and dry seasons. Three boreholes have been drilled and continuously cored using an acoustic (Rotasonic) drilling technology adjacent to existing well pairs at the tracer site. Ongoing EM flowmeter tests, point dilution tests, and discrete fracture sampling within the boreholes are being used to identify and characterize active transport zones and vertical variability in groundwater chemistry and tracer concentrations. Following completion of these tests, the boreholes will be instrumented with multilevel samplers to facilitate comparison with samples obtained from traditional screened monitoring wells as well as to test the region of influence for various purge volumes. The net result will be a measure of the impact of various sampling routines and well configurations on the representativeness of the sample that could direct changes in monitoring strategies.

* Managed by Martin Marietta Energy Systems, Inc., under contract DE-AC05-84OR21400 with the U.S. Department of Energy.

BTH 12 Sasowsky, Ira D.

SPECIFIC FLOWPATHS AND GENERAL PERMEABILITY LIMITS IN FRACTURED MEDIA: EVIDENCE FOR ALL ROCK TYPES FROM CARBONATE AQUIFERS.

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Karstified carbonate aquifers provide hitherto unavailable information on flow routes within fractured rocks of all compositions. Such information is important as a basis for understanding fractured-media flow systems on many scales, and for constraining boundary conditions and anisotropy in numerical models of groundwater flow.

The study of flow in fractured media spans scales between individual fractures and large flow systems. When studying the former, the cubic law appropriately describes flow; when studying the latter, Darcy's Law may provide a usable approximation of the flow system. At intermediate scales, the specific route (fractures) along which groundwater flows is important.

In poorly-soluble rocks, which account for the majority of fractured aquifers, it is difficult or impossible to determine specific groundwater flow routes within the bedrock mass, because the routes are a complex, multi-planar, networks which are below the scale of easy observation. However, in soluble (carbonate) rocks, groundwater flow along the most advantageous (open) routes within the rock mass results in the development of tertiary porosity (karstification) at a scale which can be readily observed. The initial fractures controlling the tertiary porosity can usually be easily identified. These fractures are the same ones that would carry significant flux in poorly-soluble rock. Numerous qualitative studies, and a few quantitative studies have evaluated the relative importance of fracture type to groundwater flow in karst aquifers, and the ways in which these fractures are linked. Modeling of the development of karst networks has confirmed the relation between initial fractures and karstified aquifers.

Furthermore, spatial (including vertical) limits on the occurrence of karstification indicate limits on the circulation of groundwater in fractured media. Such limits have been previously inferred from well studies.

BTH 13 Dreier, RaNaye B.

FRACTURE SPACING AND CONNECTIVITY OBSERVED IN MULTIPORT INSTRUMENTED WELLS

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Characteristics of hydraulically active fractures determine groundwater flow paths on the Oak Ridge Reservation (ORR). The ORR is located in the Eastern Tennessee Appalachian Fold and Thrust Belt and overlies an area of folded, faulted and moderately dipping Cambrian through Mississippian clastic and carbonate rocks. A series of 14 coreholes that have been geophysically logged and instrumented with multiport systems provide detailed vertical resolution of the groundwater system. Each well contains between 18 and 45 isolated zones for fluid pressure monitoring. The most useful methods for identifying potential hydraulically active fractures include detailed core textural analysis, temperature, fluid resistivity, and electromagnetic flowmeter logging.

Fracture spacing increases with depth, suggesting that fracture distribution is related to near-surface processes such as weathering and unloading. Fractures create a connected system that shows smooth, fairly continuous vertical changes in hydraulic head up to depths of 700 ft. This depth range contains the majority of borehole geophysical logging responses indicative of fractures. Below these depths, the fractures are more widely spaced and are probably poorly connected to unconnected, leading to unpredictable and reversable vertical hydraulic head gradients. Locally, packages of strata (up to 100 ft thick.) exhibit no vertical gradient. These regions are delimited by abrupt and significant changes in head, up to 30 ft, that probably reflect a poor hydraulic connnection between hydrostratigraphic packages. Where fractures are not observed in core at the base of deep wells, hydraulic heads at these levels show a sharp drop, greater than 60 ft., suggesting that the zone is underpressured, possibly as a result of unloading.

