the Milwaukee Waterway Confined Disposal Facility

Richard J. Martin [1] *and Richard Gilmur* [2]

Groundwater flow and solute transport models were used to assess potential movement of copper, lead, and nickel from a confined disposal facility (CDF) to adjacent surface water receptors at the Port of Tacoma, Washington. The CDF was constructed by placing a berm of clean sediments across the mouth of the Milwaukee Waterway, then in-filling with contaminated sediments dredged from the Sitcum and Blair Waterways, located in Commencement Bay. As groundwater moves through the CDF, metals on the contaminated sediments will dissolve into groundwater and may move off-site.

A single layer groundwater flow model was constructed using MODFLOW to evaluate changes in the flow regime between pre- and post-construction conditions. The model included simulating the influence of tidal fluctuations in adjacent surface water bodies on groundwater levels. The pre-construction model adequately simulated the magnitude of observed groundwater fluctuations, including hydraulic gradient reversals, associated with tidal fluctuations. The post-construction simulation was developed by modifying the model to account for filling of the Milwaukee Waterway and assigning appropriate aquifer parameters based on characteristics of the dredged sediments. The model predicted a somewhat radial flow regime around the CDF with flow from the center of the CDF to adjacent surface water bodies.

The post-construction flow model results were then used in conjunction with the solute transport code MT3D to estimate advective transport velocities over the model domain. The affects of hydrodynamic dispersion over the whole model domain could not be included because the particle tracking methods used by MT3D when dispersion is active resulted in large mass-balance errors. Instead, the advective transport velocities were used to construct three one-dimensional solute transport models along selected pathways from the CDF to adjacent surface water receptors, and included the affects of longitudinal dispersion and chemical reactions.

The results of the solute transport models indicate that the dissolved metals will move very slowly towards surface water receptors. Comparison of model predictions to applicable surface water quality criteria suggest that metal concentrations in groundwater may exceed criteria within 100 feet of a surface water receptor after 200 years. The slow movement of metals is a result of hydraulic gradient reversals due to tidal fluctuations, resulting in a low net advective velocity, and chemical reactions that will cause the metals to be adsorbed onto the soils between the CDF and the surface water receptors.

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Ground Water Sampling Techniques

Oral

Improved Ground Water Sampling Procedure And Data Interpretation For Low Solubility/Mobility Contaminants

Matthew G. Dalton[1], Terry L. Olmsted[1]

On many sites, a wide variety of field and laboratory ground-water sample analyses are completed including analyses for pH, electrical conductivity, temperature, volatile and semivolatile organic compounds, pesticides and polychlorinated biphenyls (PCBs), metals and petroleum hydrocarbons. The chemicals that are typically analyzed have a wide range of aqueous solubilities and mobilities in ground water systems.

Historical ground-water quality data is often available for a site that indicates a large variation in analyte concentrations for the same sampling location or relatively high concentrations that are assumed to be "dissolved" with the ability to migrate in ground water. Wide variability in the concentrations of volatile organic compounds is often assumed to be the result of sample handling that causes lose of the analyte by evaporation or other means. However, our experience indicates that many practitioners do not understand how sampling may cause unreliability high concentrations and/or wide concentration variability in analytes such as lead, PCBs or heavy-oil hydrocarbons that typically have low solubility and mobility in ground water. Often, especially on industrial sites, monitor wells are installed in soils/fills of variable physical and chemical composition where low solubility/mobility contaminants of concern are present. Unreliable sample analyses will result if these chemicals are present in the materials that surround a well screen and soil particles are entrained in the samples sent to the laboratory.

Low flow/low turbidity sampling techniques should be used to collect ground water samples for analysis of low solubility/mobility contaminants of concern. Typically, the procedure consists of purging the well at a low rate (0.5 to 1 liter/minute) and measuring, along with other field parameters, turbidity. Samples are obtained after field parameters stabilize and a low sample turbidity is achieved.

A comparison of data on several sites for several metals, PCBs and petroleum hydrocarbons indicates that the sampling procedure substantially reduces both the concentration and concentration variability of low solubility/mobility contaminants of concern. The procedure also reduces the need for filtering prior to laboratory analysis that can alter the sample results and often is not accepted by regulatory agencies.

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Oral

Observations on the Results of Metal Analysis of Filtered and Unfiltered Ground Water Samples

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Comparisons were made of the results of metals analysis of filtered and unfiltered water samples collected as part of a groundwater investigation at a site in the Duwamish Valley near Seattle, Washington. Sampled groundwater occurs in a 60 to 70 feet thick unconfined aquifer consisting of interbedded fine sand to silty sand with an average hydraulic conductivity of 10^{-3} cm/sec. Ground water samples were collected using a combination of 2-inch monitoring wells and push probes. Purging and sampling from the wells were initially conducted using bailers or submersible pumps and switched to using "low-flow" sampling with peristaltic pumps. Selected metals and water quality parameters were analyzed from both unfiltered and filtered water samples. Samples were filtered in the field using disposable 0.45 micron filter cartridges.

The data was evaluated using graphical and statistical methods to determine the relationship between unfiltered and filtered metal concentrations. There was little or no difference between unfiltered and filtered samples using low-flow well sampling techniques but significant differences when samples were collected using a push probe, or using bailer or pumps at relatively high flow rates. The elevated unfiltered metal concentrations are due to an artifact of the sampling method. Suspended material causes unfiltered metal concentrations in the water sample to be significantly higher than the corresponding filtered metal concentrations. Push probe sampling and well sampling with bailers and high flow pumps allow normally immobile particles of the aquifer matrix to be entrained in the sample causing a concomitant increase in unfiltered metal concentrations over filtered metal concentrations. Apparently, push probe sampling techniques cause disruptions of the native soil media during the placement of the probe. Push probes do not employ measures such as filter packs, purging and low-flow sampling techniques that can be used in wells to ensure lower particle concentrations in the collected sample. Analysis of unfiltered ground water samples collected from push probes may result in high metals concentrations that are not representative of the true concentrations in ambient groundwater.

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Oral

Organic Carbon Sampling and Analytical Method Comparison

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The magnitude of sorption is a critical parameter in determining site specific soil clean-up levels which are protective of groundwater. Sorption of hydrophobic organic chemicals (HOC) can be predicted from the fraction organic carbon (f_{OC}) content (also expressed as total organic carbon, TOC). Thus, accurate TOC measurements are of particular importance in site remediation. The specific goals of this work were: to review the four standard TOC analytical approaches; to conduct a method comparison of the two approaches which are most appropriate for subsurface materials; and, to address TOC sampling and preparation effects using field samples from Yakima, WA. The six samples used in the method comparison test had varying proportions of TOC and carbonate (inorganic carbon, IC) contents and were obtained from various geologic deposits.

There are four basic approaches to measuring TOC in soils and sediments: 1) total carbon, often as mass loss on ignition, 2) the difference method, determined as the difference between direct measurements of total carbon (TC) and IC, 3) pre-acidification prior to direct measurement of TOC, and 4) wet oxidation. Approach (1) is only accurate for samples with negligible IC because TOC is assumed to equal TC (high TOC is also required for mass loss method). Wet oxidation (approach (4)) does not generally result in complete oxidation of refractory organic matter, thus can underestimate the true TOC for subsurface samples. Therefore, only approaches (2) and (3) are appropriate for low TOC, subsurface samples. The method comparison focussed on demonstrating the applicability and limitations of the difference method and comparing different pre-acidification treatments (H_2SO_3, HCl). High temperature combustion under pure oxygen was used to evolve CO_2 for the TOC and TC analyses and acidification was used to evolve CO_2 for IC analyses. A coulometric detector was used to quantify CO_2 for all analytical determinations.

The method comparison demonstrated that:

- the difference method yielded accurate TOC values for all samples (including test samples from Yakima and Pullman, WA) *except* for the samples with IC » TOC;
- the pre-acidification method using sulfurous acid showed the lowest analytical errors.

The Yakima sample results show that exclusion of coarse grain-sizes during field sampling and/or laboratory subsampling can cause significant over-estimation of TOC (by 100 to 400%) for aquifer sediments from Yakima. The results of this study provide basic information for: evaluating the quality of TOC analyses, and selecting appropriate sampling and analytical methods for particular geologic materials.

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Oral

Sampling Irrigation Wasteways, Surface and Subsurface Drains to Monitor Ground-Water Quality in the Quincy-Pasco Basins, Washington

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In the Quincy-Pasco Basins, trends in concentrations of nitrate and other dissolved constituents in ground water can be monitored by sampling base flows in irrigation wasteways and surface drains during the winter months. During winter, when irrigation water is not delivered to farms and storms large enough to produce runoff are infrequent, water in wasteways and surface drains is derived entirely from ground-water discharges. Therefore, the concentration of any dissolved constituent in the water represents an average of concentrations in those discharges. Thus, a sample collected in winter from a wasteway or surface drain can substitute for many samples from individual wells.

Discharges from subsurface drains also can be sampled to assess the quality of ground water. Subsurface drains, which are installed beneath cropland to maintain the water table below the root zone, collect mostly shallow ground water moving along short flowpaths, whereas ground water that enters wasteways and surface drains moves along flowpaths of widely varying lengths. Wasteways and surface drains typically integrate a larger volume of ground water than subsurface drains.

The U.S. Geological Survey found that mean concentrations of nitrate, chloride, and the pesticides atrazine, metribuzin, and simazine were similar among samples from monitoring wells, subsurface drains, and wasteways and surface drains sampled during winter; in many instances these concentrations were not statistically different. Concentrations in samples from wells usually had the greatest variance because these samples represent only a small part of the aquifer. Because waters in wasteways and surface drains represent the largest volumes of ground water, concentrations in these samples usually had the least variance.

In most parts of the Quincy-Pasco Basins, concentrations of nitrate in base flows in wasteways and surface drains have increased since the 1960s – indicating an increase in nitrate concentrations in ground water. For example, from 1966 through 1990, base-flow concentrations of nitrate in Frenchman Hills Wasteway doubled from about 3 to about 6 milligrams per liter. However, not all trends are up. The concentration of nitrate in Crab Creek Lateral during base flow decreased from about 8 milligrams per liter in 1966 to about 6 milligrams per liter in 1991. This decrease is likely the result of an increase in the percentage of orchards planted, requiring less nitrogen than many row crops, and an increase in the use of sprinkler irrigation systems.

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Poster

The Effects of Temperature Increases on VOC Sample Results Using the Grundfos Redi-Flo2 Submersible Sampling Pump

Judith K. Radloff[1] *and Jeffery H. Randall*[2]

A field case study was conducted at the closed Bainbridge Island Landfill to evaluate temperature effects of sampling with the Grundfos Redi-Flo2 submersible sampling pump. The study focused on VOC sample results because of the tendency of the pumps to heat the discharge water by their water-cooled design and because VOCs are a contaminant of concern at landfill sites. Sample results were compared to samples obtained using bailers, the approved sampling method for the RI under MTCA. Eleven two-inch PVC monitoring wells were installed at the closed landfill site. The depth to groundwater ranges from 60 to 145 feet below the ground surface and the unconfined aquifer generally consists of clean fine sand with an average hydraulic conductivity of 5×10^{-3} cm/sec. Low-level VOCs were detected in the first round of samples collected using bailers in June and August 1996. In September 1996, dedicated Grundfos Redi-Flo2 pumps were installed in the wells. Prior to pump installation, aquifer temperature was measured in-situ using thermistors in Geokon pressure transducers. Purge rates ranged from 0.5 to 1 gallon per minute while sampling rates ranged from 0.4 to 1.2 liters per minute. Discharge temperature was observed to increase as the pumping rate decreases, as pumping proceeds over time at a low pumping rate, and with increasing hydraulic head. A smaller temperature increase of discharge over in-situ water was observed in samples obtained using bailers. The results indicated that a sample temperature increase of between 2 and 4.5 degrees Celsius over the in-situ groundwater temperature does not result in lower VOC recoveries compared with recoveries obtained using stainless steel bailers. In addition, a sample with a temperature increase of 4.5 degrees Celsius over in-situ showed little or no decrease in VOC concentrations over a sample with a 2 degrees Celsius over in-situ increase.

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Oral

The No-Purge Scenario

(A Review of Current Research)

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Abstract

Obtaining *representative* groundwater samples, without benefit of well purging, from most groundwater monitoring wells using newly designed sampling equipment is now possible. A review of current published and unpublished literature has revealed a new, growing, and viable trend in the groundwater investigation industry. Owing to the most recent move in both government and the private sector to spend less on environmental clean-up activities, and since the act of purging is, in and of itself a very costly enterprise, the no-purge scenario is gaining wide acceptance. Recent studies conducted at sites in several states have all reached the same conclusion; that purging a groundwater monitoring well when using a sampling instrument capable of obtaining depth-discrete samples is unnecessary in order to obtain a *representative* sample.

In an attempt to obtain *representative* samples of groundwater from beneath any site, environmental investigators have had to deal with many variables. The variables included in their scrutiny are proper well construction, consideration of parameters to be sampled for, appropriate selection of sampling device, and the methods employed to retrieve a *representative* sample. Researchers, groundwater scientists and environmental engineers have dealt with the problems of proper well construction, but the reminder of the variables have been dealt with only cursorily...until very recently.

The results of recent studies suggest that the no-purge method is both a valid alternative to the method(s) commonly accepted as standard practice for UST and CERCLA sites in much of the United States, and will provide data which is adequate to superior, ensuring environmentally protective risk management and decision making at the great majority of sites. One study compared the concentrations of BTEX compounds, MTBE, and TPH-g in samples taken prior to purging and again immediately following purging. The results are based on nearly 5000 analytical measurements from 556 wells at more than 100 sites. Another smaller study compared the concentrations of carbon tetrachloride, trichloroethane, trichloroethylene, and radio nuclide contaminants in samples taken prior to purging and again immediately following purging. The results from all studies have concluded that purging is an unnecessary action in most groundwater monitoring wells.

Ground Water Investigative Techniques

Oral

An Evaluation of Groundwater Utilization Within the Snohomish County Groundwater Management Area Using GIS

Ken Brettmann[1], Mark Cunnane[1], Rip Heminway[2]

A case study is presented in which the Geographical Information System (GIS) ARC/INFO was used to support the development of a Groundwater Management Plan (GWMP) for the Snohomish County Groundwater Management Area (GWMA). The Snohomish County GWMA covers an area of 850 mi^2 located between the western edge of the Cascade Mountains and Puget Sound. The GWMA has a population of nearly 500,000 and supports a wide variety of land use activities and population densities.

