to develop a geological model. Calibration information is also placed in the GIS. Information regarding surface water bodies, drainage, and so on is translated to the model framework within the GIS. Geospatial queries and SQL programming are used to translate these to a modeling grid. The GIS is utilized in developing input to and processing results from particle tracking modeling for well fields and critical river reaches. Maps of for example ground water age, which formations contribute to the flow system, and degree of utilization (sustainability) are easily available. Furthermore, as the results are integrated in a GIS this improves analyses as well as capabilities to communicate results to vested interests and decision makers.

H11C-0882 0830h POSTER

The Use of Geographic Information System Technologies in a Groundwater Model of the Chicot Aquifer System

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The flexibility and scalability of a regional scale groundwater model can be improved by utilizing Geographic Information Systems (GIS) technology in all aspects of the modeling effort. A groundwater model of the Chicot aquifer in southwestern Louisiana is currently being developed to assist in the development and management of the groundwater resource. Georeferencing the model allows model developers to incorporate different types of data, often from different sources, following a single coordinate system. For example, the Louisiana Department of Transportation and Development (LADOTD) maintains a GIS water well database that allows water wells to be easily incorporated into the model as analytical element wells; this database can be combined with a specified pumping rate based on the category of use and spatial location of the well. GIS also allows for non-point data such as geological structure and hydrogeological parameters (e.g., storage, recharge, etc...) to be incorporated into the model and easily updated as more detailed information and data becomes available. In terms of scalability, the modeler can decide how detailed and what data is considered important in the model; the use of GIS allows for the information and data to either be represented as specific or lumped features. This capability is being utilized through the use of telescopic mesh refinement (TMR) to model parish-scale sections of the aquifer system. The presentation will show how GIS technologies have allowed for a vast amount of information and data to be incorporated into the Chicot aquifer regional groundwater flow model and how the use of GIS has allowed for continual model improvement through the incorporation of more accurate spatial data. Finally, we will show how rainfall data and remote sensing data, identifying the location of agricultural fields, can be combined to improve our ability to accurately incorporate irrigation-related groundwater pumping into the model.

H11D MCC: Level 2 Monday 0830h

Natural Attenuation at the Fringe: Reactive Zones in Biodegrading Groundwater Pollution Plumes Posters *(joint with B)*

Presiding: **D N Lerner,** University of Sheffield**; T Ptak,** University of Tuebingen

H11D-0883 0830h POSTER

Vertical Transverse Dispersion Controls the Natural Attenuation of Spatially Variable Plumes

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Many, if not most organic contaminant plumes are spatially variable. This presents a challenge for natural attenuation assessment using traditional methods that rely on monitoring along plume centrelines that are necessarily assumed to be unique. An alternative approach is to characterise the processes that control attenuation, and delineate where those processes occur within the plume. For example, carbon turnover in many organic plumes is constrained to biodegradation at the plume fringe where contaminants mix with electron acceptors. This mixing is influenced by concentration gradients of organics (out of the plume) and oxygen and nitrate (into the plume), and vertical transverse dispersion. Where plumes consist of complex mixtures of organics, an added factor is the preferential degradation of certain compounds (target or non-target organics) due to various microbiological concerns. Accurate prediction of natural attenuation of such plumes may be possible if spatially discrete carbon turnover processes are considered in the context of spatial plume variability. A transect of four highly detailed multilevel sampling wells were installed across a well-studied tar acid plume migrating within the Triassic sandstones in the UK Midlands. The goal of these wells was to locate the upper plume fringe and quantify degradation within those zones. The multilevel sample ports were 20 cm apart to characterise both electron acceptor and donor profiles in great detail. The primary contaminants within the plume are the phenolics (phenol, xylenols, cresols), but other compounds are present that impose a demand on electron acceptor supply (tar neutrals TEX, C4-C8 benzenes, benzofuran and tar bases pyridines, picoline, aniline). The bioactive zone appears to be constrained to a narrow zone less than 1 m thick wherein all dissolved oxygen and nitrate are consumed, with phenol persisting to depth, consistent with weak vertical mixing due to weak dispersion at the scale of diffusion. The vertical position of this fringe varies in space, suggesting that natural attenuation cannot be accurately estimated by extrapolating the reactive processes quantified at one location to the plume as a whole.

