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Gravel Mining

Oral

Floodplain Mining

David K. Norman

Extensive floodplain mining in Washington state has occurred along the Yakima River and its tributaries, and the Chehalis River and its tributaries, particularly the Wynoochee, Satsop, Newaukum, and Skookumchuck rivers. Other significant mining has occurred along the Cowlitz, East Fork of the Lewis, Skykomish, Pilchuck and Stillaguamish rivers. Collectively, this mining has created lakes ranging from a few acres to several hundred acres. Collins (1996, 1997) estimates that about one-sixth of Washington gravels were removed from riverine sources from 1970 to 1991. Most of the mining was located on the flood plains. Several new large floodplain mines are proposed on the Yakima, Cowlitz and East Fork of the Lewis rivers.

Many currently permitted mines cover several hundred acres of flood plain that have been excavated or are scheduled for excavation. Several mines include lakes as deep as 90 feet, and less than 50 feet from the river. Lake bottoms can be lower than the rivers by 1 to 5 times. In some instances the water level of the mines is lower than the adjacent river. These topographic conditions leave gravel pits vulnerable to invasion by rivers at high flows. During 1995-1996 the greatest numbers of recorded stream captures occurred in Washington on the East Fork of the Lewis, Cowlitz, and the Yakima rivers (Norman and others, 1998).

Gravel pit lakes are typically wider and deeper than the river and may be out of proportion to the overall scale of the river (Collins, 1997; Woodward-Clyde Consultants, 1980a, b). The old river channel can be partially or completely abandoned in the avulsion process (a sudden change of the course of stream) . The severity of the consequences of breaching pits, either gradually or rapidly, depends on the relative scale of the mining operation and the river. In general, floodplain mines are becoming larger, deeper, and more concentrated than in the past. Channel abandonment and scouring can directly effect aquatic organisms and infrastructure such as undercutting of levees and roads, bridge supports, pipelines, and utility towers.

One example of the 1995-96 avulsions is the East Fork of the Lewis River in Clark County which now flows through the south bank gravel pits which covered about 70 acres. Some of the results of the avulsion are about 10 feet of channel down-cutting as the knickpoint migrated upstream, increased erosion along the south bank, abandonment of about 4,900 feet of channel where salmon spawned, and sluggish flow through the gravel pits as they are refilled with sediment.

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Oral

Thermal Transport Investigation
Selah Lakes Gravel Mine

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During the flood season of 1996, the Yakima River avulsed through a streamside, active 96-acre gravel mining site near Selah, Washington. Discussion of pond to river thermal interaction began due to an assumed hydraulic connection between the two water bodies. A program using Onset© thermal data loggers was developed to identify thermal interactions between the groundwater, mine ponds and river.

Just under ½ million thermal data points were collected from August 1999 to December 1999 from monitoring locations throughout the Selah Reach of the Yakima River. The data showed trends including normal daily water temperature fluctuations, and a definable weekly thermal low. These weekly thermal patterns were identified up-river (USBR Umtanum gauge), at the mine site, and downriver (USBR Parker gauge) as cooler surface water temperatures occurring on Sunday or Monday of each week. Little to no statistical correlation between weekly thermal patterns and weekly river discharges were identified for the pre and post-flip flop events. Thermal signatures within the mine ponds illustrated a several hour time lag behind the adjacent river patterns with a decrease in trough intensity. This suggested the river was thermally contributing to the mine ponds rather than the pond water leaking into the river. No such weekly trend was identified in the immediate groundwater system.

An airborne thermal infrared survey of the Selah reach identified one thermal leak originating from the edge of the southern most post-mining pond through an artificial dike. No other thermal connections between the post-mined ponds and the river were identified in the infrared analysis.

Results showed that as the post-mined ponds were continuously being filled with cool river water, the upper crustal layer of pond water would warm in the sun creating a distinctive thermal stratification. As this warm water sloughed off into the downgradient gravels, water temperatures nearly reached a state of thermal equilibrium by the time the warm pond water entered the river. This volume of solar-heated water was insignificant in comparison to the river and groundwater systems. The post-mining gravel ponds were not found to be heating the river in any significant measure, but rather were found to be recharged and cooled by Yakima River inflow.

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Oral

Effects of Flood Plain Gravel Mining in the Yakima River Basin, Washington

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Alluvial flood plain reaches are centers of biological productivity and ecological diversity in gravel bed rivers. In the pre-development Yakima River basin, alluvial flood plains connected to the unregulated river moderated streamflow and temperature and created varied surficial and subsurface (hyporheic) habitats for an abundant, diverse cold water ecosystem. Flood plain modifications including gravel mining and associated diking have degraded Yakima River ecology. Industry-generated analyses tend to acknowledge impacts, but downplay their significance. Reclamation plans have not mitigated damage to salmonids, but have focused on species such as waterfowl and exotic fish. Multi-disciplinary study is needed to assess impacts and reclamation potentials and alternative aggregate sources such as terrace gravels and crushed bedrock.

Flood plain reaches serve functions including: capturing flood flows; sustaining baseflow; moderating river temperature and providing thermal refugia; providing abundant, complex, habitats for diverse cold water fishes; and generating food web production in interstitial habitat. Historically in the Yakima River basin, interaction between surface water and the alluvial aquifer system in conjunction with fluvial processes supported a dynamic system characterized by channel migration and riparian succession, wetlands, a matrix of varying flow regimes and channel types, and a diverse abundant cold-water food web including six runs of anadromous salmonids, which yielded 500,000 to 1,000,000 annual returns.

The Yakima River system has been simplified and degraded by anthropogenic activities including sand and gravel operations that have targeted the active flood plain as a primary aggregate resource due to accessibility, harvestable volume, and size distribution and quality of the aggregate. Mining eliminates channel complexity and side channel habitat. Associated diking excludes the river from the flood plain, which exacerbates flood damage, causes channel incision, and limits surface-groundwater interactions. Mining removes subsurface (hyporheic) habitat and associated food web production. Gravel removal diminishes sediment availability, and decreases riparian succession and wetland habitat. Cool subsurface inflow to pit ponds is heated and returned to the river increasing water temperatures, stressing salmonids while creating habitats for warm water predators and exotic aquatic vegetation. Head cuts, bank erosion, and disruption of sediment transport occur when flood plain pits capture the river.

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Contaminant Fate and Transport

Oral

Theoretical Background of WAC 173-340-747 Proposed: Default Method for Assessing Leaching Potential of Petroleum Hydrocarbons Release Sites: Multi-phase and Multi-fraction Equilibrium Partitioning

Hun Seak Park[1] and Charles San Juan[2]

This paper presents the mathematical background of the default method as provided in the accompanying spreadsheet (GWProt), for implementing a simple and scientifically defensible regulatory tool for calculating the risk-based soil cleanup level of petroleum release sites, to be protective of groundwater in Washington State.

The actual workable model incorporates either three or four-phase partitioning equilibrium mechanism, depending on the detection of NAPL phase presence mathematically, that includes Raoult's law convention and a dilution/attenuation factor. A data set of contaminant-specific parameters, including solubility and organic-carbon partitioning coefficient, molecular weight, and Henry's constant, is assembled for Benzene, Toluene, Ethylbenzene, Xylenes and twelve TPH equivalent carbon fractions. In addition to distributing organic chemicals between aqueous, sorbed, air, and NAPL phases, according to traditional partitioning equations, the algorithm incorporates equations for the conservation of mass and volume. Under the controlled numerical precision, tolerance, convergence, initial values, a unique solution is obtained by solving a series of mass balance equations simultaneously using the iterative spreadsheet routine built in Microsoft EXCEL™ Solver - with the restrictions that the volume is conserved using the equations and the sum of the mole fractions is equal to one.

Range of dilution/attenuation factor for the groundwater pathway is graphically presented with EPA Composite Model for Leachate Migration with Transformation Products (EPACMTP), on a nationwide basis, using the Monte Carlo Simulation. Specific dilution/attenuation factor was generated as a function of the area of the contaminated site at various probability levels. Sample calculations are presented for a range of parameter values to illustrate use of the model and the relative leachability of a wide range of representative fuels. Sensitivity analysis is performed to quantify the effects of uncertainty in the estimates of the key model parameters on model results. Model predictions are compared to the water-fuel experiment as well as other similar methodologies to assess if any agreement exists. Non-carcinogenic Hazard Index for groundwater in direct ingestion is calculated using predetermined oral reference dose (RfD). Applications and limitations of the model are discussed.

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Oral

A Simple Modeling of Soil Vapors into Building Pathway for Complex NAPL Sites: Multi-phase/fraction Equilibrium Partitioning, Diffusive and Convective Process

Hun Seak Park

A significant concern has been raised in the past several years on the risk to human health by the migration/intrusion into and subsequent accumulation of contaminant vapors in buildings and other enclosed spaces. Complex mixtures of NAPL (Non-Aqueous Phase Liquid), such as petroleum hydrocarbons, contain components whose vapor pressure, water solubility, and partition coefficient range across several orders of magnitude. The relationship between subsurface concentrations and indoor air concentrations, arising from the migration of the petroleum-contaminated soil vapors into buildings, is affected by a number of complex processes such as the equilibrium partitioning and the attenuation.

When NAPL is released into the subsurface, the model assumes that NAPL components will reach equilibrium with four phases: air, water, adsorbed soil, and residual NAPL. The model uses a mass balance approach, such that the total mass of each TPH fraction in the system is equal to the sum of the mass of each TPH fraction in each of four phases. The equations that govern the multi-phase, multi-fraction equilibrium partitioning model in each of the four phases are Raoult's Law, Henry's Law, and the linear isotherm. As the four-phase equilibrium partitioning in the unsaturated zone provides soil pore vapor concentration of each TPH fraction, soil-gas entry into buildings is the result of both diffusive and convective transport processes. The model also incorporates both convective and diffusive mechanisms for both steady-state (for an infinite source) and quasi-steady-state solutions (for a finite source), as well as building foundation properties with modified heuristic model (Johnson and Ettinger, 1991). With resulting indoor air concentrations for each TPH fraction, under the generic exposure condition, non-carcinogenic Hazard Quotients was calculated using predetermined inhalation reference concentrations (Rfc).

Actual sample calculations are presented for a range of parameter values to illustrate use of the model. Comparisons are conducted for a wide range of TPH concentrations of seven representative fuels. Sensitivity analysis was performed to quantify the effects of uncertainty in the estimates of the key model parameters on model results. Model predictions was compared to an experimental case history to assess if any agreement exists.

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Oral

Modeling Susceptibility to Subsurface Pesticide Migration on a Regional Scale

Laurie K. Morgan

EPA is requiring states to develop State Pesticide Management Plans for protection of groundwater, currently focused on four pesticides: atrazine, simizine, alachlor, and metolachlor. The Washington State Department of Agriculture is the lead agency. The U.S. Geological Survey and the Washington State Department of Ecology are testing the feasibility of using modeling and a Geographic Information System (GIS) to screen for susceptibility on a regional scale. Ecology is running EPA's Pesticide Root Zone Model (PRZM2) model and mapping the results. The USGS is doing a statistical analysis comparing model results to observations and data obtained during the National Water Quality Assessment (NAWQA) study.

Ecology is producing susceptibility maps based on PRZM2 model results for atrazine, using NRCS county level soil data in the Columbia Basin Irrigation Project Area, Franklin and Grant Counties. Other inputs include meteorological, crop, and pesticide data obtained from the EPA Center for Environmental Assessment Modeling. Programming assistance was provided by the U.S.G.S.

PRZM2 is a one-dimensional model that tracks the mass balance of pesticide and recharge in the soil column over time. PRZM2 is coupled with a vadose zone model, VADOFT, which can extend the modeling to a specified depth. If you know the depth to water, you can model the fate of the pesticide at the top of the water table.

Because the soils data is of much better resolution than vadose zone information, the strategy was to model the susceptibility of the soils first, group the results, and run several scenarios for the vadose zone within each soil susceptibility area. The depth of attenuation to below a critical mass loading, as it relates to the detection limit or some fraction of the mcl, could then be mapped. The goal is to determine the depth to water at which an impact is probable for a range of soil conditions.

The surficial geology was used to guide the inputs to the vadose zone model, and a very generalized depth to water map for the area, based mostly on electronic well records, was generated to identify areas with the potential for shallow groundwater resources at risk. Ultimately, the PRZM2 modeling results can be compared to the hydrogeologic setting in terms of the surficial geology and the depth to water map. This is important in identifying the hydrogeologic settings that are most vulnerable to transport of pesticides to groundwater.

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Oral

Hydrogeology in a Nitrate Contaminated Region of the Abbotsford-Sumas Aquifer in Northern Whatcom County, Washington

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During a two year monitoring study, monthly groundwater levels and water quality data were collected and analyzed from 21 domestic wells in a four square mile area (study area) of a nitrate contaminated region of the Abbotsford-Sumas aquifer in northern Whatcom County. The hydrogeology of the study area, which borders Canada, was characterized during this study to determine the influence of groundwater flow on nitrates produced by both Canadian and Whatcom County sources.

Information from 50 well logs and three gravel pits in the study area was used to identify two hydrogeologic units: a gravel and sand aquifer, and a clay aquitard. The aquifer is unconfined and composed of a heterogeneous mixture of Sumas outwash gravel and sand with some scattered silt and clay lenses. The aquifer ranges in thickness from 180 feet in the northeast portion of the study area to 80 feet in the southeast portion of the study area. An average hydraulic conductivity of 929 feet/day was determined for the aquifer outwash sand and gravel. Underlying the aquifer is the confining aquitard, interpreted as Bellingham glaciomarine drift. The till like drift is a compact, unsorted mixture of clay, silt, sand, gravel and mollusks.

Groundwater flow directions and hydraulic gradients in the aquifer were estimated using contoured head distributions from field measurements and groundwater flow model (MODFLOW) results. Groundwater flow directions had a northwest to southeast trend with the exception of the northwest portion of the study area, which showed a south to southwest trend. The head contours also revealed that the hydraulic gradient for the far east portion of the study area (0.010) was about an order of magnitude higher than the gradient in the west portion (0.003). The average gradient along a northwest to the southeast transect in the direction groundwater flow in the study area was 0.0075. The pore-water velocity along the transect (13,000 feet) was estimated to be about 20 feet/day, which equated to a relatively short groundwater travel time of 1.8 years.

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Oral

The Fate of Nitrate and 1,2-Dichloropropane in the Abbotsford-Sumas Aquifer: The Role of Redox Reactions in the Riparian Zone

Anthony J. Tesoriero[1] and James C. Ebbert[2]

The fate of nitrate and 1,2-dichloropropane was evaluated by comparing concentrations of these compounds in ground water having varying redox (oxidation-reduction) conditions. This study was conducted in a vulnerable portion of the Abbotsford-Sumas aquifer in northwestern Washington and southwestern British Columbia. Measured nitrate concentrations in ground water in this aquifer often exceed the U.S. and Canadian maximum contaminant levels for drinking water. 1,2-dichloropropane (a fumigant-related compound) is frequently detected in ground water in this aquifer, at concentrations exceeding the drinking water standard in some areas.

In much of the aquifer, the presence of dissolved oxygen and absence of excess dissolved nitrogen (N_2) in ground water indicate that little or no nitrate degradation occurs. A notable exception is the sharp redox gradient observed in the riparian zone adjacent to a third-order stream as oxygen-reducing (aerobic) ground water enters reduced sediments. Redox conditions change rapidly from oxygen-reducing to iron-reducing over a distance of less than 500 meters. An essentially complete loss of nitrate concurrent with increases in excess N_2 are evidence that denitrification (conversion of nitrate to N_2) occurs in this zone. Based on mass-balance calculations, denitrification rates in the riparian zone are at least an order of magnitude faster than rates in other portions of the aquifer.

1,2-dichloropropane was found more often and at higher concentrations in oxygen-reducing and nitrate-reducing ground water than in iron-reducing ground water. Microcosm experiments using sediments from iron-reducing and oxygen-reducing conditions suggest that microbial reduction is responsible for lower concentrations of 1,2-dichloropropane under iron-reducing conditions. Microbial reduction of 1,2-dichloropropane occurred in experiments using iron-reducing sediments, but not when using oxygen-reducing sediments. The reduction of both nitrate and 1,2-dichloropropane in the redox conditions found in the riparian zone of a stream indicates that natural ground-water discharge to streams may contain much lower concentrations of these compounds than upgradient ground water. The mitigating effects of riparian zones are negated, however, when drainage systems (e.g., tile drains, ditches) are employed that bypass the riparian zone.

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Water Availability

Oral

The Groundwater Hydrology of the West-Central Portion of the Marysville Trough Aquifer, Marysville, Washington

Eric F. Weber[1] and Nicholas Garson[2]

The Marysville Trough is a broad north-south oriented lowland in central Snohomish County that is drained by Quilceda Creek and its tributaries. The western margin of the trough occurs beneath a portion of the Tulalip Tribes reservation known as the Tulalip Test Site. In 1998 a study was initiated to characterize the groundwater hydrology of the site. Seventy monitoring wells and two surface water staff gauges were installed in an area of over 1,300 acres. Monthly water levels were collected between March 1999 and June 2000. These data were evaluated to characterize groundwater recharge and discharge and regional and local hydraulic gradients. Fifteen grain size analyses were analyzed to characterize the aquifer hydraulic conductivity distribution.

The Marysville Trough extends approximately 9 miles in length from Arlington to Marysville. Stratigraphically, the trough represents an extensive Vashon age recessional outwash sand deposit. The deposit thickens from the margins to at least 150 ft near the trough axis and is underlain by Vashon till, advance outwash and pre-Vashon interglacial deposits. The Marysville Trough aquifer consists of saturated portions of the recessional sand.

