Abstracts

The 1st Symposium on the

Hydrogeology of Washington State

WASHINGTON STATE DEPARTMENT OF ECOLOGY

AUGUST 28-30, 1995 • THE EVERGREEN STATE COLLEGE • OLYMPIA, WASHINGTON

Abstracts from the 1st Symposium on the Hydrogeology of Washington State

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Contents

Acknowledgements

Welcome to Washington state's First Hydrogeologic Symposium! This year's symposium offers over 100 oral and poster presentations. *All* of the abstracts received are included in the program for the symposium as either oral or poster presentations. In an effort to enhance open dialogue and to stimulate scientific inquiry on the hydrogeology of Washington state and the Pacific Northwest, the Department of Ecology felt it was important to give all authors a chance to participate in the symposium. Each abstract enclosed is the original abstract and was not edited for scientific content.

Special acknowledgements to the committee at the Department of Ecology responsible for compiling the abstracts and developing the schedule for the symposium: Kaia Petersen, Chuck Cline, Tom Culhane, Melanie Kimsey, Cris Matthews, and Sally Safioles.

Keynote Speaker

Groundwater Remediation and its Ethical Conundrums: The Question of Mass Removal and Risk Reduction in an Adversarial Regulatory Environment

R. Allan Freeze

Most studies of groundwater contamination include technical, legal and socioeconomic components. Hydrogeological site characterization must serve the needs of remedial engineering design, within a set of constraints posed by complex regulatory compliance issues, strong social pressures, and an adversarial legal setting. One of the most difficult and contentious issues that arises at contaminated sites is the proper tradeoff between containment and contaminant mass removal. Containment is feasible, but it implies perpetual care, and it is often not considered to be responsive to public demands for restoration of environmental quality. Mass removal is usually favored by regulators and the public, and it is implicitly required by much of the relevant legislation. Many emerging remediation technologies are designed to remove mass; however, studies indicate that mass-removal efficiencies close to 100 percent are required to achieve significant long-term risk reduction, and such efficiencies are not currently feasible, nor are they ever likely to be. In this world, the hydrogeologist must tread carefully, for ethical conundrums abound: What is the responsibility of the hydrogeologist to protect the health and safety of the public in a regulated environment? How should scientists and engineers function in the adversarial legal environment? What is the role of value systems and social biases in environmental decision making? In the current framework, it is not usually clear what level of societal risk reduction must be achieved. And it is far from clear that the current adversarial style of interaction between regulators and site owner-operators leads to socially-optimal remedial decisions.

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Abstracts

Applied Science and Technology - Cleanup Technology and Case Studies

Oral

Influence of Tidal Fluctuations on Coastal Aquifers, Puget Sound, Washington: General Principles and Case Studies

Roy E. Jensen[1] and William E. Halbert[2]

The increasing number of environmental investigations of tidally induced fluctuating ground water adjacent to the Puget Sound has lead to the use of innovative techniques to understand ground water flow behavior and contaminant transport. Developing an understanding of effects of ground water fluctuations and flow in tidally influenced aquifers is a necessity for establishing ground water monitoring networks, developing ground water sampling schedules, and designing remedial systems. Puget Sound tides are classified as a mixed type with two unequal highs and lows having a period of about 25 hours with the maximum range tidal amplitude as much as 6 meters. The highest tides occur early winter and the lowest in early summer. Tide predictions based on astronomical forces do not account for regional and local effects of meteorological condition (winds, barometric pressure), coastal morphology, and river discharges. The difference between actual and predicated tide stage height can be as much as 1 meter. Tidal response in an unconfined aquifer is only partially the result of horizontal water flow; the remaining effect is the result of pressure loading. Tidal response in confined aquifer is the direct result of pressure loading. As general rule, single point ground water level measurements, which are routinely used in upland sites, cannot be used to adequately characterize net ground water gradient and flux in tidally influenced aquifers. Comprehensive tidal influence studies should be conducted using pressure transducers and data loggers to collect a time series of water level measurements for a period of 72-hours. Filtering methods which remove the solar and lunar harmonics should be used to determine the mean ground water elevations, the first step in evaluating net ground water gradient and flow direction. By comparing the tidal cycle to ground water fluctuations additional parameters such as tidal efficiency, time lag, transmissivity, and storativity can be calculated.

A number of case studies are presented to demonstrate the effect of tidal fluctuations on unconfined and confined aquifers adjacent to Puget Sound and the Duwamish Waterway. These studies illustrate the general principles of tidal study data analysis, ground water gradient and flow reversals, floating hydrocarbon stagnation, and effects of sheetpiles and bulkheads on contaminant migration. Other areas of discussion include the timing within a tidal cycle to collect representative ground water samples, temporal and spatial discharge cycles of upland ground water to coastal water bodies, and the effect of physical and biological barriers along the shoreline.

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Oral

Using Clay Soils having Sulfidic Materials to Cap Landfills: Environmental Consequences and Identification Tests

David M. Kargbo[1], Delvin S. Fanning,[2] and Steven N. Burch[2]

Extensive literature on the interaction between waste chemicals and clay liner materials and how it influences waste migration exists. However, attempts to incorporate as design components, the effects of sulfidic (sulfide-bearing) clays on the integrity of clay caps have largely been ignored. Currently, the only requirement for cover soils in landfills and surface impoundments is that the soils attain, upon compaction, a very low hydraulic conductivity of 10^{-7} cm s^{-1} or less. Sulfide-bearing clay deposits (which may be dominant in particular profiles of candidate clay deposits, or may be confined to specific layers or lenses in given profiles) have been frequently used to cap landfills. Problems observed with the use of sulfide-bearing clays include the formation of extremely acid soils. The resulting acid soils may give rise to poor vegetative cover and enhanced erosion of soils on landfills as well as acid drainage waters, in the cover soils, that may seep out from the lower slopes of landfills and contaminate surrounding waters with the equivalent of acid mine drainage. There may also be detrimental effects on the permeability of the clay cap itself from increased flocculation of the clay induced by high ionic strength of the soil solution. It is thus suggested that clay cap designers test the acid-generating capabilities of potential clay cap materials before exposing these earth formations. A physical field test is color. Acid-producing clay soils are usually grey, dark-grey, or black in color and contain pyrite, FeS_2, or its polymorph, marcasite, which are black in powdered form. Crystals of pyrite are commonly too small to be recognized in the field, so chemical tests may become necessary. Cover soils should not be sulfidic materials as defined by Soil Taxonomy, i.e., they should not have a pH (1:1 by weight in water or in sufficient water to permit measurement) of more than 3.5 and show a drop in pH of 0.5 units or more to a pH of 4 or less when a 1 cm thick layer is incubated under moist aerobic conditions (repeatedly wetted and dried) for 8 weeks. Cover soils should also not be from sulfuric horizons which, as defined by Soil Taxonomy, already have a pH of 3.5 or less and have other evidence that the pH is from sulfuric acid. Such evidence include the presence of the yellow mineral, jarosite, $KFe_3(SO_4)_2(OH)_6$, or soluble sulfate (which will form a white precipitate as indicated by turbidity when a 10 percent barium chloride solution is added to solution drawn from the soil material), or be underlain by sulfidic materials as described above. For soils that are found to contain sulfidic materials or to come from sulfuric horizons, decisions should then be made to avoid such soils and use non-sulfidic clay soils or other alternative capping materials.

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Oral

A Proposed Groundwater Remediation Strategy for Hanford

Anthony J. Knepp,[1] Bruce H. Ford,[2] Dan K. Tyler,[3] Floyd N. Hodges,[4] Vern G. Johnson,[5] Robert E. Peterson,[6] and Greg L. Kasza[7]

The remediation of contaminated groundwater caused by the operation of the nuclear fuel production and separations facilities at Hanford has been established as an important element of the CERCLA cleanup program. To support the development of a remediation strategy, this paper combines an overview of the major groundwater plumes with elements of the site specific geohydrology and presents a strategy to remediate, control and mange groundwater contamination on the Hanford Reservation.

A initial approach to groundwater remediation is proposed which emphasizes the use of existing treatment and extraction methodology in combination with proposed and existing site infrastructure. It incorporates the significant regulatory features as established under the Federal Facility Agreement and Consent Order signed in 1989. The approach minimizes extensive site characterization in favor of a graduated evaluation of pump and treat systems. Pump and treat is initially proposed as a method to control the rate of contaminant movement and to reduce the mass of contamination found in the groundwater. Other methods and techniques (such as in-well sparging, bio-remediation, etc.) are also proposed to control localized contaminates, as the specific situation warrants.

A number of pump and treatment field scale tests are currently being implemented to collect sufficient information to support future decisions on either their expansion or termination. This work is being performed in parallel with ongoing risk and other feasibility activities.

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Oral

Cleanup of the Western Processing Site

Michael G. Kuntz

In 1984 at the 13-acre Western Processing site in Kent, Washington, 81 U.S. Environmental Protection Agency (EPA) priority pollutants were present in the soil. Fifty-six priority pollutants were present in groundwater and ninety priority pollutants were present in soil, ground water and contiguous Mill Creek. The contamination was the result of a local recycling operation gone awry.

The site is being cleaned up under Superfund. The scope of work and performance standards are defined in a consent decree signed by the Washington State Department of Ecology, EPA, and more than 180 responsible parties that are financing the cleanup. Ecology and EPA oversee the cleanup.

Remediation commenced in phases with Phase I addressing surface removal of contamination. Phase I was performed in 1984 with 2,400 truckloads carrying over 30,000 tons of chemical waste to off-site disposal or treatment. A storm water collection and treatment system was installed with treated water discharged to the local treatment authority. A total of 1.8 million gallons were treated and discharged. The cost of Phase I was $10 million.

Phase II consists of dig and haul and a massive ground water pump and treat system. After characterizing the site with a $3 million testing program, 21,900 cubic yards of contaminated soil and debris were hauled to a RCRA landfill in Oregon in 1987. Before building the pump and treat system, a 4,000-foot continuous slurry wall was constructed to a depth of 45 feet, encircling the 13-acre site. The slurry wall horizontally isolated contamination from ground water and contiguous Mill Creek.

Inside the slurry walled area a ground water vacuum extraction system employing 200 well points was constructed. The system began full scale operation in the fall of 1988, with a capacity of 200 gallons per minute. The extracted ground water is pretreated on-site and then discharged to a local treatment authority.

Five other smaller ground water extraction systems have been added, each with its own objective. One of the systems is inside the slurry walled area and four are outside the walled area. Cumulative discharge from all extraction systems to the local treatment authority exceeded a half billion gallons in 1994.

State-of-the-art field tests for in situ bioremediation of contamination are also underway. One test is in an aerobic zone outside the slurry walled area and the second is in an anaerobic zone inside the walled area. An in situ metals fixation pilot project is also underway within the walled area.

To date, Mill Creek has been successfully remediated. The extraction system has pulled an estimated 100 thousand pounds of contaminants from the groundwater. Hydraulic control and operational procedures are firmly established and the focus of extraction is on hot spots. The cumulative cost of Phase II exceeds $75 million.

Effort is underway to evaluate scenarios in which pumping is reduced or terminated. The scenarios include breaching the slurry wall and placing a cap on the site. The evaluation strategy employs computer-simulated transport analysis, risk evaluation, economics of contaminant removal, institutional controls, eventual site ownership, ultimate land use, and technical impracticability of achieving certain performance standards.

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Oral

Tidally-Induced Aquifer Dispersion: Implications for Groundwater Remediation

Dan Matthews and Clay Patmont

This talk discusses natural in-aquifer mixing processes which occur adjacent to tidally-influenced receiving waters. In many such environments in industrial areas of Puget Sound (e.g., within the Duwamish Corridor and Commencement Bay tideflats), these mixing processes provide an important buffer zone between contaminated groundwater and potential receiving water environments. Under existing state and federal cleanup regulations, the primary objective of groundwater remediation projects in these areas is often protection of surface water resources, particularly when the regulatory agencies have previously determined that there is an extremely low probability that groundwater in the area is a potential future source of drinking water. In these cases, characterization of in-aquifer mixing processes, using empirical and/or modeling methods, can have a substantial effect on risk assessment and groundwater cleanup level determinations. Examples of Hart Crowser's projects in these areas are presented and summarized.

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Poster

Site Characterization Supporting In-Situ Bioremediation of Carbon Tetrachloride

Darrell R. Newcomer,[1] Llyn A. Doremus,[2] and Vince R. Vermeul[3]

The distribution of hydrogeologic characteristics with depth in a heterogeneous aquifer was investigated for designing an effective in situ bioremediation technology at the Hanford Site. This technology is being developed for the Volatile Organic Compound-Arid Integrated Demonstration program sponsored by the U.S. Department of Energy's Office of Technology Development. The characterization methods employed include lithologic description, sediment-core physical analysis, borehole geophysical logging, single-well tracer testing, hydraulic testing, and sediment and water chemistry. The characterization results were used in the design strategy for developing the bioremediation technology.

The upper 60 feet of the aquifer formation investigated is composed primarily of poorly-to-well consolidated gravels and sands. The degree of consolidation is the most significant influence on the variation of hydraulic properties with depth. The formation also showed variable neutron-porosity and bulk-density log responses that correlate with the degree of consolidation.

Two distinct permeable zones, characterized by poor-to- moderate consolidation, lie in approximately the upper 10 feet of the aquifer and approximately 40 to 50 feet below the top of the aquifer. The highest values of hydraulic conductivity correspond approximately to these permeable zones. In contrast, firmly consolidated (primarily cemented) zones, occurring at depths of about 30 to 40 feet and 50 to 60 feet, have relatively low permeability. Hydraulic conductivity was about an order of magnitude lower over a test interval corresponding to the upper, strongly consolidated zone. Results of point-dilution tracer tests, conducted in the upper 30 feet of the aquifer, showed that most ground-water flow occurs in the upper 10 feet of the aquifer. These results are consistent with hydraulic test results, and sediment physical property and geophysical data.

Concentration data from the saturated zone suggest that most of the carbon tetrachloride detected is representative of the aqueous phase. Concentrations of carbon tetrachloride ranged from approximately 500 to 3,800 ppb in the aqueous phase and from approximately 10 to 290 ppb in the solid phase. Ground-water chemistry parameter results and a 2/3 ratio of ferric iron to total iron in sediment indicate oxidizing conditions. Nitrate is the most dominant chemical constituent present, ranging from 220 to 350 ppm.

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Poster

Characterization and Enhancement of Passive Soil Vapor Extraction

Virginia J. Rohay

Wells with open intervals in the unsaturated zone have been observed to "breathe," i.e., to inhale ambient air from the surface and to exhale soil gas to the atmosphere. The principal driving force for air flow in a well that is open to the atmosphere and the subsurface is the difference in barometric and subsurface pressure. Barometric and subsurface pressures and airflow rates measured at several wells in the 200 West Area at the Hanford Site in south-central Washington show a strong correlation between the sign and magnitude of the differential pressure and the direction and magnitude of the flow rate.

The unsaturated zone at the study site consists of 66 m of relatively permeable sands and gravels interrupted by a relatively impermeable, 3-5 m thick "caliche layer" at approximately 40 m depth. The average differential pressure increases with depth throughout the unsaturated zone. However, the presence of the caliche layer increases the differential pressure dramatically. Average positive pressure differentials measured between ground surface and the caliche layer increased gradually from 0.1 inH_2O at 8 m depth to 0.5 inH_2O at 36 m but jumped to 1.6 inH_2O at 49 m, below the caliche. The average flow rate measured in one well open above the caliche layer was 1.0 ft^3/min (maximum 3 ft^3/min); average positive flow rates from wells open below the caliche ranged from 1.1 to 7.7 ft^3/min (maximum 70 ft^3/min).

The application and enhancement of this natural well breathing process for soil remediation is termed passive soil vapor extraction. However, in addition to exhaling soil gas to the surface, each well with an open area in the unsaturated zone also naturally inhales ambient air from the surface approximately half the time. To maximize the natural flux of contaminants from the subsurface, the prototype passive soil vapor extraction systems include one-way valves configured to allow airflow out of, but not into, the well.

The passive extraction system is being tested during March and April 1995 on a well open to the subsurface below the caliche layer. The average positive differential pressure measured during the field test has been 1.43 inH_20 (maximum 6.0 inH_2O); the average positive flow rate has been 5.4 ft^3/min (maximum 17.4 ft^3/min).

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Poster

Dieldrin Soil Cleanup Levels for Groundwater Protection

Keith L. Stoffel,[1] Damon A. Delistraty,[2] and Bruce F. Howard[3]

A modified version of the Summers (1980) fate-and-transport model was used to calculate dieldrin soil cleanup levels that are protective of groundwater beneath a pesticide-contaminated site. To calculate the dieldrin concentration in leachate at the base of the unsaturated zone (c_p) that will be protective of underlying groundwater, the surface water infiltration rate (Q_p), groundwater flow rate (Q_a), and targeted dieldrin groundwater cleanup (c_w) were inserted into the model's mass balance equation: $c_p = c_w \times [Q_p + Q_a]/Q_p$. Conventionally, the dieldrin soil cleanup level (c_s) would then be calculated by inserting the calculated c_p value into the model's partition equation $K_d = C_s/C_p$, along with a dieldrin soil-water partition coefficient (K_d) obtained from the literature. However, because dieldrin K_d values reported in the literature range by more than three orders of magnitude (1.7 to 5,300 l/kg), it was necessary to estimate the dieldrin K_d value for soils at the site (16.7 l/kg) by calculating a c_p value from c_w and c_s values measured at the base of the unsaturated zone. This K_d value and a c_s value measured for contaminated soils in the overlying unsaturated zone were then inserted into the partition equation, and a c_p value for pore water in the uncontaminated zone was calculated. The targeted groundwater cleanup level for dieldrin was then substituted for c_w in the mass balance equation, and a maximum dieldrin concentration for leachate at the base of unsaturated zone (c_p) was calculated. A soil cleanup level (c_s) for soils at the base of the unsaturated zone was then calculated from this c_p value and the estimated K_d value for the site. Finally, a soil cleanup level (c_s) for soils in the contaminated zone was calculated, using, the estimated K_d and a c_p value for soils in the contaminated zone, which was calculated by determining the ratio between the current and targeted c_p values for leachate at the base of the unsaturated zone. In summary, two soil cleanup levels for dieldrin were established for the site: one applicable to uncontaminated soils at the base of the unsaturated zone, and the other applicable to contaminated soils in the shallower, unsaturated zone.

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Oral

In Situ Respirometry (Bioventing Pilot Test) of Jet Fuel Contaminated Soils

Arnie Sugar

Bioventing, a form of in situ bioremediation, involves the introduction of air into the vadose zone. Because oxygen is often depleted in contaminated subsurface environments, addition of air can be sufficient to stimulate microbial degradation of contaminants. Air may be introduced by extracting soil vapor, injecting air, or some combination of the two. Air is introduced at rates sufficient to oxygenate the desired treatment area and keep up with microbial respiration (oxygen uptake).

In situ respiration testing was performed at a site with jet fuel in soil and ground water to evaluate the feasibility of employing bioventing at the site for soil remediation and ground water contamination source control. The testing consisted of initially stimulating aerobic biodegradation in the vadose zone by injecting air into a ground water monitoring well with sufficient screen above ground water level. Approximately 33,000 ft^3 of air was injected using a regenerative blower at a flow rate of 110 cfm. Oxygen and carbon dioxide levels in the injection well and three observation wells located 25 to 40 feet from the injection well were measured before, during, and after injection to determine the injection radius of influence and oxygen uptake/carbon dioxide production rates. Uptake of oxygen and production of carbon dioxide are both indicators of biological respiration.

During five hours of air injection, oxygen levels in two observation wells nearest the injection well increased from less than 2 percent to approximately 10 percent. Oxygen levels in the farthest observation well increased slightly (from 0.4 percent to 1 percent). Oxygen levels in the injection well increased from 0.1 percent to 21.5 percent. Carbon dioxide levels dropped sharply in all wells during injection. After the injection period, oxygen levels in the injection well and two nearest observation wells decreased. Carbon dioxide levels increased in all wells. The measured rates of oxygen consumption and carbon dioxide production were used to calculate the hydrocarbon degradation rates achieved during the test. Supplemented with soil permeability, nutrient availability, and contaminant degradability information, the pilot test indicated that bioventing would be a feasible remediation method at the site.

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Oral

Application of Groundwater-Source Heat Pumps for Heating and Cooling in Washington State

Michael R. Warfel

Groundwater is a potential low-temperature energy source in residential and commercial heating and cooling applications. The temperature of groundwater is fairly constant, and is not subject to seasonal temperature extremes. When used in conjunction with a mechanical heat pump, groundwater can serve as both a heat source (for heating) and a heat sink (for cooling). The ideal groundwater temperature for a combination heating and cooling system is approximately 50°F. Groundwater at 50°F can serve as a heat source for winter heating, a direct cooling medium during nonpeak summer cooling periods, and as a heat sink for chillers during peak cooling periods. Groundwater temperatures greater than 55°F and less than 45°F are only solely suitable for heating and direct cooling, respectively.

Use of groundwater for heating and cooling can be cost-effective and environmentally acceptable, depending on a number of factors such as seasonal air temperatures (degree days), groundwater characteristics (temperature, quality, yield), options for discharging water from the system, including assessment of potential thermal impacts to aquifers. Case studies from Washington state are described with respect to hydrogeologic setting, well construction and yield, recharge/discharge systems, and system performance. Examples include a 150,000-square-foot office building in the City of Tacoma that has used a groundwater - source heat pump since the 1950s, and a relatively new system at the Madigan Army Hospital at Ft. Lewis.

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Oral

The Hydrogeology and Hydrogeochemistry of Arsenic Contamination Beneath a Chemical Plant in the Commencement Bay Tidal Lowlands

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The production of sodium arsenite pesticide at the former Pennwalt (now Elf Atochem) plant in Tacoma occurred from the mid-1930s to 1972. Arsenic wastes associated with production of the pesticide were disposed of on-site in shallow pits. Leaching of arsenic from these pits occurred spontaneously from the late 1930s until the late 1960s, when the seepage of high-pH liquids from adjacent brine ponds accelerated the leaching due to the associated decrease in arsenic sorption. The high-pH arsenic plume is also coincident with high concentrations of dissolved silica, as a result of increased solubility of silicate minerals at high-pH conditions.

The ground-water system beneath the Elf Atochem chemical plant is composed of three-aquifers, known as the upper unconfined aquifer, and the intermediate and lower confined aquifers. The upper and intermediate aquifers are of primary interest in terms of contaminant transport. The surficial aquifer is composed of fine-to-medium grained sand dredged from the Hylebos waterway, and is bounded below by a silty-clay aquitard which was once the surficial tide-flat depositional environment. The intermediate aquifer is composed of fine-to-medium grained sand with some silt interbeds.

Contaminant transport pathways from the arsenic plume include discharge to the Hylebos waterway at the seepage face, and downward migration to the intermediate aquifer through localized discontinuities in the aquitard. Discharge to the Hylebos waterway has been nearly eliminated due to the precipitation of $Mg(OH)_2$ and silicate minerals that occurs when the high-pH and high-silica plume mixes with neutral-pH seawater from the Hylebos waterway. The mineral precipitates form a cemented-seepage face with a significant reduction in permeability. In addition, a sheet-pile barrier wall was installed in 1990 to prevent ground-water discharge to the Hylebos waterway. Since that time, water levels have risen in the upper aquifer and downward transport to the intermediate aquifer appears to be the primary pathway for arsenic migration. A pump-and-treat system was implemented in 1992 to remove dissolved arsenic from the ground water and to maintain hydraulic containment of the plume.

The transport of arsenic-contaminated ground water was simulated using the SWIFT II simulator. Historical arsenic flux from the Elf Atochem site to the Hylebos waterway is conservatively estimated to be in the range of 0.1 to 4 kilograms per day prior to the installation of the sheet-pile barrier wall and pump-and-treat system.

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Applied Science and Technology -
Geophysics and Monitoring

Poster

Vadose Zone Monitoring at Deer Park, Washington: A Municipal Land Application Site

Barbara Carey

Vadose zone sampling equipment was installed and sampled at two locations on the City of Deer Park land application site near Deer Park, Washington. Effluent from the municipal wastewater treatment plant in Deer Park is applied on a 160-acre field to irrigate alfalfa. The purpose of the study was to evaluate treatment in the unsaturated zone and to compare three devices for sampling soil-pore water quality. Capillary wick, suction, and barrel lysimeters were used to obtain water quality samples. Total nitrogen (total N), total dissolved solids (TDS), specific conductance, chloride, sodium, potassium, calcium, iron, magnesium, pH, and chemical oxygen demand (COD) samples were collected at least five times during the period of May 6 to October 1, 1993.