H11D-0884 0830h POSTER

High Resolution Multi-Level Monitoring and Characterization of NA Processes

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Monitored natural attenuation is a potentially valuable risk-based remediation strategy for contaminated groundwater. The most important mass-removal process for natural attenuation is biodegradation. Certain zones or fringes of a contaminant plume offer enhanced conditions for biodegradation: microbes, nutrients, contaminants and electron donors / acceptors are not only found together but also in the required reaction ratios. Due to this fact these areas show a relative rapid degradation and provide a significant contribution to the overall reduction of mass within the plume. As can be shown by high resolution numerical simulations of reactive transport in groundwater, the spatial distribution of these highly reactive zones, compared to the volume of the whole plume, is quite small and characterized by steep concentration gradients, which can not be detected using standard monitoring procedures. High resolution multi-level sampling (MLS) in the order of 0.1m or less is an essential prerequisite for the investigation of NA processes within the reactive fringes at field scale. This contribution presents results from ongoing research on high resolution MLS at six field sites in different European countries. The focus was on an optimized site-specific hydraulic design and contaminant - MLS-material interaction. Most acceptable solutions (which means MLS resolution in the order of 0.1m) were found using sampling tubes with a small inner diameter (3-4mm). This results in a small stagnant water volume prior to sampling, but is still not problematic with respect to the flow induced hydraulic losses within the tube. Another requirement for high resolution sampling was to abandon standard sampling protocols (DIN, EPA, *ldots*) which often demand huge groundwater volumes (1 liter) for every single compound to be analyzed. To estimate the effects of the tubing material on the quality of the groundwater samples, an analytical model by Reynolds et al. (1990) was used to study the sorptive uptake of different organics by different tubing polymers, considering partitioning coefficients, intra-polymeric diffusion coefficients and tube-surface to tube-volume ratios.

H11D-0885 0830h POSTER

Determination Of Transverse Dispersivities At Lab Scale: Conservative Transport And Steady State Reactive Plumes

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Effective remediation of contaminated ground water by Natural Attenuation relies on the ability to predict and quantify the processes that occur in contaminant plumes. Transverse mixing is a significant mechanism for the fluxes of electron acceptors and donors and thus may control the lengths of steady state plumes. Especially reactive mixing, which is governed by pore-scale processes, must be well understood at the local scale. This work aims to systematically investigate the influence of aquifer material properties, e.g grain sizes, grain size distributions, porosity, and variation in ground water flow velocity on the magnitude of the transverse mixing in saturated porous media. The dispersion of a conservative tracer was determined by measuring the distribution of fluorescein plumes at the outlet of a 2D flow-through tank. The dispersion values of the respective steady state plumes were evaluated by fitting the Gaussian (normal) distribution to the measured fluorescein data points. Steady state reactive plumes have been created in the tank using two different instantaneous bimolecular reactions. A complexation between copper(II) ions and EDTA and an acid/base reaction using HCl and NaOH were chosen on account of their fast reaction kinetics. The influence of flow velocity, concentration ratio and grain size on the length of the steady state plumes have been investigated for these reactions.

H11D-0886 0830h POSTER

Large-Time Behavior of GW Pollutant Plumes Subject to Biodegradation at the Fringe: Mathematical Analysis and its Application to a Large-Scale (10 km) Field Problem