The site extends from about the West Fork of Quilceda Creek west to a north-south glacial upland ridge that forms the western margin of the trough. Small perennial springs and creeks flow from near the base of the upland ridge and discharge into a network of roadside ditches that are in direct hydraulic continuity with the aquifer water table. Ultimately, these ditches coalesce and form the headwaters of Sturgeon and Coho Creeks, two small Quilceda Creek tributaries. Regional hydraulic head relationships measured during the study indicate preferential groundwater recharge occurs along the western margin of the trough at the toe of the upland. Regional groundwater flow patterns are strongly influenced by the presence of the larger tributary system of Quilceda Creek. Locally, the ditch system has a strong seasonal effect on groundwater flow. During the summer, the ditches nearest the upland recharge the groundwater system. During the winter, as groundwater levels rise, hydraulic gradients reverse and the ditches become a discharge sink. The median hydraulic conductivity value was 59 ft/day. Estimates spanned almost three orders of magnitude, but the interquartile range varied over a relatively narrow interval of 46 to 115 ft/day, consistent with relatively uniform soil characteristics observed during drilling.

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Oral

Characterization and Assessment of Ground Water and Related Surface Water Resources on the Swinomish Indian Reservation

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The Swinomish Indian Tribal Community (Tribe) has initiated an investigation to characterize and assess the current state of water resources on the Swinomish Indian Reservation. The Reservation is located west of the Swinomish Channel, on the southeast portion of Fidalgo Island near La Conner, Washington, approximately 70 miles north of Seattle. Population of the Reservation is estimated at 4,800, of which approximately 1,000 are enrolled Tribal members or other Indian nationality. For the most part, the non-Indian majority occupies homes on leased Tribal trust waterfront lands.

Since the study area is an island aquifer system, the unique recharge/discharge relationships must be understood for water resources management. Most of the Reservation is blanketed by glacial till from the Vashon glaciation, which limits the quantity of ground water recharge from precipitation. The Tribe has developed wells for a community supply in a confined aquifer at depth; in pre-Fraser glacial sediments. The aerial extent and quantity of recharge to the aquifer is currently unknown. There are several Group A community water systems and about 200 individual domestic wells that pump ground water, principally from two aquifers. Surface water from the Anacortes municipal system is piped to the Shelter Bay Community and to some individual homes on the Reservation. Increasing development pressure requires that the Tribe develop the data and management tools necessary to responsibly plan for and meet the drinking water needs for Reservation residents.

The objectives of the water resources investigation are to fully describe the ground water hydrology of the Reservation and the interactions between ground water and surface water. The information will be integrated into management tools, including a numerical model, monitoring plan and resource protection policies and ordinances. The objectives are being accomplished by updating and improving the existing hydrologic characterization of the Reservation with more detailed information about the hydrogeologic units, water level and water use data, calculating hydraulic properties of the aquifers, and developing recharge estimates for the ground water system. In addition, surface water flows and limited water quality data are being gathered.

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Oral

Hydrogeology and Potential Water Supply Sources within the Cle Elum River Valley, Washington

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An assessment of existing hydrogeologic conditions in the lower Cle Elum River Valley was completed to evaluate potential environmental impacts resulting from development of a master planned resort. Pleistocene glacial deposits and Tertiary bedrock comprise the two major aquifer systems beneath the project site. The Pleistocene outwash deposits form both a shallow water table aquifer and a deeper confined to semi-confined aquifer. A layer of glaciolacustrine sediments underlies the shallow outwash aquifer beneath many portions of the project site, and often provides a confining unit separating the two outwash aquifers. Significant differential erosion of the glaciolacustrine deposits has occurred at various locations beneath the site, and has resulted in the merging of the two outwash aquifers into a continuous unconfined aquifer in the southeastern portion of the study area.

The Cle Elum River, Cle Elum Lake, tributary streams and wetlands directly interact with ground water in the glacial aquifer system. Ground water levels measured in on-site observation wells have shown seasonal fluctuations in response to precipitation/ snowmelt, discharge in the Cle Elum River, reservoir levels in Cle Elum Lake, discharge from underlying abandoned coal mines, and pumping from Cle Elum Hatchery wells.

The two outwash aquifers were evaluated for use as potential sources of water supply for the proposed resort. Extracting water from the lower aquifer at the projected peak water demand of 12 cfs appears unlikely given the known aquifer extent and hydraulic characteristics. Although the shallow aquifer within the Cle Elum River floodplain appears to provide the most favorable hydraulic characteristics for ground water extraction, the limited thickness of the aquifer would require a large number of shallow wells to supply the projected water demand. The use of an infiltration gallery constructed in the water table aquifer adjacent to the Cle Elum River is continuing to be evaluated as an alternative to direct surface water withdrawals.

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Oral

Aquifer Storage and Recovery in the Yakima Basin – City of Yakima, Washington

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The City of Yakima is planning an Aquifer Storage and Recovery (ASR) pilot test in the winter of 2000-2001. The City is evaluating the feasibility of ASR as a potential component of its municipal water supply system.

Since the City's existing infrastructure includes both surface water and groundwater sources that are connected by an existing distribution system, a pilot test can be easily accommodated using an existing well without significant capital expense. The source of recharge water is the Naches River treated to drinking water standards. The recharge aquifer is the Upper Ellensburg Formation in the Ahtanum-Moxee Sub-basin. The basin is structurally closed in the context of groundwater and is bounded on all sides by topographic and structural highs, which forms a natural container for recharged water. Geophysical surveys have been conducted to further define inferred fault boundaries.

A detailed hydrogeological study of the Ahtanum-Moxee Sub-basin, including a compilation of approximately 1,500 well logs, has provided the most detailed interpretation of the hydrogeology in the sub-basin to date. A basin-scale groundwater flow map has been prepared and is shown to be consistent with previous conceptual models. Geochemical modeling (including interaction between recharged surface water, groundwater, and aquifer materials) indicates no major concerns with respect to drinking water or operational considerations.

ASR provides an alternative to the traditional direct diversion of surface water at times of seasonally high demand and low streamflows. Recharge of cold winter water (~40 ^{o}C) is expected to result in fewer water system customer complaints (existing groundwater sources yield water at approximately 70-75 ^{o}F). This project is the first ASR project to be evaluated to this level of detail in the Yakima Basin, and has the interest of stakeholders in the basin.

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Oral

A Tale of Two Cities, and One Well – Aquifer Storage and Recovery (ASR) in the Pasco Basin, Washington

Kenneth R. Moser[1], Christian V. Pitre[2], David Banton[3]

The City of Kennewick, Washington would like to establish a reliable municipal water source on the west side of the city. The adjacent City of Richland would like to expand its water production capabilities in the southern part of the city. The two cities recently signed an interlocal agreement and have retained Golder Associates to assess the feasibility of aquifer storage and recovery (ASR). It is proposed to recharge Columbia River water into the existing Willowbrook well. In addition to improving source distribution from an infrastructure perspective, a successful ASR project would help reduce peak demand stress on surface water sources by recharging water into the aquifer during the low demand winter season and withdrawing water for peak summer water demand (which is up to four times the low demand).

The sole water source in the southern part of the City of Richland, near the City of Kennewick boundary, is the Willowbrook well. The well is one of few in the area completed in the upper flows of the Wanapum Basalt Formation (~1,000 ft deep) and has an optimum yield of 1,000 gpm. Groundwater quality concerns include dissolved methane and hydrogen sulfide, which are removed by air stripping, and high temperature (~83^{o}F). Use of the well is currently limited to peaking demand periods.

The structural geology is interpreted to provide significant control on the hydrogeological regime. The Willowbrook well is located north of an inferred thrust fault associated with the Rattlesnake Lineament. Preliminary water quality data suggest that wells completed in the Wanapum Basalt Formation on the south side of the inferred thrust fault do not have the temperature or the dissolved gas concentrations found at the Willowbrook well. The radically different geochemical conditions of oxygenated recharge water and highly reduced aquifer water present the potential for mixing reactions. Initial conditioning of the aquifer through cyclic water recharge and withdrawal holds potential for improving the water quality and, therefore, use of this well.

Study results to be presented include: an assessment of the local hydrogeologic setting for ASR, baseline aquifer water quality, potential changes in water quality during recharge and storage, pumping test results of the Willowbrook well, and the permitting process for an ASR pilot test and full scale system.

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Oral

Aquifer Storage and Recovery: Making Washington's New Law Work

Doug McChesney[1] and Ken Slattery[2]

Aquifer Storage and Recovery (ASR) projects offer a promising means to supplement water supplies for Washington's growing cities and population and, if properly developed, without any serious environmental downside. Several projects across the state are currently undergoing feasibility studies and one has been implemented on a test basis. While such projects have long been possible within the state of Washington, the process by which they could be legally accomplished was extremely complex.

That situation changed as the result of a bill passed during the 2000 legislative session. Where previously the permitting of an ASR project required Ecology to undertake rulemaking, an increasingly expensive and time-consuming process, the new legislation allows Ecology to consider applications for ASR projects within its normal water right permitting scheme.

The legislation applies to projects where "water would be artificially stored . . . with intent to subsequently use the stored water." Projects using water from irrigation return flows or seepage losses, or water artificially stored as part of the normal operations of irrigation districts, are specifically excluded by the legislation, as are projects involving the use of reclaimed water.

Ecology is required by the legislation to adopt rules setting standards for review and mitigation for several key concerns associated with ASR projects. These concerns include such items as aquifer vulnerability, hydraulic continuity ("capture"), water rights issues, aquifer boundaries and characteristics, chemical compatibility of waters, and the overall operation of an ASR project. Ecology is also required to report back to the legislature on its progress towards those standards and on the status of any applications filed for ASR projects by December 31, 2001.

To do this, Ecology has convened a technical advisory group of individuals familiar with ASR projects and the issues involved. The group will be meeting throughout the summer of 2000 and should, by October, have developed a preliminary set of standards that should form the foundation for the eventual rule. Once those preliminary standards have undergone review by a wider audience, Ecology will commence the formal rulemaking process.

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Aquifer Test Design

Oral

Impacts of Barometric Pressure On Groundwater Levels During Pumping Tests In the Seattle Area

Craig D. Sauer[1], Richard J. Martin[2], and Scott F. Bender[3]

Aquifer testing was performed for evaluation of potential groundwater inflows and dewatering feasibility during construction of the Light Rail Tunnel in Seattle, Washington. Barometric pressure fluctuations and groundwater levels were monitored prior to each of five pumping tests performed to estimate aquifer parameters. Evaluation of the aquifer barometric efficiency was performed at each pumping test site by comparing hydrographs from wells completed in the aquifer of interest with a corresponding barograph during the same time interval. The change in barometric pressure versus the change in water level was used to produce a scatter plot to estimate the barometric efficiency for the aquifer of interest at each pumping test site.

The results of pre-test barometric pressure and water level monitoring suggest barometric pressure changes can produce significant water level fluctuations to wells completed in coarse-grained units in the Seattle area. Analysis of pumping test data without monitoring and correction of barometric induced water level fluctuations may lead to erroneous conclusions and errors during analysis. For example, analysis of uncorrected pumping test data near the University District in Seattle, Washington suggested that a recharge boundary was encountered during the test. After correcting the data using a barometric efficiency of 87 percent, however, it was apparent that the recharge boundary was from a change in water level due to a relatively large fluctuation in barometric pressure during the test.

Comparison of hydrographs with barographs revealed a high degree of variability in aquifer barometric efficiency at other pumping test sites. The observed barometric efficiency ranged from 87 percent near the University District area to 40 percent near the St. Marks Cathedral area. A poor correlation between barometric pressure and groundwater levels was observed near the Capital Hill and First Hill areas. The wide range of observed barometric efficiency may be attributed to the lateral extent, thickness, and heterogeneous nature of the glacial soils at each pumping test site. These analyses indicate that water level fluctuations due to barometric pressure changes during pumping tests should be monitored and filtered from the data set for pumping test analyses performed in Seattle and the greater Puget Sound area.

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Oral

The Impacts of Well Development Techniques and Evaluation Methods on Slug Test Results in the Seattle Area

Daniel P. McHale[1], Paul L. Van Horne[2], and Scott F. Bender[3]

Slug tests were performed at numerous observation wells in the Seattle area for the Sound Transit Light Rail Project during 1998 and 1999. The majority of the borings were drilled by mud rotary methods using bentonite drilling mud; the remainder were advanced using a polymer drilling mud. In each instance, the mud was flushed from the borehole immediately prior to well installation. Seven of the wells installed in polymer mud borings were initially developed and slug tested in 1998. Development techniques for these wells included use of a hand-operated surge block followed by bailing and/or pumping with an electric submersible pump. The slug test results indicated that residual drilling fluid was not thoroughly removed from these seven wells during the development process. In 1999, these wells were developed further and slug tested again. Redevelopment was accomplished through vigorous surge blocking in combination with pumping with a check valve-type inertial pump (Waterra™ or similar) or bailing. Slug test evaluations were performed using both the Cooper-Jacob and the Bouwer and Rice methods.

A comparison of the slug test results from 1998 (following initial well development) and 1999 (following redevelopment) demonstrates significant increases in the calculated hydraulic conductivity values for the seven wells. These analyses indicate that thorough well development is necessary prior to the performance of aquifer testing at monitoring wells. Although the Bouwer and Rice method was developed for unconfined systems, it is generally considered to be applicable to confined aquifers in many cases. However, a comparison of the results of the two slug test methods typically showed significant differences in calculated values of hydraulic conductivity, with the Cooper-Jacob result usually being higher. Therefore, the selection of the analytical method should be based on the degree to which the method assumptions are met by the specific well and aquifer geometry.

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Oral

Near-Field Effects of Groundwater Extraction in South-Eastern King County: Implications for Pumping Test Design

Joel Massmann[1] and Carla Carlson[2]

Twenty-four hour pumping tests are typically conducted as part of the application process for obtaining permits to operate groundwater wells in confined aquifers in the State of Washington. These tests typically involve monitoring water levels in the pumped aquifer and using this information to estimate aquifer transmissivity and, in some cases, aquifer storativity.

Groundwater levels have been monitored in the vicinity of the Witte well field in southeastern King County, Washington for a three-year period beginning in May of 1997. The Witte well field, which is owned and operated by the Covington Water District, is operated between May and November at approximately 1500 gallons per minute and is shut down for the remaining six months. The startup and recovery of these wells have been monitored for three annual cycles. Water levels are measured at four-hour or smaller increments throughout these cycles. Two sets of clustered piezometers have been used to monitor the groundwater levels in the pumped aquifer, in the confining unit above the pumped aquifer, and in more shallow aquifers. These two sets of piezometers are approximately 100 feet and 300 feet from the well field. The data have been used to estimate transmissivity and storativity values for the pumped aquifer and to estimate leakage coefficients for the confining units. Estimates were made using several analytical solutions, including the Theis and Hantush methods, and with several MODFLOW models. The estimates obtained using the full set of data from the clustered piezometers are compared with estimates made with the original 24-hour tests that are required for the permitting process. The estimates for transmissivity vary by approximately three-fold depending upon the amount of data that are used and the method used to evaluate this data. The estimates for storativity vary by more than an order-of-magnitude. The variability and uncertainty in these estimates have important implications with regard to hydraulic continuity issues and groundwater management options. The results also illustrate the limitations of the 24-hour pumping test in evaluating the effects of groundwater wells in geologic environments similar to the Witte well site.

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Watershed Management

Oral

Groundwater Management in King County

Ken Johnson

About 30 percent of King County's residents obtain their water supplies from groundwater sources. The County also includes two Federally-designated Sole Source Aquifers, in Renton and on Vashon - Maury Island. Finally, groundwater serves as the source of critical summer flows in area rivers, and thus provides habitat for salmonid species recently listed as threatened under the Endangered Species Act. Groundwater is thus a vital natural resource that must be protected by responsible jurisdictions.

Groundwater as a resource has many potential threats, including depletion (loss of quantity) and contamination (quality). These concerns are especially acute in the Puget Sound region because of its burgeoning population and thriving economy.

Since 1986, King County has been developing Ground Water Management Plans, under WAC 173-100, for the five Ground Water Management Areas delineated within its boundaries. Four of these Plans were finalized in 1998 - 1999, and the state Dept. of Ecology recently certified these four plans as in compliance with the authorizing regulations. This step allows groundwater protection to move from the planning stage into implementation. To guide this process, a Ground Water Management Committee has been set up in each Area.

The Groundwater Program is located in the Water and Land Resources Division of the King County Dept. of Natural Resources. The Program is pursuing a long-term plan with efforts in four aspects that address groundwater protection: data collection and management, education, regulatory and policy, and program coordination. Examples of the program's accomplishments to date include: development of a data base of well locations, locating public water system ("Group A") wells and springs using global positioning system (GPS) survey equipment, providing hydrogeologic information to the public via the County's Internet Web site, monitoring of some private and public water systems, coordination of educational / outreach efforts across the County with cities and Water Districts, delineation of Well Head Protection Areas and discussions of appropriate land use restrictions in these areas, and organization of Ground Water Management Committees and appropriate governance / advisory mechanisms.

The main limitation to the expansion of groundwater protection efforts is the lack of permanent funding. Program personnel are exploring regulatory / legislative efforts that could open new sources to supply these services for the benefit of all who rely on groundwater.

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Oral

California Water Supply Relies on Conjunctive Management

Carl J. Hauge

California's population and abundant natural resources have helped create a trillion dollar economy that ranks seventh among world economic powers. Water resources have helped maintain California as the top U.S. agricultural state for 50 consecutive years. It leads the nation in agricultural exports, is the sixth largest agricultural exporter in the world, the number one dairy state, and the producer of 55 percent of the nation's fruits, nuts, and vegetables. One out of eight U.S. residents now lives in California and by 2020 the population will have increased by the total number of persons now living in Arizona, Nevada, Oregon, Idaho, Montana, Wyoming, New Mexico, and Utah. Four of the nation's 15 largest cities are located in the state.