A key component of the GWMP was to evaluate groundwater utilization within the Snohomish County GWMA. The use of groundwater for water supply is limited by both groundwater recharge and by instream flow requirements. Because groundwater discharge to streams helps to sustain seasonally low flows in the summer, groundwater withdrawals for supply purposes have the potential to impact summer streamflows within the GWMA. An evaluation of proposed groundwater consumption within the GWMA provides important information that can be used to assess the future availability of groundwater for water supply purposes.

The analysis was performed at a sub-basin scale by dividing the GWMA into 64 areas based on surface water drainage boundaries. GIS represented an excellent analysis tool for the groundwater utilization study because of an abundance of readily available data in GIS format. The following types of GIS coverage's were used in the analysis: 1) groundwater recharge from precipitation; 2) future land use; 3) surface water drainage boundaries; 4) water district boundaries; and, 5) a delineation of future sewered areas. The consumptive use of groundwater within each sub-basin was computed based on future land use while considering the sources of water supply (water district boundaries), the use of surface water or groundwater, and the distribution of sanitary sewers. Each land use designation was assigned a water use rate based on the type of activity (e.g., residential, commercial, agricultural) and the level (density) of activity. GIS coverage showing the extent of current and proposed sewer service boundaries was used to distinguish between areas where wastewater is conveyed off-site to a treatment facility and areas where wastewater is treated on-site and infiltrated using drainfields.

An index describing the proportion of total groundwater recharge that is used consumptively was calculated for each sub-basin. Sub-basins with the highest relative groundwater consumptive use are areas that: 1) have a moderately dense population; 2) depend on groundwater for water supply; and 3) are served by sanitary sewers.

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CANCELLED

Oral

Can Teachers and Their Students Do Hydrogeological Research?

John Field[1]

The Washington Earth Science Initiative is a three week summer institute providing science teachers (Grades 5-12) with the necessary background information and skills to conduct investigations related to watershed management, groundwater resources, and natural geological hazards. During the first week of the institute the teachers learn about these topics through field trips and presentations led by hydrogeological professionals. The teachers become directly involved in researching hydrogeological problems in the second week by undertaking independent investigations or by working as an intern with local agencies. Projects range from internships with the Department of Ecology investigating nitrate contamination in groundwater to independent investigations of modifications along stream channels responding to habitat restoration efforts. The final week of the institute focuses on how to continue the teachers' research with their students. Involving teachers and their students in local hydrogeological research is motivating and relevant for the students, provides valuable and useful data for local agencies, and leads to a better educated citizenry that understands the critical need for hydrogeological research in the state. The Washington Earth Science Initiative has to now focused on issues in northwestern Washington but there are plans to offer teacher institutes throughout the state in coming summers.

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Conceptual and MODFLOW Model Applications to Predicting Ground Water Discharge to Saline, Coastal Settings

Kristine Uhlman CGWP, CPG(1)

Industrial development along the glacially derived fjords and deep water sea inlets of the Pacific Northwest are the result of the global access these natural transportation corridors allow. The hydrologic setting of these areas, however, are dynamic and complex due to tidal and saline water influence, in addition to the complexity introduced by the changes to the historic surface water drainage pattern imposed by industrial site development. A typical coastal industrial facility is constructed on 'made' land; dredged fill over natural mud flats overlaying thicker, glacial outwash significantly influenced by tidal fluctuations. Shallow creeks and other drainage features across the older mud flats are typically filled, surface topography remains subtle, and industrial structures extend across a spit of artificial land adjacent to the deep, shipping channel. Ground water is found within these three typical subsurface zones: the shallow, often perched dredged sediment and artificial fill aquifer; a confining, often aerially discontinuous natural mud flat of silt and clay; and, a confined and often cyclically artesian aquifer. The transport characteristics of environmental contaminants in ground water, and the eventual discharge of impacted ground water to the sediments and waters of the coast, are important to characterize.

In the coastal setting where saline oceanic water is in contact with fresh surface and ground water, the less-dense fresh waters float above the more-dense saline water. The Dupuit-Ghyben-Herzberg (DGH) mathematical model describes the depth to the salt water / fresh water interface in coastal aquifers, and the interface is generally found at a ratio of 40:1, i.e. for every one foot of fresh ground water elevation above sea level, forty feet of fresh water is found at depth below sea level. The vertical and horizontal extent of the mixing zone between the fresh and saline water is directly related to the amount of physical agitation induced by tidal fluctuations, which can exceed fifteen feet in the Seattle area. With shallow ground water typically only a few feet above sea level, flow will be downward and outward under topographically-induced gradients, and then upward along the DGH interface, with the thin lens of fresh water ultimately discharging along the coastline.

A series of MODFLOW based models were constructed to evaluate flow pathlines within the fresh water lens during maximum tidal fluctuations. It was found that because the aquifer system cycles from perched to artesian/confined conditions depending on tidal elevation, the resultant simulated vertical gradients are stronger during high tide, driving ground water flow inland and upwards and retaining contaminants within the shallow zones. At low tide, vertical drainage under a gravity head in the perched system remains basically constant. The MODFLOW predicted flow rates and calculated flux of discharged contaminants were consistent with observed field conditions, and the modeling tool was found to be important to the understanding of the complex, dynamic and transient natural hydrologic system.

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Poster

Field Measurement and Application of Volatile Contaminant Rebound Concentrations in the Vadose Zone

Jon Fancher[1] and Virginia Rohay[2]

To evaluate the increase, or the rebound, in subsurface carbon tetrachloride vapor-phase concentrations following shutdown of soil vapor extraction systems, soil gas concentrations are being monitored at 90 wells and probes in the vadose zone. The lateral and vertical extent of the rebound concentrations will be used to indicate the distribution of remaining contaminant sources. The magnitude and rate of the concentration rebound will be used to optimize future soil vapor extraction system operations.

The study area encompasses approximately 0.2 km^2 at the Hanford Site in south-central Washington and includes the primary carbon tetrachloride disposal sites. The vadose zone consists of 66 m of relatively permeable sands and gravels interrupted from approximately 35 to 45 m depth by a less permeable interval of silt, fine sand, and carbonate-cemented sandy gravel ("caliche"). Carbon tetrachloride was found throughout the vadose zone underlying these disposal sites during site characterization in 1992 and 1993. Vertically, the highest concentrations were associated with the fine-grained, less permeable units. Soil vapor extraction was initiated in 1992; carbon tetrachloride concentrations in extracted soil vapor have decreased from approximately 30,000 ppmv initially to 30 ppmv in 1996.

Soil gas samples are collected from both vapor extraction wells and soil gas probes. To sample 12 of the wells, sampling tubes were emplaced to the depth of the open interval, and the wells were sealed at the surface. Another 15 wells are sampled directly at the wellhead during natural venting episodes when barometric pressure is low; these wells were sealed when not being sampled. Open intervals in the wells range from 23 to 63 m in depth. Samples are also collected through 10 sampling tubes which were strapped to the outside of well casings during installation and are open at depths ranging from 16 to 64 m. The subsurface soil gas probes include sampling tubes that extend to the surface; 25 probes are shallow (1.5 m deep) and 28 probes, emplaced using a cone penetrometer, are deep (9 to 36 m). Sampling tubes at both wells and probes are purged prior to sample collection using a low-flow pump.

The highest carbon tetrachloride rebound concentrations, between 100 and 700 ppmv, have been measured in wells and probes open near the less permeable fine-grained soils and caliche layer. Maximum rebound concentrations observed in samples from the higher permeability sands and gravels have been less than 100 ppmv. Soil gas concentrations monitored from wells may be significantly affected by fluctuations in barometric pressure.

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Groundwater Contaminant Monitoring along the Columbia River Hanford Site, Washington, Using Aquifer Sampling Tubes

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Direct push, i.e., Geoprobe®-type methods were developed for installation of 49 aquifer sampling tubes (tubes) at 18 locations along Columbia River shoreline of Hanford Site, Washington to monitor contamination moving with groundwater from retired plutonium-production reactor areas, across the shoreline, and into the river. Tube installation coincided with investigations that used divers to sample pore water in salmon-spawning habitat of the Hanford Reach near retired plutonium-production reactor areas. Tubes were installed during October through December of 1995 to sample groundwater at the same horizons (elevations) as sampled by the divers in the river. All tube installations survived the winter (1995) and spring(1996) high river discharge conditions. Many of the tube locations have been configured to allow sampling during high-river stage conditions.

Each tube consists of a six inch-long Geoprobe® stainless steel wire mesh soil gas implant (the tube "well screen") connected to low-density polyethylene tubing that extends to the surface. Single tube and multiple "nested" tube installations are used to sample groundwater at different depths in the aquifer at most locations. A peristaltic pump is used to sample the tubes. Conductivity measurements made after purging were used to assess if the tube completion depth was sufficient to intercept groundwater. Tubes are completed at depths ranging from 5 to 31 ft below grade in the Hanford and Ringold Formations.

A 1-inch outside diameter probe rod is used for single depth tube installation. A 1.375-inch outside diameter probe rod allowed multiple depth "nested" tube installations in a single probe hole. The probe rod is removed as the tube is installed. Native material collapses around the tube as the probe rod is removed and no additional seal is necessary. Truck-mounted Geoprobe® equipment was used to install the tubes where terrain permitted vehicle access. Areas with steep slopes and narrow shorelines precluded use of truck-mounted equipment. Pneumatic and hand-carried equipment was used in those locations. Maximum tube completion depths were the same in both instances. However, "nested" completions using the larger 1.375-inch outside diameter probe rod were not attempted with manual-pneumatic methods.

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Poster

Increasing Utility of Well-Log Records through Precision Well-Head Location and Graphical Depiction

Lanny H. Fisk, Jon A. Cole, Carmen Prada and Bryce E. Cole[1]

Borehole lithology and water table observations can provide useful hydrogeologic information for water management decisions. Limited budgets and land ownership constraints often restrict collection of more refined and directly useful information. Well-log records from previous decades may be available in significant numbers, though all too often with less than adequate supporting data. Only approximately known relative locations and elevations of well heads, combined with other recorded well-log information of dubious value, can minimize well-log utility in hydrogeologic investigations. Wells located by section or quarter-section are grossly inadequate for drawing a realistic picture of subsurface lithologic patterns resulting from basin deposition. USGS quadrangle sheets may be helpful in approximately locating a well only when the containing section or quarter-section is sparsely populated.

Global positioning system (GPS) locations by Novatel RT-2 antennas can establish of well-head positions with centimeter accuracy. Differential GPS measurements at the well-head, with property owner's permission, establish the public record well-log position with more than sufficient accuracy. Limitations still exist if access to the well-head is denied by the property owner or when well log information has been inaccurately reported. Even so, information collected from adjacent public roadways provides greater certainty of well-head location and is potentially more useful to lithologic studies.

Once well-heads are precisely located by GPS, fence diagram software can be utilized to accurately depict spatial relationships of lithologies from existing records. The resulting representations have far greater reliability and utility than cross-sections based on inaccurately located wells. From previous studies of a limited suite of well logs from the Walla Walla Basin in SE Washington and NE Oregon, only a generalized picture of the basin-fill sequence is available based largely on a few cross-sections. We are testing commercially available software packages to determine the most appropriate graphical depictions of spatial and temporal sediment distribution in this basin. Our preliminary results show that the depositional history is far more complex than previously thought and that the shallow "gravel aquifer" is not the homogeneous, single aquifer of previous workers. Fence diagrams provide graphic representation of the extent, thickness, and hydraulic conductivity of this multi-aquifer system and provide a much more detailed view of the basin-filling, alluvial fan sediments. Coupled with the precision well-head locations, these new graphical depictions greatly aid in interpreting geologic/lithologic controls on the connectivity of the intricate system of surface waters (springs, wetlands, and streams) and shallow groundwater.

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Oral

Lagoon Leak Test Methodology: Development of Statistical Methods to Improve Accuracy and Error Estimates

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Leak testing of lagoons is a valuable technique to assess potential groundwater impacts of lagoons or ponds used for industrial process water or effluent storage. Unfortunately, standard methods lack the sensitivity required to assess the small leakage values considered to be acceptable. Two additional concerns for testing old lagoons are a) providing an estimate of testing error and b) providing areal coverage for lagoons that may have a point source leak. This latter issue has made mass balance test methods the common method of choice.

In this presentation, improvements to the mass balance/evaporation pan method for leak testing are demonstrated. The first improvement to the standard method is made by using electronic sensors with dataloggers to collect data on an hourly time scale. Regression techniques are used to assess measurement error related to the measurements of lagoon water level and evaporation pan water level. Standard daily time scale equations are used for calculations because they serve to integrate diurnal effects into measured and calculated values.

Results from several leak tests will be shown to illustrate the use of the methodology and quality of calculated results.

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Monitoring Groundwater and Rainfall Events at a Snohomish County Gravel and Sand Pit Site

Lynn Moses[1] and Jim Geringer[2]

Monitoring of groundwater and rainfall events at a Washington State Department of Transportation owned materials source was conducted from early December, 1996 through March, 1997. This information was used as part of a stability analysis for developing a mining plan for the site and to address the concerns for the method of mining the slopes near the Northwest Pipeline gas line and Puget Sound Power and Light power line easements that transect the site.

The 70 acre site is located on a 180 foot high terrace above the Stillaguamish River valley floor composed of the Arlington Gravel Member of the Vashon Drift deposited during the Fraser Glaciation. These deposits consist of mostly well-drained and stratified sand and gravel of mixed lithologies deposited by meltwater from the receding Vashon glacier. Exploration drilling at the site using a Becker-Hammer rig defined the depth of the gravel and sand deposits. Gradations of selected samples were used to categorize the type of materials encountered. Installation of three open standpipe piezometers with dataloggers allowed continuous monitoring of the groundwater through the winter of 1996-1997. Initially the sampling interval was every 15 minutes but later modified to every 180 minutes. In addition, a tipping rain gauge linked to a datalogger was installed near one of the piezometers to collect precipitation data.