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Engineered bioremediation and monitored natural attenuation are important options for the cleanup of frequently occurring subsurface contamination by organic compounds. Because the contaminant removal occurs only when the substrates, target contaminants, and degrading bacteria are present simultaneously, the controlling mixing processes of the contaminants and substrates dictate the contaminant removal rate. Due to the complex nature of subsurface environments, in-situ bioremediation often involves many physico-chemical and biological processes concurrently. Thus, mathematical modeling is a useful tool -and probably the only effective tool- to identify the rate controlling processes. As a tool for predicting the environmental impact of a spill and/or for screening the effectiveness of possible remediation technologies, its ability to correctly capture the key processes is important. However, classical modeling involving the discretized form of the governing equations over very large spatial domains and long periods is computationally infeasible at this point. In this research, we investigate the large-time solution behavior of a representative bio-reactive transport model assuming the mixing of two required substrates occurs only in the directions transverse to groundwater flow. The processes are governed by the commonly used advection-dispersion-reaction equations. The microbial growth and decay in the model are described by the double Monod kinetics terms and a linear decay term. The flow field is assumed to be uniform. We have developed a practical approach to estimate the size of the microbial reaction zone and the level of microbial concentration. We have found out that the microbial reaction rates are always limited by the transverse transport of the substrates at steady state, provided that the bulk substrate concentrations are much larger than a characteristic value determined only by the microbial kinetic parameters. Thus the reactions can be considered as instantaneous for the purpose of mathematical modeling. This simplification allows us to efficiently find the steady-state solutions for large scale field problems. We will present a field application which indicates the mixing with the ambient oxygen at the plume fringe may successfully constrain the spread

of a high total organic carbon (500mg/L) plume, generated from a passive bio-reactive barrier. But the concentration reduction along the center line of the plume is insignificant.

H11D-0887 0830h POSTER

Field Sampling and Modeling of Creosote-Derived Contamination in a Tdally Forced Aquifer

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We are investigating the fate and transport of a creosote-derived groundwater contaminant plume found in an aquifer adjacent to and beneath a large, tidally forced river. The site, located in Coquitlam, BC, is adjacent to the Fraser River, and has been an active wood preserving facility since the 1920's. In the on-shore source zone, creosote has penetrated into the aquifer and a dissolved-phase plume, composed primarily of naphthalene, flows in the site aquifer from the source zone towards and below the river, eventually discharging from the river bottom. A capture well has been operated since 1996 to contain and capture the contaminant source. Previous research at this site has documented that biodegradation of naphthalene takes place in the plume fringe in the region of the aquifer that is beneath the river, but not onshore. Abundant methane and ferrous iron in the aquifer suggests that iron reduction and methanogenesis are the dominant terminal electron accepting processes. High offshore naphthalene concentrations sampled in 1999 despite three years of source containment and degradation led to the hypothesis that the plume may be at steady state due to buffering of contaminant concentrations by desorption from aquifer sediments. Naphthalene concentrations sampled in this study show that the contaminant plume is not at steady state. Results of groundwater flow modelling and sorption data show that the continued presence of high concentrations of naphthalene offshore are likely due to incomplete source containment or to slow migration of contaminants from upgradient regions of the aqueous plume. Although naphthalene has been the focus of all previous investigations of the offshore plume at this site, recent sampling shows that two other components of creosote, indane and benzothiophene, become the dominant components of the aqueous phase plume as it approaches the discharge point. Significant concentrations of these contaminants are likely discharging to the river. Relative enrichment of these compounds along the plume profile, despite their lower sorptive properties and therefore greater susceptibility to tidally-driven mass loss, suggests that these components are not biodegraded to the same degree as naphthalene.

H11D-0888 0830h POSTER

Coupled Vapour Phase and Dissolved Gas Analysis to Elucidate Physical and Geochemical Processes in Reactive Zones