Core analysis shows that most fractures are strike-parallel, but dip-parallel fractures must occur to produce continuity in the groundwater flow paths. Continuity varies locally and connectivity can be qualitatively determined from hydraulic head patterns.

BTH 14 Whittemore, Donald O.

VARIATIONS IN MULTIPLE NATURAL AND ANTHROPOGENIC CONTAMINATION SOURCES IN A SEASONALLY PUMPED WELL

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Variations in natural salinity, oil-field brine contamination, and an agricultural source of constituents were tracked using dissolved bromide, sulfate, chloride, and nitrate as tracers occurring in water pumped from an irrigation well in the High Plains aquifer. Sources of chloride were identified using mixing relationships based on bromide/chloride and sulfate/chloride ratios for the irrigation waters relative to freshwater and saltwater end members. Agricultural input was tracked using nitrate. End member waters were based on samples from monitor wells and oil brine from the study area. Proportions of the constituent sources varied during the irrigation season as a result of pumping stress. Natural salinity increased from upconing of deeper saltwater in the High Plains aquifer derived from the underlying Permian bedrock which contains evaporite-dissolution brine. Oil-brine salinity from past pollution increased but at a slower rate. Agricultural nitrate from surface infiltration decreased. The chemical variations assist in determining the relative sources of water input from different locations in the aquifer during the pumping season. Calculation of the relative amounts of water and dissolved constituents from different locations during pumping is complicated by the recycling of constituents infiltrating from irrigation water applied at the surface and variations in natural recharge. Salinity and nitrate concentrations are substantially lower and higher, respectively, at the beginning of the next irrigation season than at the end of the previous season due to aquifer recovery during the winter.

BTH 15 Nelson, Steve

CHARACTERIZATION AND REMEDIATION FEASIBILITY OF A FORMER WOOD TREATMENT FACILITY, WASHINGTON

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A former wood treatment facility in western Washington pressure treated and temporarily stored treated logs and dimension lumber. Treatment solutions included creosote with a diesel-based carrier, chromated copper arsenate, and pentachlorophenol (PCP). Spent treatment solutions and retort condensate were apparently discharged into surrounding soil and an unlined pit on site. An independent remedial investigation/feasibility study following Washington state superfund cleanup guidelines is in progress.

The site hydrogeology consists of a perched sand aquifer deposited upon a thin estuarine silt aquitard, which overlies a tidally influenced and confined fluvial sand and gravel aquifer. Elevated concentrations of arsenic, total petroleum hydrocarbons as diesel (TPH-D), polynuclear aromatic hydrocarbons (PAHs), and PCP were detected in soil and groundwater, and as components of light, non-aqueous phase liquid at the former pit. Dense, non-aqueous phase liquid has collected in topographic depressions in the surface of the estuarine silt. Discontinuities and sand lenses within the silt apparently facilitated transport downward through the silt aquitard. Wood treatment chemicals were detected in seeps and in sediment adjacent to the site.

A feasibility study (FS) evaluated bioremediation, soil washing, and solidification/stabilization of the contaminated soil. Soil excavation, soil washing, and backfill of treated soil, followed by capping is expected to be the most effective method of soil remediation. The discontinuity and heterogeneities of the silt aquitard, the tidally influenced confined aquifer, and dense non-aqueous phase liquid increase the technical challenges of soil remediation. The effectiveness of soil remediation in reducing groundwater contaminant concentrations will be evaluated before any active groundwater remediation.

BTH 16 Bach, Jeff

THE USE OF A COUPLED FLOW-SOLUTE TRANSPORT MODEL TO INVESTIGATE THE TRANSPORT AND FATE OF DISSOLVED CHLOROFORM IN AN ALLUVIAL AQUIFER: A CASE STUDY FROM THE BITTERROOT VALLEY, MONTANA

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Between 1980 and 1985, a municipal landfill near Victor, MT. legally accepted over 1,000 kilograms of liquid medical waste containing chloroform, a dense non-aqueous phase liquid. The waste was disposed of in an unlined shallow trench dug into gravelly glacial outwash. In 1987, unsafe concentrations of dissolved chloroform were discovered down-gradient from the trench, in the local aquifer by the USEPA.

