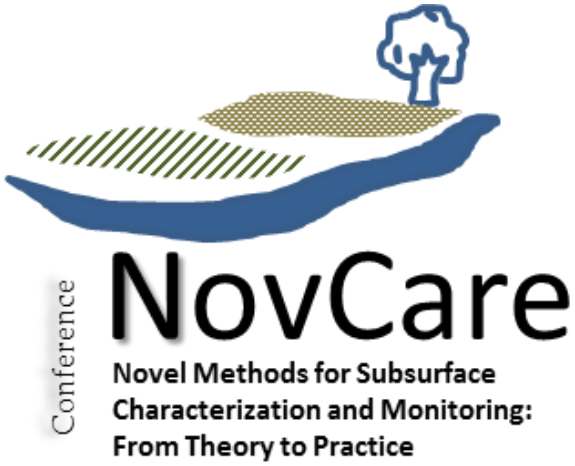
NovCare 2019 Book of Abstracts



Poster Abstracts

Abstracts are in the same order as they appear on page 20 of the NovCare program.

Integration of high-resolution hydraulic head data with equivalent porous media numerical modeling

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Keywords: EPM Modeling, Numerical Modeling, High-Resolution Head Data

Most Relevant Conference Theme: Multiscale monitoring in fracture rock environments

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Abstract

At two contaminated sites in Wisconsin and California, profiles of hydraulic head data versus depth have been collected in multilevel system (MLS) wells with exceptional spatial resolution (i.e., 3-4 monitoring intervals per 10 m) by the G^{360} Institute for Groundwater Research for many years. Researchers have used these data to aid in the conceptual understanding of groundwater flow in fractured rock systems. By examining vertical hydraulic gradients at a high resolution, hydrogeologic units can be delineated based on flow conditions, defined by multiple factors including degree of fracturing, rather than solely based on lithostratigraphy. At the Wisconsin location researchers installed high-frequency (i.e., 45 second interval) pressure transducers between spring and summer 2009 and summer to fall 2010 at select MLS wells to examine the longer-term transient hydraulic response to hydraulic stresses, such as precipitation and pumping. At the California site MLS have been used for two-decades for hydrogeologic definition, water quality and flow monitoring.

This presentation will focus on the application of high vertical resolution and high frequency head data at these sites to inform development of 3D equivalent porous medium (EPM) numerical models that represent groundwater flow through multilayered bedrock systems. Groundwater flow models were calibrated to steady-state high vertical resolution head observations, providing high quality targets to better represent the conceptual understanding of the groundwater flow system. Conventional wells that span aquifers and aquitards introduce bias and uncertainty that often is not accounted for. Use of the high vertical resolution MLS wells as targets allows the groundwater flow model to better represent these alternating transmissive and flow-resistant systems.

The combination of high vertical resolution and high frequency resolution head observations provide further insights into the groundwater flow system, particularly in response to precipitation events and pump shut-down events. The high-resolution observations were applied as model calibration targets. The ability of these models to represent the observed transient responses to hydraulic stresses gives confidence that the models can represent the site-specific characteristics of 3D groundwater flow systems at both sites. These models are key to understanding plume directions and advective travel times as well as hydraulic responses to remediation. These models inform the transport models that address the interaction of multiple processes at various scales.

Understanding the influence of ice barrier on the mobility of carbon, nitrogen and phosphorus in agricultural soils

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Keywords: Winter CO_2 Flux, Snow, Spring-Thaw, Winter Climate Change, Agricultural Soils, Nitrous Oxide, Methane

Most Relevant Conference Theme: Characterizing frozen and melting soils

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Abstract

Agroecosystems serve as a major non-point source of nutrients, contributing to the eutrophication of downstream waters and the proliferation of harmful algal blooms. Understanding the seasonal availability, transformation and speciation of carbon (C), nitrogen (N), and phosphorus (P) in agricultural soils is key to creating accurate nutrient budgets and models. In existing models, the impacts of winter soil processes are often ignored or under-developed. Current climatic trends and associated winter warming are altering the timing of snow cover and spring snowmelt, implicating biological, physical and chemical processes occurring in soils. Eruptions of greenhouse gases (GHG) such as carbon dioxide (CO_2) and nitrous oxide (N_2O) from agricultural soils have been associated with the thawing of soil, where the length of freezing has been linked to the magnitude of GHG release. This study explores ice as a barrier to gas exchange by comparing soils under a simulated ice layer with samples experiencing open gas exchange with the atmosphere in a laboratory-controlled setting. The results demonstrated that the presence of ice increases the concentrations of dissolved inorganic carbon and total nitrogen in porewaters below the soil surface. Time series data collected in this experiment will be used to model how changes in the duration of soil freezing may impact water quality in future climate scenarios and help to shape best management practices related to the application of fertilizer in the fall.