During this winter of heavy rainfall and rain-on-snow events the maximum measured ground water level variation at the pit site was 3.3 feet. Comparison of regional rainfall and site specific rainfall events, and the effects of precipitation and response of the groundwater in the permeable sand and gravel deposits at the site will be presented.

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Poster

Progress towards a digital composite geologic-map database for the Puget Lowland

Ralph A. Haugerud[1], J. Eric Schuster[2], Derek B. Booth[3], and Jill Sacket[4]

We present a preliminary composite geologic map of the Puget Lowland, plotted at 1:100,000 scale with a shaded-relief base and colored to emphasize Quaternary stratigraphy. The map is one portrayal of an expanding digital geologic-map database that is being produced by several agencies. This portrayal of the database emphasizes its utility for stratigraphic and structural studies of Quaternary deposits and raises issues of quality, usability, and availability.

As of April 1997 we have digital versions of geologic maps of the Mount Baker, Sauk River, and Snoqualmie Pass 30'x60' quadrangles, all at 1:100,000 scale (by USGS), as well as a digital map of King County, compiled from 1:24,000- to 1:100,000-scale sources (by King County). Digital versions of geologic maps of the Seattle, Port Townsend, Skykomish River, and south half Tacoma 30'x60' quadrangles, all at 1:100,000-scale (digitized by WDGER and USGS) will be available by the end of June 1997. The 1961 geologic map of Washington, at 1:500,000 scale, is available in digital form (USGS OFR 95-684) and the 1987 geologic map of Washington, SW quadrant, at 1:250,000 scale, will soon be available in digital form. Compositing such maps into one database requires meshing the differing stratigraphies of the several maps. This is a nontrivial effort with no unique solution.

Improving the quality of the database will require both further digitization, to capture primary sources at original scale (for example, 1:24,000-scale maps of the eastern part of the Port Townsend quadrangle), as well as new mapping (ongoing work by WDGER, USGS, and UW in Bellingham, Tacoma, and Centralia quadrangles). Making the database widely usable requires that it completely capture the source maps (no units lumped, no features omitted), that it be well documented, and that it have a mechanism for flexibly tailoring the level of stratigraphic and lithologic detail for various purposes. Making the database available requires navigating the data-release policies of the various agencies involved and putting the database, metadata, and mechanism for tailoring the level of stratigraphic detail on a server. We aren't there yet.

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Oral

Pump Testing Protocols for New Public Water System Wells

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Evaluating the safety and reliability of a public water source requires knowledge of the hydrogeologic setting, potential sources of contamination and the areal distribution of time dependent capture zones. This evaluation depends in part on key aquifer parameters such as hydraulic conductivity and storativity as determined by pump testing. Due to the broad range of hydrogeologic conditions in Washington, variability in data quality and availability, ranges in relative susceptibility to contamination, and disparity in resources among purveyors it is unlikely that any single pump test protocol could be developed that would be considered suitable for all applications. Four primary pump testing standards under consideration by the Washington State Department of Health (WDOH) are designed to cover a wide spectrum of circumstances and include: 1) a standard pump test; 2) modified pump test; 3) known hydrogeologic conditions test; and 4) specialized pump tests.

The standard pump testing protocol is suitable for most hydrogeologic settings, includes pre-pumping, pumping and post pumping phases and accounts for confined and unconfined aquifer conditions. The standard pump test would be used for most applications and requires the use of at least one observation well. In some situations a less rigorous modified pump test may be suitable for the evaluation of source safety and reliability. Generally, this requires the hydrogeologic setting and aquifer characteristics have been documented from other information sources. The known hydrogeologic conditions testing protocol assumes the hydrogeologic setting and aquifer characteristics are well known from other information sources and typically applies only to in-fill drilling in existing wellfields. Specialized pump test protocols are based on the specific application, such as the evaluation of seawater intrusion, but at a minimum must meet standard pump test requirements.

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Oral

Stable Isotopes in the Hydrosphere of Southeastern Washington- Part I. Measuring $\delta^{18}O$ of Water in the Vadose Zone

Justin D. Ball[1], C. Kent Keller[2], and Peter B. Larson[3]

The stable isotopes of ^{18}O and D (deuterium) can be useful in understanding hydrologic processes and, in particular, in distinguishing between isotopically distinct sources of water. This study of pore water in a loess vadose zone is part of an effort to characterize and trace various possible sources of groundwater recharge in southeastern Washington.

The standard laboratory procedure involves eqilibration of CO_2 gas with a water sample. Then the gas is analyzed by mass spectrometer. In principal, CO_2 in soil gas is in contact with pore water and equilibration occurs naturally in the vadose zone. Instead of collecting soil water samples, soil gas can be collected directly. The soil gas CO_2 can be purified, analyzed by mass spectrometer, and the $\delta^{18}O$ of water can be back calculated using known temperature dependent fractionation factors. This soil gas CO_2 method (SGCM), has the potential to be a much less time consuming method for the determination of $\delta^{18}O$ of shallow subsurface water since the extraction of pore water is not necessary. To confirm that the SGCM can be used as an alternative method of determining the $\delta^{18}O$ value of water in the vadose zone, paired soil and gas samples with duplicates were collected from 0.5m depth at the Vadose Research Site at WSU. The pore water in the soil samples was extracted using a vacuum distillation system, and then processed using standard laboratory procedure. The CO_2 was purified from soil gas samples and analyzed directly.

If equilibration exists in the soil, the extracted water and SGCM should yield the same $\delta^{18}O$ results. We find, instead, a consistent depletion of 1-2‰ in the extracted water. We hypothesize that this offset is caused by non-equilibrium conditions at the depth investigated. Calculations suggest that the residence time of the CO_2 at the depth investigated may be shorter than the time required for complete isotopic equilibration between the gas and pore water. The SGCM method may be applicable at greater depths with longer soil gas residence times.

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Oral

Stable Isotopes in the Hydrosphere of Southeastern Washington- Part II. Implications for the Water Budget.

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The water budget of the Pullman, Washington-Moscow, Idaho basin is poorly understood due to conflicting ideas regarding residence time in and recharge to the basalt aquifers. Continual decline of water levels in the basalt aquifers has prompted study of the timing, amount and distribution of recharge to the system using several different methods. Radiocarbon age dates indicate residence times on the order of 10^3 years and greater, and suggest a very small rate of recharge to the deep basalt aquifers since the end of the Pleistocene. Hydrodynamic flow modeling studies have been based on the hypothesis that recharge is, aerially distributed precipitation that percolates through an unconfined loess unit to the basalt surface where it moves vertically through fractures to the lower basalt aquifer. These studies further suggest a significant Holocene recharge rate (2 to 5 cm yr^{-1}) to the upper and lower basalt aquifers which in turn suggest smaller residence times (10^2 years).

This study is part of a larger on-going study of the stable isotopes in the hydrosphere in southeastern Washington. This work monitored stable isotopes values of ^{18}O and D (deuterium) in precipitation, which were used to develop a local meteoric water line (LMWL), along with the stable isotopes values of ^{18}O and D in groundwater at different depths of the Pullman- Moscow basin. Stable isotopes were used to independently assess the viability of recharge models by comparing local, modern precipitation to both shallow and deep groundwater. If the radiocarbon age dates are accurate, groundwater in the basalt aquifers would have been precipitated under a cooler, pre-Holocene climate and would exhibit a different isotopic composition than if it had been precipitated recently.

Water from local wells of varying depth and formation were analyzed and compared to the LMWL. Results indicate that groundwater has the same slope as the LMWL showing that no isotopic fractionation or water-rock interaction affected these waters as they recharged. The groundwater values plot toward the depleted end of the LMWL. A 2.2 to 5.0 ‰ shift in $\delta^{18}O$ groundwater values occurs between shallow loess groundwaters and deep groundwaters. The deep aquifer also has an isotopic signature distinct from water sampled from other stratigraphic units. These findings suggest that the deep waters in the basin were not precipitated under current climate conditions and that aquifer recharge rates are substantially smaller than has been supposed.

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CANCELLED

Oral

Technical Methods for Evaluating Hydraulic Continuity Between Aquifers and Surface Water Bodies

R. Bradley Severtson[1] *and Eric F. Weber*[2]

Anticipated increases in the exploitation of groundwater in Washington State will require the assessment of whether withdrawals will impact streamflow volumes and therefore infringe on existing surface water rights. Existing analytical procedures for determining streamflow depletion were reviewed and the conditions for their application were tested by comparisons with the results of numerical modeling.

Possible flow regimes were classified, the effects of partial well and stream bed penetration and stream bed clogging effects were evaluated, and guidance was developed for use of the available analytical techniques. Guidance on data requirements and calibration strategies was also developed. Applications of the analytical methods at Western Processing in Kent, Washington and the Boeing Plant in Gresham, Oregon were reviewed to test their applicability to actual site conditions.

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Poster

The Aquifer Vulnerability Project in Washington State

Laurie Morgan[1], Mary Shaleen-Hansen[2], Guorong Liu[3]

Information about ground water has largely been in the form of hard-copy reports. But with the advent of mapping software, such as ArcView, that can integrate geographic mapping with data tables, along with tools such as the Access data base software, the whole concept of how ground water data can be compiled and delivered has changed.

The Aquifer Vulnerability Project is compiling ground water data in three GIS (Geographic Information System) layers: contaminant sources; ground water quality; and hydrogeology. The pilot area for this project is the Nooksack Water Resource Inventory Area (WRIA), in Whatcom County.

Contaminant source data includes sites such as landfills, wastewater dischargers, agriculture, gravel mines, toxic clean-up sites, leaking underground storage tanks, land use data, and population density.

Ground water quality data includes Department of Health Public Water Supply water quality testing data; USGS well water quality data, data from special studies (USGS, Washington State Department of Ecology Environmental Investigation and Laboratory Section (EILS), and Western Washington University, and others), and data from regulatory ground water monitoring activities.

Hydrogeology data includes a GIS cover created by EILS that delineates the surficial aquifers in the Nooksack, which is based on NCRS SURGO soils GIS covers, USGS wells, and geology by Easterbrook (1976). The project will also incorporate GIS layers from USGS for the Lynden-Everson-Nooksack-Sumas (LENS) USGS Study, and the USGS Puget Sound Study, as soon as they are released.

In conjunction with the above efforts, soil susceptibility to leaching by pesticides is being modeled using PATRIOT (Pesticide Assessment Tool for the Rating Investigations of Transport), a model developed by EPA in support of the State Management Plans for pesticides that EPA is requiring the states to develop. Soils will be ranked and mapped using GIS as to potential risk for pesticide application to result in ground water contamination. The model and method is undergoing rigorous technical review to determine its applicability in Washington State.

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Oral

Transmissivity From Cyclic Water Level Fluctuations - An Update

William E. Halbert

The use of tidal influence studies to evaluate aquifer characteristics adjacent to coastal areas has grown in popularity in recent years. The method for determining aquifer transmissivity from cyclic water level fluctuations was described by John G. Ferris in 1958. In his paper, Ferris uses an example involving cyclic fluctuations in the Platte River having a regular period and amplitude. He describes two methods for determining transmissivity: the stage ratio and time lag methods. The stage ratio method uses the ratio between the observed change in water level within each monitored well against the corresponding change in water level in the surface water body. The time-lag method utilizes the difference between the time of a particular maxima or minima response in a well and the corresponding surface water stage.

The purpose of the study was to evaluate the Ferris methods at sites having aquifer water level fluctuations resulting from mixed, semi-diurnal tides as occur in Puget Sound, Washington, and to evaluate the accuracy of the methods in confined and unconfined aquifers. Mixed, semi-diurnal tides have two high tides and two low tides of unequal range per cycle with a period of approximately 25 hours. These fluctuations differ from the relatively harmonic fluctuations used by Ferris to explain the method.

Two aquifers were selected for the evaluation: an unconfined aquifer adjacent to the tidally influenced Duwamish River in Seattle, and a shallow, confined aquifer near the marine waters of Commencement Bay in the port area of Tacoma. Aquifer pumping tests were conducted on each aquifer and used as a standard by which to measure the accuracy of the methods. Additionally, injection slug tests were used on the confined aquifer to further evaluate the aquifer parameters.

Results of the pumping tests for the unconfined aquifer using both the Theis and Cooper-Jacob methods are in good agreement with the results of both the stage-ratio and time-lag methods. Transmissivity values using the Ferris methods were slightly higher than those from the pumping tests.

Pumping test data and slug test data for the leaky confined aquifer at the Tacoma field site are in good agreement with one another. However, results for T using the Ferris methods yield results that are over 1 order of magnitude higher than from the pumping test or slug tests. The variance is attributed to the selection of the value for S (storativity) used in the Ferris methods to calculate T. The large value of S obtained from the pumping test data is attributed to errors resulting from tidal influence during the pumping test.

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Poster

Use of Water Column and Sediment Temperatures to Estimate the Extent of Discharge Areas Feeding the Walla Walla River

Bryce E. Cole, Thomas B. Jacques and Carolyn J. Foote[1]

The interaction between streamflow and groundwater is often difficult to characterize due to substantial spatial and temporal variations of water fluxes to or from surface water bodies. Topography, hydrogeologic information and streamflow records often indicate whether a stream is gaining or losing water to groundwater systems; yet, these data are not always available for more than a few locations along a river. For this project inexpensive temperature measurement devices are used to determine sediment and water column temperatures. These temperature values indicate the direction of water fluxes through the streambed sediments, identifying groundwater recharge and discharge zones along the Walla Walla River. The focus of this work is primarily in identifying the utility of three temperature measurement devices: stainless-steel analog thermometers, digital thermistor meters, and continuously-recording, stationary devices.

Cost is the impetus for consideration of the various measurement devices. Steel thermometers are inexpensive (~$10), yet, have questionable durability under water. Additionally, probes must be inserted entirely into the stream sediments or insulation must be provided for a portion of its length. Digital temperature meters (~$200) measure temperature more accurately and allow for flexibility in the probes used for measuring in various circumstances, but are also susceptible to water damage. Continuously-recording devices ($100-$250 each) provide significant data regarding temporal variation, but two are required for each position to record sediment and water column temperatures, and a network of instruments is required to delineate entire discharge areas. Devices left in place are prone to vandalism as well.