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Dissolved and vapour phase gas data, including Ar, N_2, O_2, CH_4 and CO_2, were collected at a crude oil spill site near Bemidji, MN. The dataset includes sampling points in the saturated and unsaturated zones from upgradient of the source zone, within the source zone, and down-gradient extending beyond the anoxic vapour and dissolved phase plumes. In the source zone dissolved Ar and N_2 concentration are depleted to concentrations below 50% of water equilibrated with the atmosphere. This is indicative of gas bubble formation caused by increased levels of CH_4 from methanogenic degradation of the oil, and partitioning of Ar and N_2 into the bubbles. In the unsaturated zone, above the most methanogenic areas, vapour phase Ar and N_2 concentrations also show a depletion, to concentrations less than 90% of atmospheric levels, indicating significant methane production in this zone and/or gas influx from the saturated zone. Directly surrounding these areas of depletion vapour phase Ar and N_2 concentrations show an enrichment whereas CH_4 and O_2 concentrations are low indicating advective gas flux from the atmosphere toward this zone. Furthermore, directly downgradient of the methanogenic zones dissolved Ar and N_2 concentrations return to levels that approach water equilibrated with the atmosphere where advective flow calculations would predict depleted concentrations to be transported much further. This observation suggests either limited flux through the source zone or increased mixing of water from the dissolved plume with stagnant water in low permeability zones, or possibly with trapped gas bubbles. The results of this study demonstrate the use of naturally occurring non-reactive gases as effective tracers of both physical and geochemical processes in contaminated systems. This includes quantifying rates of methanogenesis, gas bubble formation and ebullition, methane oxidation in the unsaturated zone, and mixing within the groundwater plume. Additionally, this study highlights the importance of considering the saturated and unsaturated zone as a coupled system. In the methanogenic source zone, geochemical parameters such as CH_4 and CO_2 and pH will be affected by the gas flux from the saturated zone to the unsaturated zone. An accurate accounting of these parameters can be particularly important for models where rate estimates of geochemical processes depend on accurate mass balances. Future work will involve laboratory experiments and the use of reactive transport modelling to demonstrate these principles in a quantitative manner.

H11D-0889 0830h POSTER

Numerical Modeling of Plumes Controlled by Transverse Dispersion

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Transversal mixing of reactants through dispersion and diffusion is in many cases the controlling factor for the attenuation of contaminants. For example, it is crucial for the supply of electron acceptors, or growth limiting nutrients, to plumes of biodegradable, oxidisable organic compounds. Indeed it has been experimentally and analytically proven that in situations where one electron acceptor dominates the degradation process, the stationary length of a plume can be quantified solely as a function of the transversal dispersion coefficient α_T and a few basic hydro(geo)logical parameters (Ham *et al.*, 2003). Classical works (de Josselin de Jong, 1958; Bear, 1972) assume that the transversal dispersion coefficient consists of two terms: a molecular diffusion term and a hydrodynamic dispersion term. The latter is assumed to be a linear function of the flow velocity and the transversal dispersivity α_T, where α_T is a constant. However, recent non-reactive and reactive laboratory-scale tank experiments by Olsson *et al.* (2003) challenge this assumption. In this study a reactive multi-component transport code (PHT3D) is used in combination with statistical linear regression techniques for a detailed analysis of the experimental data and suggest a nonlinear velocity dependency for the dispersion term. The results indicate that the experimental data of the reactive transport experiment (concentration profiles of reactants, steady-state plume length) can be adequately described by the numerical model for a large range of velocities, when the nonlinear velocity dependency is employed in combination with a theoretically derived, representative single molecular diffusion coefficient.

H11D-0890 0830h POSTER

Predicting Plume Development of Reactive Solutes Using an Analytical Transport Model

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Transversal dispersion is considered to be the controlling mixing process in many cases where contaminant plumes attenuate naturally. An analytical model is presented, which describes the transport of a reactant B continuously injected at the origin through a 2-D domain initially filled with a reactant A. Moreover a simple, instantaneous chemical reaction of the form $A + B \rightarrow AB$ is considered. The flow domain is a porous medium, the aquifer assumed homogeneous with steady, uniform flow. Explicit steady state solutions (in the limit $t \rightarrow \infty$) are presented for the distributions of reactants and products in $x - y$ space in the form of the modified Bessel function of zeroth order and second kind. From this a solution is presented to quantify the length of a plume given a few basic (geo)hydrological parameters. It is proven that zeroth or first order approximations to the Bessel function, in the limit $0.1 > \beta > 1$ and $0.01 > \beta > 0.1$ respectively, where $\beta = \alpha_T/\alpha_L$; $\alpha_L = 1$, accurately represent plume lengths. Furthermore it is shown that in the first case plume length does not depend on longitudinal dispersivity α_L, but only on pre-defined (geo)hydrological parameters, including α_T. This result infers that in many practical situations the influence of α_L upon plume length is negligible. In the latter case, the plume length is written as a function of both α_T and α_L. The assumption that α_L is only important for the transient development of the plume, is verified through the use of a numerical solution. Results demonstrate that for values of β close to unity plume growth is rapid and largely linear, quickly reaching an asymptotic value. For $0.01 > \beta > 0.1$, plume growth demonstrates real longitudinal dispersive effects, growth rate being considerably slower.