Water to supply these activities in a semi-arid state is provided by surface and ground water projects that have been developed since California was first settled. The first conjunctive use project began when the Spanish missionaries used well water to irrigate crops. Today's population and accompanying demand for water have resulted in many water projects that transfer surface water from basin to basin, recharge ground water, control sea water intrusion, and store water for use during the irrigation season. Despite these successes, water shortages are projected and resolution of political, institutional, and legal conflicts lags behind potential technical solutions.

Rights to use surface water are addressed in the California Water Code, that governs "surface water and subterranean streams flowing through known and definite channels." Over 1000 local water agencies deliver surface water. Some extract ground water, but rights to ground water are not addressed in the Code. The courts have declared that landowners have an overlying right to extract as much ground water as they can put to beneficial use, correlative with the right of neighboring landowners. Disputes are settled in court. This has led to adjudication of 18 basins. Though surface water and ground water are interactive, statutory and juridical law treat them as separate resources.

Increasing demand for water for agricultural, urban and especially ecosystem uses is moving all segments toward greater water use efficiency. Agricultural interests are looking at selling their water supply to urban areas. Shortages are still projected. Concerns about costs of treating for chemical constituents in groundwater are increasing. A state—federal consortium has tried to build a consensus between the three factions to help them move toward water supply solutions. Effective solutions will require compromise and resolution of political, institutional and legal disputes.

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Oral

Water Availability and Water Right Transfers in the Upper Yakima River Basin

Thomas H. Martin Jr., P.E.

Water availability in the upper Yakima River Basin was studied to assess the impacts of proposed transfers of irrigation water rights. The transfers would change the water rights' place and type of use and point of diversion. These changes would affect streamflow, depth and velocity in the tributaries and along the mainstem Yakima River. The extent of the impact, however, depends more on the amount of water consumed rather than the amount diverted under the water right. RCW 90.03.380 permits a change in the place of use, point of diversion, or purpose of use of a water right to enable irrigation of additional acreage, or the addition of new uses, if such change results in no increase annually to the quantity of water consumed under the right. The statute essentially limits over-allocation of water rights and minimizes the impact on tributary and mainstem water resources. The study determined the actual consumptive use of irrigation water rights, and the amount of consumptive use available for transfer to a new owner and to a different place and type of use.

For tributary water rights in sub-basins of the upper Yakima River Basin, the consumptive use available for transfer is a function of the natural streamflow and the amount of water consumed by senior users in the sub-basin. The Teanaway River is the only gauged sub-basin in the upper Yakima River Basin. Ungauged sub-basin streamflows were estimated using regional flow-duration curves and Teanaway gauge data. Curves were derived historical gauge data and watershed characteristics.

Per RCW 90.03.380, consumptive use is to be estimated by subtracting return flow from diversion rate. Both diversion and return would need to be measured to make this estimate. However, return flow measurements have a large uncertainty associated with them because return flows can take ground and surface water pathways back to the water source. As an alternative to measuring return flows, consumptive use can also be estimated using evapotranspiration (ET) formulas. The State of Washington Irrigation Guide identifies irrigation requirements for Washington and references the estimation methodology. These methods were used to estimate net consumptive use within the specific irrigated areas listed in the water rights proposed for transfer.

The study showed that if only the available consumptive was transferred, then there would be no cumulative impact on the mainstem. The maximum amount of consumptive use, based on ET formulas, for some tributary water rights exceeded the available consumptive use because of over-allocation. In the past, water rights were allocated like bank checks per the state water code's prior appropriation doctrine. Water availability, however, is like the checking account, which has been overdrawn.

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Oral

A Model for Stakeholder Participation And Decision-Making In Watershed Restoration

Brad Shinn

In a strategy of watershed ecosystem restoration, one approach to reopen historic spawning grounds for anadromous fish is to build a partnership with stakeholders to determine both what the goals should be and how they will implement them. The middle reach of the Upper Yuba River is thought to have once been a significant Chinook and Steelhead spawning ground. The watershed was the location of one of several extensive hydraulic mining operations in the late 1800's and now provides irrigation and drinking water. A large debris dam at the bottom of the watershed built to stem sedimentation and resulting flooding downstream, forms one of a handful of static-elevation reservoirs providing both recreation and residential scenic opportunity.

We implemented a process that first identified the common interests among the more than 500 individual stakeholders. With similar interests becoming apparent, they formed into three workgroups of like-minded interests with 10-12 stakeholders as representatives. Working with each of the workgroups, we identified key issues, concerns and desired outcomes using a process that built credibility and trust. By building on small agreements, we formed a collaborative process where stakeholders are working cooperatively to solve regional problems based on four principles:

- Partnership, equality and mutual respect
- Finding a common language to describe problems
- Neutral process
- Clear objectives developed and agreed upon by the stakeholders

Stakeholder participation is no longer an optional project component or method of simply distributing information or managing public opinion about watershed restoration. Incorporating an inclusive, decision-sharing model can be successfully implemented to reach agreements on issues where there is a clash of public values. The advantages of using a stakeholder-directed model are:

- Avoiding the tools of objection that exist in NEPA and SEPA. Stakeholders with real decision-making authority tend not to work outside the process.
- Collaborative resolution is a more lasting solution. Distilling technical issues to their most easily understood form will help find breakthroughs in understanding.
- Public values are the ultimate drivers. By putting more of the outcome in the hands of stakeholders, they are vested with ensuring that the outcome is acceptable and implementable.

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Oral

Review of Washington State Programs Regulating Hydrogeological Processes

Karen J. Terwilleger

Watershed planning, project development, and habitat restoration can be difficult biological, social, engineering endeavors. No less complicated is the system of local, state and federal laws that regulate hydrogeological processes. A few examples include the Clean Water Act, the Coastal Zone Management Act, the Washington Water Code, the Hydraulic Code, Shoreline Master Programs, and Critical Area Ordinances. Understanding the legal system is as critical to success as understanding basic hydrology.

The complex legal system can be confusing to any person planning, analyzing, or permitting a project. This paper reviews the history of hydrogeological regulation in Washington State, assesses the scope, jurisdiction and purpose of the major regulatory programs, and examines the programs' gaps and overlaps.

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Contaminated Ground Water and Sediments

Oral

Contaminant Depth Distribution in Groundwater at the Hanford Site 200 West Area

F. N Hodges[1], V. G. Johnson, and C. J. Chou

Recent reconnaissance sampling of the deeper portion of the unconfined aquifer in the Hanford 200 West Area indicates the presence of relatively mobile contaminants throughout the vertical extent of the unconfined aquifer (60-80 m thick), and beneath the lower mud unit of the Ringold Formation, normally considered the bottom of the unconfined aquifer. Sampling was carried out during drilling at approximately 15 m (50 ft) intervals in three wells adjacent to the S-SX, T, and TX-TY single-shell tank waste management areas (WMA). Data from wells near WMAs T and TX-TY show subwater-table maximum concentrations for nitrate (530 mg/L), tritium (29,600 pCi/L), and carbon tetrachloride (1600 μg/L). In the well near WMA S-SX, nitrate (58 mg/L), tritium (32,000 pCi/L), and carbon tetrachloride (13 μg/L) are highest near the top of the aquifer, with minor concentration peaks for nitrate and carbon tetrachloride deeper in the aquifer. Data for the well near WMA TX-TY indicate a subwater-table maximum concentration for technetium-99 (556 pCi/L); however, in wells at WMAs S-SX and T, technetium-99 is at a maximum at or near the top of the aquifer (4200 and 13,000 pCi/L respectively).

Depth distribution patterns are indicative of waste disposal practices and conditions that have existed historically within the 200 West Area. Deep distributions of nitrate, tritium, and carbon tetrachloride are probably a result of large scale surface disposal of waste during Hanford's earlier years. Driving forces for the downward migration of contaminants include groundwater mounds formed under ponds and other effluent discharge sites; pump and treat systems related to remediation of carbon tetrachloride, technetium-99, and uranium plumes; liquid waste with densities significantly higher than that of groundwater; and aquifer recharge, particularly in gravel covered areas of the tank farms. The distribution of contaminants is further complicated by heterogeneity in the Ringold aquifer, which may result in diversion of groundwater from expected flow paths. The shallow distributions of technetium-99 at WMAs S-SX and T are probably related to their proximity to waste sources within the tank farms.

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Oral

The Fate of Legacy Contaminants in the Columbia River

Vernon G. Johnson

Mining and smelting have been prominent industrial activities in the upper Columbia drainage basin for the past century. The world's largest lead-zinc smelter, located at Trail, B.C. near the United States-Canada border, discharged thousands of tons of metals to the upper Columbia River. The Idaho and Montana mining districts have also contributed to upper river contaminant loading. Mercury, dioxins, PCBs, oil, DDT, agricultural chemicals and radionuclides are also present from past (and present) practices. Most of these contaminants have an affinity for particulates and thus accumulate in riverbed sediments. While effluent controls have greatly reduced some discharges, contaminated sediments remain in depositional zones of the river system. Changes in these "legacy" deposits over time have not been well documented. This presentation explores temporal changes in heavy metal content of Columbia River sediments at selected depositional sites ranging from Grand Coulee Dam to the estuary.

Sediment cores from protected areas in the estuary and from key depositional zones in the upper river (e.g. McNary and Grand Coulee dams) provide a record of (a) the recent past (last 10 to 20 years), (b) Hanford's single pass plutonium production reactor years (1944 -1971), and (c) the pre-World War II period. Cores taken in 1999 from behind McNary indicate declines in metal concentrations that can be correlated with improvements in effluent controls at the Cominco Ltd. Refinery at Trail, B.C., which were implemented in the late 1970's. Radionuclides from past Hanford operations serve as "event markers" and isotopic ratios provide clues about sources.

Dam breaching, flow augmentation, bottom sediment removal and floods can resuspend contaminated riverbed sediments and redistribute the fine fraction to downstream sites. The possible impacts of such disturbances on benthic fauna, spawning beds, and aquatic life in general are unknown. However, previous work suggests that even after a disturbance event subsides, it take several years for a 10-fold reduction in downstream surface sediment contaminant concentrations. Thus, the overall impact of riverbed sediment disturbances must be carefully considered in long-range cleanup and habitat improvement plans.

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Oral

History of Groundwater Contamination at the Frontier Hard Chrome Superfund Site, Vancouver, Washington

Roy E. Jensen[1] and Keith A. Pine[2]

The Frontier Hard Chrome site was listed as a Superfund site in 1983 because of the presence of soil and ground water contamination from the release of plating wastes. Ground water investigations, including installation of wells, water level monitoring, and ground water sampling have been ongoing at the site since 1984.

The site is located on the former floodplain of the adjacent Columbia River. Ground water occurs in a thick, sand to cobble aquifer, hydraulically connected to the Columbia River. The principal control on ground water levels is the stage of the Columbia River. The ground water gradient is nearly flat, with the predominant flow direction towards the Columbia River; gradient reversals occur during periods of rapid rise in the stage of the river, and occur periodically during the winter and spring. Aquifer testing indicates that hydraulic conductivity of the aquifer is greater than 0.1 cm/sec.

Plating operations were conducted at the site between 1960 and 1983. Development of the site included filling of wetlands and floodplain channels with hydraulic fill and construction debris. The fill unit is generally dry except in low areas of the pre-development ground surface. Storm water is directly recharged to the fill unit via surface infiltration and dry wells. Plating wastes containing high concentrations of hexavalent chromium were disposed via dry wells into the fill unit. Chromium contaminated groundwater infiltrated through the native silt unit into the underlying aquifer.

The initial distribution of chromium contaminated groundwater was controlled by pumping from nearby industrial water supply wells, preferential flow pathways within the aquifer, and multiple source areas. The highest concentration of total chromium detected in groundwater was 300 mg/L. Since the closure of the plating facility and industrial water supply wells, there has been a steady decline in chromium concentrations and the extent of the plume. Recently, chromium concentrations have stabilized, suggesting that further reductions in groundwater chromium concentrations will require the removal of source areas from the fill and silt units.

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Oral

Groundwater Arsenic Panic in Bangladesh

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Bangladesh's groundwater is now suffering seriously from Arsenic Pollution, which is the largest mass poisoning in it's history (World Bank, 1999). Till now, this poisoning is covered in tubewells in a total of 210 thanas/upazilas (administrative unit of Bangladesh) under 59 districts of the 64 districts of Bangladesh, affecting at least 15% of the country's population. This pollution is increasing almost to whole Bangladesh day by day, especially as each time a team is sent out to survey an area they identify more and more affected villages. Experts predict that if the problem is not addressed immediately and in right earnest, tens of thousand of people would be victims of arsenic pollution within the next decade. The crisis is even being described as one of world's most serious environmental problems. It has been estimated that in 200 villages, more than 7000 people are suffering from arsenic cancer, called arsenicosis, with new cases being detected everyday. This condition terminates in gangrene in the legs and arms, and eventually death; and creates a lot of negative impacts of social, environmental and economic problems of the country. Ironically, the present crisis is an unintended consequence of a country-wide program of ensuring safe drinking water for the rural people. Until 1970's most villagers in Bangladesh drank water from hand-dug wells or natural ponds, that they often shared with bathing cows and water buffaloes, and exposing themselves to such endemic and deadly diseases like diarrhoea, dysentery and other intestinal ailments. Those water-borne diseases at that time used to take a huge toll of lives every year. Over a period of nearly 40 years, the Bangladesh government, with technical and financial assistance from different donor agencies has extensively installed thousands of manually operated tubewells across the rural areas of Bangladesh to obtain the access of clean water for 100 per cent of its population. The success story of safe-drinking-water-for-all program in Bangladesh has now been sadly spoilt by the discovery this arsenic poisoning. A good number of cases of arsenic poisoning leading to loss of limbs and life showed up in Bangladesh (as also in parts of West Bengal). Many individuals and some local, national, international and UN organizations have respond to this situation in Bangladesh. Community based, low-cost, locally available solutions have been developed to arsenic contamination such as pond-sand filter, reverse osmosis and other such devices. This paper will discuss the brief history, sources and appropriate remedial measures with elaborating some case studies of this panic groundwater arsenic pollution in Bangladesh. Finally, the paper will recommend some appropriate policies on how the pollution can be controlled to reduce the health risks to the people.

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Flooding and Geologic Hazards

Oral

Description, Analysis and Impacts of the Grouse Creek Landslide, Jefferson County, Washington 1997-98

Carol Frances Serdar

In March 1997, a rain-on-snow storm dropped approximately 39 cm of rain onto an existing snowpack in the upper headwaters of the Solleks River, located on the western flank of the Olympic Mountains of Washington. This exceptional amount of rain and resulting snowmelt triggered a large deep-seated landslide. The landslide, informally named the Grouse Creek landslide, started as a rockslide displacing approximately 506,000 m^3 of sandstone bedrock and overlying soil. The slide rapidly moved down slope as a debris avalanche for 700 m, where the mass then lost velocity at an approximately 90° bend in the channel. Approximately 200,000 m^3 of material was deposited at the toe of the landslide on the upper slopes of the Grouse Creek channel. The landslide then became a debris flow that continued to pick up additional material from side slopes, which were scoured up to 54 m high. When the debris flow reached the Solleks River, it deposited approximately 78,000 m^3 of material.

Surveyed cross sections in Grouse Creek and along the Solleks River near the fan deposit, indicate variable bank erosion and primarily degradational changes over the winter of 1997-98. The remaining 222,000 m^3 of material appears to be working its way through the Solleks, lower Clearwater River and lower Queets River systems.

Landslides commonly affect downstream trout and salmon habitat. This landslide probably decimated trout and salmon living in Grouse Creek. However, a year later, there were cutthroat trout spawning in Grouse Creek and steelhead spawning in the Solleks River. Spawning-gravel composition (particle size distribution) in the Solleks River downstream of Grouse Creek was found to be as clean or cleaner than previously reported. Observations of trout and steelhead and the clean spawning gravel composition indicate that recovery is already underway in Grouse Creek and the Solleks River.

Although landslides are part of the natural processes in the Pacific Northwest, many other studies show that the rate of landsliding has accelerated due to clearcut logging and associated roads. Clearcutting of the forest and placement of fill in the 1980's for a road crossing the headwall of Grouse Creek contributed to the destabilization of the steep slopes of the basin. Determining whether these logging activities led to the Grouse Creek landslide is difficult, because the area is within a shear zone. However, I feel that the logging and the presence of the road were contributing factors that led to the slope failure.

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Oral

An Analytical and Spatially Distributed Approach to Watershed Scale Probabilistic Slope Stability Assessment

William C. Haneberg

This presentation describes the spatially distributed application of an analytical first-order, second-moment (FOSM) method to estimate the probabilistic stability of forested infinite slopes with slope-parallel seepage. The non-iterative nature of the FOSM method makes it well-suited for incorporation into spatially distributed landslide hazard assessment projects in which geotechnical properties are specified on a cell-by-cell or unit-by-unit basis over a watershed or area of similar size.

The method allows for specification of input variable probability density functions (PDFs) that include uniform, normal, lognormal, triangular, and beta distributions. The effects of trees are incorporated via areal surcharge and root cohesion terms, and can also be implicitly considered by estimating their influence on pore water pressures. Independent variables entering into the analysis are assumed to uncorrelated, although correlation could be incorporated at the expense of increased mathematical complexity. Comparison of results from the FOSM method and the US Forest Service program LISA, which incorporates some correlation in an iterative Monte Carlo algorithm, shows no significant differences. Results can be expressed in terms of spatially distributed values for the factor of safety variability, the probability of sliding or stability, and the slope reliability index. Exceedance probabilities for user-specified Newmark critical accelerations can also be calculated if earthquake triggered landsliding is a concern.