Of particular interest for this application are variations in the extent of groundwater discharge areas through the late spring and early summer as pumpage due to irrigation increases. Monthly data from the entire stretch of the discharge area indicate generally stable sediment temperatures as water column temperatures increase. More frequent temperature measurements at the edges of the discharge zone show a larger variation in sediment temperatures, reflecting the changes in the hydrologic budget due to lower stream depths and increased pumpage. Results of the study indicate that maximum information regarding the discharge area can be obtained by using continuously-recording devices (or more frequent measurements with a portable device) near the edges of the zone, whereas portable devices used for occasional measurements appear adequate for observing the majority of the discharge area.

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Poster

Washington State Sensitive Groundwater Mapping Project

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Washington State Department of Transportation (WSDOT) has compiled a database of sensitive groundwaters throughout the State for use in a Geographical Information System (GIS). The database includes the layers: sole source aquifers, critical aquifer recharge areas, and wellhead protection zones for Group A (15 or more connections) public water supply wells.

Sole source aquifer data currently exists and was provided from the EPA. Critical aquifer recharge areas, delineated by each county in compliance with the Growth Management Act, was provided in various formats. Wellhead protection zone data was delineated by each well system owner in compliance with the Safe Drinking Water Act and collected in various formats from Washington State Department of Health and individual system owners.

This data will be available in three separate state wide data layers. Built in workstation ArcInfo, it will be available for use as either ArcInfo coverages or ArcView shapefiles. This data will be available to all interested parties by August of 1997.

This data is to be used by WSDOT and other Interagency Ground Water Committee (IGWC) members as a planning tool in managing and protecting the State's drinking water supply. At WSDOT the following activities are in need of groundwater sensitivity data on a regular basis: Geotechnical Investigations, Hazardous Waste Clean Up, Roadside Vegetation Management, Emergency Response, Stormwater Management, Construction Management, and Environmental Documentation. The IGWC has served as advisor to WSDOT for this EPA funded project.

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Hanford Site Assessment

CANCELLED

Oral

Assessment Of Two Single-Shell Tank Farms At The Hanford Site

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Single-shell tanks (SSTs) at the Hanford Site store high-level radioactive waste generated from nearby chemical separations plants. Decommissioned in 1980, these tank farms are regulated by the Resource Conservation and Recovery Act of 1976 (RCRA) and the Washington State Hazardous Waste Management Act as discrete Waste Management Areas (WMAs) based on tank farm boundaries. Two SST WMAs are currently under RCRA assessment because of elevated field specific conductivity in three downgradient wells in 1993.

In the past, waste has leaked from some of these tanks into the soil column where it could potentially infiltrate to the groundwater. At present, 20 of the 36 SSTs in these two WMAs are known or suspected of leaking waste to the subsurface. The estimated total leak volume is 250,000 gallons. One of the largest known leaks from any SST at the DOE Hanford Site occurred in 1973 in the northern part of the 200 West Area and was estimated at 115,000 gallons.

Investigation of groundwater contamination associated with these WMAs is complicated by past-practice discharges of liquid effluent to surrounding nearby cribs and trenches. Because the chemistry of the effluent was sufficiently similar to tank waste, it is difficult to find tank waste analytes that can provide a unique groundwater signature. In addition, during the operational lifetime of these SST farms, supernatant was discharged to nearby cribs to increase available storage space in the tanks. For example, the supernatant volume discharged to cribs from these SST WMAs was ~100 times larger than the total estimated leak volume. Consequently, study of the surrounding groundwater contamination requires careful spatial and temporal consideration.

Groundwater monitoring results indicate that elevated nitrate and chloride are the primary anions causing the elevated specific conductivity. High salt wastes with these two anions were discharged in large volumes to both SSTs and nearby cribs and trenches. However, historical data indicate that the local groundwater was contaminated with nitrate prior to any assumed leakage from the tanks. Plume maps from the last several years display little change in elevated specific conductivity in the groundwater. These relatively static plume patterns, combined with the cessation of discharges to past practice cribs and trenches over 20 years ago, suggest there is long-term leaching of nitrate, chloride, fluoride and mobile radioactive constituents from the soil column beneath disposal sites adjacent to these SST farms. The large volume of waste discharged to the cribs and trenches implies that the past-practice liquid waste disposal sites are the primary source of continuing groundwater contamination.

This study was conducted by PNNL operated by Battelle for the U.S. Department of Energy under Contract DE-ACOb-76RLO 1830.

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Contaminant Plume Source Fingerprinting

Suzanne Dahl, R.G.[1] *and Stan Leja*[1]

A classic application of geochemical and hydrologic principals are used to fingerprint the contaminants. In this case, the question is whether the Technetium-99 contamination, found in the groundwater in the southern portion of the plateau area (200 Area) at the Hanford Site was a result of past discharges to surface sites or a result of leaks from active single shell underground storage tanks (USTs) in the SX tank farm.

The site contains two-thirds by volume of the Department of Energy (DOE) Complex's highly radioactive waste (stored primarily in 177 USTs). There are 149 single shell tanks (69 known leakers with a total leak volume of 1 million gallons) which are at least 30 years past their design life and 28 double shell tanks approaching their design life. These USTs contain 56 million gallons of waste.

The importance of establishing the source of the contamination is related to verifying the long held Hanford conceptual models for contaminant transport through the vadose zone beneath both surface discharge sites and leaking single shell tanks. Past conceptual models and monitoring data across the Hanford Site for surface discharge sites indicated that if sufficient volumes of liquid were discharged then impacts would occur in the groundwater in a relatively short period of time. In the plateau area (200 Area) alone, 346 billion gallons were released to these surface discharge sites resulting in multiple large groundwater plumes. In contrast, the conceptual models and historical interpretation of groundwater monitoring data for leaks from the Hanford tanks farms indicated that contaminants would not reach the groundwater in the near term and may not for 100 years or more. These conceptual models were heavily dependent on the Hanford tank waste binding with the soil in the 200 feet thick vadose zone and the reported leak volumes. Therefore in the past, contaminant plumes have been blamed on the surface discharge sites and the tanks have not been considered as possible sources.

Geochemical and hydrogeological methods used include: contaminant trend plots, plumes maps, waste discharge records to surface discharge sites, tank waste characterization data, and isotopic ratios of Technetium-99/Uranium, and Tritium/Technetium-99. The geochemistry was used to fingerprint the groundwater contamination and relate it back to the various sources.

It was concluded by this study that leaks from the SX tank farm has impacted the 210 feet-thick vadose zone and the groundwater beneath the tank farm. While the present groundwater Technetium-99 plume is minor by Hanford standards, this is the first documented and DOE agreed-upon case of tank leaks impacting the groundwater at the Hanford Site. New, more accurate, conceptual models for transport of tank waste through the vadose zone must be developed and these should be based on campaign specific information on the chemical nature of waste that went into each individual tank farm and when possible these models should be based on actual vadose zone characterization data.

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Oral

Mobile Transuranics: A Hanford Site Case History

V. G. Johnson and F. N. Hodges

Two-phase liquid wastes discharged to cribs and trenches from the Plutonium Finishing Plant (PFP) at the Hanford Site from 1955 to 1973 included an estimated 20,000 Ci of ^{239}Pu and ^{241}Am, and over 500 metric tons of CCl_4. Based on relative hazard (e.g., dividing contaminant quantity by the appropriate health/risk standards), these spent process solutions are among the most significant vadose zone sources at the Hanford Site. A complexant, tributyl phosphate (TBP), was used to extract Pu from a high-nitrate aqueous phase into an organic phase (CCl_4) followed by back-extraction into dilute nitric acid. Gradual radiolytic degradation of TBP created a stronger complexant, dibutyl phosphate (DBP), which would not release Pu from the organic phase. At this point the process liquids were discharged to soil-column-disposal sites (the 216-Z-1A/Z-18 cribs and the 216-Z-9 trench). A large portion of the Am and Pu in this spent liquid may have migrated downward in the CCl_4 as opposed to the highly acidic aqueous phase. The volumes discharged were generally less than the estimated pore space beneath the disposal sites but these estimates did not account for recharge and fluid density effects. The pattern of CCl_4 (to ~6000 ppb) in groundwater and recent modeling by others suggest drainage of the organic phase to groundwater beneath the trench site will continue for years.

Transuranic concentrations >100,000 pCi/g occur in vadose zone sediments at the 216-Z-1A crib and extend to depths of 20 to 30 m, compared to a depth to groundwater of ~60 m. Although the maximum depth of penetration is unknown, transuranics were not detected in groundwater at this disposal site. However, groundwater from a well at a nearby trench (216-Z-9) that received the same waste type as the 216-Z-1A crib contained low concentrations (8 ± 0.9 and 6 ± 0.9 pCi/L of ^{239}Pu and ^{241}Am, respectively) in a particulate phase (>0.4 μm). Spectral-gamma logs for this well confirmed the presence of transuranics to a depth of 40 m below surface where concentrations of ~200,000 pCi/g occur.

The large inventory of deeply distributed transuranics still existing in the subject disposal sites appears to have stabilized relative to the highly mobile CCl_4 co-contaminant. Earlier investigations (ca 1975) indicated soil carbonate and silicate mineral hydrolysis consumed the acid and raised the pH, which in turn led to adsorption or precipitation of the transuranics on mineral surfaces or amorphous colloidal material. The higher pH and carbonate species in the neutralized sediments may have also allowed transfer of (Pu,Am)-DBP from the organic phase back to aqueous pore fluid. Whether this post-disposal aqueous fraction became mineral bound or remained as an aqueous carbonate complex is unknown. Where long-term impacts are of concern, the long half lives (24,000 yrs for ^{239}Pu) provide ample time for either colloid or solute transport. Therefore, verification of *immobilization* mechanism(s) is vital in determining appropriate closure or remediation of these "mixed waste" sites.

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Hanford Site Geochemistry

oral presentation

Field Measurement of Hexavalent Chromium in Water

Richard G McCain[1]
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Potassium and sodium dichromate were used as corrosion inhibitors in reactor cooling water at the Hanford Site. Groundwater contamination plumes associated with reactor operations exist in the vicinity of the 100-K, 100-D and 100-H areas. Groundwater investigation and process control during remedial action has resulted in a need for a quick, reliable field method capable of detecting hexavalent chromium in water at concentrations below 50 ppb. One such method is based on the 1,5-diphenylcarbohydrazide reaction. A commercially available test using pre-measured reagents in evacuated glass ampuls was adapted to provide reliable field measurements at concentrations as low as 5 ppb. This test could be carried out in the field and provided results in as little as five minutes after sample collection. Results were shown to correlate well with laboratory data. The test can also be adapted to screening for hexavalent chromium in soil, using a water extaction.

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Oral

Geochemical Controls on the Transport of Strontium-90 at the 100-N Area of the Hanford Site, Washington

P. Evan Dresel[1], *Janet A. Schramke*[2]

Groundwater at the DOE's Hanford Site in eastern Washington is monitored for the distribution of radionuclide and chemical contamination which resulted from site operations. It is necessary to understand the hydrogeologic controls on the contaminant movement in order to provide a realistic interpretation of contaminant distribution and trends. Water-rock interactions including mineral precipitation, mineral dissolution, and sorption have a great influence on the distribution of many constituents in the groundwater system. Computer models of chemical speciation and mineral stability are well established but have been used infrequently in Hanford Site monitoring programs. This presentation reports a geochemical assessment of the controls on strontium-90 transport in groundwater from the 100-N Area of the Hanford Site.

Hanford Site groundwaters are generally low-ionic strength, high alkalinity solutions at near-neutral pH. Geochemical modeling showed all groundwater samples in the study were undersaturated with respect to strontianite ($SrCO_3$) and celestite ($SrSO_4$). Calcite ($CaCO_3$) saturation was attained everywhere except immediately downgradient of the 1324-N/NA facilities which had been used to dispose of acidic waste. Barite ($BaSO_4$) undersaturation is observed downgradient from the 1301-N and 1325-N facilities which received the bulk of the strontium-90 so substitution into barite will not limit strontium mobility. The modeling data support the prevailing theory that sorption is the dominant control on strontium-90 mobility.

In the northwestern part of the strontium-90 plume, higher ionic strength sodium and calcium bearing groundwater from the 1301-N and 1325-N facilities is beginning to impact the strontium-90 contaminated area. This interaction is resulting in desorption and remobilization of strontium-90 from the sediments. The field data confirm laboratory data that strontium-90 sorption is easily reversible.

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Oral

Occurrence of Chlorine-36 in Groundwater at the Hanford Site, Washington

P. Evan Dresel[1]

Chlorine-36 is a neutron activation product of chlorine-35. Chlorine-36 forms relatively easily in nuclear reactors because of the large neutron-capture cross section of chlorine present as impurities in the system. Chlorine-36 is a weak beta emitter with a long (301,000 year) half life that is often considered to be only a minimal contributor to the potential dose from site operations but may be a significant contributor to long term risk from residual material such as reactor cores.

Groundwater from the unconfined aquifer at the Hanford Site was sampled for chlorine-36. This appears to be the first attempt to assess chlorine-36 as a groundwater contaminant from Site operations. Samples were collected from operational areas, upgradient areas, and areas of known groundwater contamination. Samples were analyzed by accelerator mass-spectrometry which provides exceptionally low detection levels (less than 10^8 atoms/kg).

Detected chlorine-36 concentrations ranged from 0.013 x 10^{10} atoms/kg to 4,778 x 10^{10} atoms/kg. Chlorine-36/Cl ratios ranged from 604 x 10^{-15} atoms/atom to 216,000,000 x 10^{-15} atoms/atom. Values within and downgradient from operational areas are larger than could result from natural production or atmospheric fallout. The maximum concentration detected was from near the 100-F Area reactor building and corresponds to a chlorine-36 activity of over 90 pCi/L.

Chlorine-36 values are poorly correlated with tritium or iodine-129 activities. Thus chlorine-36 may prove useful as an additional indicator of impact by site operations.