H11D-0891 0830h POSTER

Delineating Reactive Natural Attenuation Zones: Multi-level Sampling in an Ammonium Plume

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Current natural attenuation monitoring involves observing concentrations along some transect parallel to flow, often in long–screened observation wells. Vertically integrated geochemical signals essentially compresses 3D-problems into 2D ones and the loss of process resolution does not allow for robust plume transport prediction. On the other hand, a monitoring approach that is based on process quantification will yield field data necessary for current natural attenuation assessment and allow more accurate prediction to plume behaviour. To quantify these spatially discrete processes, the resolution of sampling points must be higher to delineate reactive zones, that account for the bulk of natural attenuation. These reactive zones are dependent on aquifer properties, contaminant type, redox zonation and other factors. In many cases, the plume fringe will be the most active zone, because influx of certain nutrients necessary to support bacteria will be greatest in these zones. Most importantly, consortia of degrading bacteria are dependent on supply of electron–acceptors such as dissolved O_2 and nitrate from background ground water and recharge; electron–acceptors are rapidly consumed at the fringes and concentrations decrease significantly towards the centre of the plume. Thus, if a process–based approach is to be achieved, one has to focus not only on the overall extent and mass of a contaminant plume, but, more importantly, on a sound analysis of the most reactive zones. The site of a former coal processing plant in the UK was chosen as a field site where the afore–mentioned hypothesis is currently being investigated by means of two recently installed multi–level samplers. Previous investigations have located an ammonium plume at the site with outwash from the thick unsaturated zone as ongoing source since the demolition of the actual plant in 1970. The conceptual model drawn from the analysis of these data shows that certain zones exhibit higher rates of degradation than others, but the extent of these zones and rates of degradation could not be determined with the sampling methods used in previous investigations. Spacing between the sampling ports in the newly installed multi–level samplers is $25cm$ across the top fringe of the plume, and the ground water is analysed for contaminants, general redox chemistry of the aquifer, and isotopes. The analysis of groundwater samples from a first sampling round performed in late summer 2003 shows that i) nitrification is ongoing at the upper fringe in a zone about $0.5m$ thick, but concentrations of nitrate encountered at the ports across the fringe are higher that derived from the degradation of available ammonium; ii) concentrations of electron–donors and –acceptors change rapidly in the fringe–zone; iii) inside the plume, different processes are prevalent than at the upper fringe; iv) a trend in the isotopic composition appears to indicate a distinct consumption of carbon and sulphate by microbial activity, but these data are not unequivocal and should only be used as supportive evidence.

H11D-0892 0830h POSTER

BIOVENTING - Groundwater Aeration by Discontinuous Oxygen Gas Pulse Injections

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Groundwater aeration by discontinuous oxygen gas pulse injections appears to be a promising concept for enhanced natural attenuation of dissolved contaminants that are susceptible for oxygenase enzyme attacks. Oxygen amendments facilitate indigenous microbiota to catabolize groundwater pollutants, such as aromatics, that are considered to be recalcitrant in absence of dissolved oxygen. As a rule, natural attenuation of many pollutants under aerobic conditions is considerably faster than under anaerobic conditions. Thus, enhancing the dissolved oxygen level appears to be worthwhile. In situ aeration of groundwater has been accomplished by air sparging, H2O2-supply, or by utilization of oxygen release compounds. However, continuous aeration of previously anaerobic groundwater is not desirable for several reasons: (a) economic efforts too high, (b) pollutant dislocation towards surface (desired only in air sparging), (c) risk of aquifer clogging (gas clogging, oxidation of ferrous iron, formation of bioslimes). In contrast, discontinuous oxygen gas sparging provides only for periodical groundwater aeration which is followed by microaerobic and suboxic conditions. Microaerobic conditions can prevail spatially (e.g., at plume fringes or within biofilms) or temporarily (e.g., at discontinuous bioventing). They still allow adapted bacteria to transform environmental pollutants to less toxic compounds, e.g., aromatic ring cleavage after dioxygenasis attack. Ring cleavage products, on the other hand, may be degraded more easily by anaerobic consortia than the initial aromatic compounds, making oxygen depletion periods highly intriguing in regard to an initiation of natural attenuation processes at plume fringes. In our work we outline the effect of oxygen depletion conditions on biodegradation of monchlorobenzene (MCB) as they occur subsequently to temporary aeration periods. For microaerobic conditions, relative to the oxygen supply, a stoichiometric transformation of MCB to cis,cis-2-chloromuconate is demonstrated. In order to examine effects of enhanced natural attenuation, initiated by aeration, on geohydraulics, discontinuous oxygen gas injections were simulated in two flow-through systems. Design, processing, and first results of our ongoing research are presented for the automatized lab column system CAMERA and a pilot field reactor at a MCB polluted site at Bitterfeld, Germany. Bubble mediated oxygen gas transfer is briefly discussed in light of the model presented recently by Holocher (Environ. Sci. Technol., 2003. 37: p. 1337-1343).