Identifying Groundwater Discharge Zones in Northern Canada Using Remotely Sensed Optical and Thermal Imagery

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Keywords: Groundwater, Remote sensing, Icings, Thermal Imagery, Permafrost

Most Relevant Conference Theme: Characterizing frozen and thawing soils, Advances in groundwater – surface water interaction and critical zone monitoring

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Abstract

Landsat 4-5 TM and RapidEye-3 datasets were used to identify groundwater discharge zones in the Central Mackenzie Valley (CMV) of the Northwest Territories. Given that this area is undergoing active shale oil exploration and climatic changes, identification of groundwater discharge zones is of great importance both for pin-pointing potential contaminant transport pathways, and for characterizing the hydrologic system. Following the works of Morse and Wolfe (2015), a series of image algorithms were applied to imagery for the entire Central Mackenzie Valley, and for the Bogg Creek Watershed (a sub watershed of the CMV) for selected years between 2004 and 2017. The algorithm series extracted 'icings' from the images. Icings (also called aufeis) are surface ice lenses formed where groundwater discharges in the winter months, then freezes. Icings were statistically examined for all of the selected years to determine whether a significant difference in their occurrence and size existed. It was concluded that there was a significant difference in the spatial distribution of icings from year to year, but that there were several places where icings were recurring. During a field visit in August of 2018, high resolution thermal imagery was captured for several of these locations and it was found that groundwater was also discharging in the summer. This provides strong evidence to suggest that the recurring icings represent springs from which groundwater discharges year-round. These springs represent ideal locations to monitor the quality of discharging groundwater following the establishment of fracking operations. Furthermore, identifying these monitoring points remotely is expected to have drastically reduced the field efforts that would have been required to find them in situ. This work demonstrates the value of remote geophysical methods for hydrogeological applications, particularly in areas that have limited accessibility.

Assessing the impact of intensive shallow geothermal energy use on groundwater temperatures in a residential neighborhood

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Keywords: Shallow Geothermal Energy, Groundwater, Energy Transition

Most Relevant Conference Theme: Specific monitoring requirements in ecohydrology

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Abstract

The use of shallow geothermal energy increasingly receives attention as a suitable alternative to fossil-fuel-based space heating and cooling, warm water provision, as well as for seasonal heat storage throughout Europe. While technical solutions have matured and their carbon reduction potential in comparison to conventional fossil-based heating systems remains unquestioned (if green energy is used), a lack of knowledge still exists in terms of subsurface temperature evolution in response to an intensified thermal use of the shallow subsurface. Therefore, this study provides results from an intensive groundwater temperature monitoring program that was conducted over a period of three years with consecutive measurements at a residential neighborhood in the city of Cologne, Germany, under intense shallow geothermal use. Results show that even though energy demands of the individual houses and energy extraction rates of the shallow geothermal systems were relatively small in this case, the accumulation of shallow geothermal users had a measurable impact on overall groundwater temperatures. With this we want to raise awareness of the importance of increasing system understanding and refinement of geothermal exploration and impact monitoring to guarantee an environmental and economic sustainable intensive thermal use of the shallow subsurface.

Assessing the Hydrological Properties Influencing Nitrate Distribution in a Shallow Unconfined Fractured Bedrock Aquifer

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Keywords: Nitrate, Groundwater, Multilevel System, Fractured Bedrock, GUDI

Most Relevant Conference Theme: Advances in groundwater-surface water interaction and critical zone monitoring

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Abstract

The Davidson Wellfield is located downgradient of the Paris moraine in Acton, Ontario and is designated as Groundwater Under Direct Influence (GUDI) of surface water. Two water supply wells, near each other in a single wellhouse, are completed from 3 to 14 mbgs in a shallow unconfined bedrock aquifer. A thin overburden layer of 2 m is present, followed by the fractured dolostone bedrock of the Gasport Formation. A shallow water table resides at the overburden-bedrock interface and the supply wells are surrounded by active agricultural land in which pastures and soybeans dominate with minor parts of land used for corn and wheat. Downgradient of the Davidson Wellfield a creek flows adjacent to the wellhouse. The two wells operate individually but show similar water quality and exhibit increasing and variable concentrations of nitrate reaching a maximum concentration of 7.45 mg/L NO_3-N in the past 15 years, exceeding the drinking water standard of 10 mg/L NO_3-N for nitrate. The specific goal for this project is to determine the vertical distribution of nitrate concentrations within the context of the groundwater flow paths captured by these pumping wells. Hence, understanding the aquifer-aquitard layering within the wellfield is a primary objective using vertical profiles of stratigraphy, hydraulic head and vertical components of gradient, and hydrochemistry will help inform the position and thickness of hydrogeological units, and their hydraulic parameters. These data will refine the conceptual model for groundwater flow and improve the assessment of nitrate inputs and attenuation along groundwater flow paths highly dependent on hydrochemical conditions and residence times, providing process-based insights on the spatial and temporal variability of nitrate within the capture zone of the supply wells.

A removable, G^{360} multilevel system (MLS) with water-inflated rubber packers for isolating nine monitoring zones was installed to gain insight on the vertical and temporal variability of nitrate concentrations and isotopic composition. Observations made during logging and sampling of continuous core and resultant porewater analyses, along with borehole geophysical/hydrophysical logging, helped inform monitoring port and packer locations. Most notable of this investigation is the use of temporarily deployed RBRduets for monitoring hydraulic head transients at 24 depth intervals, preceded using active-distributed temperature sensing (A-DTS) using fiber optic cables to identify the location of hydraulically active fractures based on preferential zones of cooling, both deployed behind FLUTe^{TM} liners. These characterization methods were followed by the installation of a removable G^{360} MLS system with nine ports designed to target these active flow paths and where elevated levels of nitrate were observed in the matrix based on porewater analysis. The findings from this research will differentiate nitrate sources and pathways to determine major contributors, improve pumping and mitigation strategies, and inform agricultural best management and wellhead protection practices.