Forecasting future pore water pressures presents the most significant obstacle to meaningful watershed scale slope stability assessment. Precipitation-induced pore water pressure changes depend on a combination of storm intensity, duration, and frequency; the hydraulic properties of the soil; the pre-storm soil moisture content; and surface and bedrock topography. Attempts to simulate future pore water pressures using deterministic models of unsteady groundwater flow are unlikely to be successful because they would require the analyst to accurately predict the weather years or decades into the future. The use of steady-state flow models is equally unsatisfactory if the objective is to assess the likelihood of landslides triggered by transient precipitation-induced pore water pressure increases. Probabilistic assessments, however, provide two possible solutions: time-independent estimates of probabilistic stability given all physically possible values of pore water pressure, and time-dependent estimates based upon the maximum pore water pressures likely to occur over a given period. The latter, while being conceptually attractive, brings to the analysis its own set of complications that center around the amount of historical data required to make reliable predictions.

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Oral

A Hydrogeologic Investigation to Evaluate Flood Control Remedies in North Spokane County

Thomas D. Briggs[1] and Leslee L. Conner[2]

A residential neighborhood in north Spokane County experienced street and basement flooding as well as septic system failures during 1997 following a winter of higher than average rainfall. A hydrogeologic study of the area was conducted to refine the existing conceptual model of groundwater flow and develop a water balance for the local hydrologic basin. A two dimensional numerical model of the shallow groundwater system was developed, and served as a useful tool in identifying and comparing different flood control remedies.

The subdivision consisted of single family households that received water from outside their local basin. This water was discharged locally through individual household septic systems or through lawn and garden watering during the summer months. Stormwater within the development was routed to drywells that discharged directly to the subsurface. A stormwater pond located in the center of the development received some stormwater through piping connected to specific drywells in flood sensitive areas.

Results of a field investigation indicated the subsurface consisted of a loose to dense fine to medium sand underlain by a thick silty clay unit encountered between 10 and 78 feet below the ground surface. Groundwater was encountered between 3.75 and 67.9 feet below ground surface. Results of the water balance estimated that the impact of septic system and summer watering inputs increased loading to the water table by over 400% compared to predeveloped conditions.

An evaluation of hydrogeologic data indicated that street flooding resulted from the presence of shallow groundwater, which prevented some stormwater drywells from operating as designed. Model simulations of different flood control remedies predicted that interception of all stormwater runoff in critical flooding areas would result in a drop in the water table of up to 4 feet, enough to adequately address street flooding, while interception of septic inputs predicted a drop of only 2 feet. Model simulations of pumping from wells located within the stormwater pond predicted pumping would require approximately 6 months to relieve basement flooding adjacent to the pond, and less than 1 year to achieve the same effect upgradient of the pond. Model simulations were judged most accurate for comparing the relative impacts of different remedies due to assumptions that current conditions within the basin represented steady state.

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Oral

An Overview of the Hydrogeology Along the Sound Transit Link Light Rail Project in Seattle, Washington

Scott F. Bender[1], Daniel P. McHale[2], Jonathan E. Rudders[3], and Red A. Robinson[4]

This paper gives a broad overview of the complex glacial and interglacial deposits found along the tunnel alignment of the Sound Transit Link Light Rail Project and their influence on the local hydrogeology. The hydrogeology of the alignment was evaluated to provide input for the decision-making process for the means and methods of constructing the tunnel and stations, to address potential groundwater inflow hazards, and to estimate groundwater discharges rates for construction. This was one of few regional hydrogeologic testing programs that have been performed in the Puget Sound Region.

In 1997, Shannon & Wilson began work with the civil facilities design of the Sound Transit Link Light Rail Project. As a subconsultant to the Puget Sound Transit Consultant's (PSTC) joint venture, Shannon & Wilson provided geotechnical engineering services for both the conceptual and the preliminary engineering phases of design. A significant portion of the work required an evaluation of the hydrogeology of an approximate five mile length of the alignment that will be tunneled under the Capital Hill and University of Washington districts in Seattle. The tunnel, stations, and related structures will be some of the deepest soil excavations in the world.

The groundwater-related work of the project involved designing and installing groundwater monitoring instrumentation networks, and performing slug and pumping tests. Over 130 groundwater instruments were installed in over 80 borings. Forty-two slug tests were performed, analyzed, and statistically compared. Five major pumping tests were performed using as many as 17 groundwater measuring instruments per test. The tests were designed to provide typical aquifer parameters as well as the vertical permeability of the aquitards. These data were used for calculating potential groundwater inflow rates during construction of the tunnel, shafts, and stations. Results of the aquifer testing will be discussed and how they may provide a new understanding of the hydraulic properties of local soil units.

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Oral

Changes in the Hydrometeorological Regime in the Pacific Northwest

John J. Vaccaro

Selected hydrometeorological (HM) data for the Pacific Northwest and atmospheric and North Pacific sea-surface temperature (SST) data are examined for three successive subsets of the historical record to estimate if their characteristics have changed. The HM data consist of monthly precipitation for 50 sites in western Washington and streamflow for 112 sites in Washington, Oregon, and Idaho. The atmospheric information consists of the Southern Oscillation Index (SOI), Pacific North America Index (PNA), measures of the east-west and north-south components of geostrophic flow, and 700-mb height data.

The water year subsets of the record were identified as pre-1947 (pre), 1947-76 (base), and post-1976 (post). Means were calculated for the water year (October-September), the runoff season (March-August), the winter season (October-February), and a baseflow season (August-September).

All but two water-year and winter-season means decreased compared to the base period, indicating a spatially consistent and distinct change in the HM regime for the pre/post periods. For the runoff season, precipitation at most sites decreased for the pre period and increased for the post period, indicating two different regimes during these periods. For both pre/post periods, water-year precipitation decreased because of decreased winter precipitation. The water-year discharge for 97 of the 112 sites was less than the base period for both pre/post periods. Winter-season streamflow decreased at all but 11 sites. Except for sites with increased annual discharge, means also decreased for the runoff season.

Changes in the SOI and PNA from the base period were generally similar to those of the HM data. Negative values of the SOI for the post period were more persistent than those in the historical record. Changes in the PNA were reflected in both atmospheric flow components. The 700-mb data display trends and differences between the base and post periods that are associated with warmer and drier conditions. SSTs have a significant long-term trend with large changes in monthly values between the base and post periods. These changes in atmospheric and SST data are clearly linked to and have influenced changes in the HM regime. Together, these changes suggest that an HM regime occurred during the post period that had not occurred in the record analyzed in this study: a regime with increased runoff-season precipitation over part of the Pacific Northwest and decreased water-year precipitation and streamflow over all but one region.

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Oral

Near-real-time Flood Inundation Mapping Pilot Project

Joseph L. Jones

USGS scientists are developing a near-real-time flood inundation mapping methodology that will generate and electronically distribute storm-specific inundation maps for selected areas prior to imminent flooding. The pilot area is the Snoqualmie River between Falls City, and Duvall, Washington.

The purpose of the pilot project is to develop the capability to map flooding in near-real-time, and provide the information over the internet. Today, flood maps consist for the most part of flood maps developed for FEMA. These maps are based on statistically determined flows, for example the “100-year” flood, which has a one-percent statistical likelihood of occurring any year. Currently there are no techniques for timely creation of flood maps for storms that may generated flows of virtually any statistical likelihood, not just the “100-year” flood.

The flow forecasts to be used are hydrographs generated by the National Weather Service River Forecast Centers (RFCs). These forecasts predict the flow in major basins based on estimates of the timing, amount, and distribution of rainfall associated with an oncoming storm. For emergency response and public protection purposes, the RFCs generate predictions of flood elevation at forecast points, usually USGS streamflow stations. These flood elevation forecasts are of limited use at locations other than the forecast points. Therefore, the project is employing hydraulic models capable of using the RFC flow forecast to generate flood elevations along a reach of the river, as opposed to only a forecast point. The model being applied is TRIMR2D, a two-dimensional semi-implicit finite difference model. The advantages of this model, in addition to providing a two-dimensional flood surface, are its stability and robust solution capability. A two-dimensional solution allows the depiction of two-dimensional flow vectors, and provides information on momentum effects such as super-elevation that one-dimensional step-backwater models cannot. The stability and robustness of TRIMR2D allows simulation of flood flows in channels that are steeper and longer than can be simulated with most models. These characteristics are also critical because the model is to be applied to flow predictions that are generated only shortly before the modeling results are desired.

High accuracy elevation data are being used to provide data for the hydraulic model and to allow the generation of flood maps with a high level of detail. Geographic Information Systems are used to create flood maps, which are to be provided over the internet using internet map server technology. This allows scale dependent map content, and allows the selection of features of particular individual interest for display along with the inundation forecast.

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Databases

Oral

USGS National Water Quality Assessment Data Warehouse

Sandy (Alex K.) Williamson[1], Kalpesh Patel[2], and Nate Booth[3]

The U.S. Geological Survey (USGS) began its NAWQA (National Water Quality Assessment) program in 1991, systematically collecting chemical, biological, and physical water quality data from study units (basins) across the nation. In 1999 we developed a data warehouse to better facilitate national and regional analysis of data from the first 36 study units started in 1991 and 1994 (See http://water.usgs.gov/nawqa/nawqamap.html) Data from the 15 study units started in 1997 will be incorporated later. The data warehouse currently contains and links the following data:

- Chemical concentrations in water, sediment, and aquatic organism tissues and related quality control data (from USGS National Water Information System--NWIS)
- Biological data on stream habitat and community data on fish, algae and invertebrates
- Site, well and network information associated with thousands of descriptive variables derived from spatial analysis like land use, soils, population density, etc.
- Daily stream flow and temperature information for repeated sampling sites (from NWIS)

These data were collected at about 2,800 stream sites and 5,000 wells selected to be indicative of various land uses. In addition to about 26,000 nutrient samples, 15,000 pesticide samples were collected from the water column as well as 1200 samples from sediment and tissue, which were analyzed for hydrophobic compounds. Most pesticide, sediment, and tissue samples were analyzed for over 40 different compounds. At many of the same stream sites, the ecological data listed above were collected. Collectively they represent about 6.5 million records in the data warehouse.

The development of this database and associated software has followed two main principles, which have been essential in keeping the project on time and on budget: 1.maximum use of the most current off-the-shelf software, and 2. joint application development by USGS staff along with expert consultants hired on a time and materials basis.

The data warehouse has been in use by USGS researchers since October, 1999. Most of the data in this data warehouse was made available to the public April 25, 2000. The water, sediment, and tissue concentration data for environmental samples, as well as the site and well data and daily streamflow and temperature data are available at the website: http://water.usgs.gov/nawqa/data.

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Oral

Washington's Data Submittal Guide: Building Access to Environmental Data

Russ Darr[1], Lynn Singleton[2], Keith Hinman[3], Lewis McCulloch[4]

Washington's Department of Ecology is in the process of integrating its management and environmental data across traditional programmatic and 'media' boundaries. Integrated data management agency-wide creates wider data access, better functionality for users, and higher data quality, as well as improved priority-setting and more integrated environmental management. As a critical early step in integrating its data, Ecology has built the Environmental Information Management (EIM) System, designed as an agency-wide repository for ambient environmental data. EIM contains monitoring data and integrates tabular and GIS views of air, soil, sediment, water, groundwater and natural resource information.

To realize its potential, EIM must receive and validate data from a variety of sources outside Ecology, including volunteer monitors, consultants, grantees, contract laboratories, and local governments. To meet this need efficiently, Ecology developed a data entry tool, the EIM Data Submittal Guide, which guides users through the steps needed to create complete, EIM-compatible electronic data files. This HTML-based Guide provides a user-friendly interface, easy navigation, and flexibility in formatting, to accommodate the range of different sources from which data will come. By defining, documenting and checking needed data elements, the Guide also serves to communicate data standards for ambient environmental data and to promote data consistency and quality. Finally, through the use of optional run-time Microsoft Access database software, the Guide can itself serve as a data entry and management tool for data providers. In the future, Ecology plans to make EIM available on the Internet, allowing remote users direct access to all the functions of EIM.

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Oral

Building a Database and Leaching Index through GIS Mapping of the Central Columbia Basin

Pat Daly

Methods ranging from sophisticated satellite photos to observation from pickup trucks are being used to create a database of land use information that will help growers become more efficient and better stewards of local resources. One of the projects of the Columbia Basin Ground Water Management Area (GWMA), the GIS Database Project describes significant features of the cultivated acres in Grant, Adams and Franklin counties and provides a mechanism to help guide farmers in their application of fertilizer and irrigation water.

Significantly, this program combines land use data on a local level with topographic and hydrologic characteristics for all three counties into one useable source. While data collection is continuous on behalf of many agencies and their objectives, the GWMA's GIS database combines regional information with data specific to GWMA's ground water and agriculture concerns, including cultivated acres, and crop and irrigation patterns.

The foremost goal of the Columbia Basin GWMA is the writing of a Ground Water Management Plan, the voluntary implementation of which is designed to reduce nitrate in ground water. However, the GWMA is also undertaking a number of research and cost share projects in support of the Plan and its goals. The GIS database is one such project. The entire database is organized in such a way that it provides maps and summary reports for the GWMA's use in offering supporting data for its recommended best management practices and helps guide fund allocation.

The project uses USGS digital orthophotos with a resolution of one meter to delineate field boundaries in the three counties and to identify the irrigated and dryland portions. Besides the digitized satellite photos, input includes crops and irrigation methods on all cultivated fields. Additionally, other data—soil types, for example, and results from the well sampling undertaken by GWMA in the fall of 1998—are being integrated with the database and as overlays to the digitized field maps.

In keeping with that quest for hard science, the GIS project also provides a formula to calculate the vulnerability of Basin fields to penetration by nitrate and other undesirables. The project's Leaching Index is a calculation of nitrate leaching potential based on soil conditions, amount of applied nitrogen, effective rooting depth, allowable water depletion and efficiency of the irrigation system.

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Aquifer Protection

Oral

Wellhead Protection in a Sole Source Aquifer – The Cross Valley Water District Protects Its Groundwater Supply

Bryony Hansen[1], Robert Anderson[2], and Gary Hajek[3]

The Cross Valley Water District (CVWD) supplies drinking water to a rural area on the Snohomish / King County line, between Woodinville and Snohomish, Washington State. At present, about 89% of the water supplied by the CVWD is pumped from ten wells. The combined maximum capacity of the wells is about 5,360 gpm or 7.7 MGD. All the wells withdraw groundwater from the Cross Valley Aquifer, a water bearing sand and gravel unit that was designated as a Sole Source Aquifer in 1987 by the Environmental Protection Agency in response to petition for the designation by the CVWD.

The CVWD is experiencing high population growth which puts a continually increasing demand on its water supply. In 1997, the CVWD supplied 24,040 people or 4,708 connections. Population growth models predict that by the years 2008 and 2020, the number of connections required will reach 7,523 and 11,918 respectively. Concurrent with population growth, an increase in the number, size and frequency of contamination events is expected. In addition, over the last ten years, development of new groundwater supplies have been significantly curtailed due to regulatory uncertainty regarding the effects of groundwater withdrawals on surface waters and, more recently, habitat for endangered salmonid fish species. Finally, the Olympic Pipeline Company application to construct a major gasoline pipeline over the Cross Valley Aquifer raised community awareness; awareness that the need to maintain a good quality groundwater supply is critical to the region.

The Wellhead Protection Plan for the CVWD was designed to protect the CVWD's groundwater supply. The main objectives of the plan are to: 1) reduce the likelihood of groundwater contamination; 2) to identify actions that can be taken by the CVWD to foster and promote long-term management of groundwater quality; and, 3) to prepare a contingency plan that identifies alternate drinking water sources which could be used by the CVWD in the event that contamination of an existing source occurs. The tasks completed to achieve these objectives include: a hydrogeological characterization of the Cross Valley Aquifer; creation and calibration of a MODFLOW / MODPATH groundwater flow and contaminant transport model for the aquifer; delineation of wellhead protection areas for the CVWD wells; a GIS database inventory of known and potential sources of contamination within the wellhead protection zones; a discussion of wellhead protection strategies; and, preparation of a contingency plan.

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Oral

Aquifer Protection Ordinance and Plan Development at the City of Redmond

Phil Cohen[1], Derek Sandison[2], and Peter Mintzer[3]

The City of Redmond is one of many cities in the State of Washington that has completed a Wellhead Protection Plan (WHP) per Washington Department of Health guidelines. The City has found that it has to now implement the elements of the plan if it is to protect its drinking water supply. The City receives about 40% of its water supply from 5 municipal wells set in a glacial outwash water table aquifer that is vulnerable to contamination. The City is fortunate as a water purveyor to also have land-use planning capability; thus, it can act to protect its wellhead protection zones through ordinances and development codes. However, due to the relatively recent delineation of the WHP time-of-travel zones, portions of the areas highlighted for protection have already been zoned for light industrial and business park type of land use.

The City has chosen to move forward with development of a plan and ordinance for aquifer protection. This presentation will discuss the how the City is proceeding with this task and how it used information from the prior WHP work. Included in the presentation will be information on the process of selecting and using members of the community audience, City staff, and related professionals for the drafting and review of the plan and ordinance. Also included will be a discussion of the potential legal issues associated with this work.

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Remediation Technologies

Oral

Field Application of Hydrogen Peroxide Injection For Hydrocarbon Remediation

Maura S. O'Brien[1], Ben Amoah-Forson[2], and Timothy Warner[3]

Hydrogen peroxide (HP) injection to aid bioremediation was tested for groundwater cleanup at a former bulk fueling terminal, now the King County Metro Transit Division (Metro) Facilities North site at the north shore of Lake Union, in Seattle, WA. A consent decree was signed by all parties under the Model Toxics Control Act (MTCA) in April 1999 for the cleanup of chemicals of concern: benzene, total petroleum hydrocarbons (TPH), carcinogenic polynuclear aromatic hydrocarbons (cPAHs) and naphthalene. Pilot testing and three quarters of full-scale remediation have been conducted.