Vadose zone monitoring showed that total N was partially treated in the top three to six feet. The range of total N treatment was low (26-35 percent), despite a relatively low application rate for total N of 100 lb/acre/year. Low treatment was likely due to frequent wet weather which caused irregular timing of effluent application over the season.

Suction and wick lysimeters provided more representative samples than the barrel lysimeters. Concentrations from the wick lysimeters needed to be higher than those from the suction lysimeters and, because the wicks sample continuously, are likely more representative of water leaving the root zone. Barrel samplers did not provide representative estimates of treatment at this site because of their shallow depth.

The mean total N concentration in the wick and suction lysimeters was 17 mg/L. The mean TDS concentration was 362 mg/L. The projected increases above background in ground water concentrations of total N and TDS are 5-7 mg/L for total N and 110-170 mg/L for TDS. Increases in nitrate+nitrite-N and TDS concentrations from the facility's downgradient monitoring wells suggest that effluent loading is affecting ground water quality.

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Oral

Plume Delineation Using a Cone Penetrometer System

Bruce R. Cassem[1] and Jon D. Fancher[2]

The Cone Penetrometer (CPT) is a system that can rapidly penetrate the ground to collect data about a site. The CPT system is a tool that provides a cost-effective site characterization and remediation by reducing the number of drill holes required. This would minimize secondary waste and reduce potential worker exposure to these contaminated materials.

Standard CPT rod is 1.75 inches in diameter with an attached 60° conical tip. Hydraulic rams push the rod into the ground. CPT technology has been used for approximately 50 years for geotechnical applications, but its use in environmental restoration is relatively new.

The CPT system used on the Hanford Site is pushed into the ground with maximum downward thrust of 70,000 pounds. For geotechnical projects, as the rod progresses into the ground, sensors in the cone tip and sleeve transmit data to the CPT vehicle onboard computer.

For use in environmental investigations the CPT can provide subsurface access for soil and soil-gas sampling, monitoring probe advancement for profiling, soil-gas probe installation, sensor installation, ground water sampling, temperature monitoring, and radionuclide logging. Upon completion, the CPT rod and tools can be removed and the hole grouted, thus preventing the escape of contaminants or cross contamination of aquifers.

The CPT can advance through fine-grained soil at a rate of 40 to 50 feet an hour. When attempting to advance in gravels and cobbles this rate can be significantly reduced. With the successful development of the CPT, scientists and engineers can delineate a plume and decide if the contaminate (s) are confined to a particular confining layer. Not only will this aid the Scientist in understanding the area that may be effected, but help in cost-estimating a remediation program.

Plume delineation has been conducted at three locations on the Hanford Site and at Fairchild Air Force Base in Spokane, Washington using a CPT system. At these locations the CPT has proven to be a cost-effective method of subsurface plume delineation.

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Oral

Vadose Zone Monitoring/Characterization as Part of the Regulatory Framework at Hanford, Washington

Charles S. Cline

In the regulatory framework, vadose zone monitoring and characterization have usually followed separate courses. Monitoring has normally been linked with the Resource Conservation and Recovery Act (RCRA) and characterization efforts are usually associated with the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) as a prelude to cleanup. At Hanford, vadose zone monitoring has been conducted for many years in the operations areas to determine movement of radionuclides through the soil column using such means as borehole geophysical tools. Characterization work such as soil sampling has been coordinated with laboratory bench-scale moisture sorption/desorption and Kd retention analyses and larger scale lysimeter studies to gather information to model the atmosphere/soil interface and movement of near-surface moisture and contaminants. Today these efforts are being introduced into the RCRA/CERCLA framework at Hanford. Closure plans for RCRA treatment, storage and disposal (TSD) units may include vadose zone monitoring which would include some borehole geophysics as early warning to ground-water contamination. Full-scale CERCLA characterization has proved expensive and limited in obtaining data useful for remediation and has been replaced with limited field investigations (LFIs) which also utilize available information from previous bench-scale and pilot-scale studies tailored to individual sites. This discussion encompasses work from 1985 to the present.

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Oral

Cross Borehole Seismic Tomography at the USDOE Hanford Site

Gregory J. Elbring and Susan M. Narbutovskih

Field experiments were conducted to determine the utility of the seismic tomography method to provide details of stratigraphy between two steel-cased boreholes in unconsolidated sediments. This high resolution, subsurface imaging technique is usually applied in open boreholes below the water table. It was not clear that down-hole seismic sources, with the exception of small explosive charges, could be adequately employed in steel-cased boreholes. Furthermore, unsaturated sediments at the Hanford Reservation have very low velocities and are acoustically attenuative. Thus the ability to generate sufficient energy with down-hole sources to provide acceptable signal propagation was questionable.

To answer these technical questions, three field tests were conducted. Phase I involved comparing three down-hole seismic sources to determine: 1) if seismic energy could be coupled and transmitted through steel casing and Hanford sediments, 2) signal-to-noise characteristics, and 3) resolution limits. Next, Phase II was conducted to test capabilities and limitations of mapping lithologic boundaries and perched water horizons in the vadose zone. Also the source-to-receiver borehole distance was increased to determine maximum utility of the technique. Finally, in Phase III, a full tomographic data set was collected above and below the water table to assess mapping abilities within the ground water.

Results from Phase I demonstrated excellent signal propagation with two of the three sources tested for both compressional and shear wave signals. Also signal-to-noise ratios were adequate while the frequency content was great enough to theoretically resolve features as small as 3 feet using a shear wave velocity of 1,700 feet per second. The tomogram from Phase II provided increased stratigraphic detail and indicated a residual perched water table near an inactive, disposal crib. Migrating channels can be mapped in cross section and previously ambiguous, borehole correlations can be made. The results from Phase III are still undergoing analysis at this time.

The need for better and more complete subsurface characterization of fluid migration pathways both in the vadose zone and the ground water increases as more USDOE sites begin remediation pilot tests. For example, seismic tomography can be used to optimize withdrawal and injection well design and placement to increase efficiency and efficacy of pump and treat remediation. Also for detailed information to support barrier placement, results from this study indicate that seismic tomography can assist in stratigraphic control with the required resolution when properly deployed. Results from these preliminary tests are encouraging for applications at not only the USDOE Hanford Site but for any arid region with deep water tables and heterogeneous, terrestrial sediments.

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Poster

Preliminary Determination of Chromium Concentration in Pore Water at Groundwater-River Interface within Chinook Salmon Spawning Habitat at 100-HR-3 Operable Unit in Hanford Reach of Columbia River

Stephen J. Hope

Prior to implementation of this field investigation, no Hanford Reach pore water/in-gravel data existed to support assumptions that groundwater flow path/river dilution reduces chromium concentrations below the U.S. Environmental Protection Agency's ambient water quality criteria (AWQC) for the protection of aquatic organisms, or other dose response (toxicity) criteria such as Lowest Observed Effect Levels (LOELs). This paper describes the methodology devised to acquire river substrate water quality/contaminant data for determining the exposure and risk to ecological receptors from groundwater discharge into the river. This effort also provided groundwater/river interface information to assist hydrogeologists in their determination of groundwater cleanup levels that will be protective of Columbia River beneficial uses.

According to the 100-HR-3 Operable Unit (OU) Focused Feasibility Study (FFS) Report (DOE/RL-94-67, Draft A), the ecological receptors in the Hanford Reach of the Columbia River are potentially exposed to chromium VI (hexavalent), an ecological contaminant of concern (COC) detected in contaminated groundwater seeps at the groundwater/river interface. Chromium concentration below the AWQC of 11 μg/L, as measured in the river substrate, is considered the preliminary remediation goal (PRG) of the FFS. Additionally, the 100-HR-3 FFS report recommends that the "point of compliance" for contaminants should be the groundwater/river interface but indicates that monitoring this zone is difficult. Until recently, "near-river" well data were primarily used to assess water quality compliance. However, this resulted in an overly conservative indication of river water quality because it assumed no dilution in the groundwater pathway or in the river, and did not give an accurate assessment of receptor exposure in the river. This investigation provided important data previously unobtained.

The objective of this study was to collect pore water samples and embryonic chinook salmon from spawning sites (redds) located in the Hanford Reach to evaluate the chromium VI concentrations in groundwater (near-river wells) and in salmon redd pore water (potential receptor contact); determine if pore water chromium VI concentrations are potentially toxic to aquatic organisms; and if exposure to chromium is occurring, determine the results of chromium VI accumulation in the embryonic chinook salmon tissue. Although pore water from the interstitial gravels was collected and analyzed, embryonic salmon were not collected due to unforeseen delays in the field program.

SCUBA divers using a submarine type dive-sled and a syringe sample device, developed for the specific purpose of collecting interstitial water deep in the spawning gravels of a fast flowing river, collected the pore water in close proximity to the "point of contact" with the sensitive embryogenesis life stage of the developing salmon. These receptors were selected for analysis because they are non-motile and could be chronically exposed to chromium from riverbank seeps and/or subsurface groundwater discharge. The early life stages of the chinook salmon (i.e., egg, alevin, and fry) could be particularly susceptible to toxic effects from contaminant exposure because they spend a significant portion of their life cycle within or near the substrate of the Columbia River; as it flows past the 100-HR-3 OU where elevated concentrations of chromium VI are in the groundwater.

Preliminary results appear to indicate that the developing salmon alevins and fry may not be at significant risk from chromium VI in widespread areas of the salmon nesting habitat.

At the time this abstract was developed the ERC project team were still completing the last phase of the field investigation. The laboratory data was not yet complete or fully analyzed.

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Oral

Vertical Seismic Reflection Profiling--A New Tool for Hydrogeologists

Michael King[1] and Stephen P. Palmer[2]

A new method of acquiring seismic reflection data has recently been applied to a number of hydrogeologic studies in Washington state. In this new method seismic reflection data are acquired using a new impulsive seismic source that inhibits ground roll (large amplitude seismic waves that travel on the ground surface from source to receiver). The lack of ground roll interference from the source enables the implementation of a near-offset method of reflection seismic surveying in which a short source-receiver offset, as close as 5 feet, is employed using a limited number of geophones (usually two or three). The short offset and limited number of geophones permits rapid collection of vertically summed reflection data. This near-vertical ray path eliminates the need for long cable layouts, commonly used in the acquisition of Common Depth Point reflection data, and reduces the data processing to a few basic steps: appropriate temporal filtering, static correction, and amplitude scaling. Preliminary processed sections can be available on a next-day basis, which allows the flexibility to locate "today's" profiles on the basis of "yesterday's" data. Additionally, the near-offset method's flexibility and minimal source noise impacts allow it to be used in a wide variety of hydrogeologic settings, including noise-sensitive urban environments.

To convert the vertical seismic profile data to a depth cross-section, well velocity (check-shot) surveys are performed in available water wells. A check-shot survey involves lowering a geophone to known depths in a well and then measuring the seismic wave traveltime from a source located near the wellhead to the downhole geophone. These surveys are performed in order to estimate seismic velocities for the soil or rock units comprising the aquifer system, and to measure the two-way traveltime to stratigraphic interfaces that give rise to strong reflections.

Vertical seismic reflection profiling has been applied to mapping bedrock depth (and consequently aquifer thickness) and to the siting of future municipal water wells in the Spokane Aquifer. Seismic profile data has also been acquired across the municipal well field serving the city of Tumwater. Additionally this method has been successfully applied to hydrogeologic investigations in eastern Washington where a thin veneer of loess and Missoula flood deposits overlie Columbia River basalt.

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Oral

Direct Measurement of Groundwater Velocity and Direction at the Hanford Site

Jon W. Lindberg,[1] D. Brent Barnett,[2] and Jim A. Coates[3]

Conventional methods of determining groundwater flow direction and velocity at the Hanford Site have consisted of indirect calculations based on water table maps, hydraulic tests that estimate hydraulic conductivity, tracer tests including drift and pump-back tests, and contaminant travel time calculations. Since 1992, three methods of direct groundwater direction and velocity measurement have been evaluated and used at the Site. The three methods are the In Situ Permeable Flow Sensor (ISPFS), the model RCS-1100 colloidal borescope developed by Oak Ridge National Laboratory, and the K-V Associates Geoflo Meter® (KV flowmeter).

The ISPFS is a thermal perturbation technique utilizing a buried metal cylinder. It is capable of repetitive measurements over a long period of time, but because it is not portable it cannot be used over a region of interest. The equipment was used in an investigation by Sandia National Laboratories of groundwater/Columbia River Interaction at the 100-H Area. The method was responsive to changes in flow direction, but measured velocities were lower than those estimated from other evidence.

The colloidal borescope utilizes high magnification imaging and a high resolution video compass to determine the 3-D trajectory and speed of colloidal particles within the screened interval of a well. These images, in turn, provide data about groundwater flow velocity and direction. The method is capable of repetitive measurements over a long period of time, and the equipment is portable so that a region of interest can be investigated. The method was compared with the ISPFS and the KV flowmeter at the 100-H Area by Oak Ridge National Laboratory and produced comparable results. Flow rates measured by the colloidal borescope were generally higher than the other two methods, but were within the range of values calculated using Darcy's law and hydraulic tests.

The KV flowmeter is another thermal perturbation method. The equipment is installed in the screened portion of wells and is readily portable. A centralized heat source is surrounded by four pairs of matched thermal sensors. The heat source provides a heat pulse, the displacement of which is detected over time by the matched pairs of sensors. Under a no-flow condition the matched pairs detect the heat source similarly, but under flow conditions the matched sensors detect a net difference between the down- and up-stream side. The magnitude of this difference with time provides the data necessary to calculate groundwater flow direction and velocity. The KV flowmeter has been used at four sites at Hanford. The sites are 100-H, 100-K, 200 West, and W-049H Treated Effluent Disposal Basin. Results indicate that the method is easy to perform, and like the other two methods is good at determining flow direction. Flow rate measurements are generally within the range of results measured by Darcy's law and hydraulic tests. However, calibration problems

reduce precision and accuracy causing results to be unreliable at lower flow velocities. To resolve the calibration problems, simulation chambers were built that accommodate a mock-up resource-protection well. The chambers simulate groundwater flow with subdued boundary effects for a variety of sediments types and a range of Darcian velocities.

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Oral

Early Vadose Zone Leak Detection at the USDOE Hanford Site Using Electrical Resistivity Tomography

Susan Narbutovskih,[1] William Daily,[2] and Abelardo Ramirez[3]

Electrical resistivity tomography (ERT) is undergoing preliminary evaluation for use as an early warning leak detection system under hazardous waste storage facilities. Several studies are in progress to test the capabilities and limitations of ERT for two different applications. First, field experiments are being conducted to determine the utility of ERT to detect and map leaks from underground storage tanks (UST) during waste removal processes. Second, the use of ERT for long term vadose zone monitoring is being tested under different field conditions of depth, distance, and installation design. This presentation will cover all work relevant to the U.S. Department of Energy's Hanford Site, but will focus on the second application for long-term vadose zone monitoring.

Electrical resistivity tomography is a cross-borehole, imaging technique for mapping subsurface resistivity variations. Electrodes are placed in an array of boreholes. Electrical current is introduced into one electrode pair located in one borehole while the resulting voltage change is detected between electrode pairs in other boreholes. The calculated resistivity variations reflect lithology and/or soil moisture changes. As developed by Lawrence Livermore National Laboratory, the technique measures the resistivity distribution associated with a wetting front before and during an infiltration event. The resulting plume is mapped as a function of time. For use under USTs, two different leaks were created under a 50-foot diameter mockup tank, one at the edge of tank and the other centrally located. Both leaks were simulated with the release of 1,000 gallons of saline water and results show that the associated water migration was detectable after release of 100 gallons. Furthermore, the plume could be mapped over time as the water moved through the shallow subsurface.

For use as a long term vadose zone monitoring method, different field conditions and performance requirements exist. The depth of monitoring is increased since plume tracking through the vadose zone is needed. The longer monitoring time requires a change in the electrode design and the method of installation since arrays must remain functional for tens of years. Also the geometry of the borehole array will be constrained by current facility conditions. For example, a circular array of electrodes can be incorporated into designs for a new facility producing a horizontal tomogram with leak detection coverage provided underneath the entire facility. However when retrofitting an established facility, it may not be possible to place borehole electrodes to provide a horizontal tomogram. Site logistics may dictate that only vertical tomographic data can be acquired. This change from a horizontal circular array to two vertical electrode arrays will affect not only leak detection coverage but also the resulting resolution. These changes are included in the scope for current ERT testing at the USDOE Hanford Site.

The significance of this work reaches beyond needs at the Hanford Reservation. Vadose zone monitoring under RCRA regulated facilities provides early detection and monitoring at the incipient stages of contaminant release which assists in protecting our valuable groundwater resource and may avoid costly groundwater remediation expenses especially in arid regions with deep water tables. In 1988, EPA proposed to amend groundwater monitoring regulations to require vadose zone monitoring to assist early contaminant detection. The RCRA regulations for vadose zone monitoring have been drafted and it is expected that later this year, official EPA guidance will be released in an interim status to let owner/operators plan for the impending change in regulations while the new regulations will be promulgated in 1997.

Until recently, vadose zone monitoring techniques could only provide local coverage for leak detection and thus, are used primarily under liquid collection systems at land disposal units. As developed by Lawrence Livermore National Laboratory, ERT can provide full coverage under waste treatment and storage facilities given the right conditions.

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Poster

High Resolution Seismic Reflection Test at the USDOE Hanford Site

Susan M. Narbutovskih,[1] Finn B. Michelsen,[2] and John C. Clark[3]

Recently vibrator reflection data were acquired at a test location at the U.S. Department of Energy's Hanford Site, Washington. The purpose of this test was to evaluate the potential of using vibrators to increase resolution of shallow targets in arid regions. As the focus shifts from site characterization to remediation, high quality seismic reflection data are needed to enhance our ability to map flow migration paths in the subsurface. Now that 24-bit recording capability and swept source technology are available for shallow applications, industry experience is needed to refine fielding logistics, satisfy processing needs and improve interpretations.

Compressional wave data were acquired along a previously occupied seismic line which provides a baseline for comparison. The original survey was conducted with a 24-channel recording system and a low energy impulse source. For this recent test the T-2500 Minivib was combined with the Oyo Geospace 144-channel, DAS-1 seismic recorder, a 24-bit system. Six-second linear sweeps were run from 80 to 400 Hz with 4 sweeps per station.

The data from this vibrator test compared to that from the original survey display significant differences. First, apparent reflectors exhibited on the raw vibrator records, show better definition than on the impulse records. However, for arrival times less than 60 ms, source generated noise appears to obscure some reflected energy. The extended line length increases the ability to detect reflectors away from these noise trains, but strong refraction energy masks the signal further out on the line. Second, the apparent depth of wave penetration increases significantly with the vibrator system. On processed stacked sections from the initial survey, reflectors were weak and laterally too inconsistent to map below 90 ms. The resulting data from this current survey display mappable energy as deep as 145 ms.

Finally the frequency content and resulting resolution are greatly improved. Reflected energy from the impulsive source produced a dominant frequency of 45 Hz while the vibrator data contain a flat spectrum almost to 300 Hz. This increases the theoretical vertical resolution using the one-fourth wavelength rule from 22 feet to less than 3 feet using a velocity of 3500 ft/s. This enormous increase in resolving power is evident when stacked sections from the two surveys are compared at similar locations.

The results of this preliminary test lead to several conclusions. Swept source technology allows high quality, detailed, mappable seismic reflection data to be acquired in hard data areas such as the USDOE Hanford Site. Not only can subtle stratigraphic changes be detected due to increased recording capability and greater frequency content of the reflected signal, but signal penetration is improved. However there is still need to address further reduction of source generated noise for very shallow targets (less than 60 feet). Future work will include nonlinear and amplitude variant sweeps to further enhance signal to noise ratios.

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Poster

Regional Depth to Bedrock Mapping of the Spokane Aquifer Using Seismic Reflection Profiling

Stephen P. Palmer,[1] Michael King,[2] Charles R. Gruenenfelder,[3] Stan Miller,[4] and Lars Hendron[5]

The Spokane Aquifer is the major source of drinking water for over 350,000 people living in the greater Spokane area. It consists of sand to boulder-size sediments deposited by catastrophic outburst floods from episodic draining of Pleistocene glacial Lake Missoula. The deposits overlie relatively impermeable Precambrian to Cretaceous crystalline bedrock, and Miocene sedimentary rocks of the Latah Formation and Columbia River basalts. The flood deposits are typically 400 to 600 ft thick in the main valley east of Spokane, and more than 700 ft thick north of Spokane in the Hillyard trough.

Previous estimates of thickness and subsurface geometry of the Spokane Aquifer were based on a combination of informational sources that include outcrop mapping, gravity data, some refraction profiling, and limited water well information (few wells have been drilled to bedrock in the deeper pans of the aquifer). We conducted seismic reflection profiling to estimate the depth to bedrock and thus better define the geometry of the aquifer. Seismic reflection profile data were acquired in the eastern Spokane Valley and in northwest part of the city of Spokane between Spokane Falls and Five Mile Prairie. Check-shot surveys were performed in water wells adjacent to a number of the profile lines to measure seismic velocities in the unsaturated and saturated aquifer sediments. Seismic two-way traveltimes to the aquifer-bedrock contact were then converted to depth below ground surface using these seismic velocities. The elevation of the bedrock surface was then calculated along the seismic reflection profiles using the estimate of depth to bedrock and the ground surface elevations. This information will be used in aquifer management investigations conducted by Spokane County and in wellhead protection studies performed by the City of Spokane and other water purveyors.

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Poster

Groundwater/River Interaction, Hanford Site, Washington

Robert E. Peterson

The Columbia River is a gaining stream as it passes through the Hanford Site in southcentral Washington ("Hanford Reach"). Along some areas, groundwater entering the river channel from the Hanford unconfined aquifer contains contamination from past operations of reactors and chemical processing plants. River dynamics influence the interaction between groundwater and the river. Stage fluctuations are the result of discharge control at upstream dams, and include daily, weekly, and seasonal discharge cycles. The fluctuations create several phenomena at the groundwater/river interface that influence water quality and rate of influx. These include layering and mixing between river and groundwater, dilution of contaminants near the interface, and control of exchange rates. Current understanding of these phenomena is limited, although all are relevant to assessing contaminant impact to the river system.

Groundwater/river interaction occurs within a bank storage zone, where river water is temporarily stored during high river stage. At low stage, river water held in bank storage along with groundwater drains back into the river channel, and is often visible as riverbank seepage. If contaminated groundwater is present, a potential hazard to unrestricted use of the shoreline exists. Periodic sampling of riverbank seepage, sediment associated with seepage, and nearby river water has provided a measure of the magnitude of this potential hazard.

Interaction also occurs at the continuously submerged interface within the riverbed substrate. The depth of the interface within the substrate depends on the nature of the substrate, the hydraulic gradient, and the discharge of the river. Flow direction probably changes from predominantly horizontal to vertical with increasing depth in the substrate. The depth at which groundwater and river water meet has particular significance for gravelly substrate used by salmon for egg deposition and hatching in redds.

Hourly observations of water level, temperature, and specific conductance in groundwater wells, riverbank seepage, and nearshore river water are being used to describe processes occurring in the bank storage zone. Recent sampling of interstitial water from riverbed gravels used by salmon has provided new insight on the exposure developing salmon have to contamination from Hanford sources. Additional surveys of the Hanford shoreline are planned to better delineate areas of groundwater upwelling into the river channel.

Information on the nature, concentrations, and rate of input of contaminants from the aquifer to the river, and to sensitive receptors, helps form the technical basis for environmental restoration decisions. The impact of Hanford Site contamination, along with impacts from upstream mining activities, agriculture, and atmospheric fallout, is being assessed relative to sensitive ecological receptors and beneficial uses of the river system.