Comparing the Transport of Environmental DNA and Free DNA in a Fluvial System

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Keywords: environmental DNA, Fluvial, Tracer, Free DNA, Species Monitoring

Most Relevant Conference Theme: Advances in groundwater–surface water interaction and critical zone monitoring

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Abstract

The collection of environmental DNA (eDNA) is an affordable and non-invasive technique for aquatic species monitoring. However, there remain several knowledge gaps in terms of transport behaviour due to its complexity and polydisperse nature. Tracking eDNA through a medium and characterizing its transport allows for better understanding of its capture, isolation and its downstream applicability as a species monitoring tool. Existing literature shows that eDNA does not behave as a conservative tracer in the environment as it exists as a complex mixture of particles with different properties. However, its components may behave similarly to free DNA (fDNA) through a fluvial system. In such a system, eDNA may be transported through repeated sorption and resuspension events, where the eDNA properties and sediment characteristics are a controlling factor. To assess the differences in transport between fDNA (e.g., synthetic) and eDNA (e.g., from fish), a controlled tracer study will be conducted in Washington Creek, a tributary of the Grand River watershed in southern Ontario. Water samples containing an fDNA tracer and eDNA from caged fish species, that has not been previously detected in this stream, will be released simultaneously in the system. Following this, water samples will be collected at various distances from the source and at specific time points. Water samples will be filtered within 24 hours, extracted, and amplified using a quantitative polymerase chain reaction (qPCR). We suspect the behaviour of eDNA will differ from that of fDNA in a fluvial system. fDNA may favour sorption to clay minerals, but whether eDNA behaves the same way will be further explored. To further support our hypothesis and field-based results a series of laboratory experiments will be conducted involving the exposure of eDNA and fDNA to multiple substrate types. The sorptive behaviour of eDNA and fDNA will be contrasted using controlled flow-through columns and batch sorption experiments. Understanding the fate of different forms of eDNA relative to a conservative tracer will allow for mapping of hydrological pathways in streams and help to interpret eDNA signals. In addition, this will help optimize the standard operating procedure for isolation of various forms of eDNA present in aquatic systems.

Investigating the Effects of Freeze-Thaw Conditions on Nutrient Cycling and Fall Fertilizer Efficacy

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Keywords: Biogeochemistry, Carbon fluxes, Soil chemistry, Water chemistry, Soil temperature
Most Relevant Conference Theme: Characterizing frozen and thawing soils

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Abstract

Agricultural soils in cold regions are critical in governing water flows and quality within agriculture catchments. Increased winter temperatures caused by climate warming may expose soils to colder temperatures and more freeze-thaw events. Freeze-thaw cycles influence chemical, biological, and physical soil properties that control carbon and nutrient cycling as well as microbial activity in soils. Changes to these processes may impact nutrient export from affected soils, possibly altering soil health and nearby water quality. Determining these impacts will improve our conceptual and quantitative understanding of shallow subsurface biogeochemical processes in agricultural soils of cold climate regions. In this study, a soil column experiment was conducted using agricultural soil to assess the leaching of carbon and nutrients during the fall-winter and winter-spring transitions and during the non-growing season. The soil columns were exposed to a non-growing season temperature and precipitation model and fertilizer amendments were made to the experimental columns to determine the efficacy of Fall-applied fertilizers, which is relevant for current 4R fertilization guidelines (right source, right rate, right time, right place). Leachates from the columns were collected and analyzed for dissolved organic and inorganic carbon (DOC, DIC), total nitrogen (TN), and major cations and anions. Findings from this experiment will ultimately be used to bolster winter soil biogeochemical models by elucidating carbon and nutrient fluxes over changing winter conditions and refine the best management practices for fertilizer application.

Minimal-invasive exploration of the subsurface – direct push sensing in alluvial settings

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Keywords: Direct-Push Technology, Soil Color, Electrical Conductivity

Most Relevant Conference Theme: Emerging sensor technologies

Abstract

The application of direct push sensing provides a new approach for geomorphological and archaeological issues in alluvial settings. Direct push sensing implies a set of tools for subsurface exploration by pushing steel rods with different probes into the unconsolidated sediments, driven by a mobile vehicle. Thus, different probes allow the in situ characterisation of various parameters for a cost- and time-effective site investigation in two-dimensional sections, e.g. electrical conductivity or sediment colour. Recovered data provide a high depth-accuracy and a high-resolution in cm-scale. The technique is also combinable with geophysical exploration and drilling techniques.

Our presentation focuses on the reconstruction of Late Holocene aggradation processes of the Rezat floodplain in South Germany and on the analysis of embedded and buried archaeological structures of the Early Medieval Fossa Carolina. Our data clearly indicate the Carolingian floodplain surface, probable remnants of Carolingian constructions works, the Carolingian trench, buried dams, post-Carolingian trench fillings and the onset of flood loam deposition in the 15 century. Furthermore, we provide an additional example for direct push sensing as an exploration tool in archaeohydrology.

Our approach provides an alternative for (geo)archaeological excavations that are challenging in alluvial settings due to groundwater inflow and high labour and time effort.