It was the goal of this study to estimate the length of time, after source removal, necessary to reduce dissolved chloroform concentrations in the aquifer to safe drinking water standards. After establishing a satisfactory conceptual model and calibration targets, steady-state and transient three-dimensional multi-layer models were built with ModelCad[386] (Geraghty & Miller, Inc.) and solved with Modflow[386] (Geraghty & Miller, Inc.). Following calibration and sensitivity analysis of the flow model, MT3D (Zheng, 1990) was used to simulate the behavior of dissolved chloroform. Several remedial techniques including the use of a passive barrier wall were evaluated. The results of this model were used to suggest remedial techniques.

BTH 17 Abdo, Ginette N.

BASELINE GROUND-WATER MONITORING FOR DOCUMENTING IMPACT OF ABANDONED MINE FLOODING: BERKELEY PIT, BUTTE, MONTANA

ABDO, Ginette N., Montana Bureau of Mines and Geology, 1300 West Pk. St., Butte, MT 59701.

The effects of flooding of the Berkeley Pit, an open-pit mine operated from 1955 to 1982, and connected subsurface mines is being monitored in both alluvial and bedrock aquifers. In addition to dedicated monitoring wells, 250 residential wells, within 72 mi^2, were visited to collect water-level and ground-water quality data in the Butte area.

Water-level data show a ground-water divide between the Berkeley Pit and a residential area to the south. The present location of the ground-water divide and the

elevation of the rising ground water in the Berkeley Pit suggest that degradation of alluvial ground water in the residential area south and southwest of the pit is attributed to historic mining and milling tailings deposits and not to ground-water leakage from the pit or any underground mines. Twelve of the 55 residential wells sampled had one or more exceedances of the primary maximum contaminant levels for arsenic, cadmium and nickel. Most of these wells are just south and southwest of the pit, where a calcium sulfate water type predominates and specific conductance values are highest. Outside the area of degraded water quality, a calcium bicarbonate type water exists throughout most of the valley. The calcium sulfate type water is related to the oxidation of sulfide minerals in the tailings deposits and to subsequent transport through the vadose into the saturated zone. Tailings deposits in this area average 2 feet thick, with geometric mean concentrations of arsenic, cadmium, copper, lead and zinc of 362, <5, 1757, 468 and 3262 mg/kg, respectively. The data gathered during this study will be used to evaluate changing water quality conditions as the water level in the mining district continues to rise.

BTH 18 Tomasko, David

A SOLUBILITY-LIMITED LEACHING AND TRANSPORT MODEL FOR PREDICTING NITROAROMATIC CONCENTRATIONS AT THE WATER TABLE*

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This study presents a solubility-limited leaching and transport model for predicting the aqueous phase concentration of nitroaromatic compounds at the water table following leaching from an immobile, sorbed phase in a contaminated soil layer. For generality, the model incorporates the effects of dissolution by infiltrating precipitation, sorption to soil particles, advection, dispersion, volatilization, and biodegradation along a vertical, one-dimensional transport pathway.

The governing partial differential equation for the time and space dependent nitroaromatic concentration is solved analytically using Laplace transform techniques for the given boundary conditions: the nitroaromatic concentration goes to zero as the depth to the water table goes to infinity; and leaching in the contaminated soil layer acts like a step-function source in time.

A comparison between the results predicted with this model and those predicted with a simple distribution coefficient (K_d) approach for trinitrotoluene (TNT) demonstrates the significance of solubility-limited partitioning in the contaminated soil and biodegradation along the transport path in decreasing predicted aqueous nitroaromatic concentrations at the water table, and reducing conservatism in impact analyses.

* Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under contract W-31-109-Eng-38

BTH 19 Klingel, Eric J.

OPERATION OF AND GEOLOGIC INFLUENCE ON AN IN-SITU GROUND WATER / REGOLITH REMEDIATION SYSTEM (UVB) IN SAPROLITE IN THE SOUTHEASTERN PIEDMONT.