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Poster

The Application of Borehole Geophysical Logging Techniques at a Small Municipal Landfill in Asotin County, Washington

Nadine L. Romero,[1] Jim Whitbread,[2] and Kevin Campbell[3]

The availability of new portable slim-hole geophysical logging systems has added a new and important dimension to hydrogeological site characterizations. In this site investigation, a two-phase approach using natural gamma, induction, temperature, and the heat pulse flow meter logs were used to examine existing wells and define the site hydrostratigraphy for a small municipal solid waste landfill in Asotin County, Washington. In addition, the application of borehole geophysics at this site allowed critical field decisions, i.e., well screen placement to be made with more accuracy and certainty and helped eliminate errors at the time of drilling about lithologic boundary changes.

In contrast to the high cost of drilling and well placement, on the order of tens-of-thousands of dollars per drilling location, borehole geophysical logging including computer, log analysis software, winch, probes, printer, and overnight shipment cost less than 1 percent of the total cost of the drilling investigation. Mobilization and drilling standby time were less than one hour per logging run and did not require a commercial operator-expert. Thus, the advancements in ultra-portable logging has produced an economical technology that should be common place in most site investigations.

Although Washington state has not had the large commercial logging bases as oil-producing states, it is time to revolutionize the way traditional site investigations are conducted. Currently, the new municipal solid waste landfill regulations in Washington state encourage the use of geophysical methods for site investigations by allowing some substitution of the minimum boring numbers providing appropriate geophysical techniques are used. The intent here, is to put more emphasis on the quality of site hydrogeologic characterizations while at the same time lower owner/operator costs. The application of ultra-portable borehole geophysical logging should set us on that new course.

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Poster

Borehole Geophysical Correlations in the Suprabasalt Sediments of the Columbia Basin

Bruce A. Williams

Borehole geophysical investigation techniques have been used in shallow unconsolidated sedimentary sequences to enhance hydrogeologic and stratigraphic correlations in the Pasco Basin at the U.S. Department of Energy Hanford Site, Washington. The improvements in stratigraphic interpretations have resulted in an accurate understanding of the suprabasalt sediment hydrogeology and complete site characterization.

The integrated approach to data evaluation and interpretation illustrated in this poster is a methodology, original to Hanford, which can be successfully applied to environmental characterization at the Site. This approach provides a more complete hydrogeologic description than previous geophysical attempts and reinforces interpretations through the use of multiple data sources to confirm the analysis. Analysis is based on over five years of data gathering and interpretation from the various well drilling activities at Hanford. Geologic and hydrologic data are integrated, while evaluating the geophysical data, to determine the patterns and trends that are needed for identifying the controlling mechanisms of groundwater flow and thus contaminant flow. Inadequate characterization and failure to completely define these mechanisms may lead to unsuccessful clean-up activities, and may allow contaminants to migrate undetected toward the environment (Columbia River).

In past years several borehole geophysical logging techniques have been attempted at Hanford with limited success. Most of these techniques were developed for use in deep, fluid filled, and uncased boreholes in support of oil and gas exploration. The application of these same techniques in the environmental arena can be limiting, especially at Hanford, where the boreholes penetrate shallow, mineralogically variable, unconsolidated, and unsaturated sedimentary formations. In addition, Hanford well construction utilizes multiple casing strings (to keep the borehole open and to seal perched water zones), which attenuate the measured signal or activity during logging. Historically, gross gamma log data have been collected and archived for most wells at Hanford. The use of these logs has been largely ignored, consisting primarily of log reviews for such things as casing shoe depth, groundwater depth, and to identify anomalous zones indicative of manmade radioisotope activity.

The borehole geophysical investigative technique now being applied at Hanford utilizes the gross gamma database more completely. Gross gamma logging records the total gamma radiation emitted from the borehole. The evaluation relies on the natural gamma emitting minerals within the formations to distinguish formation changes (facies), formation/depositional boundaries, and even grain size relationships. These data are presented as continuous depth curves which are evaluated along with other hydrogeologic data and supporting sample results. With a complete data base and good borehole control, depositional environments and stratigraphic sequences can be easily and confidently mapped.

The integration of geophysics with conventional geologic and hydrologic data collected at Hanford is significantly improving the understanding of the hydrogeologic mechanisms at work in the subsurface in support of radioactive and hazardous waste characterization and cleanup at the Site.

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Applied Science and Technology - Ground Water Modeling

Oral

Estimating Recharge in the Area of Naval Submarine Base, Bangor, Kitsap County, Washington, Using a Water-Balance Modeling Technique

William R. Bidlake

A knowledge of recharge is critical for understanding and describing flow in ground-water systems. A study of recharge is being done as part of a cooperative U.S. Geological Survey and U.S. Navy investigation of ground-water resources in the area of the Naval Submarine Base, Bangor in northern Kitsap County, Washington. The goal of the recharge study is to provide estimates of ground-water recharge throughout the area of the ground-water investigation. The approach being taken is to compute recharge from the soil water balance. The soil water balance will be modeled with a daily time step for a two-year period using spatially distributed measurements and estimates of water-balance components. The modeling will be supported by a network of sites that has been installed to monitor precipitation, runoff, changes in soil moisture storage, evaporation of precipitation that has been intercepted by vegetation, and meteorological variables needed to compute evapotranspiration from dry vegetation. Spatial variations in water-balance components, including variations caused by variations in soil type, vegetation type, and topography, will be tracked using a geographic information system to produce a map of estimated recharge for the study area. Data collection and model construction are currently underway, and some preliminary results will be presented.

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Oral

The Rathdrum Prairie - Spokane Valley Aquifer Connection: How Much Ground Water is Crossing the State Line (Does Anybody Really Know)?

John P. Buchanan

The Spokane Valley - Rathdrum Prairie aquifer system, covering approximately 425 square miles, is one of the most prolific in the western United States and is designated a sole source aquifer by the U.S. Environmental Protection Agency. Numerous technical studies have been made on this important and interesting ground water flow system, yet we are unable to answer a fundamental question: nobody really knows how much water is in the ground beneath Spokane!

It is well understood that most recharge to the unconfined Spokane Valley - Rathdrum Prairie aquifer occurs in Idaho, where surface water is lost through numerous side-valley lakes and by the influent Spokane River. Ground water flow moves generally southward and westward in the Rathdrum Prairie, and then to the west across the Washington/Idaho state line where little water is added to the system in Washington.

In 1968, U.S. Geological Survey estimates based on water-balance calculations made by Pluhowski and Thomas suggested that flow from Idaho to the Spokane valley "averages about 1,000 cubic feet per second, or about 650 million gallons a day." Later USGS reports place the total Idaho recharge to the aquifer system at about 800 cubic feet per second (Drost and Seitz, 1978), and in their development of a finite-element model of the aquifer system, Bolke and Vaccaro (1981) calculated a throughflow across the state line at 457 cfs. An attempt by Painter in 1991, also utilizing a mass balance approach accounting for all recharge points in Idaho, resulted in an approximation of 753 cfs crossing the state line.

Recent modeling by this author using MODFLOW/EM to simulate ground water flow through the Spokane valley portion of the system shows 307 cfs crossing the state line. More important are the results of sensitivity analyses on the model that show a range in state line flow from 129 to 650 cfs depending on variations in hydraulic conductivity and saturated thickness.

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Oral

Hydrogeology and Computer Modeling of the Chamokane Aquifer System - A Complex Alluvial Valley Aquifer in Northeastern Washington

John P. Buchanan, John V. Wozniewicz, and Veit J. Matt

The Chamokane valley aquifer system is located in a north-south trending valley in northeastern Washington and is filled with as much as 152 m of Pleistocene age sediments of glaciogenic origin. Excellent aquifers exist in coarse-grained glaciofluvial sediments with finegrained glaciolacustrine deposits acting as aquicludes. An upper unconfined aquifer exists in the uppermost 10 to 30 m thick outwash deposit and is heavily utilized by irrigators and smaller domestic wells. A lower confined to semi-confined aquifer exists in the central and northern portions of the valley, and comprises the lowermost 80 m of sand and gravel in the valley fill sequence. The log of a deep hatchery production well in the southern part of Chamokane valley shows that there is a complex interfingering relationship between the gravels comprising the lower aquifer and the fine-grained sediments, and clear definition of the lower aquifer system in this area is problematic.

The upper aquifer is perched on a laterally extensive silt/clay unit of variable thickness that was deposited during two predominate stands of glacial Lake Columbia. Groundwater flow in this aquifer is from north to south, at an average gradient of 0.004. The upper aquifer is recharged primarily through infiltration of water from Chamokane Creek that is entirely influent in the central part of the valley, and to a lesser extent through direct precipitation and tributary watersheds. Discharge of ground water from the upper aquifer is primarily through five major contact springs near Ford, Washington. The lower aquifer has measured heads higher than the water levels in the upper aquifer, as revealed by a single deep well in the central part of the valley. Recharge to the deeper system is not well understood, and is presumed to occur in the northern part of the valley.

Eight water wells drilled into the upper aquifer at four sites show remarkably high transmissivity and hydraulic conductivity values. Average transmissivity of 9,164 m^2/d and an average hydraulic conductivity of 0.94 cm/s, while extraordinary, are realistic when compared to other similar aquifers found in glaciogenic deposits.

The ground water model MODFLOW was used to simulate flow through the aquifer system in order to assess the effects of large ground water withdrawals on the upper aquifer and the springs. Depending on antecedent conditions in the aquifer and winter/spring recharge, cumulative spring discharge can be reduced from 4 percent to 11 percent by the irrigation withdrawals. In addition, a high discharge production well has been drilled into the lower aquifer at the Spokane Tribal Fish Hatchery in the southern part of the Chamokane valley.

A second ground water flow model was used to assess the effect of the well on the nearby springs; certain pumping schedules showed a significant influence on the flow from Metamooteles spring, suggesting a hydraulic connection between the systems.

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Oral

Use of Particle-Tracking Techniques with a Numerical Ground-Water Flow Model to Estimate Zone of Transport for Wells

Leonard L. Orzol[1] and Margo Truini[2]

Particle-tracking techniques were used with the results from a numerical ground-water flow model to estimate zones of transport for a number of wells in Clark County, Washington. A zone of transport for a well is the volume of an aquifer that contributes to the discharge of the well within a specified time period. Zones of transport were derived using the U.S. Geological Survey program MODPATH, which was used to compute three-dimensional path lines from steady-state simulations of the U.S. Geological Survey modular three-dimensional finite-difference ground-water flow model, MODFLOW.

Zones of transport for time periods of 0.5, 1, 5, 10, 20, and 50 years were computed for six selected wells. The sensitivity of the computed zones-of-transport sizes and shapes to changes in the well discharge rate, porosity, hydraulic conductivity, and well interference was evaluated to illustrate the effects of data uncertainty. In the sensitivity analysis, a zone-budget analysis was used for a block of cells around each pumping well to evaluate changes in water sources to the well that were associated with changes in zone-of-transport size and shape. Zones of transport change more significantly as a consequence of varying porosity than by changes in hydraulic conductivity. The effects caused by these changes were moderated by the relative proportions of the sources of water to a well: 1) recharge derived directly from precipitation, 2) recharge derived from adjacent parts of the aquifer or confining layers, and 3) recharge from induced infiltration of nearby surface-water bodies such as streams. In addition, the relation of the well to various boundary elements such as aquifer pinchouts or the proximity of the well to a stream, superimposes additional factors that influence the size and shape of the zones of transport.

Particle tracking, in conjunction with three dimensional modeling, is the most comprehensive method for estimating zones of transport within stratigraphically complex, heterogeneous, anisotropic aquifers with complex boundary conditions such as streams, and multiple, simultaneously discharging (interfering) wells.

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Oral

Use of a Ground-Water Flow Model with Particle Tracking to Evaluate Ground-Water Vulnerability, Clark County, Washington

Daniel T. Snyder,[1] James M. Wilkinson,[2] and Leonard L. Orzol[3]

A new method of using a ground-water flow model with particle tracking was developed to evaluate ground-water vulnerability in Clark County, Washington. This method used a three-dimensional ground-water flow model constructed using the U.S. Geological Survey numerical model code, MODFLOW. Output from the flow model was used in a particle tracker to calculate individual three-dimensional pathlines and time-of-travel information for multiple particles in every cell of the flow model. The results of the particle tracking analysis were stored in a Geographic Information System (GIS). The GIS was used to evaluate ground-water vulnerability by selecting particles representing any part of the ground-water flow system, from a single well to an entire aquifer. Four procedures were utilized to define ground-water vulnerability for Clark County, Washington: (1) delineation of recharge areas by hydrogeologic unit, (2) estimation of time of travel by hydrogeologic unit, (3) determination of DRASTIC indices by hydrogeologic unit, and (4) definition of potential contaminant loading by hydrogeologic unit.

Recharge areas were delineated for a hydrogeologic unit by tracking particles backward from each cell in the unit to their recharge points. The recharge areas then were used in conjunction with contaminant loading or DRASTIC maps as one method to assess groundwater vulnerability.

Maps of travel times for a hydrogeologic unit were similarly created. Each model grid cell in a hydrogeologic unit was assigned the minimum travel time for any particle started in that cell that was tracked backward to its recharge point. Cells with the smallest travel times are expected to be at greatest risk of contamination.

Maps of the DRASTIC rating at the point of recharge also were developed for each hydrogeologic unit by tracking particles backward from each cell in the unit to their recharge points. The ground-water vulnerability at each model grid cell was determined by the highest DRASTIC rating for any particle started in that cell.

Potential contaminant loading at the point of recharge was mapped for each hydrogeologic unit by tracking particles backward from each cell in the unit to their recharge points. Each model grid cell was assigned the highest potential contaminant rating (for example, annual recharge from on-site waste-disposal systems) for any particle started in that cell.

These procedures can be used individually or in combination to evaluate ground-water vulnerability. The data stored in the GIS can be easily transferred to water resource agencies to enable them to evaluate current water resources or to aid in the identification of sites for future development. The method can be used with models of any scale or discretization, and is directly transferable to other areas that use MODFLOW to simulate a ground-water flow system.

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Oral

A Three-Dimensional Conceptual Model of Groundwater Flow at the Hanford Site

Paul D. Thorne,[1] Michele A. ("Mickie") Chamness,[2] and Signe K. Wurstner[3]

The conceptual model of ground water flow in the uppermost aquifer at the Hanford Site is being refined in an effort to support accurate numerical modeling of contaminant transport. A third dimension has been added to the existing two-dimensional ground water flow model to account for preferential flow paths, vertical head gradients, and variations in the vertical distribution of ground water contaminants. A two-dimensional model can adequately simulate head responses, even if the flow system is complex. However, for transport simulations, ignoring the layered heterogeneities that are common in sedimentary aquifers and the vertical distribution of contaminants can result in gross errors in predicted mass transport.

The Hanford Site aquifer is mainly composed of fluvial and lacustrine sediments deposited by the ancestral Columbia and Clearwater rivers. These sediments are called the Ringold Formation and reach a maximum thickness of about 150 meters in the center of the Pasco Basin. Cataclysmic floods at the end of the last ice age created erosional channels and laid down additional coarse and fine-grained deposits, which are informally named the Hanford formation. These sediments are thinner than the Ringold Formation and lie below the water table over only about half of the Hanford Site. However, permeability of Hanford formation sediments averages about an order of magnitude higher than that of the Ringold Formation.

For the three-dimensional conceptual model, nine layers were defined above the basalt bedrock to describe major lithofacies changes. Six of the layers represent alternating fine- and coarse-grained Ringold sediments. Two of the remaining layers, the early "Palouse" soil and the Plio-Pleistocene unit, are of minor extent, and the uppermost layer is the highly permeable Hanford formation. Geometry of the layers was determined by picking lithofacies contacts from more than 250 well logs. These data have been input to a geographical information system (GIS) which is used to describe the layer geometry and input it to the numerical model. The work was sponsored by the U.S. Department of Energy.

In addition to defining the three-dimensional architecture of the aquifer, the conceptual model is being refined by updating recharge and discharge boundary conditions. Hydraulic conductivity data from aquifer tests have also been updated and used to assign hydraulic conductivity distributions to each of the layers of the model. Historical plume behavior is being evaluated to determine effective porosity and dispersivity values.

Additional work is required to create and verify an accurate three-dimensional model of ground water flow and transport. However, such a model will be an invaluable tool for determining the fate of contaminants in Hanford ground water and for predicting the effects of future ground water management scenarios.

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Oral

Characterization of the Ground-Water Flow System near Naval Submarine Base, Bangor, Kitsap County, Washington: Overview of an Active (1995) Study

Marijke van Heeswijk

A joint U.S. Geological Survey-U.S. Navy study is currently (1995) being conducted to evaluate the ground-water flow system at and near Naval Submarine Base, Bangor, a 6,785-acre Navy installation located on Hood Canal in Kitsap County, Washington. The primary objective of the study is the quantification of the regional ground-water flow system, which is contained in glacial and interglacial sediments, with a three-dimensional flow model. Such a model will aid in the investigation of the flow between shallow and deeper aquifers and the effects of possible increased future ground-water withdrawals on available water resources, which includes the potential for saltwater intrusion. Another objective of the study is to determine the ambient ground-water quality of the study area.

To understand and quantify the ground-water flow system, it is important to know the hydrogeologic framework, the rates at which recharge and discharge occur from the flow system, the travel times of water through the system, and the historical ground-water withdrawals and water levels. In this study, the hydrogeologic framework is constructed on the basis of lithologic logs from domestic and public supply wells and from wells installed as part of the Installation and Restoration Program on Naval Submarine Base, Bangor with all well locations verified by field visits. To estimate flow-system recharge, selected watersheds are monitored for climatological variables, precipitation interception, continuous streamflow, and soil moisture to establish a relation between recharge and surficial geology, vegetation, precipitation, and topography. This relation and monthly streamflows measured in most watersheds during the study will then be used to estimate recharge over the entire study area.

Flow-model calibration will be based on comparisons of simulated and observed streamflow discharge, predevelopment water levels, water levels obtained from two mass water-level measurements, and historical water level changes that occurred as a result of aquifer dewatering in the late 1970s during the construction of Delta Pier, an offshore dry-dock facility. The model will be partly verified by comparing model-simulated travel times with travel times based on carbon-14 age dates of the ground water.

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Applied Science and Technology - Sampling and Data Analysis

Oral

Soil-Gas Monitoring of a Ground-Water Trichloroethylene Plume, Hanford, Washington

P. Evan Dresel and John C. Evans

Soil-gas monitoring points were installed to further define the extent of a dissolved trichloroethylene plume and to provide a cost-effective method for ongoing monitoring of the plume concentrations. The monitoring points were installed to the maximum depth possible in Hanford formation sediments using a 70,000-lb cone-penetrometer rig. Monitoring point installation was difficult in some locations due to problems in penetrating the Hanford formation catastrophic flood deposits. Combination of the penetrometer installation with global positioning system survey of the locations allowed for rapid data collection and assessment.

Soil-gas samples were collected in gas-sampling bags and analyzed using direct injection into a gas chromatograph/mass spectrometer in single-ion monitoring mode. The gas concentrations were converted to equivalent equilibrium concentrations in ground water after correcting for distance from the water table and partitioning between ground water and soil gas. Soil gas results at several locations could be compared to ground-water concentrations at nearby monitoring wells.

The success of the soil-gas monitoring program results from the favorable geologic and hydrologic conditions at the sites. The site conceptual model illustrates conditions where this technique can be applied.

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Oral

Monitoring for Pesticides Using Immunoassays

Steve L. Foss

Atrazine has become one of the most frequently detected herbicides in groundwater across the United States. However, what happens to the chemical components of atrazine in groundwater as the herbicide breaks down over time is not well understood. In response, immunoassays were used as a reliable and relatively inexpensive method of screening for atrazine in over 100 western Washington wells. Results of these immunoassay tests were used as the basis for selecting and later analysis of groundwater for the presence of atrazine and its major degradation products. The project in Washington state is part of a national groundwater monitoring study being conducted for this herbicide on over 1,600 sites in 19 states.

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Oral

An Integrated Approach to Groundwater Data Management

Garrett A. Kang,[1] Gina M. Mulderig,[2] and Glen M. Wyatt[3]

Weyerhaeuser Company's Environmental Science and Technology (ES&T) division provides technical support to facilities throughout the United States and Canada. The groundwater group assists internal clients and their consultants with data acquisition, management, and quality control.

For the past two years, ES&T has been upgrading general groundwater information contained in a ten-year old database system with site-specific groundwater data. This led to the search for a comprehensive data management system that could be used to store, retrieve, show, and tabulate data from hydrogeologic investigations. Initially, we attempted to use the U.S. Environmental Protection Agency's "Ground Water Information Tracking System with Statistical Analysis Capability" (GRITS/STAT), but its use was abandoned after flaws in the database part of the program were discovered.

Two alternatives were considered: in-house development of a database system or purchase of a commercial product. Time and budget constraints eliminated the first alternative. After obtaining information from vendors and a trial lease, the GIS\Key™ Environmental Data Management System was purchased from GIS\Solutions, Inc. (Concord, CA). GIS\Key™ was selected because of its ability to integrate information displayed on an AutoCAD® base map with dBASE III style data files. These two points are important - AutoCAD® is an industry standard CAD program and dBASE III files can be read by many other programs (e.g., Microsoft® Excel and Microsoft Access®).

We routinely use GIS\Key™ standard functions such as storing sample site information, preparing well logs, cross-sections, and contour maps; sample and QA/QC data input; preparation of data tables; and exporting data to GRITS/STAT for some statistics. For non-routine data reports, the data tables are queried using Microsoft Access®, statistics are prepared using Microsoft® Excel or Manugistics® Statigraphics®, and complex figures are prepared using Grapher™ by Golden Software.

We currently have approximately 100,000 chemical records from 350 monitoring wells at eighteen facilities stored using GIS\Key™. Much of this data has been imported into GIS\Key™ from consultants' spreadsheets.

The process of data collection, review, and entry has taught us that field and laboratory data collection and analysis must be well documented. Data collected today must be easily retrievable. Additionally, we have learned the following points:

- Entry of historical data into a facility database is made easier if consultant data files are available along with paper copies of the data;

- Spreadsheets work best for data analysis, and not for data storage;
- Field personnel must be part of the data management team; and
- Project managers need to understand that using a database can save time and effort in preparing reports for clients.

An integrated approach to data management gives Weyerhaeuser and its consultants a standardized method of storing groundwater, soils, surface water, and other chemical data. This approach allows ES&T to assist Weyerhaeuser facilities in assessing their groundwater conditions.

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Oral

Misleading Groundwater Sampling Metals Results from Traditional Bailer Techniques

Thomas A. Mercer

Groundwater at Naval Air Station Whidbey Island was investigated in 1991 and 1992 as part of a remedial investigation and feasibility study. Initial sampling was conducted using traditional bailer techniques for purging and sampling. These efforts resulted in the measurement of elevated concentrations of a variety of metals in widely dispersed wells and in all three of the aquifers sampled. Uncertainty about the quality of the water in the two lower aquifers resulted in another round of sampling which was conducted in December 1992 using a flow-flow/low-stress technique.

The two different techniques for purging and sampling the monitoring wells resulted in significantly different concentrations of metals. Bailing which produces high stress and sand pack flushing, resulted in samples with relatively higher turbidity and higher metals concentrations than those collected via low-flow/low-stress down-hole centrifugal pumping.

A comparison of results from the two different sampling efforts indicated that traditional purging and sampling techniques can result in detections of metals disparate from (generally higher than) concentrations measured in sampled collected without turbidity-causing aquifer stress. Furthermore, an examination of three-dimensional representations of the metals concentrations from samples obtained via the two different sampling techniques indicated that the concentrations resulting from bailed samples are different but not to a consistent or predictable degree. The differences between concentrations in bailed samples versus low-flow/low-stress samples vary.

The conclusion drawn from these observations is that the three-dimensional patterns resulting from bailed samples are misleading as indicators of possible sources of contamination because measured concentrations of metals are not well correlated with actual ambient metals concentrations in groundwater. Using traditional well purging and sampling techniques can, therefore, negatively influence the evaluation of groundwater metals concentrations.

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Oral

Pitfalls of Chemical Analyses

Jim Miltimore and Glen Wyatt

Many assumptions are made that chemical analyses really show what is present in a soil or groundwater sample. It ain't necessarily so, folks. Generally accepted standard testing methodologies are often poorly understood, may not be correctly followed, may have interferences, may not be measuring what you think they are measuring, and may provide a false sense of security because the methods aren't that precise.

