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Fall Meeting: November 24, 2020

Virtual Meeting

Opening Remarks at 9 AM
Tentative Program Speakers/Topics:

9:15 AM — **Mir A. SeyedAbbasi, Ph.D. PE** — "Influence of Matrix Diffusion from Low-Permeability Lenses within Source Zones on Contaminated Aquifers Cleanup Time"

9:45 AM — **Joe Krienert, Ph.D. (student)** – "Tracing surface and ground water transport of nitrate in the Middle Mississippi River Floodway"

10:15 AM — **Patience Bosompemaa, Ph.D. (candidate)** – "Recycling of nitrate and organic matter by plants in the vadose zone of a saturated riparian buffer"

10:45 AM — *Break*

11:00 AM — **S.V. Panno, M.Sc.** – "Statewide Cover-Collapse Sinkhole Database for Illinois"

11:45 AM — **Chris Greer, Ph.D.** – "Bedrock Groundwater Response and Management: NuMI Experiment at Fermilab"

12:30 AM — *Lunch Break*

12:45 PM — **Lee Anne Bledsoe, M.Sc.** – "Applied Methods of Karst Hydrogeology"

1:30 PM – Closing discussions

2:00 PM – Meeting Adjourned

Influence of Matrix Diffusion from Low-Permeability Lenses within Source Zones on Contaminated Aquifers Cleanup Time

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A key site metric for most site stakeholders is to understand how long non-aqueous phase liquid (NAPL) sources in the saturated zone will continue to contribute to the long-term dissolved phase concentrations. Low permeability compartments within source areas, and in plumes downgradient of sources, can store significant amounts of dissolved contaminant mass and therefore hinder the site cleanup efforts even with complete NAPL depletion. This "secondary aqueous phase source" can be the dominant factor governing the source longevity and downgradient groundwater quality after complete NAPL depletion.

Recently there has been an increased appreciation of the effects of matrix diffusion on source zones and secondary aqueous phase sources where extensive numerical modeling efforts were performed to evaluate the relative importance of each contributing component (Chapman et al., 2012; Seyedabbasi et al., 2012; Farhat et al., 2020). Matrix diffusion has been shown to greatly increase the remediation timeframe for plumes downgradient of isolated NAPL source zones. In this study, NAPL and secondary aqueous phase sources surrounding low-permeability (low *k*) aquitards are numerically modeled to study the relative contribution of NAPL versus matrix diffusion to source longevity.

The results of this vertically high-resolution modeling exercise show the matrix diffusion can be a critical component of source zone longevity, and may contribute more to source longevity than NAPL dissolution alone at many sites. Multiple single-component NAPLs with various degrees of aqueous-phase solubility are examined. For example, one simulation with a single-component 650 kg TCE DNAPL source indicated that dissolution of DNAPL would take approximately 50 years, while the back diffusion from low-permeability zones could maintain the source above a 5 ug/L groundwater standard for an additional 200+ years. A high-solubility contaminant (1,2-DCA) showed a much more dramatic contribution to the matrix diffusion source compared to DNAPL dissolution (99% of longevity due to matrix diffusion), while a low-solubility contaminant (PCE) showed a more equal contribution from DNAPL dissolution vs. matrix diffusion sources. The assumptions and limitations of this simulation approach will be described.

Tracing surface and ground water nitrate transport in the Middle Mississippi River Floodway

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Recent research suggests emergent wetlands along the Upper Mississippi River (MR) channel can reduce nitrate concentrations five times more efficiently per unit area than the most effective land-based strategies. These Upper MR wetlands incorporate environmental conditions (ample liable carbon, and anoxia) that promote microbial nitrate reduction, but rates were contingent on hydrologic connection to nitrate loads in the MR channel. Although this limitation has been acknowledged elsewhere along the MR, the governing hydrology that transports nitrate from source to sink, especially through groundwater pathways, remains undescribed.

This project evaluates nitrate reduction capacities in emergent wetlands of the Middle MR batture (the alluvial lands between river and levee), with a focus on tracing the surface *and* groundwater transport of nitrate through the regions critical zone. The first phase of this work is hydrologic mapping using empirical observations and numerical models to test three main hypotheses; 1. hydrologic connection between surface water, perched shallow groundwater, and deep alluvial groundwater is coupled with MR discharge rates, 2. hydrostratigraphy is the primary driver of mixing between these systems during bankfull or greater MR discharge, and 3. there is a non-linear relationship between discharge and hyporehic extents of the MR channel.