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The UVB (German acronym for Vacuum Vaporizer Well) is a patented *in-situ* ground-water remediation technology by IEG mbH, Reutlingen, Germany. The UVB consists of a dual screened subsurface well containing a specially designed remediation unit(s), and a vacuum blower located above ground. The vacuum blower produces a reduced pressure within the UVB well creating an airlift pump, which in turn causes a downward vertical gradient in the saturated zone. The combination of these effects creates a push-pull circulation cell in the saturated zone. In a standard UVB installation, ground water is pulled in through the lower screen, positioned at the base of the aquifer, and exits through the upper screen straddling the water table. Remediation of the ground water is accomplished through in-situ air stripping within the UVB unit.

The circulation cell is controlled by geologic factors including degrees of isotropy and homogeneity of the regolith as formed by textures, structures, and diagenetic processes. The saturated regolith, at the subject UVB remediation site, consists of saprolite from a depth of about 45 ft. from the land surface to the top of weathered rock at about 55 ft. below the land surface. The saprolite is heterogeneous and varies in grain size from medium to fine sand, to silt with clay, and is derived from the bedrock, a quartz-biotite gneiss. Abundant relict foliation and gneissic textures occur within the saturated saprolite. Diagenetic processes have produced clay lenses and stringers, and altered primary porosity by deposition of secondary minerals such as iron oxides. The structures, textures, and diagenetic processes have an effect on the radius influence of the UVB, the velocity of the circulation cell, and on the mobilization of contaminants.

BTH 20 Hackley, Keith

ENVIRONMENTAL ISOTOPE CHARACTERISTICS OF GROUND WATER FROM THE MAHOMET VALLEY AQUIFER IN EAST-CENTRAL ILLINOIS.

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The Mahomet Bedrock Valley Aquifer (MVA) is the western part of the Teays-Mahomet System and is a major source of fresh water in east-central Illinois. The MVA is an east-west trending buried bedrock valley aquifer composed of clean, permeable sand and gravel with an average thickness of ≈30 m. The MVA is covered by a thick sequence (≥100 m) of glacial till which contains interbedded sands and gravel of local importance. Major-ion and isotopic analyses including $\delta^{18}O$, δD, $\delta^{13}C$, ^{14}C, and ^{3}H have been completed on samples of ground water taken from the MVA and associated shallower aquifers.

The $\delta^{18}O$ and δD values obtained from the MVA are similar to present day precipitation values, which suggest that MVA waters were precipitated under climatic conditions similar to the present. We infer from the $\delta^{18}O$ and δD data a maximum age of approximately 14,000 years BP for MVA waters. The $\delta^{13}C$ and ^{14}C activities of the dissolved inorganic carbon vary significantly along the MVA suggesting differences in geochemical evolution. The highest ^{14}C activities occur in the central portion of the MVA and at the confluence area of the MVA and the Mackinaw Valley Aquifer to the west. Ground water from these two areas contains approximately 34 pMC whereas ground water from other parts of the MVA contains from 9 to 14 pMC. The regions of lower ^{14}C activities are consistent with the hydrochemistry and stratigraphy which suggest greater isolation from shallower aquifers and recharge from bedrock formations (Panno et al., 1992 & 1994). The ^{14}C activities in the shallow aquifers are related to the hydraulic gradients observed in different parts of the MVA.

Calculation of ground water ages is complicated by the presence of microbial methane and mixing of waters from different sources. Preliminary estimates indicate ages from a few thousand years BP in the central part of MVA to nearly ten thousand years in the eastern and western parts of the aquifer.

BTH 21 Swartz, Robert J.

ARSENIC IN GROUND WATER IN THE KERN WATER BANK, SOUTHERN SAN JOAQUIN VALLEY, CA: A PRODUCT OF HUMAN ACTIVITIES OR NATURE?