H11D-0893 0830h POSTER

Natural attenuation of copper in the water table aquifer below an industrial site

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The contamination of soils and aquifers by inorganic pollutants is so extensive in industrial sites that it hardly seems economically feasible to decontaminate the large areas or soil volumes involved. It is therefore worthwhile to investigate whether the local environment is capable of attenuating contamination. Natural attenuation by degradation seems realistic for many organic pollutants. We show that it can also occur for inorganic pollutants. The phreatic-fill aquifer underlying an industrial plant located on the banks of the Garonne River (Southwestern France) is contaminated by acidic water (pH down to 1) and high concentrations of sulfate (up to 50 g/L) and copper (up to 30 g/L). As acidic water, rich in Cu and sulfate, moves away from the contamination source, pH increases due to buffering of aquifer solids, dissolved Cu concentrations decrease by 6 orders of magnitude, while sulfate concentrations decrease little. The Cu disappearing from the water phase is found as solid in cores in the area of the site where pH increases to 5-6.

H11D-0894 0830h POSTER

Analytical Modeling of A By-product Transport in Chain Reactions

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Many chemical reactions of contaminants in the subsurface involve complex reaction pathways and networks. As one of those reaction networks, chain-reactions can be found in radionuclide decay, denitrification, biodegradation of chlorinated solvents, etc. For example, this reaction pattern can be illustrated by the biodegrdation of tetrachloroethylene (PCE) and trichloroethylene (TCE). PCE reacts to produce TCE and TCE reacts to form dichloroethylene (DCE). DCE will further reacts to form vinyl chloride (VC) and finally VC reacts to produce thylene (ETH). During the chain reactions, by-products, such as chloride in PCE reaction chain, can be produced in groundwater. For this reason, by-prodcut concentrations in the contaminant plumes are elevated relatively to ambient concentrations. Because of the neutral chemical behavior of some by-products, they can be treated as indicators to identify the sources of contaminants and to estimate reaction rates. Often, a single by-prodcut is produced from multiple steps in a reaction chain. Then, the partial differential equation for by-product mass balance is coupled by multiple reactants. This makes it difficult, if not impossible, to derive analytical solutions using integral transforms. Instead, we conduct singular value decomposition (SVD) analytically and develop a closed-form solution of a by-product transport in multiple chain reactions. In achieving the analytical solution, all reactions are assumed to be first-order and the system is assumed to be homogeneous and isotropic.

H11E MCC: Level 2 Monday 0830h

Moving Beyond the Model Development Stage: Groundwater Model Validation, Postaudits, and Long-Term Monitoring Posters

Presiding: **T D Scheibe,** Pacific Northwest National Laboratory**; A E Hassan,** Desert Research Institute**; B S Minsker,** University of Illinois

H11E-0895 0830h INVITED POSTER

Validation of Groundwater Models: Meaningful or Meaningless?