An 8-week pilot test was conducted at 14 injection wells, 6 supplementary and 6 compliance monitoring wells. Variables evaluated included HP volume/injection/well and method of injection (gravity flow and pressurized injection using 10-psi pressure). HP volume was varied from 2.5, 5, 10, 25 and 55 gal/injection/well and concentration was kept constant at 3.5%. Field parameters monitored included temperature, pH, conductivity, and dissolved oxygen (DO). These were measured before and after each injection event. Baseline conditions and quarterly monitoring were conducted for volatile and semi-volatile organic compounds in addition to field parameters. The site has low permeability (aquifer testing yielded 0.5-3 gpm).

Results showed that using low HP concentration (about 3.5 % HP), large volume (25-55 gal/injection) twice per month yielded the best results at this site. Results showed a substantial decrease in benzene concentrations from 15-85% in 7 of 12 wells. Best cases showed a decrease from 186 to 28.2 and 683 to 172 ug/L (ppb), however 5 of 12 wells showed an increase in benzene. This increase was attributed to the mobilization of residual contamination from the substrate. Third quarter results showed decreasing trends in those wells where increase in contaminant concentrations had been observed. A moderate decrease in naphthalene concentration was also observed. Pressurized injection was determined to improved delivery time for injection, however it did not appear to increase radius of effect or level of DO. Injection radius of effect was estimated to be 10-15 ft and 15-25 ft at the north and south yard, respectively.

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Oral

Capture and Destruction of Chlorinated Solvents in Groundwater Using a Funnel-and-Gate Reactive Iron Wall

Jeremy Porter[1], Barry Kellems, P.E.[2], and Doug Hillman, P.G.[3]

Chlorinated solvent occurrences in groundwater present many challenges to remediation, particularly in heterogeneous soils. The potential depth of DNAPL occurrences can make excavation prohibitively difficult and expensive, while soil heterogeneities limit the effectiveness of many in-situ treatment technologies. An in-situ technology that treats chlorinated solvents in groundwater and is not limited by soil heterogeneities is a permeable reactive barrier (PRB) containing zero-valent iron, which can completely mineralize PCE and TCE dissolved in groundwater.

A zero-valent iron PRB was selected as the most cost-effective remedy for controlling a 200-foot-wide chlorinated solvent groundwater plume originating on a site 200 feet from the Lake Washington Ship Canal in the Ballard district of Seattle. The groundwater plume consisted of PCE and its degradation products TCE, cis-1,2-dichloroethene (cis-DCE), and vinyl chloride (VC). Two potential source areas were identified with maximum detected constituent concentrations in groundwater of 50 mg/L PCE, 23 mg/L TCE, 8 mg/L cis-DCE, and 0.8 mg/L VC. Contaminant depth was bounded by a dense, relatively impermeable layer of glacial till at a depth that varied between 24 and 32 feet. Upper soil layers consisted of heterogeneous fill material overlying stratified estuarine deposits, which form two distinct water-bearing zones.

A 330-foot-long funnel-and-gate wall, consisting of three cement-bentonite groundwater cutoff walls (funnels) and two 45-foot-long permeable reactive gates, was installed to capture and treat the chlorinated solvent plume. The 3-foot wide reactive gates were designed based on bench tests and contained a 50/50 mix of iron filings and sand. The treatment gates were constructed using biodegradable, guar-based slurry, which avoided the need to drive sheet piling saving significant cost. The wall is imbedded three feet into the dense, impermeable till layer to prevent flow beneath the wall.

Six months after installation, measured destruction efficiencies for the iron wall downgradient of the main hot spot are 65% for cis-DCE, 95% for VC, and greater than 99% for both TCE and PCE. This is consistent with the zero-valent iron degradation pathway. Natural attenuation processes of constituents downgradient of the iron wall, including intrinsic biodegradation, are reducing concentrations to below surface water cleanup standards before reaching the Lake Washington Ship Canal.

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Oral

Natural Attenuation of Chlorinated Volatile Organic Compounds in Glacial Aquifers of Western Washington

Richard S. Dinicola

An evaluation of natural attenuation of chlorinated volatile organic compounds (CVOCs) in ground water at Naval Air Station (NAS) Whidbey Island and other Department of Defense facilities highlights the important role that organic carbon plays in regard to biodegradation of CVOCs in glacial aquifers of western Washington. Oxidation-reduction (redox) conditions in ground water greatly control the occurrence and rate of most CVOC biodegradation reactions, and redox conditions in glacial aquifers of western Washington can vary widely. The variation in redox conditions is primarily due to differences in the availability of organic carbon in ground water.

Ambient shallow ground waters in glacial deposits of western Washington tend to have little available organic carbon, resulting in aerobic redox conditions that are not favorable for the critical initial step of CVOC biodegradation. Some ground waters at greater depths or within non-glacial deposits have more organic carbon available, resulting in ambient anaerobic redox conditions that are somewhat more favorable for CVOC biodegradation. However, the most favorable conditions for complete biodegradation of CVOCs into inorganic byproducts occur where a source of anthropogenic organic carbon from petroleum spills or landfills is available to mix with CVOC contaminants. The localized abundant organic carbon can lead to the strong reducing conditions required for reductive dechlorination of highly chlorinated VOCs near a source area, followed by the aerobic or mild reducing conditions more favorable for mineralization of the toxic intermediate products downgradient in a plume.

The complete range of redox settings was identified and delineated at NAS Whidbey Island by interpreting geochemistry data. Changes in redox sensitive compounds along a ground-water flow path, coupled with changes in the relative abundance of parent contaminant compounds and daughter products, confirmed the locations where biodegradation of CVOCs was most favorable.

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Ground Water Contaminant Topics

Oral

Evaluation of Groundwater Monitoring at Closed Landfills

Mark D. Varljen[1] and Robert M. Powell[2]

Groundwater monitoring of some type has been conducted at most closed landfills, however the nature and quality of the monitoring has been found to be highly variable. This is largely due to the fact that facilities have been closed at different times under differing sets of regulations, and have been under the supervision of different State and Local jurisdictions. Furthermore, some of the facilities are managed by local governments and some by private companies, all with differing levels of expertise, funding, and motivation. Sometimes the actual groundwater monitoring has been conducted by local regulators, and other times by the owner/operator. This diversity has resulted in significant differences in monitoring practices among the facilities.

The differences in monitoring practices have made it difficult to evaluate the facilities relative to one another for the purpose of prioritization. Different parameters have been evaluated, the density of sampling varies, different sampling schedules have been utilized, different well construction practices have been employed, sampling practices are inconsistent, and the degree to which each site has been characterized (to ensure wells are located properly) varies significantly. Not only are these practices inconsistent from facility to facility, but there are often inconsistencies within the procedures at a single facility that manifest over time.

In a review of 16 closed landfills in Snohomish County, Washington, a generalized auditing procedure was developed for evaluating the existing monitoring at each facility and developing recommendations to improve quality and force consistency. This procedure could be applied to any closed landfill. The primary findings from this initial application of the procedure is that many similar problems were noted at most landfills, largely relating to problems with previous standards of practice. Upgrading monitoring to reflect modern understandings would force consistency, improve reliability, and generally ensure protection of human health and the environment.

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Oral

Volatile Organic Compounds in Fir Trees and the Model Toxics Control Act, Method B

Robert D. Miller

To assist a local farmer in evaluating water quality in a pit of buried vegetation, we analyzed buried debris and live plant material. We found good correlation between the volatile organic compounds (VOC's) in the pit water and Douglas Fir tree leaves and bark. Specifically, the VOC's detected included: toluene, methyl ethyl ketone (MEK), and acetone. We next determined the combined toxic hazard quotient of the VOC's, and set a goal for cleanup of groundwater. In the end the results of these efforts were: the site was cleaned to Ecology's requirements, there was no evidence of another party's willful intent to pollute, and the general recognition of widespread VOC's in State forests.

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Oral

Evaluation of Enhanced Biodegradation of TCE in Ground Water at Ft. Lewis, Washington

Stephen Cox

The addition of fermentable carbon compounds to ground water may stimulate indigenous microorganisms to accelerate the remediation of TCE contamination found beneath the Ft. Lewis Logistics Center. Geochemical data from ground water at the site indicate that microbial degradation of TCE is occurring in limited areas, but organic carbon necessary for microbial growth and metabolism is extremely limited. Reducing conditions that would favor reductive dechlorination of TCE are found in and near the landfill area that is considered to be the source of the TCE contamination in the ground water.

The Ft. Lewis site has been selected as one of five test sites to evaluate recently developed Reductive Anaerobic Biological Insitu Treatment Technology (RABITT) protocols, which assess the potential for utilization of enhanced bioremediation technology. The protocols describe a phased approach beginning with the assessment of field data, followed by laboratory microcosm studies that then lead to design and implementation of a field treatability test.

Evaluation of the geochemical data from near the TCE source at Ft. Lewis indicated that conditions were satisfactory as a RABITT test site. Laboratory microcosm experiments were conducted with aquifer sediment from the landfill area and were amended with yeast extract and vitamin B12 along with one or more of the following fatty acids: acetate, benzoate, butyrate, lactate or propionate. All microcosms amended with fermentable carbon compounds showed dechlorination of TCE to 1,2-Dichloroethene. Complete dechlorination of TCE to ethane was observed only in the microcosms amended with yeast extract, vitamin B12, and either butyrate or lactate. Complete dechlorination of TCE to ethane was observed in less than 180 days in the butyrate microcosms and in 240 days in the microcosms amended with lactate.

A field treatability test for amending ground water with butyrate has been designed and is being implemented during the summer of 2000 and is expected to be completed in January of 2001**.**

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Ground Water and Surface Water Interaction

Oral

Aquifer-Columbia River Interaction And Groundwater Contamination At The 300 Area Of The Hanford Site

Jonathan W. Lindberg

The 300 Area Process Trenches (300 APT) are one of the major sources of groundwater contamination in the 300 Area of the Hanford Site. These trenches were the main facility for the disposal of process waste water in the 300 Area from 1975 to 1994. Groundwater sampling and analysis shows that significant levels of a chlorinated hydrocarbon (cis-1,2-dicloroethene) and uranium remain, but concentration trends are generally decreasing with time. Concentration levels of the waste in the short term are influenced by the flow dynamics of the aquifer, which in turn are influenced by stage of the Columbia River.

Columbia River stage influences the concentration of contaminants by altering the general configuration of the water table, causing bank storage, and either concentrating or diluting waste constituents moving through the aquifer. Groundwater in the uppermost aquifer flows into the 300 Area from the northwest, west, and southwest during low stage conditions typical of late summer through winter. However, in the spring or early summer months, rising river stage causes bank storage and a change in the direction of groundwater flow. Flow direction in the immediate vicinity of the Process Trenches changes from toward the Columbia River to parallel or away from the river. As a result, the general flow of groundwater contamination changes from the typical southeastern direction to one extending considerably further south. One or more paloechannels near the water table further complicates the flow dynamics during these changes in river stage.

Examination of uranium concentration over time in 300 Area wells reveals that the effect of river stage varies with distance from the shoreline. At well 399-1-10A, which is within 4 meters of the shoreline, uranium concentrations drop with rising river stages. This indicates that the well is within the portion of bank storage where Columbia River water is actually moving inland and displacing water in the aquifer. This is also confirmed by measurements of specific conductance (river water has lower specific conductance). At well 399-1-17A near the 300 APT (about 335 meters from the shoreline) the reported uranium concentration tends to rise with rising river stages. At this location, aquifer water is not being displaced, but the higher water table allows uranium stored in the vadose zone to be dissolved and mobilized by the aquifer. At well 399-1-16A, 122 meters from the shoreline, the effects of rising river stages sometimes dilute and sometimes concentrate the waste constituents, depending on the magnitude and duration of increased river stage.

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Oral

Research Activities Associated With The Groundwater/Columbia River Interface, Hanford Site, Washington

Robert E. Peterson

Applied research and technology development activities are part of the U.S. Department of Energy's Groundwater/Vadose Zone Integration Project at the Hanford Site. One task underway focuses on the interface between the uppermost aquifer beneath the Site and the adjacent Columbia River. The three-year work scope includes (1) developing an enhanced conceptual model for spatial features and processes that occur within the zone of groundwater/river interaction, (2) investigating chemical and biological exchanges between dissolved and solid media within the zone, and (3) applying newly acquired data and interpretations in numerical models that generate estimates and predictions of contaminant concentrations in the river environment.

During the first year, a detailed three-dimensional model for the uppermost aquifer and adjacent river channel at the 100-H reactor area has been created using off-the-shelf graphics software. The model is used to illustrate the spatial relationship between the uppermost aquifer and the river channel. Products include maps that show areas where contaminant plumes are intersected by the river channel--key information for assessing impacts to benthic habitat. Given data on contaminant concentrations in a plume, the model can be used to generate estimates for the volume of contaminated groundwater, the mass of individual contaminants, and the rate at which groundwater is moving through the interface and into the main stream of the river. The model is also used as the framework for animating water movement within the zone of interaction under the influence of the fluctuating river stage.

A second focus for the first year of the project is the dilution of groundwater by river water that has infiltrated the riverbank. Previous Hanford Site work involving riverbank seepage indicated that in general, exposed riverbank seepage contains roughly equal parts groundwater and river water, although the field data show wide spatial and temporal variability. However, it has not been clear as to what might be the most appropriate representation of the dilution process to use as supporting information for risk assessments and environmental restoration decisions. A dilution coefficient is included in the Site's flow and transport modeling used to predict transport from the aquifer into the main stream of the river. Newly acquired data from a variety of observation sites (near-river wells, riverbank seepage, and aquifer sampling tubes at the shoreline) are providing improved insight on the spatial and temporal characteristics of dilution in the zone of interaction.

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Oral

Water Movement Within the Zone of Groundwater/ River Interaction, Hanford Site, Washington

Michael P. Connelly

The movement of water within the zone of interaction between the unconfined aquifer and the Columbia River at the Hanford Site has important implications at predicting contaminant concentrations within the unconfined aquifer close to river channel and within the main flow of the river. The principal complicating element is the fluctuating stage of the Columbia River as it passes through the Hanford Site. The operation of the Priest Rapids Dam, located upstream from Hanford, as a peaking power facility can cause the Columbia River's water level to fluctuate as much as 2.6 m in a single day at the 100-H Area. These fluctuations in river water levels cause large variations in pore water velocities within the near river environment. Processes occurring within this environment can significantly influence the concentrations of contaminants prior to their passing into the main stream.

A three-dimensional geologic model was constructed to distinguish the spatial relationships between the potentially-contaminated aquifer and the adjacent river bottom. The geologic model was then used to select two-dimensional vertical section for a groundwater flow model. The groundwater flow model was developed to understand the complex flow paths, residence times, and mass flux through the zone of interaction. Using hourly hydraulic head data collected from wells and the river as boundary conditions, the flow model calculates a transient particle path from the unconfined aquifer into the Columbia. Using the results from the flow model, an animation of transient particle paths was prepared to illustrate the effects of seasonal as well as daily-river stage cycles. The animation helps to create an enhanced conceptual model that can subsequently form the basis for (a) groundwater-to-river transport modeling for estimating and predicting contaminant concentrations in the river environment, and (2) designing efficient and effective near-river monitoring facilities and schedules.

To date, the model has been used to illustrate where groundwater is likely to discharge into the riverbed. This information is highly relevant for identifying areas of greatest potential ecological impact. The 100-H area modeling activity has also helped create an improved understanding of the boundary conditions created by the river, an important element in the Hanford Sitewide Groundwater Transport Model.

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Oral

Monitoring and Analysis of Ground Water / Surface Water Interactions in First Creek

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First Creek flow depth was continuously monitored during the temporary removal of an upstream diversion to investigate ground/surface water interactions. The mouth of First Creek, a tributary to Swauk Creek in the upper Yakima River Basin, is typically dry mid-July through October, because currently, its flow is diverted to the Wold-Munson Ditch about 4 miles upstream. Proposed water right transfers would reduce the diversion. However, it was not clear that additional flow in First Creek at the diversion would reach the mouth and contribute to streamflow downstream in the mainstem Yakima River. The depth hydrographs showed the travel time of the wetting front of surface flow from the diversion to each of six monitoring stations. Surface flow appeared at the mouth 11.3 hours after allowing a constant 2 cfs discharge to by-pass the diversion, but only at a maximum of 1.3 cfs. Surface flow continued for 3 days after turning on the diversion.

Six depth sensors were installed downstream of the diversion on First Creek: just downstream from the diversion, just upstream of the next downstream tributary junction, at a significant pool, at a bridge crossing, at the downstream most extent of surface flow, and at the mouth. Depths were recorded at 1-minute intervals for 2 weeks as the diversion was turned off and back on three times. The creek cross-sectional geometry and water surface slope was surveyed. Velocity was measured across the cross-sections. Manning's Equation was used to develop a rating curve for the cross-sections using the calculated streamflow and concurrent depth measurements. The depths were transformed to discharges, and the volume of flow passing each monitoring station was computed for each diversion turn-off-on cycle. The response to changes in flow at the diversion varied along the creek due to the loss/gain of flow to groundwater storage. The storage rate was estimated using classic infiltration analysis.

The monitoring station at the diversion showed a sharp, step response to each turn-off and turn-on of the diversion. Each of the downstream monitoring station hydrographs showed a sharp initial response, but a logarithmically curved final response, to the first diversion turn-off. This indicated that surface water was infiltrating to groundwater or being stored in overbank depressions. A modified Hortonian infiltration analysis was conducted to determine the initial volumetric storage rate (1.120 cfs), the ultimate rate (0.722 cfs), and first-order decay rate (3.094/day). The second diversion turn-on resulted in initial step-down response, followed immediately by a logarithmic recovery back up to a mean depth. The third turn-off resulted in initial step-up followed by recovery back down to the mean. Groundwater storage was being filled and emptied during the monitoring, which indicates underflow at the mouth, even during dry periods.