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Hanford Site Permitting and Treatment

Oral

Combination Of Three RCRA TSDs Into One Groundwater Quality Assessment Program At The Hanford Site, South-Central Washington

Jonathan W. Lindberg[1], *Stan Leja*[2]

It is proposed that three treatment, storage, and disposal (TSD) facilities near the 200 East Area at the Hanford Site in south-central Washington be combined into one Interim Status Groundwater Quality Assessment Program monitored under the Resource Conservation and Recovery Act (RCRA). This combination is being proposed to provide a more technically justified and yet efficient groundwater monitoring program for two of the TSDs and to include a third TSD that had not been monitored under RCRA. The TSDs include three cribs that have similar construction, waste disposal histories, and are in the same general area with similar hydrogeology.

Two of the TSDs (the 216-A-10 and 216-A-36B) have been in detection monitoring programs since 1988. Groundwater monitoring results show that the cribs have impacted groundwater quality. However, wells showing that the cribs are the source of contamination are older wells that do not meet the more recent RCRA standards. Using these older wells that have been a part of the Hanford site-wide monitoring effort has also shown that the cribs are responsible for a large nitrate plume (causing elevated specific conductance).

The proposed groundwater monitoring network will use up to 57 existing far-field wells and several selected RCRA-compliant near-field wells to monitor the extent and concentration of the nitrate plume, as well as other waste constituents. By combining the three sites under one groundwater quality assessment plan the combined network will require fewer new wells, thereby saving money, yet will assess the full extent of the plumes emanating from the three cribs.

Environmental managers at sites with multiple TSDs as well as regulators should consider such an approach to monitor groundwater more efficiently.

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Oral

Liquid Effluent Variability Study for the 200 Area Treated Effluent Disposal Facility at the Hanford Site

Charissa J. Chou[1] and Vernon G. Johnson[2]

The Washington State Department of Ecology issued a State Waste Discharge Permit on April 18, 1995 to the U.S. Department of Energy, Richland Operations Office to regulate the discharge of treated waste water from combined 200 Areas sources to infiltration ponds. This facility, known as the 200 Area Treated Effluent Disposal Facility is located east of the northeastern corner of the 200 East Area fenceline on the Hanford Site. A special Permit Condition required a study of effluent variability during the first year following issuance of the Permit. A statistical evaluation was conducted to fulfill this requirement. The specific objectives were to: (1) determine the overall variability of permitted constituents; (2) evaluate comparability of grab samples and composites; and (3) determine if concentrations of permitted constituents vary with season.

The statistical approach applied to effluent data collected from July 1995 through April 1996 consisted of both standard statistical methods (frequency of detection, monthly average concentrations, 95 percent confidence limits, coefficient of variation, standard deviation), and analysis of variance to evaluate seasonal and/or sample type effects (grabs versus composites). Sample population homogeneity was assessed using both Box-and-Whisker plots and goodness-of-fit test. If more than one population was indicated, the data were segregated. Statistical variability results also were used to calculate the probability of exceeding monthly average and daily maximum Permit limits under normal or baseline conditions.

Based on statistical evaluation of effluent data for four consecutive seasons, it was concluded there is a very low probability of exceeding Permit limits under normal operating conditions. Excluding a one-time occurrence of slightly elevated gross beta and one observed monthly average Permit exceedance for iron, the effluent is similar in composition to local drinking water (i.e., chlorinated Columbia River water). A seasonal effect (i.e., shift in mean concentrations) that occurs for chloroform and nitrate is attributed to biological changes in the source water or raw water (Columbia River water). An apparent seasonal effect for chloride, total dissolved solids, and iron might be more related to operational factors and/or parking lot run-off rather than natural conditions.

Results of the variability analysis, combined with process knowledge and creative use of indicator parameters, suggest a significant reduction in the analytical cost of the effluent monitoring program can be achieved.

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Oral

Management of Groundwater Contaminated with Radioactive and Nonradioactive Chemicals in 200-UP-1 Operable Unit, Hanford Site, Washington State

Dib Goswami[1] *and Shri Mohan*[1]

The Hanford site occupies about 1450 km^2 (560 mi^2) of the south eastern part of Washington State, north of the confluence of Yakima and Columbia rivers. The US Department of Energy established the site in 1943 for the production of plutonium. The production operation resulted the Hanford Site into one of the largest and most contaminated sites of the nation.

The 200-UP-1 is a groundwater operable units located in the 200 west area on the Hanford site's Central plateau. The uppermost aquifer is located in the Ringold Formation consisting of alluvial sand and gravels, and displays unconfined to locally confined or semi-confined conditions. The groundwater in the operable unit contains elevated levels of uranium, technetium-99, nitrate and carbon tetrachloride. The maximum concentrations are approximately 2300 ppb of uranium, 23,700 pCi/L of technetium-99, 1,700,000 ppb of nitrate and 320 ppb of carbon tetrachloride.

The management of these contaminated plumes involved several regulatory and stakeholders and public concerns. The issues were primarily relating to cost, remedial approach, risk to human health and the environment, handling of the listed waste and secondary waste. The interim remediation of the groundwater consists of extraction of the high concentration zone of the contaminated groundwater plume and it's treatment at the existing Effluent Treatment Facility (ETF).

The primary goals of the interim remedial measure are to;

- reduce contamination in the area of high concentrations of uranium and technetium-99 to below 10 times the cleanup level under the Model Toxic Control Act,
- reduce potential adverse human health risks through reduction of contaminant mass,
- prevent further migration of the contaminants, and
- provide data that will lead to development and implementation of a final remedy.

Groundwater extraction rate of 190 liter per minute (50 gpm) was based on modeling studies. It is expected that extraction and treatment of one pore volume of groundwater from the plume is expected to meet the interim remedial measure objectives. Final remediation will be based on site specific data of the interim remedial action.

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Total Petroleum Hydrocarbons Risk Assessment

Oral

Degradation Rates for Petroleum Hydrocarbons in Groundwater

Thomas Mercer[1] and Dr. Charles Vita[2]

A probabilistic methodology for estimating health and ecological risks associated with petroleum releases to groundwater has been developed (by Dr. Vita) to help evaluate site cleanup and closure requirements. This method requires degradation rates in groundwater for a wide range of petroleum hydrocarbons found in fuels. Required parameters include an geometric mean and the coefficient of variation of expected values of the degradation rate. A simple model of contaminant transport was used, along with conservative estimates of field conditions, to estimate apparent degradation rates for each specific analyte based on concentration measurements in downgradient groundwater.

The analytes studied included benzene, toluene, ethylbenzene, total xylenes, naphthalene, 2-methylnaphthalene, acenaphthene, acenaphthylene, fluoranthene, and carbazole. The aliphatics and aromatics detected as gasoline range and diesel range organics were also studied. Eleven sites were chosen where the source of contamination was reasonably well defined and the array of wells was conducive to measurement of plume concentrations. The change in concentration in downgradient wells was measured and analyzed. Those wells deemed most representative of each site plume were chosen for analysis.

The velocity of any particular contaminant or group of contaminants was represented as follows:

$$Vc = \frac{ki}{nR}$$

where k= hydraulic conductivity, i= groundwater gradient, n= effective porosity, and R= retardation. The degradation rate (λ) was represented as:

$$\lambda = \frac{Vc}{4\alpha_x}\left[(1-2\alpha_x m)^2 - 1)\right]$$

where α_x = dispersivity over the specified distance, and m = the slope of the lognormal concentration difference over the linear distance between measurement wells..

Estimated degradation rates were determined to be distributed over approximately 2 orders of magnitude from a geometric mean of 9.03E-5 day^{-1} for aliphatic diesel range organics (coefficient of variation = 1.07) to a geometric mean of 0.0027 for toluene (coefficient of variation = 1.22). Variations were noted and further study will help to better define some of the conservatively estimated variables. These results compare well with those of other studies as summarized in this paper.

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Natural Attenuation of Dissolved Gasoline-Related Petroleum Hydrocarbons in Ground Water Seattle, Washington

Carla R. Woodworth[1], Llyn A. Doremus[1], and Kurt S. Anderson, C.P.G.[1]

The likelihood of natural attenuation occurring in ground water was investigated at a former gasoline service station in Seattle, Washington. The service station facilities and approximately 1,200 cubic yards of petroleum-contaminated soil were removed in 1990. Residual gasoline-contaminated soil remains at depths ranging from approximately 8 to 12 feet in the southeast portion of the site and at depths ranging from 45 to 55 feet throughout the northern and southern portions of the site and extending off site to the south. The depths to ground water in the monitoring wells generally range from about 45 to 57 feet below ground surface. Ground water containing dissolved gasoline-related hydrocarbons is present in the northern and southern portions of the site and extends off site to the south. An on-site vapor extraction system (VES) was installed to treat gasoline-contaminated soil in the vadose zone in 1992. Ground water quality and the VES operation at the site have been monitored since 1992.

As part of the natural attenuation evaluation 1) five years of ground water quality data were reviewed; 2) additional ground water samples were obtained from selected monitoring wells for chemical analysis of dissolved-phase hydrocarbons, dissolved oxygen, nitrates, methane, magnesium, and phosphorus; and 3) a two-dimensional numerical ground water model (Bioplume II) was used to simulate biodegradation over 3-, 5- and 10-year periods.

The study indicated that natural attenuation was occurring at the site based on the following data: 1) the size of the dissolved-phase hydrocarbon plume has decreased since March 1992; 2) dissolved-phase hydrocarbon concentrations in ground water have declined since March 1992; 3) dissolved oxygen concentrations (exceeding 5 mg/l) outside the dissolved phase plume and dissolved oxygen concentrations (less than 1 mg/l) within the dissolved phase plume indicate that natural (aerobic) attenuation is occurring at the site; 4) the distribution of nitrates, methane and sulfates in ground water indicate that natural (anaerobic) attenuation is occurring near the plume.

Because natural attenuation was shown to be occurring at the site, Bioplume II was used to simulate biodegradation of the dissolved-phase hydrocarbons in ground water. The results of the model indicated that the areal extent of the plume will be contained within the site boundaries and off-site ground water is likely to return to drinking water quality within a three-year period. As the source of the ground water contamination is progressively reduced, the natural processes of aerobic and anaerobic biodegredation are predicted to reduce the dissolved-phase hydrocarbons in ground water beneath the site to concentrations less than the State of Washington cleanup levels within 12 years, even with termination of VES operation.

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Oral

TPH Remediation Via Steam Flooding: Numerical Modeling for Project Design

Peter Kroopnick[1], Jay Dablow[2], Bill Hughes[1], Peter Pope[3]

Remediation of volatile organic hydrocarbons from porous soils using vapor extraction has been demonstrated to be an extremely effective technology. However, remediation of petroleum hydrocarbons containing low vapor pressure compounds requires the use of higher vacuums and longer treatment times. Similarly, the extraction of semivolatile hydrocarbons from low permeability soils requires extraordinary techniques such as steam flooding. Fluid migration and associated mass transfer rates are very low in these cases and result in unacceptably close well spacings or long durations to achieve desired remediation goals.

Two case histories will be presented to demonstrate the use and calibration of numerical models to design remediation systems applicable to these recalcitrant materials. In the first case, #6 fuel oil and diesel have contaminated medium grained soils to a depth of 100 feet. Injection of steam into the subsurface increased the temperature allowing the higher vapor pressure compounds to be removed by an SVE system. The viscosity of the contaminant also decreased causing mobilization of a liquid phase that was removed by total fluid extraction.

The program T2VOC is capable of simulating multi-phase flow under non-isothermal, variable saturated conditions. Data acquired from the initial remediation of the heavy fuels, will be used in conjunction with T2VOC to scale the system up to full scale. The calibration of the model and its use to design the full scale system will be presented.

The second case involves shallow clayey soils contaminated with jet fuel (JP-8). Hydraulic fracturing will be used to create secondary permeability and accelerate the mass transfer of steam and volatile organics. Numerical simulation using the T2VOC code was used to design the spacings between the fractures and between the steam injection and SVE wells. The results of these numerical simulations indicate that the heating pattern can be controlled and hydrocarbon extraction optimized by appropriate well and fracture positioning.

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Contamination
Total Petroleum Hydrocarbons Policy

Fate and Transport of TPH in the Environment Case Study: Insulating Oil

Sarah Richards[1], *Nancy DeMond*[2]

The electrical insulating oil study was conducted to develop the technical basis for establishing TPH cleanup levels for electrical insulating oil in soil. Development of cleanup levels that are protective of human health and the environment requires a thorough understanding of the fate and transport characteristics of the hydrocarbon mixture. To this end, samples of electrical insulating oil were collected from electric equipment at five utility substations located in Washington and Oregon. At the same sites, soil and groundwater samples were collected from former oil spill locations. The samples were analyzed to evaluate:

- the chemical composition of the oil, and any changes that may occur in composition over time in electrical equipment or in the subsurface;
- the mobility of the oil and its constituents in the aqueous phase
- the mobility of the oil as a NAPL (non-aqueous phase liquid)

The oils were analyzed for physical and chemical properties, and comprehensive chemical composition data. To evaluate the mobility of the oil and its constituents in the aqueous phase, water solubility tests and soil leachability tests were conducted. Soil and groundwater samples were used to define the spatial distribution, and relevant transport processes, of the oil in the subsurface environment.

Study results indicate that electrical insulating oil is relatively immobile in the environment. Based on this study, the Washington State Department of Ecology issued interim guidance in 1996 that established a soil cleanup level for insulating oil at operating electrical substations of 2000 mg/kg (from 200 mg/kg). Under the 1997 TPH Interim Cleanup Policy, the soil cleanup level appears to be equal to the residual saturation of insulating oil in soil. Although the specific results of the insulating oil study are not directly applicable to other TPH materials, the process that was used to evaluate fate and transport characteristics for the purpose of establishing cleanup levels may be applied to any chemical mixture.

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Oral

Evaluation of Generic Risk-Based Soil Cleanup Levels for Residential/Commercial Settings Contaminated with No 2 Fuel Oil under DOE's Interim TPH Policy and its Field Verification: Leaching Potential to Groundwater and Direct Contact Pathways

Hun S. Park[1] *and James M. Sims*[1]

On January 16, 1997, Washington Department of Ecology issued a new "Interim Interpretive and Policy Statement - Cleanup of Total Petroleum Hydrocarbons," which allows owners of petroleum-contaminated sites additional flexibility in determining cleanup levels for TPH. Pollution Liability Insurance Agency is responsible for administering the heating oil pollution liability insurance program. Controlling costs and maximizing cleanup efforts were found to be the key to the survival of the program.