A lack of understanding chemical analysis methods may lead to selection of an inappropriate method for a constituent. Total phenols is a good example. Sites rich in humics or wood waste may contain materials that will create substances that respond like phenol when the 4-AAP analysis is used.

Analytical methods may not be correctly followed. The analysis you requested may not be the analysis you get. The reason for this is that different analytical methods, which appear similar, may have varying performance, equipment calibration, or basic equipment requirements. A lab may state that they are following a specific procedure, but the analyst may be following a similar, but different procedure. Examples of this are seen in the differences between analyses performed by methods in SW-846 versus methods list in the CLP manual.

Analytical detection limits, precision, and accuracy may affect the interpretation and use of a specific result. Detection limits are based on questionable and poorly understood procedures. Not reporting results below detection limits (censoring) can cause a loss of information that reduces the robustness of mystical analysis methods and may lead to a false sense of security.

Precision is a measure of how reproducible an analysis is. Accuracy is how close the analysis is to reality. Both are required to correctly represent the concentration of a constituent and have meaningful data. SW-846 lists acceptance criteria for analyses. For some compounds, acceptable calibration and QC criteria range from detection to over 200 percent of the concentration seen in a control sample.

In general, scientists and engineers collecting samples understand that meaningful data is produced when samples are properly collected, handled, and documented. What is not often understood are the procedures and pitfalls of laboratory analyses.

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Poster

Digital Data Submittals to the Department of Ecology's Toxics Cleanup Program: Why Do They Want It That Way and What Are They Doing with That Data?

Bill Myers

Burdensome paper data submittals take excessive time to review, create storage problems, and don't help the environmental investigation or cleanup process. Whereas, digital data submittals give the cleanup management team in the Toxics Cleanup Program access to an almost immediate picture of site conditions. This allows the facility manager and the regulator to focus on timely information which hastens regulatory review and helps to spawn early strategies for cleaning up the site environment. Good review of early data can insure faster and more comprehensive cleanups with less overall cost. Timely data submission allows the regulators to independently check the cleanup progress and take action on any immediate environmental threats. Faster responses to data results in less spread of contamination. The Washington State Department of Ecology's Toxics Cleanup Program has a database package, which is helpful in our cleanup process.

The database package example used by the Toxics Cleanup Program is composed of three data sets: 1) SITE_DES, the basic locational and descriptive information about the sample location; 2) FIELD_SAM, specific information about the sampling event; and 3) LAB_SAMP, the report from the laboratory in a slightly expanded EPA contract laboratory format. With a complete data set, the cleanup person can check the quality of the data set, filter the data, and get spatial and temporal distributions of the various compounds found at a site. There is complete freedom to locate and isolate the highest known levels of contamination, and identify the contaminants of concern. Additional analytical power comes from the ability to export data to a variety of computer analytical tools such as surface contouring packages with the raw or filtered data and start to focus on the most pressing contamination problems quickly and efficiently.

An example use of the data package is to screen all the analytical results against the Model Toxics Control Act Method B cleanup levels for multi-media and generate a listing of exceedences by location. These exceedences can be combined and relative risks can then be contoured on a surface plot. Other use includes contouring groundwater plumes and comparing the plot against the monitoring network to verify the sufficiency of a monitoring. With the addition of the BIOFILE, animal tissue and bioassays can also be evaluated for a site or the information can be reprocessed and exported to the Ecology Sediment Management Program. The current package is accepted by the data manager at EPA Region 10 and several Ecology programs. This package includes elements of the U.S. Geological Survey's WATSTOR Program and elements of EPA's CLP Report. Additional fields were included to better qualify data and verify field collection quality.

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Oral

A Recent Geostatistical Investigation of Arsenic-Contaminated Surface Soil Surrounding the Tacoma Smelter

Marion L. Shaw,[1] and Michael G. Ruby[2]

For many years, a copper smelter located in Tacoma, Washington, smelted high arsenical ores. Arsenic in the stack gases and also escaping as a fugitive from handling and process sources resulted in arsenic-contaminated soil in the surrounding community. This study sought to estimate the distribution of the levels of contamination from three soil sample sets: two fine-grained sample sets close to the smelter and one coarse-grained sample set covering areas farther from the smelter.

Exploratory Data Analysis accounts for the effects on the data analysis of (1) prior remediation efforts of individual property owners and (2) sample clustering due to (a) urban impediments to sampling, for instance, building complexes and paved areas, and (b) sampling methods of previous investigations.

Structural analysis demonstrating correlation between surface arsenic contamination and average wind direction will be presented.

Maps of the probability to exceed selected levels of arsenic concentration and quantile maps of arsenic concentration over the site will be discussed. Results from different kriging methods-lognormal kriging, indicator kriging, and probability kriging- and a geostatistical simulation technique will be compared.

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Ground Water Science and Policy

Poster

GIS Application for Ground Water Advisories

Russ Darr

The Washington State Department of Ecology has knowledge of ground water that for one reason or another is a problem. At this time there is no uniform way to inform the impacted community of the nature and extent of the problem. A geographical information system (GIS) project has been developed to periodically notify stakeholders of ground water status. County maps are published showing the location and reference to the detail maps. The detail maps show the area of the problem, and general information about it. This information includes a description of the problem, the depth of the affected zone and advisories. It is anticipated this application will be used by the Department of Ecology's Toxics Cleanup Program, Solid Waste Services Program, Hazardous Waste and Toxics Reduction Program, Central Programs, Water Quality Program, and Water Resources Program.

An example problem: A ground water plume from a landfill is known to exist. This plume is being monitored on a regular basis and is growing. The use of this application would allow Ecology to publish the county map and all of the detail advisory maps. The county map shows the location of the landfill plume and refers the reader to the detail map number. The detail map shows the extent of the plume, any buffer zone around the plume, and contains the text describing the depth of the contaminants, the contaminants found in the plume, an advisory that drilling in the area is prohibited, and contact phone numbers.

This map could also show the 500-foot setback for wells around the landfill as per regulation. If the Water Resources Program had closed this basin to further development because of over appropriation, this basic would be so marked and indicated in the text. Of course, there are many other possible examples.

It is anticipated these maps will be published at least twice per year and distributed to interested stakeholders. Example maps will be displayed in the poster session of the symposium.

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Oral

Approach to Assessing Potential Groundwater Quality Impacts Incorporating Uncertainty Analysis

Tim Flynn

Protection of groundwater quality is a major issue with increased land use development pressures, particularly in the Puget Sound area of western Washington. The Washington State Department of Ecology's Groundwater Quality Standards established an antidegradation policy with the goal of minimizing further degradation of existing groundwater quality throughout the state. The potential for degradation is based on assessing changes to background water quality. This paper presents a methodology for evaluating groundwater quality impacts which incorporates a quantitative estimate of uncertainty and a statistical evaluation of potential groundwater degradation and exceedence of water quality standards. Evaluation of impacts associated with alternative land uses are discussed and implication for risk management decisions are presented.

This methodology was applied in evaluating the potential groundwater quality impacts from nutrient loading (nitrogen) associated with proposed residential/commercial development, including wastewater discharges from on-site septic systems, application of lawn fertilizers, and golf course development and maintenance. Water quality impacts are evaluated based on an algorithm developed as a function of background water quality, land use density, nutrient loading characteristics, and local groundwater conditions. A Monte Carlo simulation technique utilizing a spreadsheet-based probability modeling routine is used to develop a probability distribution of the resulting nitrate concentration in the recharge water (infiltrate) and groundwater. Simulated frequency distributions for different development alternatives are then compared to the background nitrate concentrations.

A case study representative of the Puget Sound area is presented to illustrate the approach, its use in comparing land use alternatives (e.g., density of on-site septic), and evaluation of mitigation measures.

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Oral

Protection of Tribal Rights and Interests Requires Proactive Groundwater Remediation and Protection at Hanford

Thomas D. Gilmore

As one of the most polluted sites nationwide, Hanford site, southeastern Washington, poses among the greatest technical, institutional, and political remediation challenges facing modern society. Hanford is a microcosm of larger national problems reflecting rampant increases in land and waterway pollution and persistent failures to institute effective preventative controls and waste minimizing production technologies. Such foresight would preclude much more difficult and expensive after-the-fact "clean-up" and associated adverse health impacts to affected human and ecological communities caused directly by policies maximizing "acceptable" pollution.

Tribal on-reservation water resource protection regulations reflect a proactive philosophy of contamination prevention and remediation, strict regulation of well construction, stream zone alteration, and beneficial uses, preventing overappropriation of surface or groundwater, and protecting and preserving long-term quantity and quality of tribally owned reservation waters. Such holistic resource and ecosystem management strategies are far less effectively employed by state and federal agency managers off-reservation within tribal ceded lands--such as Hanford--where tribes maintain treaty-reserved rights and interests.

Tribes, regulators, and diverse public interests have long supported proactive groundwater remediation and protection at Hanford. But a proactive approach is not enthusiastically supported by the U.S. Department of Energy (USDOE) and its contractors, and (ironically) is actively opposed by some impatient local business and governmental interests. In the non-Hanford world, pump-and-treat programs are field proven for wide ranging chemical and radiologic contaminants and hydrogeologic environments, constituting among the simplest, most effective, widely employed remedial strategies to measurably reduce contaminant volume, extent, toxicity, and mobility and to control contaminant spread, commingling, future discharges, and ecosystem and human health impacts. At Hanford, each of five pilot-scale (20-50 gpm) pump-and-treat projects has resulted in >90 percent removal of contaminants of concern, leaving treated discharges below MCLs. USDOE brags little about these unabashed successes, and has no plans to continue--let alone expand--current treatment projects. *In fact, USDOE's current budget projections will totally eliminate all Hanford groundwater pump-and-treat projects by 1997!*

Diverse Hanford interests, the press, and Congress have soundly criticized USDOE for spending so much yet accomplishing so little. Only proactive pollution prevention efforts--such as full-scale groundwater pump-and-treat programs--will accomplish what most interests consider "clean-up," protect tribal treaty-reserved resources and rights, and minimize direct, indirect, or cumulative health impacts to subsistence-dependent tribal communities. Current pilot-scale programs already surpass effectiveness expectations.

Despite USDOE's dire political need to demonstrate "clean-up" progress, little *action*-directed expansion is being seriously considered, let alone aggressively implemented. Further delays will only exponentially increase true costs, remedial complexity, and adverse health impacts, while simultaneously increasing the severity and urgency of risks to affected communities, such as American Indian tribes. In addition, proactive treatment programs can only enhance plummeting USDOE credibility in the eyes of tribes, regulators, Congress, and the public through good-faith commitments to fulfill legal and moral federal government obligations.

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Oral

A Management Program for the Groundwater Protection and Remediation at the Hanford Site, Washington

Dibakar Goswami

The Hanford Site occupies about 1450 km^2 (560 mi^2) of the southeastern part of Washington state, north of the confluence of the Yakima and Columbia rivers. The U.S. Department of Energy established the site in 1943 for the production of plutonium. The production operations converted Hanford into one of the largest and most complicated contaminated sites of the world.

Over 440 km^2 (170 mi^2) of groundwater beneath the Hanford area are contaminated by hazardous and radioactive waste, out of which almost half is over federal and state drinking water standards. These mobile and non-mobile plumes often contain various mixtures of radionuclides, organics, and inorganics. In addition to the complicated nature of these plumes, Hanford groundwater is further obscured by limited application of the available treatment technologies and hydrogeological information, the presence of the liquid effluent discharge facilities, and the existing permitted discharges. Thus the groundwater protection at the Hanford Site consists of both preventive and remedial measures that are carefully implemented in compliance with a variety of state and federal environmental regulations.

A sound groundwater protection management policy based on risk analysis, available technology, and stakeholder's values was developed. The basic groundwater protection strategy involves both near- and long-term actions. Near-term actions include vadose zone and groundwater characterization, monitoring of waste source areas and contaminant plumes, have treated effluent discharges appropriately within permitted areas, and minimize/stop discharges into the ground. The long-term protection will be accomplished by containment and complete remediation of selected groundwater plumes; removal, stabilization, and/or treatment of stored waste and waste released to the ground/groundwater; and groundwater and vadose zone monitoring for the early detection of any leakage from treatment, storage, and disposal facilities.

As a part of the management policy, priorities have been set at remediation of contaminant plumes entering the Columbia River and containment of mobile plumes moving towards the river. Groundwater pump and treat is selected as one of the most effective methods of remediation for the containment of mobile plumes such as carbon tetrachloride, chloroform, TCE, uranium, technetium and a few other radionuclides. Pump and treat is also being considered for the remediation of groundwater containing hexavalent chromium near the Columbia River. Innovative technology must be developed for both treatment and removal of contaminants from the aquifer containing iodine-129, tritium, plutonium, cesium, and similar contaminants. Finally, the management policy would include application of these innovative technologies for the groundwater protection and remediation at the Hanford Site.

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Oral

Ground Water Policy in California

Carl Hauge

California uses more water than any other state, yet there is no state law that provides a basis for ground water management in California. Rights to surface water are specified in the California Water Code, but the Code contains nothing about rights to ground water. Ground water rights have been defined by court cases starting in 1903.

Twenty-two types of agencies manage water. There are 1,000 such agencies. Each type of agency has different authority to manage surface water and little or no authority to manage ground water. In many of the 450 ground water basins, each landowner has a right to extract as much ground water as can be put to "beneficial use." In basins that have been adjudicated, a court decision governs the amount of ground water that each landowner can extract.

Ground water use in each of the nine hydrologic regions varies considerably, as does the hydrogeology and institutional complexity. Less ground water is used in the north because more surface water is available. In the south, ground water has been used extensively in the past and is still used when surface water is not available during droughts and in areas that are not served by surface water delivery projects. The number of dams built for surface water reservoirs has been decreasing since the 1970s. Four dams under consideration are all off-stream storage or flood control dams and are projected to be very expensive.

Recognizing the seriousness of water shortages resulting from drought, increasing population and the effect on endangered species and agricultural and urban water supplies, the legislature recently amended the Water Code to include a procedure for developing ground water management plans at the local level. Many agencies are taking advantage of this amendment to develop ground water management plans to manage water supplies more efficiently. The complexity of each of the plans varies considerably. One benefit of even the simplest plan is that the local agency and landowners begin to discover specific facts about their ground water basin and how ground water in that basin is affected by various management actions. Some plans have already been amended.

The key to developing a ground water management plan that all the stakeholders can accept is to work toward consensus among landowners, local, state and federal agencies within the basin, and the urban population. Local agencies are being encouraged to begin public involvement early in the process and even to exceed the public involvement required by the legislation.

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Oral

The Challenges in Developing Groundwater Monitoring Network at the Hanford Reservation

Krystyna Kowalik

The Hanford Nuclear Facility, established in 1943 as a plutonium production facility, is located in the Pasco Basin and encompasses an area of approximately 560 square miles. All the formerly active reactors are decommissioned and the other operational facilities are designated for either controlled or limited operation under a permit or a closure plan. In 1986, the Triparty Agreement and Consent Order, outlining a cleanup program for the Hanford Site, was signed by the U.S. Department of Energy, the U.S. Environmental Protection Agency, and the Washington State Department of Ecology. One of the milestones in the Triparty Agreement specified that a monitoring network shall be installed as a part of compliance requirements. Drilling and installation of a detection groundwater monitoring network was accomplished by the end of 1993.

Approximately 400 wells were constructed in the RCRA program. During execution of that formidable project many difficulties were encountered and resolved. Different drilling methods were adopted for varied lithologies to expedite the completion of the network. Diminishing groundwater mounds posed a different set of problems. Some wells installed earlier were already dry and new wells were needed.

Experience gained during implementation of the RCRA program and the challenges encountered in the process serve as a background for evaluation of the monitoring network and its effectiveness. The challenges could be grouped in four categories:

1) Drilling and construction of wells,
2) Characterization of geology and hydrogeology (i.e., gaps in the data),
3) Assessment of contaminant extent, and
4) Sampling and analysis plans and execution.

In recent years the monitoring issue as a whole evolved from the initial development stage to a phase when some changes are imminent. Some aspects and tasks need to be revisited by scientific community. Certain issues are beginning to be addressed: purged water (especially if it is contaminated), alternative drilling methods, scrupulous site characterization, and determination of groundwater flow direction. Most of the monitoring problems common to any facility were encountered at Hanford and magnified due to the size of the area. What became obvious during the monitoring network installation was urgent need for using nonintrusive methods of investigation such as geophysical methods. The number and placement of wells were also issue for improvement, however some experience can only be gained through trial and error. Overall execution of the project was successful but will need careful management and maintenance.

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Oral

Use of an Interactive Water Resource Management Simulator to Clarify Water Quality and Quantity Issues

DouGlas Palenshus

Per capita water consumption has vastly increased from ancient rates estimated to be three to five gallons per day (gpd), to current industrial society rates estimated at about 1,500 gpd. Unfortunately, such consumption rates are dependent on "mining" ancient reservoirs and are not sustainable. Additionally, current societal practices often result in a continued degradation of quality water resources from pollutants. One tool that is effective at clarifying man's relationship with water resources is the multi-user Water Resource Management Simulator. This computerized technology allows group interaction and provides: speed up or slow down time, the employment of expensive or unavailable materials and procedures, objectively selected random phenomena, active participation and input by those involved, immediate feedback, reduction of complex problems to manageable size, creation of problem situations where processes and concepts from many disciplines are interrelated in the search for solutions, the exploration of alternatives without having to live with harmful consequences. The presentation/workshop will introduce participants to the simulator's strengths and limitations and will explore its use to impart a range of essential water management concepts.

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Oral

Use of a Public Survey to Obtain Information about Water Attitudes, Opinions, and Knowledge among Pre/Post Educational Outreach Citizen Groups in Clallam County, Washington

DouGlas Palenshus

Clallam County, Washington is located in the far northwestern tip of the contiguous United States and is relatively undeveloped. Forest industries, agriculture, fishing, and tourism are all important parts of its economic base and are linked to the abundant rainfall in this region. Unfortunately, the people of Clallam County have begun experience deterioration of their natural resources as rapid population increases, agricultural and industrial growth, and controversial forest management practices have worked together to exacerbate existing problems. These activities have results in especially serious threats to water resources within the county. This loss of environmental quality is important to county residents because the actual and the perceived purity of the environment in this area affect both its current prosperity and its future development.

As a result of concerns, watershed management plans which included educational efforts, were developed for two county watersheds. Prior to the initiation of outreach activities in the second watershed, environmental educators working with the Center for Environmental Education at Oklahoma State University developed and conducted a public survey of attitudes, opinion, and knowledge which compared responses within several demographic categories and between the two geographic areas. Both expected and unexpected statistically significant differences were found. The presentation will summarize the rationale, methodology, and analysis of this survey.

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Oral

Groundwater Vulnerability Assessments: Risk Management of Washington's Public Water Supplies

Virginia A. Stern[1] and Patricia Wickham[2]

The current State Drinking Water Regulations and the federal Safe Drinking Water Act (SDWA), requires the majority of the state's Group A public water supplies to conduct extensive and regular organic chemical monitoring. Currently the laboratory costs for this monitoring can run approximately $3,900 per source during a three-year compliance period. Washington has nearly 2,600 water systems that fall under these regulations. There are over 5,000 individual sources associated with these water systems that would fall under the organic chemical monitoring requirements. Under the terms of the SDWA, the state has the authority to modify monitoring requirements for those water sources that are determined to be "invulnerable" to organic chemical contamination. The Washington State Department of Health (WDOH) has developed and is currently implementing a comprehensive "vulnerability" program that considers both site specific characteristics and state wide water quality conditions to assign a chemical risk vulnerability code for each public water source. The implementation of this program is expected to save public water systems in excess of $15,000,000 in the 1993-1995 compliance period.

The WDOH vulnerability program consists of three major components: 1) a site specific assessment process that considers source and aquifer characteristics, 2) a state wide water quality monitoring program for organic chemicals, and 3) a deterministic groundwater vulnerability model. The model was developed specifically to identify those public water sources considered to be "at risk" for pesticide, herbicide and related synthetic organic chemical (SOC) contamination. The model considers four risk factors that can be assigned for any public water source. These include water source location, dominant land-use, well depth and average nitrate value. Each factor is assigned a relative risk ranking and the combined risk code is then assigned an overall vulnerability rating of low, moderate or high.

The construction of the SOC groundwater vulnerability model and the development of the associated implementation policies is the subject of this presentation. The process used to meld the analytical data and source characteristics into a standardized policy and implementation tool is analyzed. The strengths and limitations of the model are discussed within the context of public health protection. A description is provided of the criteria used by WDOH to develop and evaluate various implementation options it considered. Future applications and refinements of this model, the vulnerability program, the related database, and implications for other state programs are discussed.

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Cancelled

Groundwater Pioneers of Washington State

Dale A. Stirling

Ground water is an important issue for the citizens of the Evergreen state. This is natural for a state which has abundant surface and subsurface water resources. In recent years federal, state, and local agencies, as well as private interest groups and industry, have poured millions of dollars into ground water planning analysis, and legislation. But every so often those involved with ground water issues should step back and look to the past in order to better appreciate the present and to anticipate the future. Accordingly, the purpose of this paper is to provide an overview of ground water history in the State of Washington.

The paper will examine the human side of ground water history, from aboriginal utilization to the earliest efforts at quantifying and developing ground water resources, to the present era of legislation and resource management. A variety of resources will be used in preparing this paper. Much of the information will be derived from reports and studies prepared by federal and state agencies such as the U.S. Geological Survey, U.S. Environmental Protection Agency, Washington State Pollution Control Commission, Washington Department of Ecology, Washington Geological Survey, and Washington Department of Natural Resources-Division of Mines and Geology and Division of Geology and Earth Resources. In addition, the personal papers and business records of key individuals and industry involved in ground water development will be reviewed.

Visual aids will be used to supplement and support the written paper. These will include historical photographs, maps, drawings and other informational graphics.

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Oral

Technical Problems With Standard of Practice in Environmental Hydrogeology

Mark D. Varljen

A Further Development of Ideas Presented in "A Challenge to the Environmental Consulting Culture," Published in Ground Water Monitoring and Remediation, Summer 1994

Many opinions have recently been expressed concerning current standards of practice in environmental hydrogeology. The Summer 1994 Ground Water Monitoring and Remediation article "A Challenge to the Environmental Consulting Culture" took a stab at what was perceived to be a dangerous industry culture that has developed during the rapid growth of the environmental hydrogeology field. This culture encourages application of frequently inappropriate methods and displays a distaste for innovation. The article made a general statement about the culture and started a useful dialogue. One of the next steps to address the problem is to identify specific technical areas where "industry standard" approaches are failing, and encourage some inspired thinking about these points.

Frequent problems with "industry standard" practice include focusing characterizations on contaminant detections rather than understanding conditions, locating, designing and constructing monitoring wells without regard to objectives; developing wells inadequately; sampling wells immediately after construction; using primitive ineffective ground water sampling technologies; failing to measure hydraulic conductivity properly (or at all); failing to recognize spatial and temporal variability in gradients; failing to collect basic geochemical data; failing to consider spatial variability of porosity; and failing to recognize regional relationships.

These are specific technical areas where we have developed "rote" approaches that do not serve us well in many situations. Specific discussions about technical issues associated with each of these areas must be encouraged for every project. Also, young professionals must be made aware of these issues so they don't get so indoctrinated with "industry standard" that they can't imagine that other approaches could be acceptable. It is particularly important that we address these issues, not only to immediately improve our work, but to encourage the most talented professionals to stay in this field by giving them an opportunity to utilize their scientific skills.

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Hydrogeochemistry - Fate and Transport

Oral

Organic-Carbon Controlled, Nonlinear Sorption of Chlorinated Organic Solvents in a Natural, Clay-Rich Aquitard

Richelle M. Allen-King,[1] Larry D. McKay,[2] Mark R. Trudell,[3] and Hester Groenevelt[4]

Chlorinated solvents are among the most frequently detected groundwater contaminants. Because chlorinated solvents are typically denser than water, solvent spilled into the subsurface environment typically accumulates on lower permeability strata (aquitards). Although not well understood, the sorptive interactions between chlorinated solvents and naturally occurring aquitards are important in controlling the environmental fate and transport of these chemicals.