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Oral

Stream Seepage Loss Estimation Using Differential Temperatures With and Without Stage Data

Bryce E. Cole

Water management models require large data sets to predict water heads and flows in a region of study. Stream and groundwater interaction in particular is complicated by variation in streambed hydrogeology, requiring significant data to determine seepage rates over an area. A one-dimensional heat transfer model has been used previously to inexpensively estimate seepage out of streams. Data requirements are continuously-recorded temperatures for the stream and a known depth in the sediments.

Differential temperature estimation of seepage, however, assumes a constant seepage velocity, ignoring diurnal variations in seepage due to temperature dependence of viscosity or changes in the hydraulic gradient. Here analytical and numerical solutions to one-dimensional flow and heat transfer equations identify the impact of ignoring temperature-dependence of viscosity and changes in stream. Three questions are addressed: 1) Are mean daily seepage velocities the same for constant and temperature-dependent viscosity models, 2) How would discrepancies impact annual water budget estimates based on the constant seepage velocity model, and 3) How do seepage velocities vary during a diurnal cycle for stage and viscosity changes?

An analytical solution determined the average-daily seepage velocity for constant viscosity at the mean temperature and temperature-dependent viscosity for a stream with sinusoidal diurnal variations for water stage and temperature. The ratio of the average-daily seepage velocity for temperature-dependent viscosity to that for constant viscosity is greater than one and is most sensitive to the head difference between the stream and water table. For streams hydraulically connected to shallow water table aquifers, the seepage velocity ratio yielded annual stream loss estimates too low for the constant viscosity model.

A finite difference model was used to solve coupled differential flow and heat transfer equations: 1) when stream stage is known and water table is assumed static, and 2) stream stage and head under the stream at water table height are known. Data models from the Burlingame Ditch SE of College Place, Washington, indicated average seepage velocities were lower than the constant seepage value estimated by the differential temperature method. The difference between the two numerical models depended on the distance used between the base of the stream and the water table. However, daily seepage variation for both numerical was only ±5%. Differential temperatures provide an order of magnitude estimate of seepage, but coupling with stage and water table data can improve estimates by a factor of 4.

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Oral

Hydraulic Continuity in the Lower Deschutes River Valley, WA: Groundwater, Rivers and Oceans

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The Quaternary stratigraphy of the Lower Deschutes River Valley is not well-understood. We have synthesized a variety of data, including information from well drilling, mineralogy, water levels, geophysical surveys, radiocarbon dating, and previous work, to build a conceptual model of the recent depositional sequence. In this model, portions of the aquifer system are in direct hydraulic continuity with Puget Sound.

Geology: A borehole immediately east of the Deschutes River Valley encountered 260 feet of silt, underlain by 208 feet of clean sand (both of post-Vashon age), before encountering interlayered peat, gravel and sand of pre-Vashon age. Ground surface elevation is 195 feet above mean sea level (msl). Bedrock outcrops at the Deschutes River, and dips eastward under unconsolidated sediments. A gravity survey identified two north-trending subcropping bedrock ridges at an elevation of approximately mean sea level, between the borehole and the Deschutes River to the west.

Depositional Environment: We hypothesize that the erosional contact between pre- and post-Vashon sediments is a result of downcutting by the Deschutes River immediately after the retreat of the Vashon glacier. In this scenario, the Vashon glacier must have receded to the north of the Juan de Fuca Strait such that Puget Sound was open to the Pacific Ocean. The elevation of this contact, and its formation by erosion, is consistent with periglacial sea levels. We interpret the sand to be a fluvial sediment deposited in a deltaic environment. The mineralogy of the sand is consistent with Cascade Range provenance. Outcrops of the overlying silt contain drop stones, and the depositional environment is interpreted to be glaciolacustrine. The mineralogy of the silt is felsic (i.e., 70% quartz), which is consistent with Vashon glacier (i.e., British Columbia granitic) provenance. Kettle lakes in the area may have been formed by calved icebergs that drifted south and beached as they entered shallower water.

Hydraulic Continuity: Although the site is located approximately two miles from Puget Sound, preliminary water level monitoring at the borehole site reveal the presence of tidal influences. This evidence suggests that the borehole site is in direct hydraulic continuity with Puget Sound. Additionally, we expect the bedrock ridges to be a barrier to direct hydraulic continuity between the aquifer in the vicinity of the borehole and the Deschutes River. The bedrock ridge tops lie above the elevation of the contact between the sand aquifer and overlying silt aquitard.

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Riparian Ecology

Oral

The Effect of a Gasoline Pipeline Leak and Fire on Whatcom Creek Turbidity in Bellingham, Washington

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Whatcom Creek is a 4.3-mile urban stream between Lake Whatcom and Bellingham Bay. On June 10, 1999, a ruptured pipeline spilled up to 277,000 gallons of gasoline into Whatcom Creek. Gasoline flowed down 1.5-miles of this watershed prior to igniting and the subsequent fire killed fish, trees, and three people. Prior to this incident, the City of Bellingham collected water samples upstream and downstream from the area affected by the pipeline fire for the Urban Stream Monitoring Program which began in 1990. Pre-incident turbidity variation between these sampling sites were analyzed along with the influence of stream discharge and daily precipitation to compare with post-incident results.

After the incident occurred, monthly and special event samples were collected upstream, within, and downstream from the burn zone during fall 1999. Special event samples focused on stormwater events because of the likelihood of surface runoff carrying sediment into the watershed from the burn zone. The burn zone included a steep inner gorge in a city park. The decreased vegetation within this gorge after the fire increased the potential for soil erosion during stormwater events.

Pre-incident studies and the analysis of city data indicated that most of the sediment at the downstream site originated from sources downstream from the inner gorge. Post-incident results, including data collected for this study and City data, showed that the burn zone did not impact turbidity variation within Whatcom Creek when precipitation ranged from none to light. During moderate to heavy precipitation events, the burn zone contributed a significant amount of turbidity measured at the downstream site. The effect of stormwater events on Whatcom Creek turbidity should diminish as vegetation density increases within the burned riparian zone.

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Oral

Sediment Loading from Construction of a Fish Habitat Enhancement Project

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Maplewood Creek, a tributary to the Cedar River, is located approximately 16 kilometers southeast of Seattle, King County, Washington. Approximately 1,100 acres of urban watershed drains into Maplewood Creek. The peak flows for two-year and 100-year storm events are 1.4 m^3/s and 3.4 m^3/s, respectively. The Maplewood Creek project involved placement of boulders and woody debris in order to stabilize the channel, enhance fish habitat, and improve fish passage. The project was constructed using a crane, helicopter, and hand labor to minimize water quality impacts. Temporary erosion control measures, such as silt fences, straw bales, and check dams, were also utilized. An existing in-stream sedimentation pond was used to control sediment transport to the Cedar River. Because of the Endangered Species Act, the National Marine Fisheries Service required water quality monitoring during construction. A comprehensive monitoring plan was developed and implemented to meet permit conditions and to study the impacts to water quality. This paper presents the sampling plan, monitoring results, and recommended measures to minimize construction impacts to water quality.

The purpose of this study was to measure the water quality impacts during construction at various distances relative to construction activities, to estimate sediment transport and to compare results of various construction techniques. Three automated ISCO samplers and three continuous-reading YSI turbidity meters were used at three sampling stations. Samples collected by ISCO samplers were analyzed at a laboratory for total suspended solids (TSS) and turbidity. Instantaneous increases of turbidity from 2 NTU to 66 NTU and TSS from 1.7 mg/L to 433 mg/L were observed at a sampling station located approximately 35 meters downstream of the construction area.

Results of turbidity and TSS monitoring indicated the use of a crane and a helicopter both had modest impacts to water quality during construction. Continuous monitoring showed brief excursions above the State water quality standard for turbidity (5 NTU above background) at approximately 35 meters downstream while work was underway. Approximately 44 kg of sediment was transported during the first day of construction; however, the in-stream sedimentation pond captured 29 kg of the total. The use of low impact construction techniques, best management practices, and on-site water quality monitoring was effective in reducing sediment discharge.

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Oral

Consideration of Forests & Fish Rules in a Design Context

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New Forests & Fish rules (F&F) go a long way toward improving forest management in terms of aquatic resources; defining riparian, road, wetland and slope stability prescriptions to protect fish, amphibians and water quality. F&F is a science-*based,* multi-caucus negotiated agreement defining policies and practices relative to management of forest watersheds.

We examine several key components of the F&F plan with respect to how well they link key environmental variables (e.g. sediment, temperature, large woody debris, etc.) to the management action typically associated with degrading habitat and/or water quality conditions. We also examine the spatial and temporal scales that are reflected in the F&F rules and compare them to those recommended within the scientific literature. Finally, we consider the accepted tolerances implied by the rules, and assess the potential for such tolerances to provide the desired response in real systems. We found that, for the most part, the F&F plan correctly linked the management action to key resources. However, F&F does not challenge the homogeneity or independence assumptions commonly applied to forest management systems.

Scientific appreciation for the dynamic and interdependent nature of forested watershed systems is well grounded in the literature. Yet, management systems that recognize these important relationships have generally not been well developed, despite nearly a decade of effort. We propose that a significant factor limiting progress in this area is a rigid commitment to prescription-based management models, usually imposed by i) uncertainty in expected response to management and ii) regulatory systems that require stringently uniform and enforceable rules. As an alternative, we demonstrate how a paradigm shift toward a design-based management model can take advantage of the heterogeneous and interdependent nature of forest watersheds to achieve greater internal synergies, higher levels of resource protection, and more effective & efficient management protocols. By utilizing intensive information systems, being able to predict future consequences, and understanding system tolerances, design-based systems may offer significant improvements over F&F prescriptions. We conclude with suggestions for a research agenda dedicated to the development of design-based systems and methods.

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Oral

Rehabilitation of Urban Streams in the Pacific Northwest

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A multiplicity of watershed conditions is required to achieve and to maintain excellent stream quality, and so the loss of any one generally results in degradation. Urban development can impose a tremendous range of watershed impacts, suggesting that watershed management must address a wide range of potential problems and be tailored to the particular conditions of specific locales. Yet a few specific consequences of human activity are ubiquitous in most urban and urbanizing watersheds; in particular, degraded hydrologic conditions are virtually universal. Other stream conditions with physical, biological, and/or aesthetic consequences (notably water quality, woody debris loading, channel-bank scour, and riparian-corridor conditions) are also commonly, but not consistently, impacted. "Traditional" hydrologic parameters, such as flood recurrences and flow durations, incompletely characterize urban influences; hydrologic changes that affect sediment transport and biological integrity can occur without commensurate change in these hydrologic parameters. Urban development, however, is not the sole determinant of hydrologic conditions, insofar as watershed geology, climate and weather, and channel-network hydraulics also influence flow patterns. Thus no single assessment, particularly "impervious area percentage in the watershed," can adequately predict stream conditions, although this measure can be a useful indicator variable for a variety of environmental stresses. Similarly, no single spatial scale is adequate for assessing or understanding the complex effects of urbanization on the biological and physical character of streams in urbanizing environments.

We conclude that rehabilitation success is most likely in degraded watersheds with paradoxically low levels of development, because managers may be able to identify the primary factors responsible for poor biological and/or physical conditions, and because we see numerous empirical examples where the desired outcome, namely low watershed development and good in-stream conditions, coexist. Rehabilitation is least likely to produce improvements in highly developed watersheds, because the inverse state (high levels of development with very good biological and/or physical conditions) is simply not observed.

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Oral

Variation of Riparian Biodiversity In Response to Watershed Condition

Matthew Kimble Ph.D.

This study examined streamside remnant old-growth sites in paired watersheds. The study site was a selection of 8 forested wilderness, partial wilderness and second growth watersheds within the Skagit and Stilliguamish river basins in the North Cascade Mountains of Washington State, USA. The study examined the effects of watershed condition on: (1) water and stream flow; (2) aquatic macroinvertebrate and plant populations; (3) terrestrial floodplain plant populations; and (4) streamside large woody debris, stream boulders, and the floodplain surface: the substrate for riparian populations.

Standard field surveying and sampling methods were used Macroinvertebrates were collected and identified in the laboratory. Water quality was sampled instream with electronic instruments. All vascular plants, lichens and bryophytes were identified and characterized. Boulder size and plant cover was measured. Historical flow and landslide data was collected and analyzed. Water quality, species richness, and community composition data was compared between the watershed types and classes using ANOVA and principal component analysis techniques.

The results of this study indicate that water quality, and structural complexity are significantly higher at sites in wilderness watersheds than those in second growth watersheds. Water quality data showed better habitat conditions in watersheds with wilderness. Volume of stream peak-flows and landslide rates both were significantly higher in second growth watersheds. Instream invertebrate communities in these watersheds had significantly fewer sensitive specialist species. Second growth watersheds showed lower biodiversity and lower vegetative cover. Wilderness watershed plant and invertebrate communities had significantly more disturbance-sensitive specialist species and significantly fewer disturbance-tolerant generalist species than second growth watersheds. Substrate results showed substrates to be significantly more larger and structurally complex and stable in watersheds with wilderness.

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Oral

Subsurface Cooling of Effluent Using Subsurface Discharge Outfalls

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Temperature is a key water quality limitation for Pacific Northwest surface water where salmonids have relatively low thermal stress tolerance. This directly affects dischargers with elevated temperature effluent. If temperature cannot be decreased to be suitable for fish using conventional mixing zone outfalls, then elimination of discharges may be considered.

Effluent discharge alternatives including subsurface discharge, wetlands, and land application are becoming more popular and may be least cost alternatives when Total Maximum Daily Load allocations force a reduction in pollutant loads. These land-based discharge methods are regulated under state groundwater rules.

Use of groundwater discharge methods is particularly effective when temperature is the water quality limitation of an effluent. The thermal properties of soil can be used to moderate temperature and a knowledge of flow regime can be used to site and size effluent discharge systems to minimize or eliminate impacts to groundwater.

In this presentation, two case studies of alternative discharge methods are presented to demonstrate how these outfalls can be used to manage temperature of discharges. One case study makes use of a heat and water flow modeling procedure to demonstrate how subsurface flow affects cooling of effluent. This model can be used to develop outfall designs that optimize amount and duration of effluent cooling based on specific site and project conditions.

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Geophysical Investigations

Oral

Geophysics and Water Resource Exploration Successes in Washington State

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Using conventional intrusive exploration methods to find productive aquifer is often a hit or miss process. Geophysics can be a cost-effective method to improve the success rate and design a successful drilling programs. Three recent case studies are presented that illustrate the application of geophysical methods for water resource development in Washington State.

The City of Ocean Shores, located on a longshore spit at the mouth of Grays Harbor, WA, needs new groundwater sources. Seven exploratory wells that were developed found only one well that was considered acceptable for municipal use. Using time-domain electromagnetics, (TDEM) a gravel channel was identified that was subsequently drilled. The channel proved to be an aquifer with a yield of greater than 500 gpm and a specific capacity of 33 ft/gpm.

The target for the City of Tumwater's new well field was an alluvial aquifer. It was important to show that this aquifer was in direct hydraulic continuity with the Deschutes River since this might preclude obtaining new water rights. Bedrock, exposed at Tumwater Hill and at Tumwater Falls, dips eastward under the selected site to an unknown depth. A gravity survey performed at an available test well site indicated shallow bedrock, and the unlikely presence of an alluvial aquifer. The gravity survey was extended and an alternative site was identified where bedrock was interpreted to be considerably deeper. Furthermore, the gravity survey supported the interpretation of hydraulic separation of the test site from the Deschutes River. A productive test well was installed at this site.

The City of Yakima is planning to replace an aging municipal well and possibly using the new well in an Aquifer Storage and Recovery (ASR) program. The existing well is located near a fault zone, the location of which was not well-defined since it is covered by more than 100 feet of alluvial material. In order to avoid well installation complications, to increase the life of the well, and to obtain more desirable boundary conditions for an ASR program, it is desirable to install the replacement well outside of the fault zone. A very low frequency (VLF) survey was successful in identifying a fault zone consisting of at least three parallel major faults. The city can now proceed with confidence that the site for installation of a well, which will ultimately cost on the order of one million dollars, is outside of the fault zone.

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Oral

Yacht Harbor Breakwater-Sunken Ship Geophysical Investigation, Alameda, California

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Alameda Point (formerly Naval Air Station Alameda) was constructed on hydraulic fill placed on tidal flats between 1900 and 1975. The fill material was placed during roughly ten datable episodes. During the 1930–1939 fill episode, a Yacht Harbor in the western section of the base was constructed. The Yacht Harbor breakwater was constructed by placing decommissioned WW I era ships on an L-shaped (north-south and east-west) alignment to form a breakwater outboard of the western margin of the island. This breakwater is evident in early air photos (circa 1938) of Alameda.

Record reviews could not confirm the ships' removal prior to the placement of fill west of the Yacht Harbor. A geophysical technique, magnetic(s), was used to evaluate whether the breakwater ships are still present below the fill material.

Data interpretation required the characterization of a ship's "typical" magnetic signature. Magnetic signature characterization was conducted using an abandoned WW I vintage destroyer located on the Napa River in California. Magnetic modeling routines simulated burial of ship hulls below ground surface. Data was collected using a Geometrics G-826 proton magnetometer. A base station magnetometer was used to monitor variations in the earth's dynamic magnetic field. Artifacts such as power and fence lines partially interfered with the collection of data along some of the suspected locations but evaluation of the signal, based on wavelength and visual observation in the field, allowed production of a contourable data set.

Contoured magnetic data revealed only one magnetic anomaly potentially representing a ship's hull. The anomaly has the same orientation of a cargo ship near the entrance to the former Yacht Harbor. This was the only anomaly found during the survey with sufficient magnitude, continuity and waveform to represent a buried ship superstructure. The investigation suggests that most of the ships forming the breakwater were removed, although some remnants may remain. Documentation discovered after the study confirms that contractual activity pursuant to the ships' removal had been ongoing during the pre-WW II years. Geophysical surveys and available documentation suggest that ships used to construct the Yacht Harbor breakwater have been largely removed. The investigation does suggest that isolated remnants remain of some of the vessels.