Due to the potentially significant cleanup cost savings and expedited remedial action efforts, conservatively-derived, risk-based, and generic threshold soil cleanup levels for residential/ commercial settings contaminated with No 2 Fuel Oil were evaluated, using DOE's new Interim TPH Policy. A substantial amount of actual samples, representing all Washington State geology, were analyzed and the results of study have been implemented as a formal policy.

The study focused on the evaluation of two major exposure pathways, as well as aesthetic/odor concerns: soil leaching potential to groundwater pathway and direct soil contact pathway, including soil ingestion, dermal absorption, inhalations of ambient vapors and particulate. Statistical analysis of actual data and extensive literature review were conducted to establish generic cleanup levels. The results were compared with other states' cleanup standards to see any major deviation. Additionally, current "W-TPHD values" (Washington method for TPH analytical method) were also evaluated for possible substitution of the surrogate TPH values (i.e., summation of all surrogate fractions) measured by new interim TPH analytical method.

The economic impacts of adopting the generic risk-based cleanup levels on PLIA's current heating oil pollution liability insurance program and the petroleum industry in general were investigated thoroughly for the practical aspects. Methodology used herein can be adopted as a potential tool for calculating a Method "A" type of lookup table for other petroleum contaminated sites.

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Oral

Make the Most of Your Existing TPH Data
Establishing Risk-Based Petroleum Cleanup Levels

Mike Ehlebracht, P.G. [1] *and Tim Flynn, C.G.W.P.* [2]

One of the most significant challenges associated with establishing risk-based cleanup levels under Ecology's Interim Petroleum Cleanup Policy (Policy) is how to utilize existing TPH soil data. There are many sites where a significant amount of TPH characterization data has been collected prior to the implementation of the Policy and the development of surrogate-based analytical methods. Although TPH soil quality data produced using Ecology's WTPH methods were designed to be compared to MTCA Method A cleanup levels, they can also be very useful for establishing Methods B and C risk-based cleanup levels.

We have developed an approach for utilizing existing TPH data to establish risk-based soil petroleum cleanup levels at a large industrial complex in the Puget Sound area. Hundreds of surface and subsurface soil samples were collected at the site and analyzed for petroleum hydrocarbons using the WTPH methodologies. Results of this testing indicated that the cost for remediating petroleum-containing soils to Method A cleanup levels would likely exceed 10 million dollars. Given the high cost of meeting the Method A criteria, it was decided to evaluate the petroleum occurrences using the Interim Policy's risk-based approach.

The first step in our evaluation procedure is to identify the types of petroleum products present on the site by performing a detailed evaluation of the GC-FID chromatograms associated with the WTPH analyses. We then select representative samples from each of the impacted areas and request that the laboratories re-quantitate the petroleum concentrations in accordance with the equivalent carbon number ranges presented in the Policy. Known product standards matching the types of petroleum encountered on the site are analyzed using the new surrogate VPH/EPH methodology to provide conservative estimates of the aromatic/aliphatic contents. Based on this information, we can evaluate risk to human health via the direct contact and soil to groundwater pathways. We can also use the existing TPH data to identify areas where the collection of additional samples for VPH/EPH analysis will be necessary.

Given the industrial nature of the site, the relatively low concentrations of carcinogenic PAHs and benzene, and the predominance of low mobility fuel oils and oils, risk-based soil cleanup levels established at the site will be much less stringent than the Method A petroleum cleanup levels, providing protection of human health and the environment at much lower cleanup costs.

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Poster

WDOE's Interim Total Petroleum Hydrocarbon (TPH) Policy Statement: An Improved Method for Multiphase Partitioning

Lonna M. Roberts[1], Jonathan R. Ferris[1], Jennifer P. Martin[1], Scott Meyer[1], Michael J. Pickering[1], John Roland[1], Caroline Scherony[2], and Richelle M. Allen-King[1]

In order to simplify the solution of multicomponent partitioning problems, the Washington Department of Ecology Interim Interpretive and Policy Statement: Cleanup of Total Petroleum Hydrocarbons (TPH) includes a number of simplifying assumptions. The validity of three of these assumptions was assessed through the development of computer spreadsheet models. The methods used in the development of these models is presented here and the results of those models are presented in a companion abstract.

The model is based on a mass balance approach with partioning into four phases: air, water, soil, and oil. Equilibrium between the phases is assumed. Raoult's Law was used extensively to determine the partitioning between the oil and the other phases. Typical compositions for weathered and unweathered gasoline were obtain from the literature and input into the model. Once the model was determined, various parts of the model were used to test three different assumptions presented in the policy.

The first assumption evaluated states "the fractional composition of the NAPL is the same as the fractional composition of total soil sample". The model was used to determine if the fractional composition of the NAPL (non-aqueous phase liquid) left in the soil after equilibration is equal to the fractional composition of the NAPL added to the soil. The fractional composition of the NAPL left in the soil after equilibration was calculated and the ratio between the fractional compositions of the soil and the inputted NAPL was determined.

In addition, the TPH report assumed the fractional composition of the NAPL does not change over time. The model was used to calculate the changes in mole fractions over time for all compounds of interest. To further quantify the potential for leachate generation, the area (m^2) contaminated by the spill was also approximated.

Finally, the policy also assumed that partitioning of the contaminant into other phases was linear. Methods for determining estimated nonlinearity were found by using sorption as a function of solubility. Averaged Freundlich distribution coefficients were obtained from previous studies and scaled with solubility to find an estimated distribution coefficient using TPH surrogate values. The model was then used to determine chemical saturation concentrations and soil cleanup levels. These values were then compared to linear based results and TPH policy defaults.

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Oral

WDOE's Interim Total Petroleum Hydrocarbons Policy Statement: Testing the Validity of the Multiphase Partitioning Assumptions

Jennifer P. Martin[1], Jonathan R. Ferris[1], Scott Meyer[1], Joe Namlick[1], Michael J. Pickering[1], Lonna M. Roberts[1], John Roland[1], Caroline Scherony[2], and Richelle M. Allen-King [1]

The Washington Department of Ecology Interim Interpretive and Policy Statement: Cleanup of Total Petroleum Hydrocarbons (TPH Policy) includes a number of simplifying assumptions. The validity of three of the geochemical assumptions used in the policy was assessed in order to evaluate their effects on the determination of TPH concentrations protective of groundwater systems. In order to test these assumptions, multiphase equilibrium partitioning relationships were used for typical fresh and weathered gasoline compositions. This abstract focuses on the results while the methods are described in a companion abstract.

The first assumption evaluated states "the fractional composition of the NAPL is the same as the fractional composition of total soil sample" (Assumption 2, TPH Policy, pg. 18). To test this assumption, a mass balance approach was used to determine if the fractional composition of the NAPL (non-aqueous phase liquid) left in the soil after equilibration is equal to the fractional composition of the NAPL added to the soil. The results show this assumption is not valid until at least 0.1 moles/kg soil (9000 mg/kg of nonweathered and 10600 mg/kg of weathered gasoline) are present in the soil. These concentrations are approximately 100 times the cleanup levels for gasoline using MTCA Method A (WDOE, 1997).

In addition, the TPH report assumed the fractional composition of the NAPL does not change with time. Using Raoult's law, the change in mole fraction was calculated for the contaminant versus time. The mole fractions of a fresh spill of regular unleaded gasoline are shown to continually change over a period of 100 years. The rate of removal by leachate generation is heavily influenced by the size (area) and depth of the contaminant spill, biodegradation, volatilization, and depletion by partitioning into solution.

Since the policy assumed linear behavior, a comparison of linear and non-linear partitioning behaviors using the equivalent carbon petroleum surrogate fractions was performed. Linear soil/water distribution coefficient isotherms used in the policy can potentially over-, or under-estimate actual sorption and can affect cleanup levels and estimated soil saturation levels. Over wide solubility's, the results show that the linear soil/water distribution coefficients are conservative for the aliphatics for deriving cleanup levels protective of groundwater, while less consistent for aromatic fractions.

Finally, the policy uses default values in the estimation of C_{sat} concentrations protective of groundwater (TPH Policy, pg. 18). The results of a sensitivity study show that the use of default values can over- or under-estimate C_{sat} concentrations thus inaccurately predicting leachate concentrations protective of groundwater.

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Contamination and Remediation

Oral

Cone Penetrometer Technology—A Cost Effective Tool Site Closure Case Study in the Duwamish Corridor

James Beaver[1,2] *and Doug Hillman, P.G.*[1,3]

There are perhaps many relatively small sites along the industrial corridor of the Duwamish Waterway that have groundwater impacted from past chlorinated solvent release. Attaining environmental closure is dependent upon adequate site characterization and remediation, both of which are complicated by the potential for DNAPL within the stratified alluvial deposits. We used cone penetrometer techniques (CPT) to resolve multiple site assessment issues and to support environmental closure based on natural contaminant attenuation. The subject property consists of a small manufacturing facility located about 500 feet from the Duwamish Waterway.

Initial site investigation data suggested that chlorinated solvents beneath the subject property originated from dilute or dispersed sources, but questions regarding conditions at depth remained. Direct push drilling techniques were used to collect groundwater quality samples and map the lateral extent of two distinct chlorinated solvent plumes beneath the subject property. A TCE-dominated plume was centered beneath the subject property septic system and a PCE/TCA-dominated plume was mapped in the vicinity of an on-site repair shop. Total solvent concentrations ranging from 75 to 125 ug/L were noted in shallow groundwater from each area. Soil sampling efforts focused in the likely source areas identified chlorinated solvents in soil, but the concentrations were relatively low and below regulatory cleanup levels.

CPT equipment was used to resolve outstanding issues regarding vertical chlorinated solvent migration in a single field mobilization. Most importantly, these explorations confirmed the absence of DNAPL and provided confirmation that active groundwater remediation was not warranted. At locations in the immediate vicinity of each likely source area, the CPT equipment was used to generate a continuous profile of geologic conditions and pore water conductivity to depths of 90 feet. These data identified sandy alluvium with discontinuous silty layers overlying a layer of dense silt and bedrock at the base of each exploration. The pore water conductivity measurements demonstrated that salinity increased with depth and that brackish conditions likely limit groundwater use as a drinking water resource. Modified CPT tooling was then used to collect depth-specific groundwater samples immediately above fine-grained layers at increasing depth. These data demonstrate that chlorinated solvent concentrations decrease with depth, and drop to non-detectable concentrations beneath the first significant silty layer encountered at a depth of 40 feet.

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Oral

Containing Solvent Compounds Affecting Drinking Water Aquifer, SUBASE Bangor, Washington

Thomas C. Goodlin

Foster Wheeler Environmental Corporation (Foster Wheeler) is supporting the U.S. Navy in implementing two time-critical removal actions under CERCLA at Operable Unit (OU) 8 at the Naval Submarine Base (SUBASE) Bangor. These actions address volatile organic compounds (VOCs) detected in the shallow unconfined aquifer that originate on the base and migrate off-base beneath residential property, of which 1,2-dichloroethane and benzene represent the highest potential risk to human health. Under the first removal action, Foster Wheeler provided an alternate water supply to residents, confirmed that contamination originates on Navy property, and defined the nature and extent of contamination in the shallow aquifer. Under the second removal action, Foster Wheeler designed and is now implementing containment of compounds in the shallow aquifer to reduce further migration off SUBASE Bangor. A pump-and-treat containment system is scheduled for startup in early May, 1997 to extract groundwater along the SUBASE Bangor property line, treat the water, and reintroduce the clean water to the subsurface. This presentation summarizes determinations of groundwater flow, contaminant extent, and aquifer properties that support containment design and evaluates the effectiveness of containment under startup and operation.

Knowledge of flow and aquifer properties is essential to effectively contain groundwater contamination and to begin restoring the aquifer. The uppermost stratigraphic units that underlie OU 8, from shallow to deep, consist of the Vashon Till (aquitard), Vashon Advance Outwash (shallow aquifer), and Lawton Clay (aquitard). The shallow aquifer is encountered in the Vashon Advance Outwash at a depth of 15 to 30 feet below ground surface and averages 100 feet thick. Horizontal groundwater flow for OU 8 is generally to the southeast at a hydraulic gradient of about 0.004, wherein horizontal flow is influenced strongly by both topographic and stratigraphic controls. The shallow aquifer has a hydraulic conductivity of about 0.02 centimeters/second (67 feet/day), based on pump tests and slug tests. Combined with the hydraulic gradient and a measured porosity of about 0.3, the groundwater flow velocity is approximately 0.4 feet/day. Capture of contaminated groundwater at the SUBASE Bangor boundary will be accomplished by pumping from two extraction wells screened at intermediate depths within the shallow aquifer. Extracted water will be air stripped and reintroduced at two wells positioned just beyond the lateral periphery of aquifer contamination and slightly downgradient of the extraction wells. Three-dimensional groundwater flow modeling indicates that an extraction rate of 90 to 120 gpm will achieve containment.

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Oral

DEMONSTRATION OF ELECTROKINETIC REMEDIATION OF CONTAMINATED SOILS

Martin A. Wills[1], John C. Haley[1], Gene L. Fabian[2], R. Mark Bricka[3]

Military and industrial activities such as electroplating and metal finishing processes, explosive and propellant manufacturing and use, and the use of lead-based paints, have resulted in widespread contamination of military facilities. The US Army Environmental Center (USAEC) is conducting a field scale demonstration of electrokinetic remediation for heavy metals-contaminated soils.

Electrokinetic remediation is being demonstrated because of its potential for being less invasive in ecologically sensitive areas and more cost effective than other metals-removing technologies. This technology demonstration, jointly sponsored by the Environmental Security Technology Certification Program (ESTCP) and Southwest Division, Naval facilities Engineering Command, will be conducted in and around two 30x60-foot waste pits at Site 5 (Old Area 6 Shops), Naval Air Weapons Station (NAWS) Point Mugu, California. The principal contaminants of concern at Site 5 are chromium, cadmium, copper, nickel and silver. The technology will be monitored for its metals removal performance and cost effectiveness as well as its effects on the surrounding environment.