Concept Design of a Canadian Water Microsatellite Mission

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Keywords: Microsatellite, Water Quality, Water Quantity, Smart Sensor Networks

Most Relevant Conference Theme: Emerging sensor technologies

Abstract

Canada has vast water resources that span an enormous range in geography, climate, and ecosystems. Water supply and water quality are the two critical issues relevant to water resources, not only in Canada but also globally in a warming climate. Global Water Futures: Solutions to Water Threats in an Era of Global Change (GWF) is a Canada-wide, collaborative research program, which aims to place Canada as a global leader in water science for cold regions. The main objective is to address the strategic needs of the Canadian economy in adapting to climate change and managing the risks of uncertain water futures and extreme events. Transformative Sensor Technologies and Smart Watersheds (TTSW) is a project supported by the GWF program. The goal of TTSW is to develop, improve, and test transformative technologies ('smart' sensor networks; terrestrial, drone, airborne, and satellite remote sensing systems) which will be implemented on a pan-Canadian scale and targeted to support water research throughout cold regions at national and international scales. One component of the TTSW project is to develop the design concept of a water microsatellite mission. This mission is a multi-pronged solution for water research needs. The goal of the mission is to explore the design of a microsatellite mission focused on freshwater monitoring (also including observations over marine and terrestrial environments), and to advance water research and support the research community. The intended mission design could address the need for collecting coincident ground and remote observations of water parameters at spatial, temporal, and spectral resolutions not offered by current satellite missions. A survey was launched in November 2018 to assess the needs of the community in order to shape this mission as it progresses. Preliminary survey data indicate that the current design plan for the microsatellite mission would satisfy the needs of the science community and improve their research impact as well as cost-effectiveness. The specifics of this mission design will be provided in a poster presentation.

Geophysical Investigations using 2D Electrical Resistivity imaging for the study of soil and groundwater contamination near Bazian Oil Refinery, West of Sulaymaniyah City, Iraqi Kurdistan Region

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Keywords: Ground Water Contamination, Electrical Resistivity, Pollution Plume, Sulaymaniyah, Bazian Oil Refinery.

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone/ Near-surface and borehole geophysics

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Abstract

Bazian oil refinery is located 35 km west of Sulaimani City over an area estimated to be about 10 square kilometers. It was constructed in 2009 over a very fertilize land in Bazian basin which considered as one of the strategic areas in groundwater potential according to several studies carried out in the region. This oil refinery is one of the greatest refineries in Kurdistan region, it provides Sulaymaniyah City and it's surrounding with different type of oil products. The capacity of refining approached more than 25 million liters per day in 2018.
For the current 2D electrical resistivity study, several selected locations were investigated to indicate whether the soil and/or groundwater near the refinery are contaminated during the past 9 years of continuous oil refining. IRIS - Syscal R1 plus-72 resistivity meter is used for surveying six profiles using Wenner-Schlumberger array with 5 meters of electrode spacing, 72 electrodes were used and the length of each profile is 355 m. The 2D model interpretation was performed using the updated new software package "RES2DINV" version 3.54.53. It performs smoothness-constrained inversion using finite difference forward modeling and Quasi-Newton techniques.
The inverse sections of the interpreted profiles show the appearance of three distinct layers. The top surface layer that covers the investigated area is a layer of intermediate resistivity ranging from 15 to 40 Ohm.m. This layer shows a wide range of resistivity due to its varied components composed of clay, silt, and sand of recent sediments which is partially saturated with groundwater. Several locations of the polluted plume were detected within this layer, they show higher resistivity than the surrounding materials and they have penetrated depths not exceeding more than 3 meters.

The second Layer is represented by an impermeable clay which has low resistivity ranging from 6 to 10 Ohm.m, it is detected at depths ranging between 3 to 20m. The third layer representing the gravel, sand, and clay of high resistivity ranging from 20 to 45 Ohm.m and forming an excellent aquifer in the area. The pollution did not reach this layer due to the existence of the impermeable clay above this layer. The results revealed that the 2D electrical resistivity imaging is very effective for indicating locations, depths, and extent of soil and groundwater pollution plumes.

Characterization of Groundwater Flow Dynamics in Discontinuous Permafrost

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Keywords: Permafrost, Groundwater/Surface Water Interactions, Tracers, Conceptual Model

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone monitoring

Abstract

Surface water and groundwater resources in the Canadian North are under transition. Between unconventional oil and gas development and a changing climate, uncertainty remains about how these hydrologic resources may be affected. Shale oil and gas development projects often utilize large amounts of water and may pose a potential contamination hazard to surface and subsurface water should active vertical transport pathways be available. Warming temperatures and thawing permafrost may create new surface and subsurface pathways that could influence upward migration of deeper fluids and may influence flow dynamics in the shallow subsurface. This is due to the unique hydrogeology of permafrost environments, as water is partitioned between shallow active-layer flow and a deeper perennial flow beneath and within discontinuous permafrost. Gaps in permafrost known as taliks may exist, typically around surface waterbodies. In a discontinuous permafrost region taliks act as windows, allowing for groundwater to exchange between shallow and deep zones. Surface water and groundwater in discontinuous permafrost remain inextricably linked. Regional baseline characterization and monitoring of surface water and groundwater in these remote northern environments may provide the reference information required to be able to detect environmental impacts over time. However, few protocols and approaches are in place to undertake these studies. Traditional hydrologic monitoring remains difficult due to short field seasons, limited site access, and the tendency for monitoring wells to freeze even during warmer months. This research aims to investigate potential monitoring methodology in northern discontinuous permafrost environments. The importance of the linkage between groundwater and surface water provides a potential avenue of approach. By using less direct or invasive methods and focusing efforts on groundwater and surface water interactions, characterization of overall groundwater movements and quality could be achieved. Several field techniques have been explored and applied during a summer field season in a discontinuous permafrost region south of Norman Wells, NT. Sampling site selection was guided by current industry monitoring activities as well as a previous study utilizing remote sensing to discover locations of winter icings at a regional scale. These icings potentially represent areas of perennially discharging groundwater. Actual discharge locations were pin-pointed using an airborne thermal imagery survey. Data collection included vertical temperature profiles and hydrologic parameters, as well as isotope and geochemical tracer samples from icing locations and other seeps, waterbodies and shallow groundwater. This data was used to characterize some aspects of the groundwater sources and potential flowpaths in the region. Data compiled from industry and government sources provided the background knowledge of site characteristics and guided fieldwork. When combined, these datasets provide a clearer conceptual model of baseline conditions and potential future changes to this sensitive hydrologic system.