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Poster Presentations

Poster

Nitrate Variations and Sources in the Abbotsford-Sumas Aquifer, Northern Whatcom County, Washington

Scott Babcock[1], Robert Mitchell[2], Sharon Gelinas[3], and Leora Nanus[4]

The purpose of this study was to document the spatial and temporal variations of nitrate values in a highly contaminated part of the Abbotsford-Sumas aquifer located in the vicinity of Judson Lake, just south of the US-Canada border. Monthly sampling over a 2-year period revealed a complicated pattern of nitrate distribution. The wells with the highest initial nitrate concentration (>20 mg/L) all showed a systematic decrease over the study period. However, other wells in the NE part of the study area showed an increase in nitrate. Most of the wells sampled displayed no consistent trends; but overall the nitrate concentration in ground water decreased. The decrease could be due to increased denitrification coupled with decreased vadose zone transport related to drier than normal conditions. However, correlation analysis revealed no apparent relationship between precipitation and nitrate concentrations (i.e. no consistent seasonal trends). There was also a positive correlation between chloride and nitrate. Since chloride is a conservation element, a negative correlation would be generated by systematic denitrification. Best management practices and regulation would also decrease nitrate loading, but land use at 100, 500, and 1000 meters up-gradient was not consistently related to ground water nitrate values. Thus, the observed nitrate values are the product of local sources superimposed on regional plumes generated up-gradient in Canada. The patterns are further complicated by variable amounts of denitrification controlled by soil and ground water composition.

Nitrogen isotope studies indicate that both synthetic fertilizers and animal wastes are contaminant sources. Only one well had $d^{15}N > 10^{o}/_{oo}$, which would indicate a predominant manure source. This was just down-gradient from a large dairy farm. Three wells, just down gradient from berry farms had $d^{15}N < 2^{o}/_{oo}$, reflecting synthetic fertilizer sources. However, most wells sampled had values between $2^{o}/_{oo}$ and $10^{o}/_{oo}$, reflecting the mixing of nitrate from different sources, both local and regional.

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Poster

Ground Water and Soil Nitrate at Two Sites in the Nooksack Basin Where Dairy Waste is Land-Applied

Barbara M. Carey[1] and Dave Garland[2]

Dairy waste is applied to agricultural land throughout Washington State as a fertilizer or soil amendment. The rate and method of manure application, crop type, meteorlogical, soil and hydrogeologic conditions affect nitrogen uptake by crops and leaching of nitrogen to ground water. The purpose of this study was to document the effects of manure applications on ground water beneath two grass fields in Whatcom County.

The sites differed in several ways including depth to water, soil type, manure application rate and application method. Site 1 is underlain by moderately permeable soils. The depth to ground water varied seasonally from zero to ten feet. Manure was applied with a traveling big gun at about 1,200 lb/acre. The depth to water at Site 2 was 18-25 feet below ground surface. The site is underlain by well-drained sand and gravel soils. Manure was applied to Site 2 with a tank spreader at 400-500 lb/acre.

Ground water was sampled monthly for two years at both sites from monitoring wells constructed upgradient, downgradient, and within the fields receiving manure. Samples were analyzed for ammonia, nitrate+nitrite, total N, as well as other constituents. Composite soil samples were collected at each site in the fall to estimate the nitrogen available for leaching in the winter. Estimates of application rate are based on the volume applied and the total nitrogen concentration from manure samples.

All nitrogen indicators were higher at Site 1 than at Site 2. The mean downgradient nitrate-N concentration was 16.4 mg/L at Site 1 and 11.6 mg/L at the Site 2. The maximum nitrate-N concentration at Site1 was 74 mg/L, while that at Site 2 was 42 mg/L. The disproportional differences relative to loading differences may be due to denitrification, which could have been a significant nitrogen loss factor during winter anoxic conditions at Site 1. Timing of high ground water nitrate concentrations often coincided with winter precipitation. The mean soil nitrate concentration at Site 1 was in the NRCS guidelines' extremely high range (162 lb/acre; 90mg/kg) and in the low range at Site 2 (34 lb/acre; 17 mg/kg).

This study emphasizes the importance of coordinating both quantity and timing of manure application with crop uptake to minimize the amount of nitrogen remaining in the soil at the end of the growing season.

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Poster

Enhancing the Usefulness of Well Drillers' Logs: New Driller's Field Guide and Geologic Training

Burt Clothier[1], Kathy G. Troost[2], Scott Fowler[3], Richard Galster[4], John Murnane[5], Susan Roth[6], and Rod Thompson[7]

In order to renew their licenses, well drillers are now required by the State of Washington Department of Ecology to obtain 12 CEUs over a two-year period. This requirement presents an opportunity to improve the quality of geologic information available on drillers' logs. We have prepared a driller's field guide and a technical training program for drillers that not only meets Ecology's requirements for CEU's, but has the potential to improve the soil and rock classification efforts by drillers to allow geologists to more easily use these data in hydrogeologic and stratigraphic applications. The field guide provides drillers with a convenient tool for use when drilling. A prototype has been in use since late summer of 2000, with a final version expected by the end of the year. The plasticized card includes information on basic soil and rock classification such as grain size, hardness, density, moisture content, percent fines, marker beds, and color. The training module will be used by drilling firms and Ecology to cover topics such as geology of the Puget Lowland, depositional processes, and soil and rock classification. Use of hand samples of the common soil and rock types enhance the training and provide a basis for future field classifications using the field guide. The effort was initiated by a committee from the Seattle Area Geologic Mapping Project technical advisory group. The field guide and training program have been reviewed by multiple agencies and consultants from the Puget Sound region and are available to the professional community.

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Poster

Geophysical Methods Applied to Ground Water Exploration

Philip H. Duoos and Sigmund D. Schwarz

Geophysical exploration techniques can often play a key role in the investigation of sites where ground water is of concern. Whether searching for clean water for water supplies, contaminated water for environmental assessments, or determining the impacts of development on ground and surface water, the use of geophysics in the early stages of an investigation is an efficient and cost-effective means of characterizing subsurface conditions.

Recent projects using both surface and borehole geophysical methods show that the data provides a wealth of information that can be used to plan future phases of the site investigation. Borings, wells and test pits are all valuable and necessary aspects of an exploration program - and the geophysical data helps to make sure that they are placed at the optimum location.

Water supply wells can be accurately placed in buried bedrock channels or bedrock fracture zones. Direct detection of contamination sources and plumes can be made prior to the installation of monitoring wells. Stratigraphic features that control the flow of ground water can be mapped. Dams and storage facilities can be designed using basic information on the depth and quality of rock, and detection of leakage paths in existing structures can be made.

Geophysical logging of existing wells can accurately determine geologic conditions before placing new wells. New wells can be logged so well screens are located precisely, and to provide a continuous record of the stratigraphy that is independent of the conventional professional geologist's log or driller's record.

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Poster

Estimating the probability of elevated nitrate (NO2+NO3-N) concentrations in ground water in the Columbia Basin Ground Water Management Area, Washington

Lonna M. Frans

Logistic regression was used to relate anthropogenic (man-made) and natural factors to the occurrence of elevated concentrations of nitrite plus nitrate as nitrogen in ground water in the Columbia Basin Ground Water Management Area, central Washington. Variables that were analyzed included well depth, depth of well casing, ground-water recharge rates, presence of canals, fertilizer application amounts, soils, surficial geology, and land-use types. The variables that best explain the occurrence of nitrate concentrations above 3 milligrams per liter in wells were the amount of fertilizer applied annually within a 2-kilometer radius of a well and the depth of the well casing; the variables that best explain the occurrence of nitrate above 10 milligrams per liter included the amount of fertilizer applied annually within a 3-kilometer radius of a well, the depth of the well casing, and the mean soil hydrologic group, which is a measure of soil infiltration rate. Based on the relations between these variables and elevated nitrate concentrations, models were developed using logistic regression that predict the probability that ground water will exceed a nitrate concentration of either 3 milligrams per liter or 10 milligrams per liter. Maps were produced that illustrate the predicted probability that ground-water nitrate concentrations will exceed 3 milligrams per liter or 10 milligrams per liter for wells cased to 78 feet below land surface (median casing depth) and the predicted depth to which wells would need to be cased in order to have an 80-percent probability of drawing water with a nitrate concentration below either 3 milligrams per liter or 10 milligrams per liter. Maps showing the predicted probability for the occurrence of elevated nitrate concentrations indicate that the irrigated agricultural regions are most at risk. The predicted depths to which wells need to be cased in order to have an 80-percent chance of obtaining low nitrate ground water exceed 600 feet in the irrigated agricultural regions, whereas wells in dryland agricultural areas generally need a casing in excess of 400 feet. The predicted depth to which wells need to be cased to have at least an 80-percent chance to draw water with a nitrate concentration less than 10 milligrams per liter generally did not exceed 800 feet, with a 200-foot casing depth typical of the majority of the area.

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Poster

A Deep-Seated Landslide Inventory of the West-Central Olympic Peninsula, Washington

Wendy J. Gerstel[1], Anne C. Heinitz[2], and Charles G. Caruthers[3]

Under the Endangered Species Act listing of Pacific salmon, any forest practice activity-related initiation of, or increase in, the rate of deep-seated landslide movement that results in sediment delivery to a public resource, could be in violation of the revised Forest Practices Rules. Washington State's Habitat Conservation Plan goes a step further to say that *all* unstable or potentially unstable slopes are excluded from harvest.

Because of the variability in the nature of deep-seated landslides, models predicting their location are of only local value. This makes landslide hazard maps an essential tool for the land manager, land-use planner, and scientist. This inventory was funded by the U.S. Forest Service and the Olympic Natural Resources Center, Forks, and contributes to the compilation of the state geologic map. The results of the inventory are being compiled with a growing state-wide, GIS-based landslide inventory managed by the Washington Dept. of Natural Resources, and used in screening forest practices applications and their effects on groundwater recharge of deep-seated landslides.

The most reliable method of mapping deep-seated landslides is by field observations in combination with air photo interpretation. Existing landslides are the best indicators of the potential for future landslide activity. Adjacent areas are also prone to sliding if they have similar geologic, hydrologic, and geomorphic conditions. The results of this study suggest that deep-seated landslides on the Olympic Peninsula fall into two broad categories: bedrock slides, and slides in valley-bottom glaciofluvial terrace deposits.

For this project, mapped landslides were compiled on USGS 1:24,000 quadrangle maps, then digitized using AutoCAD®, and electronically transferred into a geographic information system (GIS) for final presentation and data tabulation. Some fields of the database were determined in the office or field, others were calculated by the GIS. In compiling a landslide inventory remotely (i.e. by air photo), confidence levels in the accuracy of the identification should be assigned to each mapped feature. A five-tiered system was used here to allow for flexibility in the determination, with "1" indicating a high confidence level and "5" a low confidence level.

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Poster

Hydrogeology of Northern Lummi Island, Whatcom County, Washington

Michael Hutchinson[1] and Robert Mitchell[2]

Lummi Island is a 10.8-square mile island west of Bellingham in Whatcom County, Washington. The majority of the population of Lummi Island is concentrated on the northern half of the Island and groundwater is the primary source of potable water. Between 1989 and 1999 the population of Lummi Island has increased 5% annually with the current population at approximately 900 permanent residents. A few of the private wells providing water to the residents of the Island have been noted going dry during the late summer months along with some wells being impacted from adjacent salt water. This has increased the need for a characterization of the hydrogeology.

The current understanding of the stratigraphy on Lummi Island has been based on work by Parker Calkin in 1959. Calkin's work primarily focused on the bedrock and did little to further our understanding of the sediments which mantle the bedrock. Reports concerning groundwater resources of Lummi Island are generalized and have been based completely on descriptions of surface geology.

In this study, we present a preliminary assessment of the hydrogeology of the northern half of Lummi Island. Well logs from the Washington State Department of Ecology were used to identify two distinct hydrostratigraphic units: a veneer of glacial deposits and sandstone bedrock. The glacial deposits are Pleistocene in age and are comprised of unsorted and unstratified pebbly and silty clay identified as Bellingham glaciomarine drift. The drift varies in thickness and overlies the sandstone unit, which is part of the Chuckanut Formation.

North of Legoe Bay Road, wells tap through the glacial deposits and are completed in the sandstone, which is the dominant aquifer on this portion of the Island. Contoured water level measurements from domestic wells and mapping of the sandstone topography has aided in the identification of groundwater flow directions and recharge zones north of Legoe Bay. South of Legoe Bay, domestic wells are primarily completed in the Bellingham glaciomarine drift, indicating that the sandstone has a southward dip in this region. The drift has a relatively low permeability and it is in this area where select wells have been going dry in the late summer.

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Poster

Aquifer Storage and Recovery and its Application to Aquifer Systems Typical of the Puget Sound Region

Laura Landauer[1] and Joel Massmann[2]

Aquifer storage and recovery (ASR) is a method of water management by which the earth's subsurface is utilized as a natural storage facility. ASR allows storage of excess water during periods of low water demand until a time when there is high water demand. The necessary conditions for ASR include an appropriate cyclic supply and demand for water, subsurface geological characteristics that sustain water storage, and reasonable construction costs of the ASR facility.

Groundwater monitoring data was combined with computer modeling to study the response of a typical western Washington aquifer system to ASR. The model generally represented the Witte well field in the Jenkins Creek basin. The area was chosen because of the availability of significant site characterization information obtained during pumping and monitoring activities conducted at the well field in 1996 and 1997. The model was composed of five layers representing the three aquifers and two aquitards in the vicinity of the well field. Pumping and injection scenarios were conducted in the deep aquifer.

The results of the evaluations indicate the aquifer system is not conducive to using ASR as a water supply management tool. Water injected into the deep aquifer is unable to be stored in the vicinity of the wells for longer than 30 days, evident by the rapid decline of water levels once the injection period ends. The deeper aquifers exhibit the greatest change in flow within 10 days of starting or stopping pumping and injection. In terms of maintaining natural subsurface flow rates, flows can be expected to recover quickly upon terminating pumping, and can be increased rapidly by initiating injection.

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Poster

Seasonal and Interannual Variability of the Chemistry of West Twin Creek in Olympic National Park, Hoh River Valley

Stephanie McAfee[1], Georgia Murray[2], and Robert Edmonds[3]

Stream chemistry was monitored in West Twin Creek located in the Olympic National Park, Washington, from 1985-1999. Vegetation is old-growth forest dominated by western hemlock and pacific silver fir and the site receives on average 350 cm of rain per year. Bedrock is composed of uplifted marine sediments, primarily dark gray to black greywackes and sandstones with quartz and calcite veining. Soils are classified as Typic Dystrochrept. Water grab samples were collected bimonthly (1984-1991) and then monthly (1992-present) and were analyzed for pH, major cations and anions, alkalinity and EC.

Calcium and sulfate are the dominant cation and anion present in West Twin Creek stream water. Seasonally calcium, magnesium, sulfate concentrations are highest in the summer and lowest just after fall rains set in due to dilution of ground waters. Interannual variability in calcium, magnesium, and nitrate concentrations were related to the variability in precipitation patterns. Often weathering rates are calculated on short term sampling of surface waters. This long-term record provides a valuable opportunity to understand factors other than rock weathering controls on stream chemistry.

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Poster

Seawater Intrusion May Be Occurring on Lopez Island, Washington

Laura Orr

Results of ground-water sampling, conducted by the USGS in 1997 in cooperation with the San Juan Conservation District, indicated that seawater intrusion may be occurring on Lopez Island, Washington. Forty-six percent of water samples from 184 wells and one spring had chloride concentrations in excess of 100 milligrams per liter. These values have increased significantly since a previous study in 1981, and may be due to seawater intrusion. However, the data do not show trends of consistently higher concentrations near the shoreline or consistently higher concentrations with depth. Ruling out sources of chloride other than seawater intrusion would require further investigations.

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Poster

Computer Algorithm and PC Demonstration of WAC 173-340-747 Proposed: Deriving Method B Soil Cleanup Levels for groundwater Protection in Petroleum Hydrocarbons Release Sites

Hun Seak Park[1] and Charles San Juan[2]

An algorithm that allows the proposed Washington's default method calculating the risk-based soil cleanup level of petroleum release sites to be protective of groundwater will be presented. The algorithm is built into the iterative spreadsheet routine in Microsoft EXCEL™ Solver called "GWProt" which is tested and applied to core soil samples from the wide range of representative fuels.

To illustrate use of the model, sample calculations as a function of wide range of different parameters and the different kind of fuels (different composition ratio), will be demonstrated. Sensitivity analysis will be performed to quantify the effects of uncertainty in the estimates of the key model parameters on model results. Questions and answers session on the workable model will be held to illustrate the use of the model.

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Poster

Exploration, Testing and Development of the Robert's Ranch Aquifer Near the City of Westport, Grays Harbor County, Washington

Michael F. Piechowski[1] and Max T. Wills[2]

Robinson & Noble recently completed the first phase of the development of a new wellfield to supply the City of Westport and the surrounding area. The City of Westport is located on a narrow sand peninsula at the mouth of Gray's Harbor. Their primary aquifer is a coarse sand deposit found at depth in the peninsula. Since the peninsula aquifer receives all of its recharge directly through the infiltration of precipitation on the peninsula, vulnerability to pollution has been a concern. Additionally, since the sea essentially surrounds the peninsula aquifer, salt-water intrusion concerns are very real. For this reason, an exploration-drilling program was carried out in cooperation with the Anderson & Middleton Company of Hoquiam.