Perchloroethene (PCE) and trichloroethene (TCE), two representatives of chlorinated solvents, sorption was determined for a natural, clay-rich aquitard (from approximately 12 to 15 ft depth) over a wide concentration range (approximately 5 orders of magnitude) in laboratory batch experiments. The results were markedly different from predictions based on organic carbon (f_{oc}) and clay mineral contents. The study included evaluation of the form of the sorption isotherms for both compounds and determination of relative contributions of organic carbon and mineral matter to TCE sorption.

Over a limited and low concentration range (0.5 to 70 μg/L), TCE sorption isotherms could be approximated as linear with sorption coefficients (K_d) between 46.4 to 151 L/kg. The f_{oc}s were 0.50 percent to 1.95 percent. The organic-carbon normalized sorption coefficients (K_{oc}) for the untreated samples were 16 to 500 times greater than those typically reported for TCE in sediment and soil samples, indicating the more lipophilic character of the organic matter in the aquitard. K_{oc} estimates which accounted for the oxidation state of the f_{oc} in the aquitard sediment assuming the carbon is primarily from Devonian-age shale fragments resulted in estimated K_{oc}s within a factor of 2 to 5 of those observed. To ascertain the importance of sorption to the clay minerals, aquitard samples were treated, thus reducing the f_{oc} by 44 to 90 percent. TCE K_d were reduced to 0.48 to 4.64 L/kg in treated samples. Surface area measurements suggested that treating the aquitard samples appeared to have little effect on the mineral matter. The results indicated that TCE sorption is dominated by the naturally occurring and geologically old organic matter.

When a wide concentration range was considered, the data were best described by Freundlich isotherms, $q = K_F C^{1/n}$ (q and C are the equilibrium sorbed and solution concentrations, K_F reflects the magnitude of sorption and 1/n the degree of isotherm nonlinearity) with $1/n < 1$ for both TCE and PCE. This suggests decreasing adsorption energy with increasing concentration. Sorption isotherm nonlinearity is important because solute retardation is therefore dependent on concentration. For example, the PCE retardation factors predicted from the nonlinear parameters range from 1,300 to < 50 for corresponding solution concentrations of 1 to 220,000 (solubility) μg/L. Isotherm nonlinearity also implies that competition between co-occurring solutes could be significant suggesting that sorption and retardation of chlorinated solvents should not be treated independent of solution chemistry.

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Oral

Metal Mobility at Landfills and Other Waste Disposal Facilities

Bill Deutsch

Metals and other inorganic compounds in the subsurface are generally mobile only as dissolved constituents of the soil water or groundwater. The mobility of these compounds can thus be considered from the standpoint of water/rock processes that either enhance mobility by keeping the compounds in solution or inhibit mobility by sequestering the compounds in the solid phase. The most direct water/rock interactions that partition metals between the solution and solid phases are mineral dissolution/precipitation and adsorption/desorption between dissolved species and the surfaces of minerals. Many other indirect processes such as ion complexation, oxidation-reduction, and neutralization may also play important roles under site specific situations. Because of the complexity of these interactions, it is important to consider the broader geochemical system in developing an understanding of metal mobility in the environment.

Landfills and other waste disposal facilities with degradable organic debris are examples of fairly complex geochemical systems in which the mobility of metals may become an issue. The reactive organic matter in the debris creates a localized chemical environment that is out of equilibrium with the original oxidizing conditions of the near surface. This disequilibrium drives many chemical reactions that lead to enhanced movement of metals. Dissolved oxygen naturally present in rainfall/snowmelt is consumed by the organic matter in the debris, and the leachate produced has a relatively low redox potential, Eh. Oxidation of organic matter also produces carbonic acid thereby lowering the pH of the subsoil beneath landfills. The combined impact is one of increased metal mobility, especially in the case of iron and manganese. The iron and manganese oxyhydroxide minerals common to soil are relatively insoluble under oxidizing conditions at near neutral and higher pH values, however they are soluble under low Eh and pH conditions. This leads to their dissolution into the landfill leachate and elevated groundwater concentrations below and downgradient of the disposal area. Because of the higher solubility of these minerals, it is common to find dissolved iron and manganese concentrations in groundwater 100 times higher downgradient from landfills compared to upgradient.

This paper describes the geochemical processes that impact metal mobility at landfills and discusses methods of data collection to adequately characterize the system. Methods of simulating water/rock interactions are presented in the context of designing and implementing in situ and ex situ restoration to address metal contamination in these environments.

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Oral

Tritium and Plutonium: A Tail of Two Contaminants

Floyd N. Hodges,[1] Vernon G. Johnson,[2] Anthony J. Knepp,[3] and Bruce H. Ford[4]

Tritium and plutonium represent two extremes of groundwater contamination at Hanford. Tritium, included within water molecules, is highly mobile and contaminates groundwater over a large portion of the Hanford Site. Plutonium is strongly sorbed on Hanford sediments and occurs as a significant groundwater contaminant at only one rather restricted area of the site.

Tritium is wide spread in groundwater beneath the Hanford site and exceeds the U.S. Environmental Protection Agency's drinking water standard (20,000 pCi/L) beneath approximately 180 square kilometers of the site. However, the total tritium load in Hanford groundwater (approximately 220,000 curies) represents only 28 grams of tritium or approximately 180 ml of tritiated water molecules. This relatively small quantity of tritium is distributed through approximately 10^{12} liters of groundwater. Thus, separating a significant portion of the tritium from groundwater is, for practical purposes, an impossible task. There are two major sinks for tritium at the Hanford Site, radioactive decay ($t_{1/2}$ = 12.3 years) and outflow into the Columbia River. Thousands of curies of tritium enter the Columbia River each year; however, because of the high flow volume of the river the increase in tritium concentration in the river is insignificant. Thus, tritium in groundwater does not represent a significant off-site risk, but practically precludes most uses of a large portion of the groundwater under Hanford until the tritium has been flushed into the Columbia River or has decayed away.

Plutonium is generally below detection in Hanford groundwater. However, at the 216-B-5 reverse (injection) well, located in the Hanford 200 East Area, approximately 4,000 grams or 250 curies (as plutonium-239) was emplaced below the water table and constitutes a significant groundwater contaminant. Groundwater concentrations of up to 1,000 pCi/L, well above the proposed EPA drinking water standard of 62 pCi/L, have been reported in the vicinity of the reverse well. The plutonium, largely contained within 15 meters of the injection site, was emplaced as an impurity in bismuth phosphate particulates and its distribution within the aquifer is probably controlled to a large extent by phosphate phases (calcium phosphate) within the aquifer. Even if not contained within highly insoluble phosphates, the plutonium would be strongly sorbed on aquifer sediment, and would not migrate a significant distance from the point of injection. However, the half life of plutonium-239 is 24,100 years, well beyond any reasonable institutional control or memory. Because of the long-term potential hazard (drinking water pathway), this disposal site should be remediated. The small volume of aquifer containing most of the plutonium solids indicates that enhanced leaching (solution mining) or some type of physical excavation could be used to remove plutonium from the aquifer.

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Oral

A Case Study of Diffusive Contaminant Migration in a Compacted-Clay Liner: Implications for Aquifer Protection

K. Scott King

Unique instrumentation installed in and under a compacted-clay liner below a landfill has produced a 10-year record of monitoring data regarding the performance of such barriers. Extensive construction control, sampling and laboratory testing indicated that the mean hydraulic conductivity (K) of the liner is 7.7×10^{-9} cm/s. Determination of *in situ* hydraulic conductivity from lysimeter effluent collection rates showed a decrease in K over time. Ultimately, the *in situ* K agreed with the laboratory measurements.

Electrical conductivity sensors within the liner and lysimeter effluent chemistry have shown the advance of leachate-derived chemicals into the liner. Liner exhumation, pore water analysis, and model calculations have confirmed the importance of diffusion as the dominant transport mechanism through this low-K liner. Good cross-agreement between field and laboratory testing and the field monitoring programs have indicated that the liner has performed close to preconstruction predictions. Although the leachate fluid flux across the liner is low due to the low K, the mass transfer due to diffusion was significant. For certain contaminants with low environmental concentration tolerances, the diffusive flux may significantly impact underlying aquifer quality.

This case history documents the behavior of diffusion controlled transport in a relatively homogenous, low-K porous media. Implications exist for other hydrogeologic settings where aquifer protection by engineered barriers of naturally-occurring aquitards are relied on to protect underlying groundwater resources.

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Oral

Analytical Solutions for Contaminant Transport with Langmuir Sorption

V.S. ("Mano") Manoranjan[1] and Andrew James[2]

It is widely accepted that the sorption process plays an important role in the transport and disposition of contaminants in subsurface systems. Consequently, there have been a number of studies involving sorption isotherms coupled to transport models. However, most of these studies assume either linear sorption or local equilibrium conditions when constructing analytical formulae for the concentration profiles of the contaminants. We present a method to obtain analytical solutions for contaminant transport coupled to Langmuir sorption under nonequilibrium conditions. The results are illustrated by making use of some experimental sorption data for the cationic surfactant hexadecyltrimethylammonium chloride (HDTMA).

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Oral

Desorptive Behavior and Leachability of Total Petroleum Hydrocarbons (TPH) in Contaminated Soil

Charles San Juan

An investigation on the desorptive behavior and leachability of contaminated soils containing gasoline, diesel, JP-4, Bunker C, and related compounds as total petroleum hydrocarbons (TPH) was conducted. Currently, little information exists on the leachability and desorptive behavior of complex chemical mixtures such as TPH. Most studies have been dedicated to individual compounds. Determining the mobility of organic pollutants in soil is key to risk assessments for hazardous waste sites where soil pollutants pose a direct threat to ground water. Three sites with in-situ weathered or aged (older than 20 years) TPH-contaminated soil were selected. Laboratory leaching tests, including the Toxicity Characteristic Leaching Procedure (TCLP) and the column leach (ASTM D 4874-89) test, were used to test the leachability of TPH compounds (mg/l). In addition, a sequential batch equilibrium test, developed by the Army Engineers, was used to construct desorption isotherms and to calculate distribution coefficients (Kd) for the target compounds. High-speed centrifuging was also used to extract pore fluids from vadose zone samples for analysis. Ground water samples were also collected at each site for data-comparison purposes. The leachability and desorption information from this study will be used by the Department of Ecology to derive soil cleanup levels for TPH and related compounds that are protective of ground water.

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Poster

Evaluation of Chromium Speciation and Transport Characteristics in the Hanford Site 100D and 100H Areas

Edward C. Thornton,[1] James E. Amonette,[2] Julia Olivier,[3] and Deborah L. Huang[4]

Field and laboratory investigations have been conducted to define the fate and transport characteristics of chromium contamination present in the 100D/H Areas of the Hanford Site. This information is relevant to assessing the impact of the release of hexavalent chromium to the Columbia River associated with the discharge of groundwater from the Hanford unconfined aquifer. Included in this study was the determination of the concentration and aqueous speciation of chromium in the unconfined aquifer, and an assessment of potential changes in speciation as groundwater passes through the river/aquifer transition zone and mixes with the Columbia River.

The fate of chromium was evaluated through the determination of chromium speciation of water samples collected from the Hanford unconfined aquifer, from seeps along the river, and from the river itself. The potential for uptake of chromium in the riverbed and riverbanks resulting from interaction with organic matter and oxide components associated with sediments was assessed by characterization of riverbank sediment samples. Mixing tests involving chromium-contaminated groundwater and river water were also conducted to determine if alteration of chromium speciation could occur subsequent to entering the Columbia River. In addition, groundwater plume maps were prepared from existing monitoring data of the 100-D and 100-H Areas to provide information regarding groundwater flow paths and potential chromium sources.

The results of this study indicate that chromium present within the Hanford unconfined aquifer of the 100-D and 100-H Areas is predominantly in the hexavalent oxidation state. Chromium is apparently relatively stable in the oxidized form owing to the lack of organic matter within the aquifer. A portion of the chromium is removed as groundwater passes through the river/aquifer transition zone due to reduction and precipitation associated with sediment/water interaction processes. Chemical data collected from seep water samples, however, suggests that most of the hexavalent chromium ultimately discharges into the Columbia River. Dilution of hexavalent chromium subsequently occurs during the mixing of groundwater and river water, with relatively little change taking place in speciation.

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Hydrogeochemistry - Ground Water Quality and Contamination

Oral

An Assessment of On-Site Sewage System Management and Drinking Water Well Contamination Potential at Five Mobile Home Parks in Western Washington State

Steve Bubnick

The United States Environmental Protection Agency has conducted a nationwide examination of potential ground water contamination from various near-surface sources. This endeavor is named the Shallow Injection Well Initiative (SIWI). The project was authorized by the Safe Drinking Water Act, and was begun in 1991 and completed in 1994 in EPA Region 10. The SIWI focused on assessing the contamination potential of community drinking water wells by shallow well injection. To fulfill the Region 10 objectives associated with the SIWI, five mobile home park (MHP) communities in western Washington State were studied. A literature search, and quarterly sampling of the drinking water wells at each MHP, was conducted to assess the potential of the wells becoming contaminated by effluent from the injection wells. Sampling results found no contaminants exceeding maximum contaminant levels (MCL) in the five mobile home park water wells. However, nitrates were found at more than 75 percent of the MCL in one well, and low levels of chlorinated solvents were detected in two other wells. Therefore, it was concluded that there is still a significant potential for well contamination at each mobile home park attributed to problems associated with on-site sewage system (OSS) management, insufficient operations and maintenance education, and/or poor understanding of the local hydrogeology and hydrogeochemistry during system siting. Recommendations aimed at decreasing the potential for on-site sewage systems to contaminate drinking water wells include community growth control, strict enforcement of regulations and ordinances, and periodic operator permitting and training.

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Oral

Nitrate Contamination of Ground Water As A Result of Waste Water Management At Six Potato Processing Facilities in the Columbia Basin

Kirk V. Cook

Ground water data, collected within the mid-Columbia Basin over the past forty years indicates that nitrate has contaminated numerous surficial aquifers. The evidence collected to date, reveals a majority of the contaminated aquifers are less than 100 feet deep. Ground water collected from aquifers deeper than 200 feet show a marked decrease in nitrate contamination. The extent to which these aquifers have been impacted is, at this time unknown. It has been hypothesized that the shallow ground water present in localized areas of the Columbia Basin exists due to massive irrigation of arid lands over the last forty years and the dominance of agricultural activities within the area. The source of the nitrate contamination has been the subject of several ground water studies conducted by the Washington state's departments of Ecology and Health, the U.S. Geological Survey, and various conservation districts. Several possible sources are continuing to be investigated by federal, state, and local regulatory agencies.

Recently, attention has turned to industries located in the Basin which manage waste water discharges via land application, as a significant possible source of nitrate contamination. Among the sources most suspected of contributing to nitrate overloading of shallow ground water has been the major potato processing facilities.

As a result of this concern, the Washington State Department of Ecology has conducted a comprehensive review of six major potato processing facilities in the mid-Columbia Basin. The findings of this review indicate a majority of the facilities are currently being operated within or beyond requirements set forth in their discharge permits. These requirements, have been constructed to prevent ground water contamination at some facilities while reducing existing contamination at those facilities which have impacted ground water via past practices. Progress toward environmentally protective operation of the potato processing facilities has been significant during the past seven years.

To date there exists no evidence to support a cause and effect relationship between the operation of the facility waste water disposal areas and contamination of domestic or community water supply systems. The state in cooperation with the potato processing industry is implementing comprehensive measures to further reduce both actual and potential ground water contamination resulting from facility operation.

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Oral

Nitrate Ground Water Contamination in the Sumas Aquifer

Dave Garland

The Abbotsford-Sumas aquifer is a large unconfined glacial outwash aquifer located between the lower Fraser River Valley in British Columbia and the Nooksack River Valley in Washington state. The aquifer is an important source of water for municipal, domestic and agricultural use on both sides of the border, and provides tributary streamflows to the Fraser, Sumas and Nooksack rivers in Canada and the United States. The Washington side of the Abbotsford-Sumas aquifer, referred to here as the Sumas aquifer, is 60 square miles in area and is bounded by the Canadian/U.S. border on the north, the Sumas River on the east, the Nooksack River to the south, and Bertrand Creek to the west. The aquifer study area consists of permeable sand and gravel situated over a flat outwash plain known as the Lynden Terrace.

Several ground water studies have documented elevated nitrate concentrations in the Sumas aquifer. Ground-water samples from the aquifer are highly variable in nitrate and in many cases are highly polluted with concentrations above 25 mg/L nitrate. Areas of high ground water nitrate correspond with areas where significant amounts of dairy waste are land applied. In one incident involving domestic wells on Pangborn Road near Lynden, nitrate contamination appeared in the wells about six weeks following a nearby land application of dairy waste. Recent field sampling of wells at Pangborn Road and at Halverstick Road near Sumas indicate that significant nitrate contamination problems continue to exist in the Sumas aquifer.

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Oral

Groundwater Contamination in the Northern Portion of the USDOE Hanford Site

Mary J. Hartman,[1] Robert E. Peterson,[2] and Bruce N. Ford[3]

The northern portion of the U.S. Department of Energy's Hanford Site (known as the 100 Areas) is home to nine retired nuclear reactors and associated liquid waste disposal facilities. The reactors, located adjacent to the Columbia River, were used to produce weapons-grade plutonium. The first reactor began to operate in 1944, producing fuel for the atomic bomb dropped on Nagasaki in World War II. The newest reactor was built in 1963 and shut down in 1989.

Reactor operations produced large volumes of cooling water and other radiological and chemical wastes. Much of this waste was disposed of in pits or ditches. Many of the waste constituents sorbed to sediments in the unsaturated zone and the rest reached groundwater.

Groundwater in the 100 Areas is sampled and analyzed under several environmental programs by separate USDOE contractors: RCRA and operational monitoring (by Westinghouse Hanford Company), CERCLA investigations (by Bechtel Hanford), and Hanford sitewide monitoring (by Pacific Northwest Laboratory). This study integrates recent results of these monitoring programs and summarizes them in the form of contaminant plume maps.

The uppermost aquifer in the northern Hanford Site comprises highly transmissive sands and gravels of the Miocene to Pliocene-aged Ringold Formation and the Pleistocene-aged Hanford formation. The water table beneath the reactor areas ranges in depth from a few meters near the river to 30 meters further inland. Unconfined groundwater in the northern Hanford Site flows primarily to the north and east, and discharges to the Columbia River.

Radioactive contaminants of interest in groundwater are tritium, strontium-90, technetium-99, and uranium. Hazardous, nonradioactive contaminants include chromium and nitrate. Tritium, the most widespread contaminant, is present in all of the reactor areas and over a large extent of the aquifer between the areas. Strontium-90 is above drinking water standards in smaller contaminant plumes, especially in the 100-N Area. Technetium-99 appears to be migrating into the northern Hanford Site from facilities to the south, and also has sources in the 100 Areas. Uranium is present in a small plume in the 100-H Area. Nitrate is a widespread contaminant and is above background ln all of the reactor areas. Dissolved chromium, primarily in its hexavalent form, is present in 3 plumes.

Most of the contaminants found in groundwater are also present in springs on the banks of the Columbia River. River sampling indicates that the contaminants are rapidly diluted below detection limits.

Maps of contaminant plumes such as the ones produced in this study are used to support the design of groundwater remediation programs. A pump and treat system for hexavalent chromium currently is in operation in the 100-D Area, and a system to remove strontium-90 is being installed in the 100-N Area.

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Oral

Vertical Variations in the Background Chemistry of Groundwater in Central Washington: Implications for the Characterization, Monitoring, and Remediation of Groundwater

James D. Hoover[1] and James P. McKinley[2]

The composition of groundwater in the unconfined aquifer within the Pasco Basin has been found to vary significantly with depth at intervals of several centimeters to several meters. Compositional variations at this scale have not been previously recognized in the region because they are not discernible using conventional sampling methods. The existence of compositional variability at this scale, however, may have important implications for characterization and monitoring of groundwaters, and also for contaminant remediation.

Vertical variations in groundwater chemistry were determined from samples collected from a single well at 20 cm intervals within the upper 17 meters of the aquifer using an innovative multi-level sampling technology. The well is located at the USDOE Hanford Site, hydrologically upgradient from known contamination plumes. Compositional zonation and layering of the groundwater was (observed to be) manifested as compositionally uniform or smoothly variable zones a few meters to over 10 meters thick, and as thin, compositionally distinct intrazonal layers $\leq$20 cm thick.

The transitions between zones and intrazonal layers were often distinguished by sharp differences in pH and EC, and in the concentration of Si, Al, Ca, Mg, K, Na, Fe, Mn, Sr, U, Pb, Ba, Zr, Cu, Cr, NO_3, SO_4, Cl, and F over a few tens of centimeters. The concentrations of some analytes differed by as much fifty times within a seven meter interval (e.g., 2 to >25 mg/L for Cl, 6 to >300 μg/L for Sr, <4 to >45 mg/L for Ca and NO_3, 0.15 to >9 μg/L for Pb). The natural concentrations in some layers also exceed regulatory limits (e.g., NO_3, Fe). The causes for these compositional variations are under evaluation, but are believed to be attributable to rock-water reaction kinetics and intrinsic variability in the geologic composition of the aquifer materials.

It is indicated from these and other multi-level sampling results that vertical stratification in the chemistry of uncontaminated and contaminated groundwaters may be more significant at a finer scale than previously believed. It is indicated from these findings that groundwater sampling practices and the identification groundwater contamination could be improved by sampling at a finer scale.

Conventional sampling methods (e.g., pumping from screened intervals) provide composite samples of groundwater over the sampled interval. The composition of composite samples depend on the position and dimension of the sampling interval relative to the position, dimensions, composition, and hydraulic conductivity of the zones or layers sampled. The implication of compositional stratification for the characterization and monitoring of groundwater is that composite samples may seldom have compositions that represent the natural analyte or contaminant levels in individual zones or layers. Composite samples obtained over an interval larger than that of a contaminated layer, for example, would underestimate the level of contamination in the layer. It is indicated that these sampling issues are integral to determining the presence or absence of contamination in groundwater.

The implications of compositional stratification also extend to the mitigation and remediation of contaminated groundwater. Where stratified contamination is recognized, cross-contamination of uncontaminated parts of the aquifer within subsequent boreholes could be avoided. Strategies and decisions regarding the remediation of contaminated groundwater and/or the selection of appropriate technologies would also be impacted where "pervasive" contamination plumes are recognized to exist in zones or layers of limited vertical extent.

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Oral

Comparison of Pesticide and Nitrate Data from Shallow Piezometers and Domestic Wells near Irrigated Fields in the Central Columbia Plateau, Washington

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To study the quality of shallow ground water near irrigated fields (primarily irrigation circles) in the Central Columbia Plateau in eastern Washington, we sampled 30 shallow (median depth 125 ft) domestic wells and installed and sampled 18 very shallow (median depth 40 ft) piezometers during the growing seasons (March through October) of 1993 and 1994. Pesticides were detected more frequently and in larger numbers per well in piezometers. Nitrate concentrations were also larger in piezometers than in domestic wells.

One or more pesticides were detected in 83 percent of piezometers compared with 70 percent of domestic wells. Atrazine or its degradation product desethyl-atrazine was found in 67 percent of piezometers and 40 percent of domestic wells. The median atrazine concentration for both sets of wells was 0.02 microgram per liter (μg/L) and was well below the drinking water criterion of 3.0 μg/L. An average of 2.5 pesticide compounds was found in piezometers that had detections compared with 1.7 in domestic wells. Median nitrate concentrations in piezometers and domestic wells were 7.8 and 6.5 milligrams per liter as nitrogen, respectively.

Data from piezometers gave a better indication of the effects of irrigated agriculture on the quality of shallow ground water than those from domestic wells because piezometers were designed to sample water at depths as near to the water table as practical, whereas domestic wells are typically drilled as deep as necessary to obtain an adequate water supply. Additionally, piezometers were located as close to irrigation circles as possible without interfering with farming operations, whereas domestic wells area located for the convenience of the water user. The frequency of detection of pesticides and the concentrations of nitrate were lower in the domestic wells than in the piezometers because contaminants were adsorbed, degraded, or transported away laterally before reaching the intakes of the domestic wells. Similarly, some of the ground water from domestic wells may have flowed in laterally from an area of different land use or from leaky canals. The blurring of the seasonal pesticide signature in the domestic wells appears to result from mixing of water that recharged during different times of the growing season.