The electrokinetic process is an in situ continuous process which can be applied to removal or capture of: heavy metals, radionuclides, and selected organic pollutants from sands, silts, fine-grained clays, and sediments. Electrokinesis involves the use of ceramic electrodes arranged in cathode and anode arrays. The electrodes are positioned inside permeable, water-filled casings that are inserted into the soil. Energizing the electrodes initiates hydrated ionic movement through the soil and ground water toward the electrodes. Through electromigration and electro-osmosis the contaminants are transported through the soil for recovery at the cathode. The contaminant metals can either electroplate onto the cathode in the casing annulus or be concentrated in the annulus for removal. This process has been successfully demonstrated on a pilot scale by the US Army Corp of Engineers Waterways Experiment Station (USACEWES) and is ready for full scale demonstration.

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Poster Presentation

Enhanced Leachate Recirculation - Summary of WMI's Landfill Bioreactor Projects

John A. Baker

Waste Management, Inc. (WMI) has experience in recirculating leachate at over 30 landfill facilities. The Federal regulations for Subtitle D Landfills allows leachate recirculation within the waste mass if the landfill has a composite liner (i.e., 2 feet of compacted clay and a 60 mil geomembrane liner and leachate collection system). The intent of the regulation is to encourage stabilization of leachate and the waste mass prior to and during landfill closure. As opposed to the "dry" landfill techniques practiced at most sites, USEPA believes that leachate recirculation should decompose biologically the MSW and provide for a lower potential for environmental risk at the landfill during the 30 year post-closure period.

WMI has reviewed many different methods of leachate recirculation and will recommend specific practices at the poster session. Also, water balances conducted at many sites (especially those in the western half of the country) have indicated that there is not enough leachate to provide adequate moisture to the total landfill mass. Prior research indicates that high moisture content must be achieved in order to provide an adequate matrix for biological degradation. WMI believes that additional liquids (i.e., liquid special wastes or sludges that do not pass the paint filter test) will be required in order to achieve the goals EPA has identified for leachate recirculation.

WMI also is directing several "enhanced" leachate recirculation projects that "boost" the biodegradation processes, especially concentrating on paper wastes (e.g., cellulose and hemi-cellulose). Two different types of anaerobic bioreactors that enhance existing microorganisms in the waste will be displayed as well as an aerobic bioreactor landfill.

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Oral

Geochemical Evolution of TCE Plumes, Duwamish Valley, King County, Washington

K. Scott King[1], Roy E. Jensen[2], Keith Pine[3]

Two well-defined plumes containing the chlorinated solvent trichloroethene (TCE) have been delineated on an industrial facility using monitoring wells and the results of Geoprobe™ sampling. The site is underlain by fill and a thick coarsening upward sequence of deltaic sands in turn underlain by a silty clay aquitard. Saline groundwater is encountered at depth and saline intrusion from the Duwamish Waterway was observed. Tidal influence from the adjacent Duwamish Waterway causes daily hydraulic gradient reversals but a net discharge.

The presence of 1,2 dichloroethene and vinyl chloride in the plumes indicate that reductive dechlorination reactions are occurring. Associated with the chlorinated solvent plumes are elevation concentrations of iron and manganese. In addition, elevated dissolved concentrations of arsenic and copper occur within the plumes. Measurements of dissolved oxygen and Eh indicate that the plumes are highly reducing and redox conditions would support the reductive dechlorination of TCE. A comparison of two TCE plumes indicates that the most reducing plume has elevated manganese, iron, and arsenic strongly associated with TCE degradation products. A second plume is reduced enough to degrade TCE and dissolve manganese minerals but apparently not iron hydroxide minerals. Benzene, susceptible to aerobic biodegradation, appears to be recalcitrant in the reducing plume. At some portions of the plume, aquifer conditions become less reducing due to mixing with oxygenated surface water which intrudes into the aquifer. The geochemical interactions appear to reduce the concentrations of some metals.

The conceptual geochemical model for the site suggests that oxidation of hydrocarbon compounds associated with the plumes have caused reducing conditions resulting in reductive degradation of TCE, dissolution of hydroxide minerals and release of iron and manganese into solution. The dissolution of hydroxides is also presumed to have resulted in the release of arsenic and copper sorbed to the hydroxide minerals. The results of the investigation indicate that conditions suitable for intrinsic biodegradation of TCE may occur at the site.

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Oral

Hydrogeology and Chemical Transport Near Landfill at Keyport Naval Facility, Kitsap County, Washington

Thomas E. Dubé[1] and Mark A. Dagel[1]

At the Naval Undersea Warfare Center, Division Keyport, the 9-acre Area 1 Landfill was in use from the 1930s until 1973. The landfill has locally contaminated two aquifers with chlorinated aliphatic hydrocarbons (CAHs) derived from disposed waste solvents. These aquifers are termed the upper and intermediate aquifers, which overlie a thick (100-200 ft) aquitard of silt, clay, peat, and sand referred to as unit Qn4, which likely correlates to the Clover Park unit. Above Qn4 is a widespread glacial deposit (unit Qg3) that probably correlates to the Double Bluff Drift. This drift is up to 28 feet thick and includes sand/gravel outwash, till, and silt layers. The intermediate aquifer largely occurs within this outwash. Overlying the drift is the Kitsap Formation (unit Qn3), which is up to 40 feet thick and comprises a local lower sand, an interbedded sand/silt, a middle silt, and an upper sand. The upper sand is the main permeable zone of the upper aquifer. The middle silt forms the primary aquitard between the two aquifers and ranges up to 23 feet thick. A channel that is eroded into this middle silt trends NW-SE across the landfill and is filled with the upper sand. In the central part of the landfill, this channel cuts down through the silt aquitard to the underlying outwash, opening a 1-acre "window" connecting the two aquifers. Above unit Qn3 are Vashon glacial deposits, including glaciolacustrine silt/clay (Lawton Clay), outwash, and till. The Lawton Clay forms local deposits to more than 120 feet thick in steep-sided basins cut down to unit Qn4. Vashon till and outwash are thin or absent near Area 1, but thicker in adjacent locations. In low-lying areas are recent estuary or marsh deposits of silt and silty sand, which rest on unit Qg3 outwash in the northern part of the landfill. Fill material directly overlies marsh deposits and is typically up to 10 feet thick. The water table is situated within fill or in Vashon deposits.

CAHs in the upper aquifer occur in three zones under the landfill. Highest total concentrations (~20,000 ppb) occur in the southern zone. Lower concentrations (~2000 ppb and ~50 ppb) occur in the central and northern zones, respectively. Detected CAHs are primarily trichloroethene and its degradation products 1,2-dichloroethene and vinyl chloride. Other CAHs include 1,1,1-trichloroethane and its degradation products 1,1-dichloroethane, 1,1-dichloroethene, and chloroethane. Upper aquifer groundwater flows westward, discharging to a wetland which drains into a tidal lagoon; at low tide, the lagoon discharges to Dogfish Bay. CAHs are detectable in low ppb levels in these surface water bodies as far downstream as the lagoon outlet. Groundwater in the intermediate aquifer contains CAHs up to about 2000 ppb just downgradient of the landfill. Intermediate aquifer groundwater flows northwestward and discharges to Dogfish Bay. Fresh (non-saline) intermediate aquifer water containing CAHs up to about 1 ppb extends beneath the lagoon more than 500 feet downgradient of the landfill. CAH composition and concentrations provide clues to transport from the upper aquifer contaminant zones to the intermediate aquifer through one or more windows in the silt aquitard.

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Oral

Innovative Applications of Phytoremediation of Soil and Related Regulatory and Stakeholders Issues

Dibakar (Dib) Goswami[1] *and Robert T. Mueller*[2]

Developer of new technologies for environmental remediation are often faced with unanticipated and difficult times from issues related to regulations, costs and concerns from pubic and stakeholders. Beyond the "better, quicker, cheaper" forces that drive the marketplace, new technologies must deal with gaining regulatory and public acceptance before they are used in the field. Recognizing these barriers, the Interstate Technology and Regulatory Cooperation (ITRC) Working Group of the Western Governors Association taking steps to lower these hardles and simplify interstate acceptance. ITRC is a group of 26 states.

Numerous laboratory and a few field demonstrations have shown that phytoremediation of metals is a cost effective "green" technology based on the use of metal-accumulating plants to remove toxic metals, including radionuclides. Of the various phytoremediation technology, phytoextraction represents one of the largest economic opportunities for phytoremediation because of the size and scope of environmental problems and costs associated with metal contaminated soils. A number of regulatory and stakeholders issues are raised by a cursory examination of phytoremediation technology. Following are a few of the major issues:

- How will protection of other habitat/endangered species from entrance of contaminants into the food chain be facilitated?
- Is the projected time for cleanup acceptable to public/regulatory agencies?
- Are there sensitive ecological species that may be affected by the phytoremediation plants? Are these plants competitive to already existing natural habitat?
- What kind of measures will be taken to track/deter the risks associated with inhalation and ingestion of soil treated with soil amendments? How will toxic metals not targeted by the specific approach interfere with remedial process?
- Without incentive to recycle what happens to root bound metals?
- What is the possible effect of "discharges" to the atmosphere? Etc.

Both academia and the industry should be aware of these and other related issues. Some of these issues may turnout to be mere "speculation" or of no concern. However, both academia and the industry must be able to address these issues in a scientific manner. It seems, a majority of these issues can be addressed based on the present knowledge of the subject with site specific examples.

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Long Term Ground Water Remediation - Operational and Regulatory Lessons

By: James S. Bailey, R.G.[1] *& Lisa Rutan P.E.*[2]

A former RCRA regulated metal plating facility and adjacent Aerospace manufacturing company near Seattle, Washington have been cooperating for the last five years on the operation of a ground water recovery and treatment system. Chlorinated solvents up to 300 ppm have impacted the shallow aquifer beneath the site. In 1992, a ground water recovery system consisting of six recovery wells were installed. Ground water was pumped to a treatment system which utilized a pack tower stripping unit to remove VOC's at a rate of 64 gallons per minute. The system which is run 24 hours a day, is operated and monitored remotely using a programmable logic control (PCL) technology. Over time the system has been modified to address maintenance issues such as chemical fouling of air stripper, clogging of piping, optimizing data collection activities and meeting regulatory requirements. These modifications have included an acid injection system, an air monitoring system, pH control system and modifications to the recovery well pumping and monitoring systems.

Since the system is operated for two completely separate companies, effective communication procedures have had to be developed to address issues such as cost allocation, regulatory liaison and work product reviews. These procedures have included allocation of costs based on water treatment flow rate or ownership of wells, pipelines, etc., development of joint documents for regulatory review, and assignment of day to day regulatory interface to local site representative.

A comprehensive database has been developed in order to document system operation, enhance ground water cleanup and optimize the efficiency of the system. This information has been critical to the understanding of the dynamics of the recovery system on the hydrogeologic system and long term water quality impacts. A network of 60 monitoring wells across the site have been monitored for water level and water quality conditions. Water quality data has been collected quarterly in some wells since 1984. Long term trends and impacts on the recovery system are well documented. Water level data is collected either continuously, monthly or quarterly depending on the location of the well. This data has allowed the development and calibration of a detailed and reliable numerical computer model for the site. This information has been successfully used to convince regulatory agencies to allow reduction in the pumping rates, reducing disposal costs. Monthly effluent water quality data has shown the recovery system has been successful in reducing overall concentrations of VOC's in the aquifer.

Finally, long term goals and objectives have been developed to continue reducing operational and maintenance costs and enhance the speed and effectiveness of ground water cleanup. Alternative ground water treatment methodologies have been evaluated and pilot testing performed.

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oral presentation

Metal-Bearing Alkaline Groundwater at the Cement Kiln Dust Waste Pile in Metaline Falls, WA

Keith L. Stoffel[1], Martin D. Werner[2], Gerald D. Lenssen[3], and William J. Fees[4]

Approximately 600,000 metric tons of cement kiln dust (CKD) were disposed in a waste pile along the margin of the Sullivan Creek valley between 1952 and 1989, covering 6.8 acres to a maximum thickness of 20 meters (65 feet). The CKD is strongly alkaline (mean pH = 12.3) and exhibits acute toxicity to fish. As a result, the CKD is a *corrosive* and *toxic* dangerous waste in Washington state (Chapter 173-303 WAC). The CKD contains arsenic, lead, and chromium in concentrations which frequently exceed soil cleanup levels established in the Washington Model Toxics Control Act Cleanup Regulation (Chapter 173-340 WAC).

Between 1992 and late 1996, the pH of groundwater beneath and downgradient of the CKD pile consistently exceeded 13 standard units, and periodically approached 14. The groundwater also contained elevated concentrations of arsenic, lead, and chromium, apparently mobilized from the CKD pile under the strongly alkaline conditions. Downgradient of the pile, the metal-bearing alkaline groundwater emerged from springs and temporarily ponded on the Sullivan Creek floodplain. It drained into a narrow channel and flowed into Sullivan Creek approximately 325 meters (1,100 feet) downgradient of the pile.

In 1996, an "impermeable" cover and internal drainage system was constructed on the CKD pile to minimize the infiltration of surface water into the pile and to reduce the volume of alkaline leachate draining from the base of the pile. A peripheral stormwater drainage system was also constructed to minimize run-on of stormwater from the adjacent mountainside.

Borehole and monitoring well data collected between 1992 and late 1996 (prior to construction of the cover) indicate the elevation of groundwater under the north half of the CKD pile fluctuated only about one foot throughout the monitoring period. Groundwater was apparently in contact with the base of pile during most, if not all of this time period. Because construction of the cover and storm water drainage system will probably have little impact on the elevation of groundwater beneath the north half of the pile, it is probable that groundwater will remain in contact with the base of the pile in the future, and the generation of metal-bearing alkaline leachate will continue.

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Promoting Brownfields Redevelopment through Area-Wide Designation Duwamish Corridor Case Study

Lori J. Herman[1]

This presentation will discuss work being done to designate an alternate highest beneficial use for groundwater in a selected area of the Duwamish industrial corridor. The work was conducted as part of City of Seattle and King County efforts to promote reuse and redevelopment of the "brownfield" properties in the Duwamish industrial corridor. The work begins by defining the criteria which support an area-wide designation and centers on the definition of a distinct hydrogeologic environment appropriate for such a designation. Conceptual and numerical groundwater flow modeling are being undertaken to support the designation. This type of area-wide designation will help streamline the regulatory process and remove uncertainty of environmental liability in real estate transactions and financial lending for the area.