Combining High Resolution, Depth Discrete Hydraulic and 1,4-Dioxane Assessment to Estimate Mass Discharge in a Karst Aquifer

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Keywords: Karst, 1,4-Dioxane, Mass Discharge, Floridan Aquifer System

Most Relevant Conference Theme: Multiscale monitoring in fracture rock environments

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Abstract

Trace 1,4-dioxane detections in the karstic Eocene-Miocene aged carbonates of the Upper Floridan aquifer caused the municipality to regulate pumping in its supply well. The source of the contamination is unclear. This study was initiated to assess the potential contributions from one nearby industrial site. High aquifer transmissivity and size of the site made it difficult to use conventional Darcy's law-based mass flux calculations from conventional monitoring well data. This was further complicated by the karstic nature of the aquifer. To address measurement uncertainties, multiple, depth-discrete, complimentary measurement methods were applied to characterize the aquifer. Two boreholes were continuously cored using rotosonic drilling and core was sampled frequently with depth to document lithologic and contaminant mass concentration variability in matrix porewater, adjacent and away from active flow features inferred from detailed core inspection. Conventional borehole geophysical and hydrophysical logs were collected to complement the porewater profile. Physical caliper profiles captured the significant variability in borehole diameter, identifying zones that could be sealed using FLUTe™ borehole liners. Nominal and oversized liners were installed to mitigate the impact of boreholes on the natural gradient flow conditions. These combined datasets informed the placement of a novel, fractured rock passive flux meter (PFM), each 1-2 m long, in thirteen depth-discrete zones to quantify both water and contaminant fluxes. These devices utilized an adsorbent resin well-suited for 1,4-dioxane and co-deployed with conventional granular activated carbon and forty-two pressure and temperature sensors to capture transient hydraulic conditions. Challenges common to karst boreholes and novel adjustments made for the site conditions and specific study objectives regarding groundwater and contaminant flux distributions will be discussed.

Assessing physical controls on greenhouse gas mobility in partially saturated agricultural soils and riparian areas

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Keywords: Greenhouse *Gas Movement in Soils, Permeability Measurements, Hydraulic Properties, Pneumatic Properties, Seasonality*

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone monitoring

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Abstract

Driven by a growing concern of increasing greenhouse gas emissions, research aiming to assess best management practices (BMPs) in agricultural activities was undertaken. This study examined how BMPs affect soil structure and how soil structure in turn affects greenhouse gas emissions. Data was collected using physical measurements, and pneumatic and hydraulic techniques at an active agricultural field in St. Albert, Ontario, south-east of Ottawa. Two soils types, a riparian soil and an actively farmed cornfield soil, were selected and a full suite of tests was completed in the spring, summer, and fall to assess changes in water and gas movement in the soils throughout the growing season. Macropore size and density classification, pressure and tension infiltration tests, air permeability tests, and bulk density and particle-size distribution analysis on soil core samples were carried out. Combining multiple data collection techniques shaped a more complete picture of soil structure processes and their effects on gas movement in the soil. It was determined that the macropore area fraction in the soils increased throughout the growing season in both the riparian and cornfield soils, with the riparian zone soil exhibiting up to 1.7 times more macropore area than the cornfield by the end of the growing season. The hydraulic properties displayed much greater variability in the riparian soils than in the field soils and had the greatest average values in the middle of the growing season. The field data collection for this project was designed to also support a subsequent modeling effort using the finite-element model HydroGeoSphere. Emphasis was placed on maximizing the number of in-situ measurements of model parameters to accurately predict long-term behaviour of water and gas movement in the soil profile at the study site.

Closing the Seasonal Data Gap: Emerging application of optodes for characterizing frozen and thawing soils

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Keywords: Optode, Oxygen, Soil Characterization, Freeze-Thaw, Non-Growing Season

Most Relevant Conference Theme: Characterizing frozen and thawing soils

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Abstract

Environmental field data collection during the winter non-growing season (NGS) is a common challenge that has resulted in an imbalance of information about processes during growing seasons (warmer months) and the NGS, which can skew understanding of environmental systems in an annual time-frame. Understanding of soil biogeochemical processes during the NGS, particularly with a higher frequency of freeze-thaw cycles anticipated to occur with climate warming, is important in environmental sciences under current and future climates. The use of optodes (an optical analogue for electrodes) in marine and freshwater studies can be translated into applications in soil systems to characterize the oxygen dynamics in soils under freezing and thawing conditions. In this study, we focus on presenting the application of a low-cost optode designed for monitoring soil oxygen under freezing and thawing conditions. In this presentation, we will show how a customizable optode system has been applied to an artificial soil column system and how the design was modified for field deployment in an agricultural site in Southern Ontario. Preliminary results from the field experiment will be presented along with the lab results for a comparison of how using the optode in each setting can provide insight into soil processes during the NGS.