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Dissolved arsenic (As) in ground water has reached concentrations as high as 0.211 mg/l in the Kern Water Bank, a proposed ground water recharge project. Stiff diagrams, Piper plots, δD and $\delta^{18}O$ analyses were utilized to identify three distinct ground water types: 1) a Sierra Nevada sourced, low TDS (avg. 128 mg/l), Na-HCO_3 water; 2) a Coast Range sourced, high TDS (avg. 1148 mg/l), SO_4/Cl-rich water; and 3) an anthropogenically altered, Na/Ca-Cl water with moderate TDS (avg. 322 mg/l). High concentrations of dissolved As (avg. 0.036 mg/l,) are associated with the Na-HCO_3 ground water. Oil field and agricultural activities, such as brine disposal and pesticide applications, account for the anthropogenically altered waters. These waters have very low As concentrations (avg. >0.001 mg/l). An evaluation of historic land use records and existing hydrochemical data indicates human activities are not the source of dissolved As.

Direct speciation of several waters indicates that arsenate is the dominant As species. Dissolved oxygen concentrations are inversely related to dissolved As indicating local redox control. No methylated species were detected in surface or ground water samples indicating biological processes do not affect dissolved As. Low As content (>0.005 mg/l) in Sierran recharge waters at the head of the flow path, combined with minimal increases in TDS along the ground water flow path, suggest that dissolution of volcanic glass or anion exchange are the most likely sources of dissolved arsenic.

BTH 22 Mahan, Shannon A.

Sr, O, AND H ISOTOPES AS TRACERS OF REGIONAL GROUND-WATER FLOW THROUGH THE SPRING MOUNTAINS TO ASH MEADOWS, SW NEVADA.

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Water samples collected from two wells and thirteen springs were analyzed for $\delta^{87}Sr$, $\delta^{18}O$, and δD to elucidate ground-water flow west through the Spring Mtns. to the Ash Meadows discharge area. Two wells and one spring representing the northeastern part of the Ash Meadows flow system, were sampled in Mercury Valley. The range of $\delta^{87}Sr$, $\delta^{18}O$, and δD values are 3.6 to 1.4, -14.0 to -13.6, and -101.5 to -98.9‰, respectively. The one sigma analytical precision for these measurements is ± 0.05 ($\delta^{87}Sr$), ± 0.18 ($\delta^{18}O$) and ± 1.4 (δD).

Springs in the Spring Mtns. discharge from two different lithologies separated by the Wheeler Pass Thrust Fault. Northwest of the fault, four springs emanating from Precambrian/Cambrian quartzites and siltstones yield relatively higher $\delta^{87}Sr$, and heavier $\delta^{18}O$ and δD (15.2 to 39.0, -13.0 to -13.2, and -89.5 to -92.0‰, respectively). $\delta^{87}Sr$ becomes higher (increasingly radiogenic) as you move away from the fault to the northwest, with Diehert Spring having a value of 39.0‰. Southeast of the fault, springs that emanate from Paleozoic limestones/dolostones yield markedly lower values. At Willow Spring for example, the $\delta^{87}Sr$, $\delta^{18}O$, and δD values are -0.7, -14.4, and, -97.1‰, respectively.

Groundwater moves west through the Spring Mtns. to the Ash Meadows discharge area which is controlled by a 16 km-long fault. Three springs (Big, Bole, and Last Chance) at the southern end of the line, have an isotopic signature distinct from the five main springs sampled farther north. The range for $\delta^{87}Sr$, $\delta^{18}O$, and δD values of the southern springs are 11.1 to 13.9, -12.4 to -13.9, and -91.3 to -101.0‰, respectively. The four northern springs (Fairbanks, Rogers, Longstreet and Point of Rocks) exhibit lighter values ranging from 4.6 to 5.0, -13.6 to -14.1, and -102.9 to -104.3‰.

These isotopic differences are related to recharge and multiple flow paths. The higher $\delta^{87}Sr$ values from Big, Bole and Last Chance springs appear to reflect a component of flow through the Precambrian rocks, or alluvium derived therefrom. Ground-water discharging the four northern springs may have passed to the north, around the Spring Mtns., avoiding interaction with the Precambrian/Cambrian rocks. The correlative differences in $\delta^{18}O$ and δD values between high (Paleozoic) springs and lower (Precambrian) springs also reflects a difference in altitude of the recharge areas, which is carried through to the discharge sites.

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