Observations of water elevation in wells and drainage-ditches across the batture suggest the hydrologic connection between surface and ground water systems generally proceeds quicker laterally than vertically. Conservative tracer mixing models of δ2H/δ18O isotope values and chloride/sulfate concentrations suggest that piston-flow extends > 1000 ft transverse from the channel into the deep alluvial aquifer during flooding (river discharges of >400kcfs or 10% exceedance probability at Chester, IL). During these piston-flows, artesian waters leaving levee relief wells showed nitrate concentrations consistently (n=25) below ion chromatograph detection limit < 0.1 ± 5% mg/L, while neighboring source reservoirs expressed average concentrations ranging from 0.5 (precipitation) to 9.3 (MR channel) ± 5% mg/L. These preliminary findings suggest subsurface pathways exist that promote nitrate reduction, potentially more efficiently than surface water and land-based systems.

Recycling of nitrate and organic matter by plants in the vadose zone of a saturated riparian buffer

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Excess nitrate in the soil is an issue in agricultural land-use regions, contributing to eutrophication and pollution of water bodies. This study examines the role of plant uptake within the vadose zone of a saturated riparian buffer (SRB) to remove nitrate from the groundwater. Two hypotheses were explored:1) During the growing season, nitrate removal will be greater in the presence of plants than where plants are absent (barren) and 2) Following the growing season, nitrate concentration in the soils underlying a barren plot will be less than in the soils underlying a plot with plants. Within the SRB, three experimental blocks composed of two plots were established. One plot allowed the growth of plants, switchgrass (*Panicum virgatum* L.), and the other plot was barren with plant growth inhibited. Statistical comparison of among the treatments, Pre-growing season, plot with plants, and barren plot, and among the different depths, 30 cm, 60 cm, and 90 cm identified significantly different soil NO_3^--N concentrations. Plots with plants experienced a reduction in nitrate from the soil and vadose waters. Plants withdrew nitrate from the vadose zone, generating organic matter. Nitrate concentrations in the soils underlying the barren plot were high because there was no uptake and the residual plants materials decomposed, returning nitrogen to the vadose. The observed nitrate concentrations in the soil were similar to measured values four years prior, suggesting that the nitrate concentrations in the vadose remain stable, suggesting that the plants serve as a short-term nitrate sink.

Statewide Cover-Collapse Sinkhole Database for Illinois

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Karst in Illinois can be defined as terrain and associated bedrock aquifers formed by the dissolution of carbonate bedrock resulting in features that include solution-enlarged crevices, conduits, caves, bedrock springs, and cover-collapse sinkholes. Karst terrain is present throughout the world, and groundwater from karst aquifers is a major source of drinking water supporting roughly a quarter of the world's population. However, because of human activities, the land surface in such regions is vulnerable to accelerated erosion, and underlying karst aquifers are susceptible to contamination by surface-borne pollutants due to their open nature.

Karst regions of Illinois were first mapped by the ISGS in mid-1990s through a) examination of closed contours present on USGS 1:24,000 and 1:62,500-scale topographic maps, b) cave locations collected by the Illinois Natural History Survey, c) use of the statewide 1:500,000-scale bedrock geology compiled by the Illinois State Geological Survey (ISGS) as a guide for the distribution of carbonate bedrock, and d) field work conducted throughout the state. This effort culminated in the 1997 ISGS publication of the Karst Terrain and Carbonate Rocks of Illinois. Twenty-three years later, funding provided by federal and state agencies has recently concluded in the first-time statewide completion of airborne lidar enhanced elevation data and following extensive QA/QC analyses of the resulting data, the establishment of a county-based accessible database at ISGS of the lidar deliverables.