Innovative method to monitor groundwater and surface water interactions

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Keywords: Monitoring, Groundwater-Surface Water Interaction, Artificial Intelligence, Real-Time Data, Big Data Analysis

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone monitoring/Big data synthesis and aspects of artificial intelligence

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Abstract

Groundwater and surface water interactions under extreme hydrological events can be difficult to predict and capture. Incomplete data collected from these events can lead to inappropriate conclusions and decisions in water management and environmental assessment. Therefore, an innovative method to understand, forecast extreme meteorological event and collect hydrological data in time is needed.

In this study, a smart system called iWT is developed in cooperation with Solinst Ltd. This reactive system allows communication between varieties of sensors, which permits capturing critical and temporal events in real-time. An editable triggering algorithm allows it to use different hydrologic and climatic parameters to control data collection that is often missed. Its capability of real-time data transmission also provides decision makers immediate attention in order to make quick response.

To help deploy and apply this method to various watersheds, a pilot experiment will be performed in Alder Creek, ON. An integrated HGS model will be developed to help understand the hydrological cycle of this watershed and determine the threshold and algorism for the triggering rules. Historical meteorological and hydrological data will be analyzed as initial condition and real-time data will be continuously feed to the model for calibration.
Provided with extremely large data collected from different watersheds all over north America, a rigorous analysis will be done and modelled to help reveal a general pattern using the experience learned from the pilot experiment. An adaptive model that generate proper threshold for triggering rules which applies to diverse watersheds is expected.

On the importance of groundwater in the water balance of one of the world's largest lakes (Lake Erie, USA-Canada)

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Keywords: groundwater, Water Budget, Surface Runoff, Lake Erie

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone monitoring

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Abstract

So far, there have been only a few studies focusing on the role of groundwater in nutrient and water budgets of the Laurentian Great Lakes (LGLs). As a consequence, the role of groundwater in LGLs is still not well understood and, therefore, often neglected. However, inputs of groundwater constitute a significant portion of the total discharge in lake tributaries and sustain flows between precipitation and snowmelt events. Such inputs of groundwater may also be important for nutrient inputs during low-flow periods to support the ecological functioning of LGLs. To illustrate the important role of groundwater discharge for one of the LGLs, Lake Erie, we constructed the annual lake water budgets for 2003 through 2013 to quantify the flow of water into and out of the system which also included the estimates of groundwater contribution (base-flow) to its tributaries. The latter was quantified for each Hydrologic Unit Code (US part of the watershed) and tertiary watersheds (Canadian part of the watershed) for the whole lake as well as for each of its three basins. Our results indicated that indirect groundwater discharge can account for more than half of the total tributary flow, and more importantly, illustrated the existence of essential basin-specific differences in the proportions of groundwater in the total tributary flows in all three basins of Lake Erie. These findings may have some important implications for both lake and watershed nutrient management in the Lake Erie basin. As a further step, we are planning to estimate the role of indirect groundwater discharge in the overall phosphorus load to Lake Erie.

Groundwater flow quantification in poorly cemented sandstone using active distributed temperature sensing

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Keywords: Active Distributed Temperature Sensing, Flow Quantification, Fluorescein Tracer Injection, Rock Core, Flow and Heat Transport Numerical Modeling.

Most Relevant Conference Theme: Multi-scale monitoring in fracture rock environments

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Abstract

Characterization of preferential flow paths is important for assessing the delivery of treatment amendments to contaminated portions of an aquifer. Field investigation methods with high spatial resolution are required to capture the flow variability in unconsolidated or discretely fractured aquifers, and to identify the nature of flow pathways (i.e. fracture vs matrix flow) relative to the contaminant distribution. The active distributed temperature sensing (A-DTS) method, originally developed for fractured rock boreholes, was adapted for application in a poorly cemented sandstone aquifer contaminated with chlorinated solvents in southern France.

The composite fiber optic cable was attached to a PVC pipe and grouted in the borehole to avoid cross-connected flow and to recreate natural-gradient flow conditions in the aquifer representative of flow conditions over the past decades of plume transport at this aged contaminated site. The A-DTS tests consist of heating the cable for up to 24 hours with constant heat input and recording temperature along the cable continuously using a DTS unit. Active groundwater flow in preferential flow paths causes an enhancement of heat transfer from the cable creating a cooler thermal response than zones with lower or no flow. The geometry of the test was recreated in a numerical heat transport model and a relationship was developed between the thermal responses measured with the A-DTS, and the volume of water flowing through the preferential flow paths.

The results show variable flow rates along the borehole indicating the presence of preferential flow zones. A fluorescein tracer injection experiment followed by detailed core logging and sampling, with visual inspection of fluorescein tracer distributions under UV light to guide high frequency, depth-discrete rock core sampling, provided additional evidence for the presence and distribution of preferential flow paths, also indicating flow anisotropy and tracer transport retardation. The results from these two methods, combined with detailed profiles of contaminant concentration distribution from rock core and groundwater sampling, inform and optimize the design for in-situ remediation.