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Poster

Monitoring for Pesticide Contamination in Public Supply Wells--The Area Wide Groundwater Monitoring Project

Patricia Wickham,[1] Alex K. Williamson,[2] and Stephen Swope[3]

In 1994, the Washington State Department of Health spearheaded a comprehensive evaluation of the extent to which drinking water sources had been, or are threatened to become, contaminated by pesticides. The Area Wide Groundwater Monitoring Project was a cooperative effort that included two federal agencies, three state agencies, one county agency, three private environmental firms and five independent private laboratories. The project was completed in less than eight months and was funded through a loan authorized by the 1994 Washington State Legislature when they enacted Second Substitute House Bill 2616 (2SHB2616).

The presentation will highlight five stages of the project:

1) Water-quality data collection from 1,326 wells,
2) Compilation of well logs and site information forms for each well sampled,
3) Design and creation of a database to store site-specific information for water quality data,
4) Statistical correlation of water quality data with site-specific information, and
5) Development of a decision matrix for issuing monitoring waivers.

Washington State's Area Waiver Program uses the data from this project as the foundation for issuing monitoring waivers mandated by the federal safe Drinking Water Act (SDWA). The SDWA expanded costly organic chemical monitoring requirements for sources of public drinking water. Monitoring for synthetic organic chemicals, most of which are pesticides, could cost as much as $5,000 per year per well. The SDWA also permits states that have accepted primary responsibility for implementing the federal drinking water quality laws to waive some of monitoring requirements. The Area Waiver Program is consistent with federal criteria but is unique in its combined analysts of (1) well-site vulnerability to contamination and (2) pesticide contamination risk factors as determined from the monitoring project.

The results of the Area Wide Groundwater Monitoring Project corroborate the DOH's preliminary projects that pesticide contamination of Washington's drinking water presents a low public health risk. Pesticides were detected in 6 percent of 1,103 randomly selected wells and 14 percent of 223 wells considered to be at higher risk of contamination (based on area and nitrate level). The most statistically significant risk factors were area, local land use, depth, and nitrate level. These factors were used to estimate risk levels for more than 3,000 public supply wells and to specify an appropriate frequency of monitoring for each well. Overall, the results demonstrated a low incidence of pesticide detections, low concentrations when there were detections, and a limited variety of compounds detected.

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Hydrogeochemistry - Isotopes and Ground Water Tracers

Oral

Hydrogeochemical and Isotope Characterization of Groundwater Near Wenatchee, Washington

John A. Baker

A hydrogeochemical and environmental isotope study was conducted in groundwater for a landfill facility near Wenatchee, Washington. The objectives of the study were to use geochemistry and isotope groundwater data to enhance the hydrogeologic and groundwater quality investigation of the landfill. The groundwater was sampled for major anions and cations; leachate indicator parameters; stable isotopes including carbon-13, oxygen-18, and deuterium; and radioactive isotopes including tritium and carbon-14. The objective of the groundwater investigation was to confirm the conceptual hydrogeologic flow mode, confirm the hydraulic balance calculations with a mass balance geochemical analytes and isotopes, and to determine the source of trace levels of volatile organic compounds (VOCs) at an upgradient well.

Landfill leachates also were sampled for the same parameters as the groundwater monitoring wells. Results of the geochemistry and isotopic composition of other municipal waste landfill leachates in WMX Technologies' database will be presented. A general description of how isotope and geochemical data of leachate are compared to ambient groundwater data to evaluate potential groundwater quality impacts from municipal and hazardous waste landfills also will be discussed.

The groundwater quality data collected will at the landfill near Wenatchee showed the following:

1) The conceptual model of groundwater flow was confirmed showing that groundwater in three upgradient wells of the site are in separate water bearing zones and that groundwater in downgradient wells were in one aquifer that was a mixture of the upgradient zones.
2) The groundwater in the Wenatchee Formation was thousands of years old and the groundwater in the alluvial and landslide formations was a mixture of older and modern groundwater.
3) Groundwater quality in downgradient wells were not impacted or degraded by the landfill.
4) The source of trace VOCs in the upgradient wells were from landfill gas
5) Some inorganic impacts most likely were from upgradient sources

The process used by WMX Technologies, Inc. to evaluate groundwater quality is geochemical fingerprinting.

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Oral

Recharge from Precipitation in Three Small Glacial-Till-Mantled Drainage Areas in the Puget Sound Lowland, Washington

Henry H. Bauer and M.C. Mastin

Detailed water budgets for three small drainage areas (catchments) in glacial till mantled terrains in the southern part of the Puget Sound Lowland, Washington, were computed for the purpose of quantifying direct ground-water recharge from precipitation through glacial till. Water-budget calculations using time series data of precipitation, streamflow, incoming solar radiation, and temperature for two- and three-year periods, together with soil and foliar cover data, were calibrated against periodically observed soil moistures, saturated soil-water levels, and forest throughfall amounts. Also, recharge was estimated independently at one location in each catchment by sampling and accounting for the distribution of H-bomb-produced tritium in the unsaturated zone.

Water-budget-computed recharge to the water-table aquifer in the three catchments were 1.49, 5.29, and 6.84 inches per year, or 4.0, 13.5, and 16.8 percent of precipitation, respectively. A tritium-tracer-estimated average recharge rate of between 1.68 and 1.93 inches per year, for the 1952-92 period, in one of the catchments compares favorably with the water-balance estimate of 1.49 inches per year for that same catchment. Only approximate lower-limit recharge estimates were obtained using the tritium method for the other two catchments (3.1 and 3.6 inches per year). Differences in the recharge rates between the catchments appear to be largely due to regional variations in the amount of silt- and clay-sized particles in the till. Estimates of recharge made in this investigation are considerably lower than those of most other investigations in the Puget Sound Lowland.

The components of direct runoff were examined by sampling and accounting for the concentrations of the stable oxygen-18 isotope in precipitation, soil water, and streamflow in one of the catchments during three storms. The observed isotopic compositions indicate that there is no significant overland flow contribution to direct runoff in forested, till-mantled areas of the Puget Sound Lowland. Instead, streamflows caused by storms consist mostly of antecedent soil water displaced by storm precipitation.

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Oral

Preliminary Estimates of the Residence Time of Ground Water beneath SUBASE Bangor, Kitsap County, Washington

Stephen E. Cox

Uncorrected estimates of ground-water residence time range from modern to 6,000 years for water samples collected from five wells near SUBASE Bangor in Kitsap County, Washington. The wells, located along a regional flow path, tap either a shallow or a deep glacial aquifer; the two are vertically separated by a confining unit, The samples, one from the upper and four from the lower aquifer, were analyzed for isotopic composition and other water-quality constituents to provide preliminary information on the average residence times of ground water flowing beneath SUBASE Bangor and to provide data to guide additional sampling. The deuterium and oxygen-18 values of the five ground-water samples were similar, indicating a similar source of recharge for all samples. The tritium concentration in the sample from the upper aquifer was 13 tritium units, indicating modern water with all average residence time of about 20 to 30 years. Tritium was not detected in samples from wells tapping only the lower aquifer, indicating the absence of modern (post-1950) water in this aquifer. The carbon-14 concentrations in the samples from the lower aquifer near the regional recharge and discharge areas were 70 and 40 percent modern carbon, respectively, on the basis of the half-life of carbon-14, these values yield uncorrected estimates for the residence times of these ground waters that range from several hundred years near the recharge area to about 6,000 years near the discharge area. However, on the basis of carbon-13 values, which also vary in samples along the flow path, these estimates may need to be reduced by as much as 50 percent because of suspected interactions of carbon in ground water with carbon from carbonate minerals or organic materials within the aquifer matrix.

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Oral

Modification of the Stable Isotopic Composition of Local Precipitation Prior to Groundwater Recharge in the Rattlesnake Mountain Area, Washington

David L. Graham[1] and Vernon G. Johnson[2]

The isotopic content of groundwater collected from aquifers in the Pasco Basin is characteristically shifted to the right of the global meteoric waterline. In an attempt to determine the mechanism responsible for the shift, a sampling program was initiated to characterize the stable isotopic content of precipitation collected in the Rattlesnake Mountain area of the Pasco Basin. The purpose of the investigation was to determine if the isotopic shift observed in the groundwater data could be accounted for by secondary fractionation effects that occur in local precipitation. One hundred thirty samples were collected over a two-year period from eight separate sampling stations that ranged in elevation from 322 to 1,067 meters. All samples were analyzed for $\delta^{18}O$ and δD. The data were used to establish a local meteoric waterline for the study area. The data trend along an evaporation line described by the equation: $\delta D = 6.0\delta^{18}O - 29‰$. This shift was attributed to non-equilibrium fractionation as a result of evaporation that occurred during the rainout process and the "amount effect." However, the shift observed in the local precipitation data was not sufficient to explain the trend observed in the groundwater.

Snow collected during one sampling event was allowed to melt and the sample was collected as water. Fresh, unmelted snow samples were collected at the same time and both sets of samples were analyzed for $\delta^{18}O$ and δD. The results indicated that a 15 percent enrichment of the heavy isotopes occurred as a result of evaporation. Evaporation of recharge water prior to entering the subsurface would result in the isotopic signature of the infiltrating water being shifted to the right of the local meteoric waterline, thus, accounting for at least a portion of the shift observed in the isotopic signal of the groundwater. Conceptually, this process would be expected to occur several times prior to infiltration.

There are numerous springs that issue from the basalts in the Rattlesnake Mountain area and the isotopic content of the springs supports the theory of multistage evaporation. The spring data fall within the general range of values measured for precipitation. The data parallel the local meteoric waterline but demonstrate considerably more variability. This increased variability was due to the fact that waters from ephemeral, low flow, high elevation springs have undergone several stages of evaporation. Water discharging from the mouth of the smaller springs undergoes evaporation and then moves downslope and reinfiltrates. This process can happen several times leaving the residual water isotopically enriched relative to the original water. This trend was not observed in high volume perennial springs. Larger springs had very stable isotopic signatures that were very similar to snow sampled from the study area.

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Oral

Single-Well Tracer Methods for Hydrogeologic Testing

Stephen H. Hall

Single-well tracer tests, when combined with a program of conventional aquifer testing and water-level measurements, offer an economical means for estimating flow parameters that affect ground-water mass transport, but that are otherwise often difficult or costly to obtain. A drift-and-pumpback test using a conservative flow tracer such as bromide yields values for ground-water seepage velocity and effective porosity. The test is conducted by introducing the tracer into a test well and by allowing the tracer to drift away from the well bore under natural gradient for a period of time, typically a few days. The tracer is then recovered by pumping the test well while monitoring the concentration of the tracer in the effluent stream. Porosity and velocity are calculated from the amount of time required to recover the tracer, the hydraulic conductivity of the well, and the local hydraulic gradient.

Multiple, simultaneous point-dilution tests yield a vertical profile of hydraulic conductivity for a well's screened interval. These tests are conducted by introducing a flow tracer to the water column in the same manner as for the drift-and-pumpback test. As the tracer is swept from the well bore by natural ground-water movement, tracer concentration is monitored as a function of depth and time using a submersible, portable, cable-deployed chemical sensor developed specifically for this test. No packers are required to isolate test intervals, and no ground-water samples are collected. For both the drift-and-pumpback test and the point-dilution test, the flow tracer must be quickly and evenly emplaced in the water column. A simple, effective, and inexpensive apparatus and method have been developed to meet this requirement. These cost-effective tracer methods and tools were originally developed for detailed characterization of aquifer thermal energy storage project sites. They have been applied at the Hanford in situ bioremediation test site and are currently being used in environmental restoration investigations where movement of contaminated ground-water is an important factor in risk analysis and the engineering design of remediation methods.

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Oral

A Characterization Study Using Field Data From A Controlled Experiment

V.S. ("Mano") Manoranjan[1] and Thomas B. Stauffer[2]

In order to get a better understanding of plume migration of contaminants in heterogeneous systems, we carry out a characterization study using data collected at a groundwater tracer test site located at Columbus Air Force Base, Mississippi. We analyze the spatial variation of hydraulic conductivity by making use of grain-size data and characterize the concentration data employing some deterministic concepts. The study involves vertical kriging, co-kriging, and the construction of trend surfaces. It is found that such an investigation can provide a good characterization of the site of interest even with a limited data set. We also look into the effects of different scales associated with the heterogeneous system on macrodispersion.

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Oral

Multiple Tracers of Groundwater Flow and Recharge in Loess, Southeastern Washington

R. O'Brien,[1] C. Kent Keller,[2] and T.K. Kafka[2]

Vertical profiles of tritium and nitrate porewater concentrations were determined to ≈ 8 m depth across two loess hillslopes. Mean recharge fluxes, estimated from chloride mass balance, are 5-10 times larger at the mid- and toe-slope positions than at the top-slope; the magnitudes of the values compare reasonably with results from other methods. Preferential flow may explain much of the discrepancies and is in fact suggested by groundwater chloride concentrations. The tritium and nitrate profiles exhibit multiple peaks which indicate that piston flow is not the sole flow process in this system. Results of a simple one-dimensional model suggest that infiltration-exfiltration cycles in zones of plant root activity explain the shallow tritium peaks. Deeper peaks result from preferential vertical and/or lateral flow. The importance of these dispersive process is underlined by great dilution of observed tritium concentrations, relative to expected concentrations assuming piston flow. In this setting, chloride is useful as a recharge estimator while tritium and nitrate serve as tracers of landscape-scale water movement.

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Oral

Estimating Deep Percolation of Precipitation at Hanford Using Total Chloride and Chlorine-36 as Soil-Water Tracers

Edmund A. Prych

Knowledge of long-term average rates at which water from precipitation percolates downward through soils and sediments on the U.S. Department of Energy Hanford Site in semiarid southcentral Washington is necessary for assessing environmental risks posed by radioactive and other wastes in the soil at Hanford and for selecting appropriate isolation or remediation strategies. Calculations that use chloride concentrations in soil water and are based on a mass balance of total chloride from precipitation and dry deposition gave estimates of deep percolation that ranged from 0.008 to 0.3 millimeters of water per year for nine undisturbed locations at Hanford with deep rooted plants. Estimates by this method for four locations vegetated only with shallow-rooted grasses were larger and ranged from 0.4 to 2 millimeters per year. Calculations using soilwater contents and the depth to which chlorine-36 fallout from 1950s atmospheric nuclear weapons tests in the Pacific Ocean has percolated into the soil provide another method of estimating deep-percolation rates. Estimates of the upper limit of deep-percolation rates by this method for three of the locations with deep-rooted plants were less than 4 millimeters of water per year.

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Physical Hydrogeology/Hydrology - Hydrostratigraphy

Oral

The Hydrostratigraphy of the Bellingham Drift and Associated Deposits, Blaine, Washington

Linda Baker

The hydrostratigraphy of the Bellingham Drift, the surficial sediments and underlying Deming Sand were studied in detail in northwestern Whatcom County. The purpose of this study was to define the hydrostratigraphic units, to identify aquifers and aquitards and to evaluate horizontal and vertical groundwater flow. Characteristics of these units were studied in two areas separated by approximately a half mile. Four sets of nested piezometers were installed in the first 35-acre area and three sets of nested piezometers were installed in the second 4-acre area. Each piezometer nest consisted of five piezometers. Within each nest, piezometers were installed in the upper, middle and lower portions of the Bellingham Drift and in the surficial sediments (where present) and the underlying Deming Sand. Water levels were monitored monthly for one year and horizontal and vertical gradients were analyzed. Slug tests were conducted to evaluate hydraulic conductivities.

The study indicated that the Bellingham Drift can be subdivided into lower and upper hydrostratigraphic units based on color, structure, and hydraulic characteristics. The upper Bellingham Drift is the upper unconfined water table aquifer. Although this unit is waterbearing and referred to as aquifer, the potential for groundwater production from this unit is limited. The thickness ranges from 6 to 16 feet and the mean hydraulic conductivity is 1.13×10^{-4} cm/sec. The upper Bellingham Drift is a stiff, brown to gray silty clay and has a angular, blocky soil structure. The lower Bellingham Drift is sticky, blue-gray and massive. It is an 25 to 40 foot thick aquitard and has an average hydraulic conductivity of 2.2×10^{-7} cm/sec. Lithologically it consists dominantly of blue-gray silty clay, massive and sticky. The Bellingham drift is underlain by the Deming Sand, the second, confined aquifer. The hydraulic conductivity of the Deming Sand averaged 1.7×10^{-5} cm/sec. Locally surficial sediments are included in the upper aquifer and consist of lenses of sands, gravelly sands and silty sand fill material.

Vertical gradients between the surficial sediments and upper Bellingham Drift, and between the upper and lower Bellingham Drift vary from upward to downward. The gradients between these units average 0.05 ft/ft downward and 0.04 ft/ft downward, respectively. Within the lower Bellingham Drift and between the lower Bellingham Drift and the Deming Sand gradients are downward and average 0.64 and 0.66 ft/ft, respectively. Horizontal groundwater flow directions and gradients in the upper sediments and upper Bellingham Drift generally follow topography in direction and magnitude. In the lower Bellingham Drift, horizontal gradients vary vertically and between the study areas. Limited data from the Deming Sand at the site suggests a southeast to southwest flow direction with an average gradient of 0.015 ft/ft.

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Poster

Hydrogeologic Implications of Refined Central Pierce County Stratigraphy

Rich Borden[1] and Kathy Goetz Troost[2]

Environmental investigations at several sites in central Pierce County have provided new stratigraphic and hydrologic data from the upper 300 feet of the Quaternary section. Geologic logs, soil samples, and groundwater potentiometric data from more than 50 deep borings and numerous outcrops have been used to refine the hydrostratigraphy of the area.

As originally defined in central Pierce County, the Vashon Drift Aquifer included the entire Quaternary section above a laterally extensive nonglacial unit, the Kitsap formation. This sequence actually consists of several water-bearing units (outwash deposits) separated by discontinuous aquitards (till, glaciolacustrine clay, and nonglacial deposits).

The Lawton Clay, a discontinuous aquitard marking the base of the Vashon Drift in the Seattle area, was not previously mapped in central Pierce County. During this study, a Lawton Clay equivalent was recognized in many of the borings. There are typically about 50 feet of nonglacial and glacial sediments between the Lawton Clay and the Kitsap Formation in the borings. The nonglacial sediments consist of sand, peat, and silt which, based on radiocarbon dating from this study, correlate with the Olympia nonglacial interval. A glacial outwash sand has also been recognized between the Olympia sediments and the Kitsap Formation, which may correlate with the Possession Drift.

Based on stratigraphic position, the Kitsap Formation as identified in central Pierce County is believed to correlate with the Whidbey Formation. The Kitsap Formation is typically composed of nonglacial silts, fine sands, and peat, and is the shallowest regionally extensive aquitard in the area. However, local erosional features or coarse depositional sequences exist within the Kitsap Formation, which allow mixing of groundwater between the aquifers above and below. An erosional window through the Kitsap Formation was discovered beneath the Fort Lewis Army Base that allowed trichloroethylene contamination to migrate from the shallow aquifer to the deep Salmon Springs Aquifer. This permeable window was identified and delineated by steepened groundwater gradients, lithologic variations, and contaminant plume mapping. Because of the Kitsap Formation's depositional environment, similar localized permeable windows likely exist elsewhere and could provide conduits for rapid vertical contaminant movements.

Nonglacial depositions are recognized as regional aquitards throughout the Puget Lowland. However, as this study shows, these nonglacial units may be locally absent or represented by relatively permeable deposits. Other significant findings of this study include the recognition of sediments that are equivalent to the Lawton Clay, the Olympia nonglacial, the Possession Drift, and the Whidbey Formation in the southern Puget lowland. The Lawton, Olympia, and Possession were not previously recognized south of the King/Pierce County line. Besides the Kitsap Formation, other aquitards such as the Lawton Clay and Olympia sediments, may be present locally in hydrostratigraphic sequences in central Pierce County.

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Oral

Effective Aquifers

James R. Carr and Robert C. Palmquist

Practicing hydrogeologists typically apply locally popular stratigraphic names to describe subsurface units that are subsequently interpreted as aquifers or aquitards. Puget Sound examples are the Colvos Sand -- aquifer -- and Kitsap Clay -- aquitard. We believe this traditional approach is both difficult and inappropriate. It is difficult and time-consuming to correlate an incompletely described subsurface unit to a completely described surface unit. It is inappropriate because ground water flow is controlled by the permeability and porosity of the sediments within the named stratigraphic units. Thus, the finer-grained portions of the Colvos Sand may act as aquitards and the coarser-grained portions of the Kitsap Clay may act as aquifers. In our opinion, stratigraphically identified units provide little understanding of the permeability, capacity, and extent of the actual hydrogeologic units in an area.

This paper proposes a new concept described by the term "effective aquifers." As defined here, these units have specific hydrogeologic characteristics that may not correspond to traditional stratigraphic or lithologic units. Effective aquifers are defined by water level position and response, such that:

- All wells completed in an effective aquifer have water levels with similar elevations (after considering ground water gradient).
- Water levels in wells completed in the same effective aquifer demonstrate predictable hydraulic responses to stresses such as pumping, tidal, barometric, and seasonal water level changes.

Proper designation of effective aquifers clearly requires extensive water level data with elevations established by survey. Designation based on response should use long-term monitoring information to establish seasonal responses and long-duration pumping test data to establish the extent and location of each effective aquifer.

Effective aquifer designation provides a practical method of understanding the complex nature of local ground water resources. Properly used, the designation helps to clarify hydraulic continuity, define the resource capacity, and resolve water right issues. Defining effective aquifers also provides a more meaningful approach to evaluating water quality, quantifying recharge, and delineating critical recharge areas.

Successful application of the effective aquifer identification system is illustrated by several of examples:

- The City of Bremerton's Gorst Creek Basin, has three effective aquifers which integrate six previously defined "hydrostratigraphic" units.
- Issaquah Valley's aquifer system long believed to be a single unconfined alluvial

aquifer is better understood as a confined system consisting of three effective aquifers.

- Fort Lewis' ground water resources consists of four effective aquifers that include portions of stratigraphic aquitards.
- Tacoma Public Utilities Water Division operates 14 high capacity production wells completed in two distinct effective aquifers in what was formerly designated as a single unconfined aquifer.

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Oral

Recharge of a Perched Aquifer by a 13-Acre (5.3-Hectare) Pond Located in a Glaciated Area of Northwest Washington

Douglas S. Dillenberger

A ground water investigation conducted in early 1993, at a proposed golf course site in Skagit County of northwest Washington State, led to the discovery of a perched aquifer located approximately 130 feet beneath a 13-acre (5.3-hectare) pond. The area, located near Puget Sound, was impacted by Pleistocene glaciation. Final retreat of the ice sheets left thick outwash gravels, which produced many excellent aquifers, overlying the older till deposits adjacent to Jurassic-aged metasedimentary rocks. The perched aquifer is composed of well sorted glacial outwash gravels having an average thickness of about 40 feet (12.2 meters); the regional water table aquifer is composed mainly of silty sand. The top of the perched aquifer overlies the regional water table aquifer by approximately 50 feet (15.2 meters), and the perched aquifer base lies about 25 feet (7.6 meters) above the regional water table aquifer. In 1968, nine water wells averaging 165 feet (50.3 meters) completion depth were drilled at the site and completed in the perched aquifer. Offsite domestic water wells, having an average completion depth of about 190 feet (57.9 meters), are completed in the regional water table aquifer. A 72-hour-long aquifer test conducted at the site demonstrates the perched aquifer has a high average transmissivity of 10,800 ft^2 per day, while the regional water table aquifer has a lower estimated transmissivity of about 2300 ft^2 per day. An analysis of ground water movement directions in the regional water table aquifer and the perched aquifer shows different gradients and movement directions for each. The perched aquifer has a limited areal extent of approximately 150 acres (60.7 hectares) with a storage capacity of approximately 450 million gallons (1.7 million cubic meters) during the wettest times of the year. The pond was formed some 40 years ago after construction of a dam across a small creek and is probably the source of the ground water in the perched aquifer.