Because of the significant improvement in both the horizontal resolution and vertical accuracy of lidar bare-earth digital elevation data models, it became possible to undertake a statewide inventory all cover-collapse sinkholes. The purpose of this presentation is to describe this just-completed, first-time statewide inventory. Shaded relief imagery derived from county-based lidar bare-earth data models were used as the primary source of information for digitization of sinkhole features. Because many depressional areas can appear analogous to cover-collapse sinkholes on lidar shaded relief imagery, several ancillary GIS databases were employed during the digitizing for making interpretative decisions whether depressions are naturally-formed, cover-collapse sinkholes including the following: 1) statewide 1:500,000-scale bedrock geology map layer to define generalized areas of underlying carbonate bedrock; 2) U.S. Geological Survey Mineral Resource Data System (MRDS) digitized point location of known mine sites in Illinois; 3) Sinkhole Areas of Illinois GIS dataset showing generalized areas cover-collapse sinkholes interpreted in 1997 from a combination of various scales of USGS topographic maps and field work; and 4) ISGS Illinois Coal Maps depicting active and abandoned mines and their known extent, both as GIS point & polygon databases as well as PDFs depicting the information represented on USGS 1:24,000-scale topographic quadrangle maps. The mining-based datasets were used collaboratively to reduce the likelihood of mistaking surficial mine-related excavations and spoil piles within likely areas of naturally-formed sinkholes. Relict depression features from lead-zinc, fluorite, and coal mining are prevalent in several northwestern, southwestern, and southern Illinois counties. Other artificially-created features such as dammed ponds, ditches and culverts were identified and discounted.

Bedrock Groundwater Response and Management: NuMI Experiment at Fermilab

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Established in 1967 as America's national particle physics laboratory, Fermilab operates powerful particle accelerators for investigating sub-atomic particles. Today, the accelerator complex has grown to comprise seven particle accelerators and storage rings, delivering proton and other beams to detector and research experiments that involve international scientists from more than thirty countries.

The majority of the subsurface accelerator enclosures and targets at Fermilab are at an average depth of thirty feet below ground surface, with the exception being the NuMI (Neutrinos from the Main Injector) tunnel that dips downward into bedrock and ends at the MINOS near-detector hall at an approximate depth of 360 feet. Multiple aquifers within these depths are regularly monitored as part of the Groundwater Management Plan at Fermilab, with particular attention paid to the groundwater-bearing zones within bedrock that intersect the NuMI tunnel.

Groundwater residing in or below the Silurian dolostone bedrock aquifer, the upper surface of which is 50 to 80 feet below the ground surface in the Joliet Formation at Fermilab, as well as water in the immediately overlying Batestown Member or Henry Formation, is considered Class I resource groundwater. The NuMI tunnel directly intersects and interacts with the bedrock aquifers, particularly in the Kankakee and Elwood Formations of the Silurian dolostone and the Brainard Formation of the Maquoketa shale group. The entire NuMI tunnel system acts as a French drain, channeling the captured groundwater to a sump in the MINOS hall where the water is pumped to the surface for use in the accelerator industrial cooling water system.

Historical bedrock groundwater response during NuMI construction in the early 2000s and recent bedrock groundwater monitoring in preparation for the next-generation high-intensity neutrino experiment LBNF/DUNE (Long-Baseline Neutrino Facility/Deep Underground Neutrino Experiment) have helped refine our understanding of the depth intervals of the bedrock groundwater zones intersecting the NuMI tunnel. Flow directions and monitoring results are evaluated annually to ensure that the NuMI tunnel underdrain maintains capture of Class I groundwater around the potential NuMI target hall and decay region activation area. As the NuMI facility has aged, chemical treatment systems have been installed and adjusted to keep the drainage system open and will need to be maintained for decades following the eventual decommissioning of the NuMI experiment.

Applied Methods of Karst Hydrogeology

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Karst landscape/aquifer systems are estimated to constitute about 15% of the earth's ice-free land surface and supply water resources to up to 25% of the world's population. But karst hydrogeology is extremely challenging and complex, and karst landscape/aquifer systems have difficult water supply problems both with access, as surface water can be lacking, and quality, as available groundwater may be susceptible to contamination. This presentation will introduce the principles of karst hydrogeology and important methods for studying karst groundwater. Specialized methods, different from those used in porous media or other "traditional" groundwater environments, are required to understand and monitor karst groundwater. These methods include identification of subsurface flow paths through direct exploration and mapping, dye tracing, potentiometric surface mapping, geophysics, and geochemistry. Groundwater case studies will be used to discuss these various methods and their applications.