Characterizing Soil Microbial Diversity through Freeze-Thaw Cycles and the Winter Transition

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Keywords: Freeze-Thaw Cycles, Microbial Diversity, Nutrient Availability, Snowpack Insulation, Winter Transition

Most Relevant Conference Theme: Characterizing frozen and thawing soils

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Abstract

Microbial activity in soil persists under snow and ice throughout the winter transition, before reaching its apex during thaw events. With the onset of climate change, the active layer of soils will experience colder temperatures as snowpack insulation is lost. Consequently, soils and their microbial communities will undergo a higher frequency of freeze-thaw cycles. Evidence of impacts to activity and bulk changes to microbial community structure under winter and freeze-thaw conditions have been identified, but specific changes to microbial phyla over the course of the entire non-growing season remain unclear. The objective of this study was to characterize changes in microbial diversity and bioenergetics through winter conditions, including planned freeze-thaw cycles, as a function of the changing environmental metrics of soil geochemistry and nutrient availability. We dynamically simulated a condensed climate model of the winter transition in laboratory soil columns, allowing for high resolution of depth and temporal sampling. We used agricultural soil to additionally investigate the efficacy of pre-winter fertilizer amendments, as higher frequencies of thaw events may hasten microbial consumption of fertilizer, decreasing fertilizer availability and efficacy in spring. Our microbial analyses included high-throughput community composition profiling and bulk metabolic assessment for community activity. This longitudinal study will provide insights as to the specific development of the soil microbiome through the winter transition and establish causative links to geochemical conditions, clarifying impacts of winter freeze-thaws on agricultural best-practices and microbial impacts on biogeochemical cycling.

Oral Presentation Abstracts

Abstracts are organized by session. Keynote and invited speaker abstracts can be found in the NovCare program.

Session 1

Recent Advances in Flexible Liner Methods

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Keywords: Contaminant Distribution, Transmissivity Distribution, Head Monitoring, Multi-Level Sampling

Most Relevant Conference Theme: Multiscale monitoring in fracture rock environments

Abstract

Four years ago FLUTe presented in the Kansas NovCare conference the general state of the art of flexible liner measurements including sealing blank liners, NAPL/FACT mapping of contaminants, transmissivity profiling, and multi-level sampling systems. Those were all everting/inverting liner methods. Numerous refinements have extended the range of those methods, added other kinds of measurements, and more importantly, field experience has provided data demonstrating the actual use of those methods and comparisons with traditional measurement results.

The results of mapping of contaminants with an activated carbon felt are compared with water samples collected over two years. This is a brief update on the method named a FACT.

A new liner method for mapping of the vertical head distribution in the formation uses the high resolution transmissivity data and the same blank liner as used to map both the transmissivity profile and the contaminant profiles. Using the detailed conductivity profile and the new head profile data, one can calculate the flow into the open borehole which can then be used to calculate a synthetic flow log for comparison with the actual flow log measurement as a test of the validity of the very detailed liner measurements. More commonly the flow log is used to deduce the head and conductivity profile with limited resolution.

The newest extension of liner methods is the addition of two multi-level water sampling and head measurement designs. The main advantage over the Water FLUTe method, long in use, is the new methods are one third to one fourth the cost of the Water FLUTe method. They still offer the same capabilities of water samples, head, and head history with limitations mainly of borehole depth. These systems have been installed in casing as small as 2 and 3 inches to a depth of 255 ft. and into uncased holes. Simultaneous purge and sampling is attractive for sample isolation. The total installation procedure of only 10 to 30 minutes is another significant economy. The use in sediments and unstable boreholes is yet another benefit. A variation of the design allows the injection of viscous remediation fluids and the pumping of large water volumes at numerous discrete intervals in boreholes sealed with a continuous liner.

High resolution time-elevation-head profiles from temporary deployed sensors in boreholes for assessing variable flow conditions in fractured rock aquifers

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Keywords: Fractured Rock, Hydro-Geophysics, Hydraulic Characterization, High Resolution, Pre-Screening
Most Relevant Conference Theme: Multiscale monitoring in fracture rock environments

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Abstract

Over the past two decades, novel and improved field methods employed at industrial sites on fractured rock have providing extremely high-resolution data sets. Techniques such as rock core contaminant sampling, FLUTe transmissivity profiling, geophysical and hydrogeophysical borehole logging have identified the occurrence of numerous, hydraulically active fractures influencing VOC contaminant mass distributions. These studies consistently point to the importance of both large and small aperture fractures on controlling flow and transport within interconnected fracture networks. Often these data are used to inform the design of monitoring wells or better yet, multilevel monitoring systems (MLS) for monitoring hydraulic transients and long-term trends in groundwater chemistry. However, most of these conventional monitoring systems are permanent installations and recent investigations have shown that the best placement of seals and ports can be difficult without apriori information about the depths of key zones where vertical head profiles change or hydraulic transients occur when boreholes are not open and cross-connected. Hence, there is strong interest in obtaining high-resolution spatial and temporal data sets prior to committing to these permanent monitoring systems so as to properly identify aquifer-aquitard boundaries, avoid cross-connection of distinct hydrologic units to optimize monitoring intervals, improve data quality and site decision-making.

The 'Temporary Deployment' technique is a removable and reusable installation of sensors placed at numerous discrete depth intervals along a borehole length, and then sealed with a FLUTeTM liner (Alcarde, NM). Typically, rock core, geophysical and hydro-geophysical data are used to design 20-30 sampling intervals, wherein pressure transducers and high sensitivity (0.0001 C°) thermistors are deployed at targeted, depth-discrete intervals, each hydraulically isolated with a continuous seal created by the liner. Subsequently, responses to either natural or artificially induced hydraulic stresses are used to identify hydraulically active fractures, their connectivity, as well as the vertical components of hydraulic and thermal gradients that provide insights into hydrologic unit boundaries and infer groundwater flow directions, respectively. These data create an improved basis for a permanent MLS design and avoid cross-connection of units with distinct hydraulic, hydro-chemical and/or contaminant conditions. The temporary deployment methodology also supports multi-borehole data collection techniques (e.g. cross-hole testing). Removability is a key feature for cost-effectiveness, allowing components to be reused in other boreholes or reconfigured for the same borehole. Data from two sites, a turbidite sandstone in California and a dolostone in Ontario, Canada, will be presented to demonstrate the method versatility and unique insights obtained.