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Poster

Hydrogeology of the Northeastern Columbia Plateau: the Wanapum and Grande Ronde Hydrostratigraphic Units in Lincoln and Spokane Counties, Washington

William B. Deobald, John P. Buchanan, and Fritz E. Durham

Recent detailed investigation of basalt aquifers in eastern Lincoln County and western Spokane County has revealed a complex hydrogeology, in contrast to the often simple conceptual models often visualized for the basalt systems. In this area, the Wanapum Formation has a maximum thickness of 89 m, while the Grande Ronde Formation approaches 157 m. The contact between the two basalt formations generally occurs at an elevation of 640-670 m and is typically marked by the presence of a sedimentary interbed (Latah Formation) that varies in thickness from absent to 37 m. These two basalt formations, and their interbedded sediments, are the most important hydrostratigraphic units at the northeastern edge of the Columbia Plateau.

Ground water in both aquifers generally flows from topographic highs to topographic lows, moving away from steptoes and towards the more deeply incised surface drainage systems. The system is mostly recharged through precipitation, through areas of exposed basalt or basalt overlain by thin and/or permeable sediments. The Wanapum aquifer discharges downward to the Grande Ronde aquifer, which in turn discharges to the basement rock below and possibly to the Spokane Valley - Rathdrum Prairie aquifer. The steptoes around Medical Lake form a ground water divide that isolates the aquifer system from the eastern Columbia Plateau aquifer system, where groundwater flow is mostly toward the southwest. Ridges of basement rock also separate the deeper part of the groundwater flow system. Interestingly, a leaky wastewater system at Fairchild Air Force Base has caused an artificial mound of groundwater in the Wanapum aquifer beneath the base, resulting in radial groundwater flow.

The Wanapum and Grande Ronde aquifers are semiconfined to confined systems, with hydraulic gradients ranging from 0.006 to 0.121 and 0.011 to 0.182 respectively; the vertical gradient is downward. The interbed between the two aquifers forms an aquiclude and causes a difference in head ranging between 6-64 m, and tends to increase to the north and east. From May to October, 1994, heads were observed to decline about 1.5 m in both aquifers. Wanapum aquifer parameters are estimated as: hydraulic conductivity, 0.06 to 3.69 m/d; transmissivity, 0.4 to 1.9 m^2/d; and storativity, 0.00002 to 0.0005.

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Poster

Hydrogeologic Implications of the Subsurface Geometry and Extent of the Mid-Holocene Osceola Mudflow, Puget Lowland, Washington

Joe D. Dragovich,[1] Patrick T. Pringle,[2] and Timothy J. Walsh[3]

The Osceola Mudflow (OM) originated as a huge sector collapse from the northeast flank of Mount Rainier about 5.7 thousand years ago (ka). Later Holocene debris-flow, alluvial, and deltaic deposits in Puget Lowland river valleys have buried much of the OM deposit and obscured its distal extent and geometry in the Green, Puyallup, and Duwamish valleys. Using 950 geotechnical boring and water-well logs, we systematically traced the subsurface OM as far as Kent in the Duwamish valley and Fife in the Puyallup valley, both more than 100 km (channel distance) from Mount Rainier. The OM is a stratigraphic marker for pre- and post-OM paleogeographic reconstructions and facilitates determination of post-OM sedimentation rates and sedimentary environments. The OM is also an important aquiclude in the valleys due to its very poor sorting (as much as 17 percent clay, with boulders, gravel, sand, and silt) and valley wall-to-wall distribution. Many wells that penetrate the OM have artesian flow from aquifers; source beds directly below the OM include sands and gravels of fluvial channel, deltaic platform, non-cohesive lahar, and glacial outwash origin. We constructed a pre-OM topographic map and both OM and post-OM valley-fill isopachic maps using OM top and bottom elevations. The OM overrode ancient deltas below West Puyallup, south of Auburn, and along the present mouth of the Green River and flowed down delta foreslopes of 2-3 degrees. Delta platform elevations suggest that sea level was about 8 m (or less) below present sea level at ca 5.7 ka. Using the isopachs we have revised the OM volume up to at least 3.7 km^3 -- 2.0 km^3 (average 6 m deep over 330 km^2) for the surface OM and 1.7 km^3 (average 8 m over 165 km^2) for the subsurface OM. Post-OM valley-fill sediments downstream of the ancient deltas in the Puyallup and Duwamish valleys are dominantly deltaic in origin; post-OM sedimentation rates are about 2,000 cm/1,000 years, favorably comparable with deltaic sedimentation rates worldwide. (Alluvial rates are typically $<$ 1,000 cm/1,000 year). Knowledge of the nature, distribution, and geometry of the OM and other Holocene deposits in these valleys is necessary for understanding the nature, extent, and behavior of local groundwater resources. Similar conditions may exist in valleys draining other composite volcanoes in Washington.

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Oral

Unusual Barometric Pressure Responses in a Till-Capped Water Table Aquifer, Kitsap County, Washington

Steve Germiat[1] and Marvin (Nick) Saines[2]

Apparent barometric efficiencies (B.E.) which vary with time and can exceed 100 percent have been documented in a till-capped water table aquifer in Kitsap County. The stratigraphic sequence in the study area consists of 20 to 40 feet of low-permeability (Vashon) glacial till, overlying 30 to 70 feet of unsaturated (Vashon) advance outwash sand, overlying a 60- to 100-foot thick water table aquifer within the outwash sand. Several data sets from simultaneous, continuous monitoring of barometric pressure and water levels in monitoring wells confirm a nearly perfect correlation between barometric fluctuations and water level (head) changes of up to 0.5 feet. As barometric pressure increases heads in the wells decrease and vice versa, consistent with conventional knowledge. However, the data demonstrate that the apparent B.E. (water level change in feet of water/barometric pressure change in feet of water) are not constant over time, with values commonly ranging from 50 and 120 percent for individual periods of increasing or decreasing barometric pressure. One data set even showed a reversal from decreasing to increasing heads during a uniformly increasing barometric pressure trend.

We attribute the transient barometric response in this aquifer to the influence of air pressure within the air pocket (unsaturated sand) separating the till and water table, consistent with observed flows of air in/out of monitoring wells screened across the water table (conduits between the air pocket and atmosphere). Pressure within the air pocket is exerted on the water table, except within the monitoring wells. We hypothesize that pressure fluctuations within the air pocket below the till (P_{a2}, acting on the aquifer) lag behind changes in barometric pressure above the till (P_{a1}, acting on the well). This results in a constantly changing pressure gradient at the well screen, resulting in variable rates of flow in/out of the well which we measure as variable rates of water level change in the well. The high apparent B.E. (above 100 percent) presumably occur when P_{a1} and P_{a2} are changing in opposite directions, creating a reinforcing effect which causes accelerated rates of flow in/out of the well, thus faster rates of water level change. We hope to conduct additional research to quantify the air pocket's effect (magnitude and lag time).

Barometric responses have important implications for water level monitoring, particularly during pumping tests. Aquifer test analysis without recognition of barometric influences can seriously compromise aquifer parameter estimates. Without the benefit of detailed monitoring data on P_{a1} and P_{a2} to allow barometric correction of pumping test data, the authors suggest continuous water level monitoring during the pumping test in an appropriate control well located outside the zone of pumping influence. Water level fluctuations in the control well can be subtracted from the pumping test data as an empirical method of removing barometric effects.

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Oral

Complex Flow Patterns Observed in Unconfined Aquifer, Naval Submarine Base, Bangor, Washington

Bryan S. Graham[1] and Thomas C. Goodlin[2]

A shallow unconfined aquifer contained within the Vashon Advance Outwash deposits at the Naval Submarine Base, Bangor, Kitsap County, Washington demonstrates complex horizontal flow patterns. The area currently is receiving a high level of scrutiny due to the presence of organic compounds in the groundwater detected at concentrations above EPA MCLs. The portion of the shallow aquifer being evaluated in close detail is situated just east of a flow divide on the Kitsap Peninsula between generally eastward flow to the Puget Sound and generally westward flow to Hood Canal. The shallow unconfined aquifer, which receives significant recharge from precipitation, is perched above lower aquifers near sea level. The shallow aquifer in the coarsening upward Vashon Advance Outwash sequence is separated from deeper aquifers by a basal clay (Lawton clay equivalent) aquitard and by discontinuous till deposits (Possession Drift). For the underlying aquifers, one is situated within the Possession Drift and upper part of the Whidbey Formation, and a second is formed within the lower part of the Whidbey Formation and Double Bluff Formation; fine-grained sediment in the middle of the Whidbey Formation separates the two. All three aquifers are utilized by water supply wells. The horizontal gradient in the shallow aquifer is very flat in the central portion of the site, steepens sharply to the southeast and also appears to decrease towards the east-northeast, thereby exhibiting a bifurcation in flow. In fact, previous studies have indicated conflicting flow directions. Horizontal flow appears to be influenced strongly by both topographic and stratigraphic controls. Understanding of flow in the subject area is essential to effect containment of groundwater contamination and to begin restoration of the aquifer.

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Oral

Deep Alluvial Channel Aquifer, Gold Bar, Washington

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A municipal water well drilled in Gold Bar, Washington along the front range of the Cascade Mountains reveals an alluvial channel aquifer. The 220-m well was drilled in the eastern portion of the City of Gold Bar, near the center of the Skykomish River valley. The geology of the Skykomish River valley, approximately 1.4 km north and south of the well, is dominated by Paleozoic metamorphic rocks locally overlain with a thin layer of glacially deposited Quaternary sediments. A limited geophysical survey indicates that bedrock is located at a depth of at least 230 m in the vicinity of the well. The valley narrows considerably approximately 4.8 km upstream (east) of the well, along the alignment of a mapped fault with a fault length of at least 17 km.

The boring encountered 6 m of water-bearing sand and gravel overlying more than 200 m of non-water bearing silt. The top of a single 5-m-thick sand and gravel aquifer was encountered at an elevation of 139 m below sea level. The flowing artesian aquifer had a potentiometric level approximately 18 m above ground surface. The bedrock floor of the valley was not reached at an altitude of 160 m below sea level. Constant rate aquifer testing did not reveal obvious aquifer boundaries and indicated an aquifer hydraulic conductivity of approximately 100 m/d. The safe yield of the well is estimated at approximately 2,250 m^3/d. Chemical analyses of water samples obtained from the well indicate excellent water quality with relatively low mineralization. Ground water likely flows from east to west through the aquifer with the primary recharge area being located at least 4.8 km east of the well, where the valley constricts and bedrock is present near the base of the valley.

The deep aquifer encountered in the Gold Bar well is interpreted to be an alluvial channel deposit that may grade eastward into a buried deltaic sequence. The aquifer likely originates near the valley constriction, at least 4.8 km east of the well site. It does not appear that other wells are completed in the deep alluvial aquifer. However, existing wells located east of the Gold Bar well may be completed within a deltaic sequence that is in partial hydraulic continuity with the deep alluvial aquifer. The deep aquifer in the vicinity of the Gold Bar well is effectively isolated from potential sources of surface contamination by the overlying fine-grained sediments. The alluvial and deltaic aquifer system may be capable of supplying substantial quantities of ground water for use in the Skykomish River valley.

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Poster

Stratigraphy and Hydrogeology of the Mountain View Upland, Whatcom County, Washington

Charles S. Lindsay,[1] Harold J. Cashman,[2] and Michael D. Watkins[1]

The Mountain View Upland is located west of the City of Ferndale, Washington. The 110 km^2 upland ranges in elevation from sea level to approximately 115 m. The upland is bordered on the north by the Custer Trough, west by the Strait of Georgia, and south and east by the Nooksack and Lummi rivers. Lake Terrell (1.8 km^2) is located near the central portion of the upland.

The oldest stratigraphic unit identified beneath the upland is the pre-Fraser Cherry Point silt, consisting of stratified marine clay and silt with minor sand interbeds. The thickness of the unit is variable and likely exceeds 30 m. The Mountain View sand and gravel, consisting of stratified and crossbedded sand and gravel with lenses of silt and clay, unconformably overlies the Cherry Point silt beneath the upland. The unit is interpreted to be glacial outwash deposited by meltwater streams in front of the advancing glacial ice during the Vashon stade of the Fraser Glaciation. The Mountain View sand and gravel generally ranges in thickness from 10 m to 25 m and is locally overlain by up to 10 m of Vashon till. The till consists of unsorted, unstratified cobbles, gravel and sand in a matrix of silt and clay deposited directly by glacial ice. The till, where present, or the Mountain View sand and gravel are overlain by unsorted and unstratified Kulshan and Bellingham glaciomarine drifts, which mantles most of the upland area and ranges in thickness from less than 1 m to approximately 35 m. Up to 3 m of stratified sand and gravel overlies the glaciomarine drift in the central and southern portion of the upland.

The regional aquifer is located within the Mountain View sand and gravel. The aquifer also appears to be in hydraulic continuity with more permeable zones within the Cherry Point silt. The aquifer is unconfined beneath the central portion of the upland and becomes locally confined beneath dipping lenses of till and/or glaciomarine drift near the north, south, and east margins of the upland. Flowing artesian conditions are present in several wells located along the southeastern and eastern flanks of the upland. The average specific capacity of wells completed in the regional aquifer is approximately 16 m^2/d and safe yields range from less than 4 m^3/d to approximately 10,000 m^3/d. Ground water appears to flow radially outward from the central portion of the upland with an approximately north-south trending ground water divide located east of Lake Terrell. Ground water recharge to the regional aquifer is primarily from the infiltration of precipitation through the glaciomarine drift and till, or directly into the Mountain View sand and gravel in localized areas where the glaciomarine drift and till are absent or have been removed by human activities.

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Oral

Hydrogeology of the Jackson Prairie Underground Natural Gas Storage Project, Chehalis, Washington

Terry Olmsted[1], Matthew Dalton[1], and James Janson[2]

The paper provides an assessment of the geologic and hydrologic conditions in the vicinity of a major underground gas storage project in western Washington state. Data from the installation, logging, and operation of 77 injection/monitoring wells (generally ranging from 1,500 to 4,000 feet deep, with one well over 8,000 feet deep) within the project has afforded an unusual opportunity to evaluate "deep" hydrogeologic conditions and water quality of the region as well as to gain an understanding of the impact of geologic structure on ground water flow.

The gas-storage project assures a stable winter supply of natural gas for Washington state residents. The current storage capacity of approximately 34.4 billion cubic feet can provide sufficient natural gas to heat one million Washington homes through one month of cold winter weather. The project has a daily delivery capacity of 450 million cubic feet.

The geologic structure that provides the necessary underground confinement was first discovered in the late 1950s as part of regional explorations for oil and gas. The development of the Jackson Prairie gas storage field began in 1963 and the project was certified in 1970 by the Federal Power Commission. From it's inception, the project was developed through the joint efforts of Washington Natural Gas Company, Washington Water Power, and Northwest Pipeline Corporation (initial participation was through its predecessor, El Paso Natural Gas Company).

Natural gas is injected into, and later withdrawn from, permeable zones located within a thick sequence of marine and non-marine sediments comprised of interbedded sand/sandstone, siltstone, shale, and coal. Isolation of the gas is provided by structural traps resulting from an anticlinal structure and adjacent faulting.

The paper provides a history of the gas storage project development, a comprehensive summary of the regional and local hydrogeologic framework, including information on the Quaternary deposits, Tertiary bedrock formations, bedrock structure, and on the storage/injection zones and confining layers of the gas storage project area. The paper includes detailed subsurface profiles and structural contour maps illustrating the relationships between the various injection zones and the associated confining layers and structures. Also included is information on the storage project area ground-water flow directions and gradients, hydraulic properties of the injection zones, and ground-water quality of the Quaternary and Tertiary deposits.

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Poster

Hydrogeology and the Stability of Coastal Bluffs: Implications for Shoreline Property Owners

Hugh Shipman[1] and Rian Myers[2]

Much of Puget Sound's shoreline consists of coastal bluffs zoned for single-family residential development. These bluffs are inherently unstable and many qualify as Landslide Hazard Areas under local Critical Area Ordinances, yet property owners are often unaware of the dynamic character of their property nor of the potential for exacerbating slope instability through unwise landuse practices. Hydrogeologic factors are of primary consequence in triggering coastal landslides and are easily impacted by vegetation removal, site disturbance, surface water modifications, or inadequate or failed drainage systems. Slope failures are often triggered by heavy rains and saturated soils. Increased soil moisture or surface runoff resulting from either new construction or existing development can exacerbate stability problems. Uncontrolled surface runoff can lead to serious erosion and downslope sedimentation, particularly on steep slopes of poorly consolidated materials. These problems not only threaten the immediate site, but may adversely affect adjacent property or valuable public resources. Shorelines are environmentally sensitive areas, providing many critical habitats to both upland and aquatic wildlife, and are an essential component of a healthy Puget Sound. Proper management of drainage represents a valuable method of protecting shoreline property without the adverse environmental impacts associated with major bluff modifications, shoreline bulkheading, or extensive removal of natural vegetation. The Shorelands Program at Ecology recently completed a publication on bluff hydrology and residential drainage practices for property owners interested in protecting both their property and the environmental quality of the Puget Sound shoreline. In this paper, we review the role of hydrology in affecting the stability of coastal bluffs, we describe specific examples of hydrologic problems on shoreline properties, and we will present the recently completed manual for coastal bluff property owners.

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Oral

A Lithologic and Stratigraphic Comparison of Field Mapping and Well Logs in a Groundwater Availability Analysis, near Maryhill, Washington

Jennifer A. Whitebread[1] and Ansel Johnson[2]

The geology of the Maryhill Museum, 2,400 hectares near Maryhill, Washington in the Columbia River Gorge, was studied to determine potential water resources for proposed development of the lands owned by the museum. The study involved mapping the wells and springs in the study area and developing cross-sections using well logs as stratigraphic data. The cross-sections were compared to field data to determine the accuracy of the well logs, then analyzed to determine if interflow zones were aquifers in the area and to determine how the structure controls ground and surface water flow.

The main recharge to the study area comes from precipitation, which is seasonal and limited to approximately 76.2 cm per year (1.8×10^4 m^3/yr over the 2,400 hectares extent of the study area). Despite being in a semi-arid environment, there are some areas of the Columbia River Basalt Province where local geology allows for groundwater accumulation. The province consists of basaltic flood lavas of the Columbia River Basalt Group.

Surface water resources are abundant in many springs that flow constantly throughout the year in the study area. The springs on the plateau below the Columbia Hills anticline are structurally controlled by thrust faults that run parallel to the river. A northwest-trending monocline that dips southwest controls lateral flow; springs west of the fold have an average flow of 1.4×10^{-2} m^3/s, but those east of the fold have an average flow of 2.7×10^{-2} m^3/s. The total discharge from all the springs is approximately 1.6×10^7 m^3/yr. Currently, only three of the springs are being used as a water source.

Groundwater resources are found in interflow zones and in the fault zones between some of the basalt flows. There are approximately 35 wells that range in depth from 20-310 m. The main water-bearing zone appears to be in the Frenchman Springs member where it contacts the Vantage Sandstone, but yields depend on permeability of the brecciated interflow zone and range from 3.2×10^{-4} m^3/s to 1.6×10^{-3} m^3/s. The total discharge from the wells is 7.67×10^5 m^3/yr. Currently, the Columbia River cannot be considered a resource because it is over-allocated.

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Physical Hydrogeology/Hydrology - Water Resources

Oral

Groundwater Resource Investigations in the Upper Snoqualmie Basin

Robert Anderson,[1] David Banton,[2] and Geoff Clayton[3]

The Upper Snoqualmie Basin is located above Snoqualmie Falls and consists of the North Fork, Middle Fork, and South Fork sub-basins. The area has been the focus of numerous geologic investigations because of its distinct geologic history. More recently, investigators have focused on the potential for the upper basin to provide a regional groundwater supply source ranging from 10 to over 40 million gallons per day (MGD).

A recent study of potential water sources for the City of North Bend indicated that geologic deposits and hydrologic conditions favorable for the storage of groundwater are located in the upper Snoqualmie Valley. The possibility that these deposits could produce large volumes of groundwater, especially from deep aquifers, is more probable in the vicinity of North Bend than elsewhere in the Puget Lowland because of the valley's unique history of glacial erosion and deposition and the huge annual flux of fresh water through the valley.

Between 10,000 and 20,000 years ago, the North Bend area was the site of interaction between the vast Puget Lobe glacier, mountain glaciers flowing out of deep bedrock valleys, and rivers controlled by these glaciers which deposited huge volumes of sand and gravel close to the mountains. A natural dam at Snoqualmie Falls backed water up through the upper valley, and now this sediment-filled lake is recharged by heavy rainfall and large tributaries from undeveloped drainage basins. There are no gasoline stations or other commercial developments, or even many residences upstream of the principle exploration area.

In 1993, geophysical investigations were carried out using Time Domain Electromagnetic (TDEM) to determine the nature and extent of potential aquifer materials in the North, Middle and South Forks. The method was selected over other geophysical reconnaissance tools because of it's ease of use in rugged terrain, rapid data acquisition and interpretation facility, and limited cost. The survey was carried out over a 40 square mile area in over a two to three-week period. The TDEM method resolved the Quaternary stratigraphy to potential aquifers to depths of over 1,000 feet. The method identified potential aquifers within ancestral channels of the North, Middle, and South Fork channels. Test well drilling subsequently verified the geophysical interpretations.

Based upon the investigations completed to date, the Middle Fork Snoqualmie Aquifer has the potential to be developed as regional supply source. The aquifer is estimated to be capable of supplying between 10 to 40 MGD with a greater capacity provided by artificial recharge. The aquifer receives recharge from infiltration and seepage from the Middle Fork

Snoqualmie. The degree of hydraulic continuity between the river and the aquifer has been investigated by seepage runs along the river and by the installation of wells. The water quality in the aquifer is excellent and meets all Safe Drinking Water Act requirements.

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Oral

A Multi-Disciplinary Study Of Groundwater in Toppenish Creek Basin, Yakama Indian Reservation

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Toppenish Creek Basin, on the east slope of the Cascade Range in south-central Washington, encompasses 627 square miles and lies within the Yakama Indian Reservation. Part of the traditional homeland of the Yakama people, the basin now holds over 100,000 acres of irrigated agriculture, several towns, and 25,000 people. Residents of the basin are entirely dependent on groundwater for drinking water supply. Contamination of shallow groundwater and mining of deeper groundwater have placed the groundwater supply at risk. Staff of the Yakama Indian Nation, working with consultants, have been investigating groundwater flow and quality in the basin to develop groundwater management tools. This paper summarizes the work.

Toppenish Creek Basin is a broad east-west-trending synclinal trough in the Yakima Fold Belt. The basin is rimmed on north and south by Ahtanum and Toppenish Ridges respectively, two thrustfaulted anticlines, cored with Miocene basalt flows of the Columbia River Basalt Group. The western divide is the broad, forested Lost Horse Plateau, underlain by subhorizontal basalt flows. The plateau rolls over into an east-facing dip slope which descends about 3,500 feet to the valley floor, where the basalt trough is covered by valley fill of Quaternary alluvium over volcanigenic sediments of the Miocene Ellensburg Formation reaching at least 1,250 feet thick. The valley floor receives less than 10 inches of precipitation per year, compared to about 50 on the Lost Horse Plateau, which holds the headwaters of Toppenish and Simcoe creeks, tributaries to the Yakima River, the eastern margin of the basin. While natural precipitation occurs mostly during the winter months, the valley is heavily irrigated through the summer with diverted Yakima River water, causing the water table to rise in summer. Groundwater recharge is from precipitation, mostly in the uplands, irrigation on the valley floor, and seepage from streams. Discharge is to agricultural drains, Toppenish Creek, and the Yakima River.

The basin was modeled using the analytic element method, which represents features such as streams and wells as analytic elements embedded in a continuum, rather than a nodal grid. Currently the model simulates four aquifers: alluvial, upper Ellensburg, lower Ellensburg, and a single basalt aquifer, which will likely be further subdivided in the future.

Data for model development and calibration were collected through several tasks. Mass water level measurements were taken and stored in a data base created to hold all hydrogeologic data for the project and interfaced with the model. Well drilling and aquifer testing were conducted. Twelve hundred well logs were correlated and isopach and structure contour maps prepared. Environmental isotopes were used to determine groundwater source areas. A system of automated discharge gaging stations was established.