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Reintroduction of Treated Water as a Component of Groundwater Remediation: A Sensible Proven Solution

Steve Germiat[a] *and Tim Flynn*[b]

Reintroduction of treated water at a groundwater remediation site has been demonstrated to be a highly effective water disposal solution in terms of cleanup enhancement, resource conservation, and cost. Reintroduction of treated water to an aquifer via wells has been successfully implemented at a relatively large scale groundwater pump-and-treat site at SUBASE, Bangor in western Washington. Reintroduction of treated water, often discouraged by State regulatory agencies in the past, was selected for disposal of treated water at the site, largely as a result of public demand for conservation of the local groundwater resource. All extracted water from the site is treated to meet drinking water standards, and returned to the aquifer from which it was removed, providing no net resource depletion. In addition to resource conservation, the reintroduction wells are strategically positioned to enhance containment of the plume, reducing the pumping required to achieve containment. This, in turn, reduces lifecycle operating costs. Use of on-site reintroduction wells at this site is also less expensive than off-site conveyance and disposal. Although not an issue at this site, reintroduction wells can be used to limit saltwater intrusion during remediation of tidally influenced aquifers.

Successful design, construction, and operation of the reintroduction wells has resulted in their operating generally maintenance-free to date, with little evidence of efficiency loss caused by clogging over the first 2+ years of operation. Based on the reintroduction wells' demonstrated success as part of the interim groundwater containment system (300 gpm) at the site, additional larger-capacity reintroduction wells were constructed as a component in enhancement of the existing pump-and-treat system at the site (to 600 gpm). In light of the current issues regarding water resource development in Washington, and the need to design increasingly cost-effective cleanup solutions, reintroduction of treated water is a technology warranting greater consideration at groundwater remediation sites.

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Separate Phase Hydrocarbon Recovery in a Tidally Influenced Area

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Groundwater contamination by surface and underground hydrocarbon spills is a ubiquitous problem that has received widespread attention. Following large spills, free product, or separate phase hydrocarbon (SPH), is often encountered floating upon the water table in monitoring wells installed to assess the situation. Recovery of SPH may be performed by skimming hydrocarbon from the wells, usually in conjunction with water pumping to increase the gradient. The efficiency of such systems will depend on soil and fluid properties (e.g., hydraulic conductivity, capillary retention properties, hydrocarbon density and viscosity), environmental variables (water table gradient), as well as design variables (number and locations of recovery wells, and rates of water pumping). The volume of SPH that can be recovered is related to the observed thickness of the hydrocarbon layer. However, it is common knowledge that the observed thickness tends to decrease when the water table rises and increase when the water table falls. In a tidal area, the calculation of the expected volume to be recovered is complicated by the twice daily water table fluctuations as well as the seasonal highs and lows (spring and neap tides).

Assessment and remediation of Jet Fuel (JP-4) at a large above ground fuel storage facility located adjacent to Puget Sound will be described. Monthly groundwater and SPH thickness observations recorded for over a year, were graphed and used to quantify the variation of SPH thickness across the site in response to tidal fluctuations. The thickness decreases linearly as the groundwater elevation rises in some of the monitoring wells. However, in several wells, following this decrease, an increase occurs while the groundwater continues to rise. The optimum depth and pumping cycles for the SPH extraction pumps were determined from such graphs.

An aquifer test was conducted to determined the hydraulic conductivity of the aquifer. Evaluation of the aquifer response during pumping required correction for the tidal effect. The volume of recoverable SPH and the desired well spacing for remediation were then calculated using the computer code SpillCad™. Good agreement was found for the calculated versus observed recovery rates during pilot testing, and a progress report on the full-scale remediation will be available for this presentation.

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Oral

Steady State Plume and Remedy Selection Tumwater, Washington

Janet N. Knox[1]

An RI/FS was conducted on a former public works site in Tumwater, Washington. The public works site occupies a block in a residential neighborhood. A stream ravine lies to the northeast, where shallow groundwater discharges.

The RI found a localized plume in shallow groundwater approximately 180 feet long and 30 to 40 feet wide. The plume was found not to extend to the stream, as contaminants were not detected in downgradient groundwater samples, seep, and stream samples. The source of the plume was a gasoline underground tank which was installed in 1971 and removed in 1987. Approximately 250 cubic yards of soil were excavated. The excavation was restricted on one side due to a public roadway. As shallow groundwater was found at 5 feet below ground surface, the vadose zone source of contamination was largely removed. Although samples were not collected to confirm the removal, photographs and volume estimates document the removal.

The shallow aquifer soil type is sandy gravel with steep hydraulic gradients, indicating relatively high groundwater velocities (i.e. >100 feet/year). However, the plume was found to be steady state at less than 200 feet long. The steady state plume is supported by chemical evidence for microbial degradation of the plume: oxygen, carbon dioxide, and major ion chemistry of the site indicates greater microbial action in groundwater near the most contaminated well, less microbial action in less contaminated wells, and very little microbial action in groundwater samples downgradient from the plume.

Ecology recommended that minimal enhancement of the natural bioremediation was appropriate to decrease the time to achieve cleanup levels in groundwater. Recent studies have shown the value of adding nitrate to enhance bioremediation in BTEX-contaminated aquifers. Nitrate provides the nutrient nitrogen and serves as an election acceptor, resulting in anoxic biodegradation via nitrate reduction and denitrification. However, calculations show that very large amounts of amendments would be necessary to degrade the limited plume. The short-term impracticality of greatly amending the groundwater with oxidants may not be worth the long-term effectiveness, and may be more detrimental than beneficial.

MTCA remedy selection requires that remedies be protective of human health and the environment. Yet, the process of selecting a remedy shall be commensurate with site complexity and conditions. If a localized plume in shallow groundwater does not have complete exposure pathways and natural bioremediation is occurring, an active remedy may not be appropriate.

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Oral

The Palermo Wellfield - Washington's Newest Superfund Site

Chris V. Pitre[1]

Tumwater's Palermo Well Field, located near Olympia, provided 50% of the city's drinking water capacity until recently. In 1993, three of the six production wells were found to be impacted by trichloroethene (TCE). The city removed the impacted wells from service and modified the pumping regimen of all wells to prevent impact to the clean wells. Within two weeks, a Geoprobe™-based investigation by the city outlined the contaminant plume within several blocks of the wells. Ecology and EPA were invited to respond to the continuing threat to the well field. Ecology conducted a contaminant source inventory of the area and EPA conducted a soil gas and groundwater sampling program half a mile upgradient of the wellfield. It is believed that a dense non-aqueous phase liquid (DNAPL) is a continuing groundwater contaminant source. At some locations, the plume is up to 100 feet thick. By 1996, several potential contaminant sources were identified, along with wide-spread low-level contamination. The site was submitted to the National Priorities List (Superfund list) in December, 1996.

One contaminant source is a drycleaners located 1,500 feet away from the wellfield. At this site, tetrachloroethene (PCE), and possibly TCE, were released in a dry well. Other potential sources exist, not all of which may yet be identified.

Groundwater flow patterns are complicated by Barnes Lake, the surface elevation of which is maintained constant by a dam. As the lake level remains constant, and groundwater levels vary seasonally, groundwater flow directions are expected to vary seasonally. These changing groundwater flow directions complicate tracing of contamination to sources, and smear the plume perpendicular to the average groundwater flow direction.

Receptors include municipal drinking water sources, other groundwater users, seepage of groundwater to surface in a residential area, volatilization to structures, and the Deschutes River. The foremost interest of the City of Tumwater is to protect remaining unimpacted drinking water wells, and to recover use of the impacted wells. The city's Wellhead Protection Program, in conjunction with ongoing work by EPA, continues to improve the understanding of the problem. EPA is currently considering source removal, installation of interceptor wells between sources and the wellfield for pump-and-treat, and treatment options at the wellhead to restore municipal capacity.

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Poster

The Queen City Farms Superfund Site: Natural Attenuation Poster Child?

Marcia Knadle[1]

The Queen City Farms Superfund Site in Maple Valley, Washington features several types of environments favorable for natural attenuation of chlorinated volatile organic contaminants in ground water. There are three contaminated aquifers, each with its own distinctive suite of attenuating processes. Altogether, these processes appear to have effectively contained contaminants exceeding human-health risk levels on site.

Various waste oils, solvents, and metals plating wastes were disposed in a series of ponds at Queen City Farms from the mid-1950's to the mid-1960's. Contamination from the ponds (now closed) has affected three aquifers. Immediately below the ponds, glacial till grades laterally into outwash, resulting in a complex and very heterogeneous deposit varying from silt to open-work gravels which contains perched Aquifer 1. This contaminated aquifer discharges to springs and leaks down to the outwash sands and gravels of Aquifer 2. In addition, much of the surface runoff from the till-floored drainage basin to the north recharges Aquifer 2 at the same location, fortuitously resulting in radial flow within the secondary contamination plume beneath the site. The lacustrine silt aquitard underlying Aquifer 2 is locally leaky, and there is a relatively new tertiary plume in the interglacial fluvial sands of Aquifer 3.

Aquifer 1 beneath the disposal area contains a complex mix of contaminants and has a highly reducing environment because of the co-disposal of waste oils. Consequently, much of the dominant solvent trichloroethene (TCE) has been degraded to cis-1,2-dichloroethene (DCE) and some vinyl chloride (VC). Virtually all of the other contaminants are bound to the soils near the disposal ponds. Dissolved TCE and DCE have migrated vertically through 50 feet of unsaturated sands and gravels to Aquifer 2. Here, little chemical degradation or sorption occurs because of the relatively oxidizing conditions and coarse soils. However, the radial flow results in enough dilution and dispersion to contain the plume within the site. In one area, the Aquifer 2 TCE/DCE plume has leaked through the aquitard to Aquifer 3, which is more reducing because of natural organic material incorporated in the sands, including coal clasts locally derived from Puget Group rocks as well as minor amounts of woody material. While there has been remarkably little sorption of contaminants within the aquitard, there is significant conversion of TCE to DCE and traces of VC with depth within Aquifer 3. Aquifer 3 is unlikely to return to the oxidizing conditions which could facilitate VC degradation, but the levels are low enough that dilution and dispersion may attenuate it below detection limits before leaving the site. Confirmation of this will require additional monitoring.

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Forum Abstract

Oral

Quaternary Stratigraphy of the Tacoma Area - Status of Mapping Efforts

Kathy Goetz Troost [1]
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Understanding the geologic framework of the Puget Lowland has been hampered by intrinsically complex stratigraphic relationships, obscured by dense vegetation, and impeded by limited knowledge of Quaternary history. These problems are nowhere better expressed than in the Tacoma area, where the distribution and sequence of glacial and nonglacial deposits have been contemplated and debated by geologists for decades. Of particular interest in this rapidly-growing area are the continuity and effectiveness of local and possibly regional aquitards; structural deformation expressing the region's active tectonism; and geologic hazards associated with slope instability, the potential for volcanic activity, and Pleistocene and Holocene earthquakes. A variety of field researchers are utilizing radiocarbon dating, paleomagnetic studies, pollen analyses, tephrochronology, and basic geologic mapping to determine the distribution of and to establish a regionally based chronology for the distribution and deformation of aquifers, aquitards, and other critical Quaternary deposits. Because of the long history of public and private geologic studies in this area, a broadly collaborative effort is being emphasized by those working most directly on these stratigraphic and structural complexities. Research is being conducted as part of the U. S. Geological Survey's "Pacific Northwest Urban Corridor Mapping" and "Regional Aquifer Systems Analysis" projects, as part of the Washington State Department of Natural Resource's State Mapping Project, and in coordination and collaboration with other, more area-specific mapping efforts by private individuals and firms. Products of these efforts will include many new 7.5-minute geologic quadrangle maps, contributions to the new state geologic map 1:100,000 scale quadrangles, updated stratigraphic column(s) and regional correlations across the area, and additions to the existing inventory of local and regional hydrostratigraphic maps.

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Late Additions

Sustaining Watersheds and the People Who Need Them: From Hydrology to Drinking Water

Dr. Susan Lisa Toch, Ph.D., M.P.H.

The assumption is often made that progress demands degraded surroundings. You put up with a lowered quality of life as long as you have to, then run away from it as soon as you can afford to. This either-or approach is based on the premise that economic development requires deteriorated landscapes and debased communities; that these are simply a given, something we all have to live with. The general consequences of running from the problem rather than solving it are apparent. Perhaps not so apparent is the possibility of running becoming the only option, and living in a state of permanent crisis becoming the "natural" condition.

The relationship between human beings and the natural environment is basically two-way. Human beings rely on environmental resources, are affected by their environment, while at the same time having the capacity to modify that environment. The watershed is a classic example of this because flows of water connect virtually all needs, activities and interests. Watersheds are unified systems in which actions in one place affect conditions in another. However, a watershed is often made up of many different social, political and economic systems that overlap, sometimes randomly, in a particular drainage area. The causes for actions in watersheds often originate for reasons, in places and on scales far distant from their geographic location.

Where human beings exist, so do the use of natural resources. Most watersheds in the West demonstrate this by remnants of logging, mining, grazing, homesteading, and water development projects. They often contain roads, dams, ditches, pumps and pipelines, built by different people at different times, for different reasons, all which have transformed the flow of water. These uses and related environmental change traverse time, with current examples ranging from the San Francisco drinking water supply, originating in Yosemite National Park, to the conflicts between forest extraction and the protection of community watersheds in the West Kooteneys, British Columbia. With less than one half of one percent of the total water on the planet available as fresh water, the link between the protection of hydrologic systems and the quality of human welfare is inescapable.

The concept of resource management implies that people can develop resources without destroying them. While most land use activities can be associated with ecosystem change, resource use does not necessarily comprise a water contamination source. It is the methods by which human activities occur on a watershed that have the potential to promote or reduce mechanisms for human illness. The degree and extent of these specific land use practices can be identified and controlled. Effective watershed management strategies can be viable means to the preservation and management of potable supplies. An investigation into land use as it relates to the effects on hydrologic processes serves as a basis for the connection of effective alternatives in resources management with human well-being, linking protected areas with human needs.

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