At the culmination of this drilling program, five locations had been drilled south and southeast of the City. A highly productive sand and gravel aquifer was encountered and tested at three of these locations. The best aquifer material was encountered near the center of Anderson & Middleton's Robert's Ranch Property. The positive results from the exploration programs guided further regional analysis, which determined that the aquifer might have the potential to support long-term production. The City elected to proceed with the drilling of two production wells tapping the Robert's Ranch Aquifer.

Drilling sites were selected within the geologically favorable area, and the wells were drilled to depths of 441 and 428 feet. Well 1 was completed in a sand aquifer with some gravel from 380 to 440 feet; Well 2 was completed in a gravel and sand aquifer from 348 to 367 feet. Geologically, these wells may tap the deposits of an ancestral Chehalis river, which is quite different and separate from the sand aquifer of the peninsula.

Both wells were tested for 72 hours, Well 1 at 850 gpm, Well 2 at 1010 gpm. During both tests, water levels were monitored in up to eight wells and piezometers surrounding the new wells. These data records, coupled with barometric logs and tidal data, were analyzed to determine aquifer characteristics and response to production.

The water produced from these wells is of excellent quality. This new wellfield taps a confined aquifer system that is separate from the aquifers currently serving the City. Ultimately, the new wellfield may supply the City as well as many of the homes along the coast currently served by individual wells or small water systems.

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Poster

Tanwax Creek-Ohop Valley Late-Glacial Flood—Evidence that Discharge from an Ice-Dammed Lake in the Carbon River Valley was Augmented by a Temporary Landslide Dam, Puget Lowland, Washington

P. T. Pringle[1], B. S. Goldstein[2], and N. R. Anderson[3]

Clusters of andesitic and minor granitic boulders, some as large as 2 m, locally are scattered along a southwest-trending network of valleys that cuts across the generally north-south-trending fabric of the drumlinoid Vashon drift plain in the Puget Lowland. These boulders provide striking evidence of a local catastrophic flood from the sudden draining of an ice-dammed lake in the Carbon River valley in the Cascade Range northwest of Mount Rainier (referred to herein as "glacial lake Carbon"). The discontinuous train of boulders deposited by the flood extends from the Fox Creek valley, northeast of Electron, to the southwest, across, and along the general trend of the Ohop Valley. One distributary of the flood flowed through Tenino via the McIntosh Lake and Scatter Creek valleys and probably flowed along the Skookumchuck River valley as far as the Chehalis River. Similar andesitic boulder clusters are scattered atop the Vashon glacial outwash south of the Nisqually River about 5 km southeast of Yelm. The present day Tanwax valley, marked by Tanwax Creek and a line of lakes, and extending from slightly east of Lake Kapowsin southwest to its confluence with Nisqually River, marks the southernmost extent of the receding Puget Lobe at the time of the outburst flood. The floodway in the vicinity of the Ohop Valley-Nisqually River confluence extended from Tanwax Creek on the northwest to as far east as Eatonville (9 km wide), and no doubt backflooded up the Mashel River valley. The flood was augmented when meltwaters draining from glacial lake Carbon apparently undercut the southwest valley wall of Fox Creek, composed of thick, andesitic volcaniclastic deposits of the (1 Ma) Lily Creek Formation, and the resulting landslide created a temporary blockage in the glacial lake floodway. Andesite boulders that lie 120 m above, and east of present Lake Kapowsin in the Ohop Valley provide a minimum depth for the flood; we estimate the volume of glacial lake Carbon at about 10^7 to 10^8 m^3. The Tanwax Creek-Ohop Valley flood may have been much larger than other floods from ice-impounded Cascade Range drainages blocked by the Puget Lobe because the Carbon River valley was being fed by runoff from Mount Rainier.

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Poster

The Hydrogeologic Characterization of Bainbridge Island as a Portion of the Bainbridge Island Level II Basin Assessment

Joel W. Purdy

The Kitsap County Level I Basin Assessment completed in 1987 by Kitsap Public Utility District (KPUD), identified Bainbridge Island as one of eighteen subareas within the County. That study, a compilation of existing hydrologic data available for the county, included recommendations for a Level II Basin Assessment for the Bainbridge Island subarea. The overall goal of the Level II Assessment was to build upon the preliminary analysis and improve upon the understanding of the hydrogeology of the island, allowing for proper management of the island's water resources. Robinson & Noble recently completed the hydrogeologic portion of this Level II Assessment. The study addressed aquifer characteristics, surface water and ground water quality, land use, water right allocations, and water budget analyses.

A characterization of the hydrogeology was conducted using a well database provided by KPUD, upgraded to include recently drilled wells and improved well locations. In all, 938 wells, some reaching to 1,500 feet below sea level, were used to develop an extensive amount of subsurface information. Where information was believed to be reliable, well completion zones were assigned to hydrostratigraphic units based on correlation with five cross sections created for the study.

The subsurface deposits below Bainbridge Island were divided into 13 hydrostratigraphic units based principally on their hydrologic characteristics. For the major aquifer units on Bainbridge Island, maps were developed showing aquifer boundaries, potentiometric surface elevation, and hydraulic conductivity. Hydrographs were developed for 23 monitor wells completed in four of the six aquifer units. Water level trends were compared to local recharge and discharge trends. The analysis showed that water levels in the aquifers of Bainbridge Island are influenced mainly by seasonal and annual precipitation trends. The deeper, highly confined aquifers show trends that correspond to production rates in addition to precipitation trends.

Comparisons were made of water budget estimations derived using three methods: a simplified water balance equation; a regression model; and an empirical model. The estimations ranged from 13 to 16 in. of annual recharge, implying a groundwater resource of more than 19,000 acre feet per year for the entire island. By comparison, actual use, based on a per capita usage rate of 150 gallons per day, is estimated to be 2,326 acre feet per year in 1990 (12% of the estimated resource).

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Poster

Fine-Tuning Thurston County Hydrostratigraphy Through Continuous Core Retrieval

Nadine Romero

Over 100 continuous cores were retrieved from Thurston County through direct-push drilling techniques from 1999 through January of 2000. Saturated soils and severe ground water flooding conditions in the winter of 1998-1999 prompted deeper subsurface investigations by clients to better understand ground water flow paths and hydraulic characteristics of sediments.

We present detailed lithologic information of the upper 30 to 70 feet of Vashon Recessional Outwash sediments in Thurston County including our compilation on the location/presence of glacio-lucustrine sediments from Lake Russell stages and identification of the top of till surface.

Continuous core retrieval through direct-push drilling methodologies not only allows detailed examination of types of sediments but of depositional structures, facies analyses, clay mineralogy and weathering, volcanogenic distributions, and most importantly identification of confining units and other hydrostratigraphic controls on subterranean water movement. Relatively few wells logs and geologic maps accurately identify soil lithologies above the Vashon Till, thus our compilation represents the first comprehensive high-resolution look at near-surface hydrostratigraphy in Thurston County.

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Poster

An Assessment of Passive Soil Vapor Extraction (PSVE) at the Queen City Farms Superfund Site, Maple Valley, WA.

Rachel Stansbery[1], Richelle M. Allen-King[2], Brian D. Anderson[3], Brian Lamb[4] and C. Kent Keller[5]

Passive Soil Vapor Extraction (PSVE) is a remediation technique that relies on natural barometric pumping as a means of removing volatile organic compound (VOC) mass from the subsurface through a borehole or extraction well. When atmospheric pressure is greater than pressure in the subsurface, an open well will "inhale," when the gradient is reversed, the well will "exhale." The goal of this study was to assess PSVE as a remediation technique at the Queen City Farms (QCF) superfund site located in Maple Valley, WA. Gas sampling results suggest a complex mixture and heterogeneous distribution of contaminants at the site and provide insight as to the types of physical and chemical processes occurring in the subsurface prior to, during, and after approximately one year of barometric pumping.

In an effort to determine how physical properties of a venting well and the surrounding subsurface play a role in barometric pumping, two wells with different characteristics (MW-7 and X-3) were chosen for study of PSVE. Airflow in the two wells was monitored to determine gas flux into and out of the subsurface over a period of 9 months. Using this information, it was determined that less that 1% of the entire subsurface was affected by barometric pumping in MW-7 and X-3.

Data obtained while monitoring VOC concentrations in the wells over a barometric cycle was used in conjunction with flow data and physical property data to determine contaminant mass removal through each well. Low flow rates and low contaminant concentrations resulted in small amounts of mass removal from both wells. Mass removal from X-3 due to barometric pumping was not enough to reduce contaminant concentration in the vicinity of the well over a period of months due, apparently, to rapid diffusion of mass from other areas in the subsurface.

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Poster

Effects of Precipitation on Landfill Ground Water Monitoring Data

Arnie Sugar

Ground water monitoring data over a 12 year period was evaluated at a landfill in Pierce County. The landfill was closed under the *Minimum Functional Standards for Solid Waste Handling* (Chapter 173-304 WAC) in 1991. Closure included a 60 mil membrane, drainage layers, topsoil, surface water control, and passive gas venting. Ground water quality samples were collected from four years before closure to eight years after closure, and were analyzed for volatile organic compounds, four metals (arsenic, manganese, iron, and zinc) chloride, sulfate, total organic carbon, total coliform bacteria, pH, and specific conductivity.

Post-closure ground water monitoring data indicated a general decrease in concentrations of most indicator parameters after closure, then a marked increase four to five years after closure. Long term (1-5 years) trends in analyte concentrations correlated to precipitation trends, with soluble and mobile parameter concentrations exhibiting the greatest apparent sensitivity to precipitation. This data suggests that long term precipitation trends may strongly influence ground water monitoring results, and therefore must be considered during performance and regulatory compliance evaluation.

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Poster

Non-Point Pesticide Transport to Surface and Ground Water at the Field and Basin Scale: an Update

Thomas P. Van Biersel[1], Richelle M. Allen-King[2], C. Kent Keller[3], Jeffrey L. Smith[4], and Amy N. Simmons[5]

The goal of this project is to determine the contributions of subsurface and surface runoff at the field-scale and to use these to understand basin-scale loading to aquifers and rivers. The study looks at the migration of triallate [S-(2,3,3-trichloroallyl) diisopropylthiocarbamate] and other environmental tracers (NO_3, O^{18} and Si) through hydrologic pathways under a semi-arid dryland agricultural setting near Pullman, WA. This paper will report on the results of triallate sample collection from an array of capillary wick lysimeters located at the hydrologic outlet of a topographically-confined and actively farmed field. Triallate is the active ingredient in FarGo® herbicide (Monsanto), which was incorporated in the soil in the fall 1999 in a granular form. Triallate analyses used solid-phase microextraction (SPME) and gas chromatography with electron capture detection. This method allowed for relatively rapid sample processing while maintaining high quality and a relatively low detection limit estimated as <0.01 μg/L.

The triallate concentration in surface water was >20 μg/L in early fall and declined steadily through the winter and spring (3 μg/L in April) until the ephemeral stream ceased to flow. Triallate was detected in pore water from lysimeters at all three depths sampled. The irregular concentration patterns suggest that preferential flow pathways were active and contributed to transport. Peak triallate concentrations can be observed after the first ground thaw and directly after no-till wheat planting. Triallate was present in the surface runoff and shallow (18 cm deep) lysimeters at concentrations above a surface water quality standard.

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Poster

Discrete Depth Groundwater Sampling During Drilling

V. G. Johnson[1], C. J. Chou, and F. N. Hodges

This paper describes some cost efficient drill and test sampling and field screening methods that were used to obtain contaminant depth distribution data from three extended boreholes at single shell tank farm waste management areas in the 200 West Area of the Hanford Site. The cost of obtaining such data is often excessive, especially in relatively deep aquifers.

Discrete depth groundwater samples were obtained with a packer/pump assembly at 6 to 7 selected depths from 0.5 to 100 meters below static water level. In addition, at one site samples of produced water were collected during the reverse circulation air rotary drilling process. In this case, ~100 meters of the aquifer (in semi-indurated sand, silt and gravel) was penetrated. Field measurements of nitrate and technetium-99 (major mobile tank waste constituents) were available within 20 to 30 minutes of sample collection. Standard HACH® methods were used for field nitrate and the 3M Empore® technetium disks (coupled with a portable pancake GM detector) were used for field technetium-99. The onsite results were used in selecting (or confirming) depths for setting the packer/pump assembly. Produced water samples were collected after each new section of pipe was added (6.1 meters). Thus 20 additional sample depths were obtained without interrupting the drilling process, which significantly minimized costly downtime. The sharp decline observed in contaminant concentrations with depth below the major zone of contamination at the top of the aquifer suggests leakage around the outside of the drive casing was minimal.

The drill and test method (pump and packer) by itself provided multiple depth characterization data from a single borehole. However, field screening of water produced during drilling greatly increased the amount of depth distribution data for the target analytes (technetium-99 and nitrate). This in turn allowed more selective use of the pump and packer sets and reduced the number of samples submitted for laboratory analysis.

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Poster

Fate of Subsurface Carbon Following Tree Cut in an Experimental Forest Ecosystem

Timothy M. White

Surface CO2 fluxes from an artificial red pine ecosystem at Hubbard Brook Experimental Forest, New Hampshire were calculated before and after harvest of the trees. The ecosystem is a 7.5 m x 7.5 m x 1.5 m “sandbox” lysimeter, filled with granitic sand and fully lined on all sides to collect all water and solute exports. The trees were 17 years old at the time of their removal in May 1998.

Time integration of the surface fluxes indicates that decomposition of labile organic following tree cut is proceeding rapidly. CO2 concentrations at depth during the photosynthetic regime (trees growing) cannot be distinguished from concentrations during the decomposition only regime (trees removed). Two years after tree cut, approximately 22% of the total C available has left the system as CO2 gas.

Calculated surface fluxes were independently checked using an infrared gas analyzer (IRGA) with flux chamber. The non-coincidental nature of surface CO2 flux and nitrate flux in discharge water offers evidence for the processes responsible for the rapid decomposition of subsurface C in response to tree cut.

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Poster

An Indicator Study of the Environmental Health of the Clover Creek Watershed

Jill Whitman[1], Elissa Broekema, Douglas Burns, Pia Dam, Joel Flores, Michael Giuliani, Jenifer Hill, Betsy Kellenbeck, Christina Knowlton, Joshua Miller, Melissa Montgomery, Christina Murray, and Cheyanne Zahrt

The class "Environmental Methods of Investigation" at Pacific Lutheran University has conducted an ongoing assessment the health of the Clover Creek watershed in Pierce County. This course is designed to stress interdisciplinary preparation and to model a team approach to environmental decision making for students in the Environmental Studies program. The students work closely with local government agencies, businesses and community-based activist groups to study the local watershed. The Clover Creek watershed has land use ranging from high density residential to small farms and large industries. It includes the city of Lakewood, unincorporated Pierce County and McChord Air Force Base.

We worked in the watershed for a semester during each of the summers of 1992-1996 and the spring of 2000. We collected geological, chemical and biological field data from the stream as well as assembling land use, economic, demographic, and political data from the entire watershed. These data reveal a creek system that meets most state standards for water quality of a Class A stream (temperature, pH, and dissolved oxygen) and that appears to be improving in health slightly over time. However, the impact of human activity is of concern for the health of the watershed as the population continues to grow and the pace of development remains high.

Using the goals of various stakeholders in the watershed (Pierce County, City of Lakewood, McChord Air Force Base, Chambers-Clover Watershed Management Committee and Clover Creek Council) and the data gathered, we developed a preliminary indicator study of the environmental health of the watershed. These indicators include measures of the creek: turbidity, temperature, fecal coliform, discharge, dissolved oxygen, and benthic macroinvertebrates as well as characteristics of the watershed: building permits numbers, persons per acre of park and open space, household income, wetland acreage, population growth, and traffic counts. For each indicator we attempted to identify a goal or benchmark value and made specific recommendations to help the community improve the environmental health of the watershed. It is hoped that this study will be of use to various stakeholders as strategies for management of the Clover Creek watershed are developed in the future.

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Poster

Identification of Separate Suprabasalt Aquifers and Temporal Changes in Groundwater Contaminant Preferential Flow Paths within the Hanford Site 200 East Area, Richland, Washington

Bruce A. Williams[1], Bruce N. Bjornstad[2], R. Schalla[3], and William D. Webber[4]

A comprehensive and integrated evaluation of new and existing hydrogeologic and groundwater chemical data provides a significant revision to the interpretation of groundwater and contaminant movement within the 200 Area Plateau at the Hanford Site. The suprabasalt aquifer system underlies the entire Hanford Site. It is the most significant and direct pathway for contaminants disposed to the ground in the 200 Area (via cribs, ponds, ditches, leaking single-shell tanks, or accidental discharge) to migrate off the Site and potentially impact the public via the Columbia River. Two separate suprabasalt aquifers were identified. Data suggests that these aquifers are in hydraulic communication beneath the 200 East Area where sediments have been removed during Plio-Pleistocene fluvial/catastrophic flood erosional events.

Temporal changes in groundwater flow are occurring at this two-aquifer juncture due to cessation of liquid effluent discharges in the area. Large-scale artificial groundwater mounds created by the liquid effluent disposal activities between the 1940's and early 1990's are now dissipating. The data suggests that water potentials in the lower confined suprabasalt aquifer remain higher as the water table drops resulting in upward flow from the confined aquifer into the unconfined aquifer along the erosional interface. Once in the water table aquifer, previously trapped contaminants will travel to the Columbia River along with known regional plumes.

The declining water table (uppermost suprabasalt aquifer) is also encroaching on less transmissive hydrostratigraphic units that create natural horizontal and vertical groundwater flow barriers. Groundwater and contaminant flow directions are changing where the aquifer is juxtaposed to these subcropping geologic barriers.

This revised hydrogeologic conceptual model will allow a design of monitoring networks at Hanford to capture the effects of the changing groundwater flow regime and track the affected contaminant plumes. This model allows for a more accurate evaluation of groundwater data that is representative of a specific hydrogeologic unit along the groundwater flow path of interest.

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