The model has been used to interpret water quality data, study aquifer vulnerability, address groundwater contamination problems, and assess effects of proposed groundwater pumping,

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Oral

Development and Implementation of a Aquifer Protection Program for the City of Renton, Washington

Carolyn Boatsman,[1] Michael R. Warfel,[2] Charles Ellingson,[3] and Geoff Clayton[4]

The City of Renton is situated at the mouth of the Cedar River on the southeast shore of Lake Washington. The majority of the City's water supply wells are completed at depths of less than 90 feet below ground surface in the Cedar Valley Aquifer, an unconfined aquifer consisting of coarse sands and gravels. With a prevailing static water level less than 25 feet below ground surface, the potential for leaks and spills of hazardous substances to contaminate the Renton water supply is extremely great. In recognition of the importance of protecting this aquifer as Renton's only viable water supply source, the U.S. Environmental Protection Agency designated the Cedar Valley Aquifer as a sole-source aquifer in 1988.

A aquifer protection program initiated by Renton in 1983 has included characterization of aquifer hydrogeology, an inventory of potential contamination sources, installation and regular testing of monitoring wells, development of a water quality database, application of flow and transport modeling, delineation of wellhead protection zones, adoption of an aquifer protection ordinance, coordination with other land use jurisdictions regarding protection of the aquifer, an ongoing study of surface and ground water interaction, and implementation of a public education program with the theme "aquifer awareness."

Future program development will include an updated inventory of potential contamination sources, improved coordination with local emergency responders, and expanded communication with both the agencies who regulate and operators of facilities and other potential sources of contamination.

The City's goal is to effectively integrate all program elements in a comprehensive aquifer and wellhead protection program.

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Poster

Construction and Application of a Resource-Protection-Well Simulation Chamber

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Ray E. Clayton,[5] and Jon W. Lindberg[3]

Direct measurements of ground water flow velocity within monitoring wells are possible with a variety of sensitive flowmeters. These flowmeters require calibration, evaluation of performance, and assignment of error ranges and sensitivities. Calibration cells provided with some instruments are known to have construction flaws that limit the accuracy of instrument calibration and evaluation. In addition, ground water flow velocity magnification or attenuation may occur in the near-well environment, depending on contrasts in hydraulic conductivity between the well environment (which includes any flow-measurement instrumentation) and the aquifer. This effect, and flowmeter accuracy and precision must be quantifiable to accurately assess ground water velocity at a particular location within an aquifer. Although standardization of instrument response was accomplished in a smaller flow standard, a device was needed to more accurately account for the flowmeter's response in actual field application. To this end, simulation chambers were built that accommodate a mock-up resource-protection well (ground water monitoring well). Changeable drive gears facilitate different Darcian velocities to be generated. Separate, removable cells containing media of unique effective porosities were constructed to demonstrate instrument performance over a range of linear flow velocities. Chamber design subdues boundary effects imparted by the walls of the chamber to flow field, in the vicinity of the well mock up, and helps eliminate preferential flow routes. Each chamber is operated at several different Darcian velocities for each medium. Families of calibration curves are thereby derived for different velocities and media of differing effective porosities.

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Oral

The High Rock Aquifer Break: October 1993

Dave Garland[1] and Jerry Liszak[2]

An example of unexpected hydrologic impacts from sand and gravel mining occurred in late 1993 at a mine near Monroe, in Snohomish County, Washington. Cadman (Rock), Inc. has operated its rock quarry and sand and gravel mine near High Rock Road since 1984. The mine is situated on the east wall of the Snoqualmie Valley near its confluence with the Skykomish Valley, about three miles south of the City of Monroe. The surficial aquifer in the area consists of Vashon recessional sand and gravel deposited on a valley terrace, and covers an area of approximately one-half square mile straddling High Rock road. The aquifer, referred to here as the High Rock aquifer, is an unconfined water-table aquifer over most of its area, but appears confined in places near its western margin. The aquifer is recharged by infiltration of precipitation and by surface water runoff. The aquifer provides water for numerous domestic wells and springs in the vicinity of High Rock Road.

On Friday, October 29, 1993, mine workers breached some fine sandy silt deposits, which were acting as confining beds for the High Rock aquifer. Discharge from the aquifer breach increased dramatically until Friday evening when flow from the break had to be diverted to avoid significant erosion at the mine. The aquifer break created an hydraulically excavated area 80 feet wide by 200 feet long and approximately 50 feet deep. An estimated 25,000 yards of material were eroded and washed below the aquifer break causing sedimentation damage in a stream, wetlands, adjacent private property and in Crescent Lake. The initial flow of around 2,000 gallons per minute (gpm) gradually diminished to about 500 gpm ten days after the break. The spring discharge has fluctuated around 300 gpm since the mine installed a rectangular weir below the break area in March 1994.

Water levels in 13 wells, located within three-fourths of a mile of the new spring at the mine, were monitored approximately twice a month for 22 months following the aquifer break. The wells range from 15 to 104 feet deep. Water-level hydrographs were produced and interpreted in terms of separating aquifer break impacts from the normal seasonal variation. In general, water levels in the aquifer have shown a declining trend since the aquifer break occurred, with recovery responses in spring and winter of 1994. Well hydrographs indicate that most aquifer drainage due to the break occurred within the first 100 days following the incident. The estimated ground-water impact from the aquifer break is an average water-level drop of about four feet over an affected aquifer area of 100 acres. The estimated volume of the drainage effect is 120 acre-feet of water or about 39 million gallons. The affected aquifer area was drafted by nine domestic wells, two industrial wells, and three springs at the time of the break. Three springs, one industrial well, and two domestic supply wells were adversely affected.

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Oral

The Hydro-Potential (HP) Value: A Proposed Rock Classification Technique for Evaluation of the Groundwater Potential in Fractured Bedrock

William C.B. Gates

Groundwater development in mountainous terrain continues to present challenges because surficial aquifers have been largely removed by erosive activity leaving fractured bedrock aquifers. To locate these bedrock groundwater sources, hydrogeologists employ a blend of investigative techniques to include terrain and fracture trace analysis coupled with structural mapping. Their goal is to locate large concentrations of open fractures which will convey groundwater.

The hydro-potential (HP) value, is a new rock-mass classification technique employed to evaluate the potential of developing groundwater in bedrock. This method is a simple, quick and quantitative technique used to evaluate the rock outcrops surrounding the target basin.

The technique is a modification of the engineering rock mass quality designation (Q) originally developed for evaluation of rock competency in tunnel design (Barton, Lien and Lunde, 1974) and seismic rock fall susceptibility (Harp and Noble, 1993). The method describes six fracture characteristics of the rock mass and assigns a numerical value from reference tables based on their fracture properties. The HP-value = $(RQD/J_n) \times (J_r/J_k) \times (J_w/J_{af})$, where the characteristics are: rock quality designation (RQD), joint number (J_n), joint roughness (J_r), joint hydraulic conductivity (J_k), joint water (J_w), and joint aperture factor (J_{af}).

Comparison of HP-values to yields of bedrock wells in volcanic and granitic rocks display an inverse exponential relationship; well yields increase as the HP-value decrease, suggesting the fractured rocks surrounding the basin mirror the fractured bedrock aquifer.

The benefit of the HP-value coupled with fracture trace analysis and structural mapping increases the probability of locating suitable test well sites in bedrock. The technique forces the hydrogeologist to focus on the fracture characteristics of the rock mass.

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Poster

Mapping Missoula Flood Deposits in the Spokane Valley: An Interdisciplinary Approach to Sole-source Aquifer Management, Spokane County, Washington

Wendy J. Gerstel,[1] Charles W. Gulick,[2] and Robert E. Derkey[2]

Detailed surficial geologic and geomorphic mapping of the Spokane Valley is refining characterization of the Glacial Lake Missoula flood deposits and the Washington portion of the Spokane Valley-Rathdrum Prairie Aquifer. Subsurface conditions of the aquifer (dimensions, grain-size variability, bedrock topography) are characterized through interpretation of water well logs and seismic profiling data and are correlated to the deposits observed at the surface. Digitized geologic mapping for fourteen U.S.G.S. 7 1/2' quadrangles has been integrated into the Spokane County ARC/INFO-based GIS program.

The distribution of material grain-size varies among locations in the Spokane Valley. Finer-grained deposits are generally found along the valley margins and in tributary valleys, whereas coarse-grained deposits primarily occupy channels in the main valley. The variability in grain-size of the Missoula flood deposits influences the distribution and rate of transport of groundwater and contaminant flow. Increased contaminant concentrations, specifically nitrate and chloride, have been noted along some valley-margin areas, and appear to be associated with wastewater discharge in areas of high density development.

Geologic mapping and subsurface geologic information further illuminate the complexity of the Spokane Valley Aquifer system. Our data point to a very uneven bedrock surface, much different from that used in previous groundwater models for the region. The data suggest an irregular contact between the Missoula flood sediments and the subjacent rocks, characterized by local bedrock highs, paleo-channels, and bedrock steps possibly suggesting paleo-waterfalls, all now buried under a thick sequence of sands, gravels, and boulders. Groundwater flow through the Spokane Valley must therefore be controlled not only by the permeability of the sediments, but also by the bedrock irregularities.

Combining geologic and geomorphic mapping with seismic profiling and data from water well logs provides a more accurate representation of the Spokane Valley Aquifer system. Geologic cross sections, constructed from the combined data along selected transects in the valley, improve groundwater modeling and aid in water resources and water quality management planning.

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Oral

The Hydrogeology of the East Covington Upland for Wellhead Protection Planning

Lori Herman

The City of Kent's spring water sources originate from Vashon Recessional Outwash deposits that lie in the Covington Upland area of southeast King County. The spring sources are prolific - with the Clark Springs source producing as much as 3,000 gpm of continuous, high quality, water supply. They are also very susceptible to contamination because of their shallow and coarse-grained nature, the common lack of significant confining units, and their location in low lying confined basins which tend to funnel surface water into the aquifer recharge area. The City of Kent is nearing completion of a Wellhead Protection Program that has identified the source and flow of water to the springs, and developed risk-based protection strategies in cooperation with the other major water purveyors in the area: the Covington Water District and King County Water District #111. Most of the study area is within the Soos Creek drainage basin.

This paper presents the hydrogeology of the 50-square mile study area and discusses the cooperative regional planning approach used by the area purveyors to define aquifer management strategies. We will describe how the surficial geology, stratigraphy, recharge, and drainage influence groundwater flow to the City's spring and well sources. We will describe the development and use of numerical modeling to define capture zones and discuss the modeling findings relative to future additional groundwater development and concerns regarding maintaining baseflows in the Soos Creek basin. Finally, we will discuss the cooperative regional effort to define potential and real concerns and the management strategies being developed to address those issues.

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Oral

Implications of Dam Removal on Elwha Basin Groundwater and Water Supply

Doug Hillman,[1] Tim Flynn,[1] and Kayti Didricksen[2]

In 1992, the U.S. Congress passed the Elwha River Restoration Act calling for the purchase and removal of two privately owned dams on the lower reach of the Elwha River which is located on the north slope of the Olympic Peninsula. The underlying objective is to restore native salmon runs to the upper 45 miles of the Elwha River, a majority of which is located within the protective borders of the Olympia National Park. Once a river with legendary salmon runs, spawning access to the protracted upper reaches of the valley has been blocked since dam construction in 1911. The fate of dam removal awaits completion of an environmental impact statement, a determination that demolition is the best way to restore the salmon runs, and Congressional budget debates.

Groundwater is an important resource in the lower Elwha River basin and the proposed dam removal raises questions about baseline conditions and potential impacts associated with changes in the hydraulic system. Virtually all area residents, including the City of Port Angeles and the Lower Elwha S'Klallam Tribe, depend on groundwater withdrawals for their source of drinking water and support of fishery operations. A layered sequence of glacial and non-glacial deposits overlie a north-sloping bedrock surface projecting north from the Olympic Mountains. The Elwha River cuts a relatively narrow valley into these deposits and flows over a bed of recent alluvium. The City of Port Angeles obtains their water supply from a high-capacity Ranney Collector installed into coarse-grained alluvium that forms the principal groundwater supply aquifer for the region. Alluvial aquifer properties and water balance data indicate that hydraulic connection to the river is necessary to sustain the current rates of groundwater withdrawal. Potential implications of dam removal on water supply include siltation and reduced infiltration through the river bed, accelerated lateral meandering, and the release of high iron and manganese concentrations with the lake bed sediments.

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Oral

Washington's Water Resources

Kris G. Kauffman

Just how physically extensive are Washington's water resources? This oral presentation will provide the macro setting for all water resources in Washington state and is fundamental to both hydrologic and hydrogeologic efforts. The presentation includes several overhead projections displaying the extensiveness of water resources in Washington. While some maintain we don't have the basic data, in fact, the U.S. Geological Survey (USGS) and many other public and private groups have, and continue to acquire, a wide variety of basic water resource information.

This short paper characterizes readily available information in a comparative way to make some sense of Washington's overall "Water Budget." Those familiar with various water measurement terms should relate to one or more of the four units of measurement used. For those less knowledgeable, but concerned with both flowing and stored water resources in Washington, a unit equivalent to the long-term yield of the entire Colorado River Basin is introduced and used.

The natural flow of the Colorado River Basin is used because this basin, like the Columbia, occurs in seven states and another nation. While the Columbia River flows to the Pacific Ocean, the Colorado flows, primarily, to the Gulf of California with various upstream diversions contributing to both the Gulf of Mexico and the Pacific Ocean.

This state has over 80 named rivers, nearly 8,000 lakes and reservoirs and a complex geologic history which provides for extensive and varied groundwaters with about 80 million acre feet in groundwater storage, as well as a few glaciers!

A summary table will show that Washington has a total annual water resource equal to over 27 times the recognized annual yield of the Colorado River Basin.[1]

When statewide extreme highs and lows, on an annual basis, of most of our rivers and streams are correlated with the USGS surface water outflow of Washington state, the state has between 11 and 28 Colorado River annual flow equivalents.

The Columbia River is recognized as the 19th largest river in the world by volume.[2] When the Columbia River is analyzed at The Dalles (1878-1990) it is found to yield an equivalent to 10.3 Colorado River Basins, on an average annual basis. The total state water resources

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[1]The Colorado River Basin Water Resource is recognized as 13.5 million acre feet per year (maf/yr); 18,646 average cubic feet per second (cfs); or, 12,052 million gallons per day (mg/d).

[2]The Water Encyclopedia; Frits van der Leeden et al., 1991, pg. 181.

are equivalent to the average annual flow of the 11th largest river in the world (the St. Lawrence River).[3]

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[3]ibid; St. Lawrence River - Average Flow = 500,000 cfs, Drainage Area = 489,000 square miles.

Oral

Hydrogeology, Aquifer Testing, and Ground Water Modeling of the Upper Snoqualmie Valley

Curtis J. Koger and Louis R. Lepp

Continuing development in the vicinity of Snoqualmie, Washington has required the development of a new ground water source to meet community domestic, business and irrigation needs. One of the primary requirements imposed by the Washington State Department of Ecology prior to approval of the new water supply source is an evaluation of potential hydraulic continuity between ground water and surface water. The primary surface water features in the vicinity include the Snoqualmie River and Tokul Creek. A detailed hydrogeologic, aquifer testing and ground water modeling program was developed to quantify potential impacts to surface water and existing wells.

The geologic setting of the Snoqualmie Valley, near the City of Snoqualmie, can be characterized as a valley incised in bedrock and subsequently filled by a series of Pleistocene glacial and nonglacial units, overlain by Recent alluvial deposits. Two primary aquifers have been identified in deep (550 feet) Olympian nonglacial fluvial sediments and shallower (200 feet) Vashon age recessional glacial deposits. Secondary aquifers include a Vashon advance deposit consisting of silty fine sand and Recent Snoqualmie River channel deposits. The shallow (30-50 feet) Snoqualmie River aquifer system is directly hydraulically connected to the Snoqualmie River.

Aquifer characteristics have been determined from a series of pump tests in the deep Olympian age aquifer. An extensive network of observation wells was monitored in deep, shallow, and Snoqualmie River aquifer systems to document effects from pumping. The testing program included an 8 day dual well pump test which discharged nearly 12 million gallons from the deep aquifer. Pump test results indicated the deep aquifer behaved as a leaky confined aquifer system. Pumping from the deep aquifer induced some leakage from overlying aquifers through intervening semi-confining layers, but most of the flow to the wells was from through-flow in the deep aquifer.

Potential impacts to existing wells and instream flows, due to pumping from the well field, were simulated for several long term average and peak pumping rates with a ground water flow model (MODFLOW). Results from this evaluation indicate there would be no impairment of existing well yields at the proposed average annual pumping rate of 425 gpm. Impairment of existing well yields would likely occur with annual flow rates greater than 1000 gpm, and would require mitigation. Potential instream flow reduction was calculated to be about 0.5 percent of Tokul Creek base flow and less than 0.02 percent of Snoqualmie River base flow. These very minor flow reductions could be fully mitigated by return flows of polished effluent from the City's waste water treatment plant.

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Oral

Inter-Decadal Trends in Glacier Mass Balance and the Snowpack of the Cascade Mountains of Washington

Robert M. Krimmel[1] and Edward G. Josberger[2]

The U.S. Geological Survey has measured the mass balance at South Cascade Glacier in the North Cascade Mountains from 1959 to the present. Other measurements for this time period, at this location, include the discharge from the basin containing the glacier, temperature at this gauging station, and discharge from a nearby non-glacierized basin. The glacier mass balance record shows a dramatic shift in 1977. For the period 1959 through 1976, the average mass balance over the entire glacier was -0.09 meters per year. For the last six years of this interval, the yearly mass balances reached positive values of 1 to 2 meters. For the second half of the record, 1977 to 1993, the average mass balance was -0.94 meters per year. Throughout this latter interval, the mass balance was generally negative with the extreme values as low as -2 meters per year. A similar change has been observed in a large number of environmental parameters throughout the Pacific Northwest. The U.S. Department of Agriculture snow course observations for the same period of record show the same behavior as observed in the mass balance measurements, with significantly thinner snowpacks occurring throughout the entire Cascade Mountains since 1977. A standard deviate analysis is used to compare the mass balance measurements with the snow course data. This analysis shows that the mass balance is responding not only to changes in precipitation, but also to changes in thermal regime. The discharge measurements for the period 1977 to present generally increase for the glacierized basin and decrease for the non-glacierized basin. Hence the presence of the glacier offsets the loss of flow that would normally result from thinner snowpacks.

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Poster

Hydrogeology of Western Snohomish County - Regional Aquifers, Groundwater Supply, and Groundwater Protection

Steve Nelson

Western Snohomish County, Washington, is currently undergoing significant population growth. This growth is expected to continue for several decades. It will increase the demands on existing water supplies, require the development of new supplies, and magnify the need to protect existing groundwater supplies from impacts by surface contamination. A recently completed study has identified and described 17 regional aquifer systems underlying western Snohomish County. These aquifers are composed of alluvial and glacial deposits. They range from ten to several hundred feet below the ground surface.

The study evaluated the extent of groundwater available for public and private water supply, identified areas of higher vulnerability from land use activities, and recommended groundwater protection in these areas. The study consisted of a compilation of previous geologic, hydrogeologic, and water supply studies, as well as water well drillers logs. Geologic maps, geologic cross-sections, generalized groundwater flow maps, and aquifer recharge maps were prepared to identify and describe the significant regional aquifers. Water supply records, results of aquifer pumping tests, aquifer materials, and aquifer dimensions were evaluated to estimate potential aquifer yields. Areas of significant industrial, commercial, or waste management activities were identified. Areas underlain by surficial soil with high potential for surface water recharge were designated as groundwater protection areas.

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Poster

Low-Temperature Geothermal Resources of Washington

J. Eric Schuster[1] and R. Gordon Bloomquist[2]

This report presents information on the location, physical characteristics, and water chemistry of low-temperature geothermal resources in Washington. The database includes 941 thermal (>20°C or 68°F) wells, 34 thermal springs, lakes, and fumaroles, and 238 chemical analyses. The compilation of the database was supported by a grant from the U.S. Department of Energy. Most of the information in the database is from published literature and from the files of the Washington State Department of Ecology and the U.S. Geological Survey's Water Resources Division.

Most thermal springs occur in the Cascade Range, and many are associated with stratovolcanoes. In contrast, 97 percent of thermal wells are located in the Columbia Basin of southeastern Washington. Some 83.5 percent are located in Adams, Benton, Franklin, Grant, Walla Walla, and Yakima counties. Yakima County, with 259 thermal wells, has the most.

Thermal wells do not seem to owe their origin to local sources of heat, such as cooling magma in the Earth's upper crust, but to moderate to deep circulation of ground water in extensive aquifers of the Columbia River Basalt Group and interflow sedimentary deposits, under the influence of a moderately elevated (41°C/km) average geothermal gradient.

Thermal well waters are quite dilute, averaging only 260 ppm total for eight major chemical species (Na, K, Ca, Mg, HCO_3, CO_3, Cl, and SO_4). All thermal well waters have HCO_3 as the dominant anion. The dominant cations are either Na+K or Ca+Mg with Na+K dominant somewhat more commonly. Thermal springs are less dilute, averaging 1570 total ppm. N+K is the chief cation, and the chief anions are either HCO_3+CO_3 or $C1+SO_4$, with the latter somewhat more common.

At least 250 of Washington's thermal wells are publicly owned, and many of these are located near public buildings that might be economically heated through the use of geothermal water-source heat pumps. However, the common collocation of the resource and potential users is no guarantee of development. Today, development is being slowed by a lack of widespread knowledge of the availability of low-temperature geothermal resources, by a lack of knowledge about the reliability and efficiency of geothermal water-source heat pumps, by a legal and institutional framework that does not always facilitate using ground water for space heating, and by the generally high front-end capital costs of geothermal water-source heat pump systems.

This report is available in paper, disk, and geographic information system form. Contact the authors for more information.

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Poster

Geology, Water Resources, and Sea-Water Intrusion Assessment of Marrowstone Island, Jefferson County, Washington

Kirk Sinclair[1] and Robert Garrigues[2]

In 1990, the Washington State Department of Ecology's Water Resources Program initiated a hydrogeologic investigation of Marrowstone Island in northeast Jefferson County. The study was undertaken in response to public concern about the effects of sea-water intrusion on the island's fresh water aquifers.

Ground water on Marrowstone Island is contained within two principal hydrogeologic units: Eocene bedrock consisting of fractured sandstone and shale and Pleistocene glacial drift composed of sand, gravel, silt, and minor clay.

Recharge to the island's aquifers is derived from local precipitation which averages approximately 20.4 inches per year. The island's ground water generally flows from areas of recharge in the island interior toward the island perimeter. Ground water that is not withdrawn for human use, discharges along the coast via seeps and springs and as subsurface discharge to the Puget Sound.

The most productive aquifers on the island are contained in glacial drift deposits, where well specific capacities average about 7.23 gpm/ft of drawdown and range from <0.01 to 30 gpm/ft of drawdown. The bedrock aquifers are generally less productive, where well specific capacities range from <0.01 to 1.5 gpm/ft of drawdown and averaged 0.19 gpm/ft of drawdown.

The island's ground water is generally acceptable for domestic drinking water purposes, with the exception of TDS, pH, and chloride. TDS concentrations in water from 23 wells exceeded the recommended Maximum Contaminant Level (MCL) of 500 mg/L, for drinking water. Four wells produced water with pH values falling outside the recommended MCL range of 6.5 to 8.5. Chloride concentrations in 46 wells monitored, ranged from 13.4 to 1310 mg/L with a median value of 59.3 mg/L. Eleven wells produced water that exceeded the 250 mg/L MCL for chloride. Twenty-one wells produced water that exceeded the chloride concentration threshold of 100 mg/L chloride.

A comparison of chloride concentrations in wells sampled during this and previous investigations (Dion and Sumioka, 1984), indicates that sea-water intrusion has worsened over time in some areas of the island.

We used five analytical methods, with varying degrees of success, to identify sea-water intrusion: 1) chloride concentrations compared to the 100 mg/l threshold; 2) ion ratios and grouping by water types; and 3) graphic analyses including (a) cumulative percentages of TDS, (b) mixing diagrams, and (c) trilinear diagrams. Sea-water intrusion was indicated by all five methods.

To minimize sea-water intrusion effects, it will be necessary for the residents of Marrowstone Island to use the limited ground water that is available as wisely as possible. Water conservation is the most economical line of defense against sea-water intrusion on Marrowstone Island.

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