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Although numerical simulation models are valuable tools for analyzing groundwater systems, their predictive accuracy is limited. People who apply groundwater flow or solute-transport models, as well as those who make decisions based on model results, naturally want assurance that a model is "valid." To many people, model validation implies some authentication of the truth or accuracy of the model. History matching is often presented as the basis for model validation. Although such model calibration is a necessary modeling step, it is simply insufficient for model validation. Because of parameter uncertainty and solution non-uniqueness, declarations of validation (or verification) of a model are not meaningful. Post-audits represent a useful means to assess the predictive accuracy of a site-specific model, but they require the existence of long-term monitoring data. Model testing may yield invalidation, but that is an opportunity to learn and to improve the conceptual and numerical models. Examples of post-audits and of the application of a solute-transport model to a radioactive waste disposal site illustrate deficiencies in model calibration, prediction, and validation.

H11E-0896 0830h INVITED POSTER

Development of an Integrated Ground-Water Monitoring Strategy for Supporting Performance Assessments of Nuclear Facilities

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The U.S. NRC is funding research to develop an integrated ground-water monitoring strategy to support performance assessments (PA) of nuclear waste and decommissioning sites. These PAs provide the scientific and regulatory bases for a risk-informed decision as to the long-term safety of waste disposal and decommissioning sites. The strategy will assist in NRC staff reviews of predicted consequences related to potential radionuclide releases from licensed nuclear facilities. The strategy couples site characterization and PA through identification and monitoring of hydrogeologic system performance indicators such as distributions of water content in the unsaturated zone and ground-water potential in the saturated zone, as well as radionuclide concentrations. The strategy considers the need to monitor for a range of alternative conceptual groundwater models, and to quantify parameter and model uncertainties. The strategy will be tested using real-time monitoring datasets. Recognizing that each site has its unique set of features, events and processes, the strategy will focus on methods for designing monitoring systems to detect both current conditions and changes in the system's behavior relevant to radionuclide leaching and transport. Beyond identifying and mapping contaminant plumes, the monitoring goals are to: identify the presence or potential for preferential transport pathways; assess the effectiveness of contaminant isolation systems; identify and support alternative conceptual flow and transport models; and communicate the monitored performance indicators through effective data management, analysis and visualization techniques for decision makers and stakeholders. Progress to date involves the review and harmonization of monitoring programs, strategies and guidance presently used to evaluate both radioactive and toxic waste facilities.

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Linking the Model Validation Process and Long-Term Monitoring Design for Central Nevada Test Area

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A multi-staged approach for development of the long-term monitoring well network for the Central Nevada Test Area (CNTA) is proposed. This multi-staged approach will proceed in parallel with the validation efforts for the groundwater flow and transport model of CNTA. The first stage of the plan is to use the hydrogeologic insight combined with the simulation and probability-based approaches to select the first set of monitoring wells that will serve two purposes or objectives. The first high-priority objective is the collection of data for the initial evaluation of the groundwater flow and transport model. The selection criteria will thus be tailored more toward meeting this objective and facilitating the collection of the most relevant data from the most important locations for evaluating the different model components. The second objective, which has a lower priority, is to place this set of wells in locations likely to encounter fast migration pathways, and thus benefiting from the wells in the long-term &a

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Analysis of Measurement Error and Estimator Shape in Three-Point Hydraulic Gradient Estimators

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Three spatially separated measurements of head provide a means of estimating the magnitude and orientation of the hydraulic gradient. Previous work with three-point estimators has focused on the effect of the size (area) of the three-point estimator and measurement error on the final estimates of the gradient magnitude and orientation in laboratory and field studies (Mizell, 1980; Silliman and Frost, 1995; Silliman and Mantz, 2000; Ruskauff and Rumbaugh, 1996). However, a systematic analysis of the combined effects of measurement error, estimator shape and estimator orientation relative to the gradient orientation has not previously been conducted. Monte Carlo simulation with an underlying assumption of a homogeneous transmissivity field is used to examine the effects of uncorrelated measurement error on a series of eleven different three-point estimators having the same size but different shapes as a function of the orientation of the true gradient. Results show that the variance in the estimate of both the magnitude and the orientation increase linearly with the increase in measurement error in agreement with the results of stochastic theory for estimators that are small relative to the correlation length of transmissivity (Mizell, 1980). Three-point estimator shapes with base to height ratios between 0.5 and 5.0 provide accurate estimates of magnitude and