A Geological Approach for Locating Petroleum Facilities Appropriately to Protect Subsurface Resources

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Keywords: Permeable, Fractures, Contaminant, Tracers, Integrity

Most Relevant Conference Theme: Advances in isotope tracers for subsurface characterization and fingerprinting

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Abstract

The objective of this study is to present a geological approach for selecting the least permeable sites available for constructing petroleum facilities where there is high risk of releasing contaminant fluids, which can infiltrate to the subsurface.

Petroleum facilities like Field or Central Processing Facilities, tanks, lined pits, and refineries, contain and may possibly release contaminant fluids, such as liquid hydrocarbons, oily sludge, chemicals, sewage, and produced water that pose a direct threat to the environment. Such fluids should supposedly be contained within containers or properly lined pits, as required usually by the regulatory authorities, for the sake of protecting the environment. Nevertheless, spills, system failures, and unplanned discharges may still happen. Consequently, measures that are more stringent should be taken to prevent direct contact of such contaminants with the environment, particularly drinking water and soil resources. These measures should start, most importantly, by selecting the safest location in terms of infiltration capacity for contaminant fluids. Accordingly, this study aims to discuss the importance of the geology of the subject area as one of the essential site selection criteria, as well as to outline an approach for choosing the most appropriate site for constructing a petroleum facility onshore, utilizing application examples from Sudan oil fields.

High integrity is the rule of site selection. To abide by this rule, geological mapping of the proposed region is an essential step followed by detailed characterization of the suggested area. A site occupied by a porous formation, such as sand or even silt, is obviously not suitable, due to its high permeability that would allow infiltration and transport of possible contaminants to the underlying horizons, and eventually, aquifers. In contrast, a site located on an impermeable media, such as unfractured crystalline rock if available, should be the best choice. Otherwise, a tight formation such as a clayey one would be suitable choice, if its integrity was high enough, which means absence of hydraulically active deep fractures and stratigraphic windows. Presence of hydraulically active fractures and estimation of their depth could be done by the use of artificial tracers. In case of saturated tight formations, it is possible to measure a natural tracer such as atmospheric tritium (^{3}H). Absence of natural and artificial tracers in deep horizons of such formations is a strong indication of absence of deep fractures.

It is concluded that such approach of selecting the site that is covered with the highest integrity layer should be followed, in order to maintain the highest level of protection for the underlying soil and groundwater resources when it comes to locating facilities that may possibly release contaminant fluids.

Session 2

Modeling root processes along a successional forest transect using a coupled hydrogeophysical inversion approach

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Keywords: Electrical Resistivity, HYDRUS, Roots

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone monitoring

Abstract

Modeling water balances and projecting climate forecasts at regional and global scales relies on accurate estimates of transpiration, one of the largest terrestrial fluxes of water to the atmosphere. As more places experience severe drought and aquifer depletion, projecting groundwater recharge is critical to sustaining life in both agricultural and urban settings. Earth systems models of transpiration and recharge depend on vegetative root distributions, which are highly dynamic and difficult to validate. New tools are thus needed to better understand root water dynamics in a variety of field settings.

Recent advances with coupled hydrogeophysical inversion methods have shown great promise for understanding critical-zone hydrological processes by parameterizing hydrological models with electrical resistivity (ER) data. ER data is highly sensitive to water and temperature dynamics in the unsaturated zone and its implementation is minimally invasive. Furthermore, the ease of extensive ER data collection makes it well-suited to monitoring water dynamics at the relevant time and spatial scales for understanding how land cover affects the annual water balance.

In this work we use a novel coupled hydrogeophysical inversion approach to quantify root and soil water dynamics along a transect that progresses from mature forest to shrub and grassland. At this site, located in southwest Michigan, USA, variations in soil moisture and temperature are controlled by the seasonal temperate climate and vegetative cover. Using in-situ soil moisture and soil temperature data from soil pits located at the beginning and end of the transect, we first constrain the hydrological and heat transport parameters of 1D-HYDRUS models. We then use multiple 2D ER surveys obtained throughout the 2017 and 2018 growing seasons to inform the along-line soil and root heterogeneity that is then incorporated into a pseudo 2D hydrological model. After converting the modeled 2D soil moisture into 2D resistivity using Archie's Law, we forward model the potential field and compare the estimated potentials directly with our ER measurements. The parameters of the hydrological model, including the root distribution in time and space, are then updated by minimizing the difference between the modeled and measured potentials.

This method allows us to quantify how the differences in canopy and root structure impact the water balance at this site; providing valuable insight into the potential effect of large-scale land use change on groundwater recharge and transpiration in the Great Lakes region.

Is an inversion always the most efficient solution?

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Keywords: ERT, Surface Geoelectrics, Data Evaluation

Most Relevant Conference Theme: Advances in critical zone monitoring

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Abstract

We want to detect and delimit hydrogeologically relevant features in a 10 km² floodplain environment near Tübingen, Germany. The spatial extent of such features needs to be determined for a general characterization of the floodplain, for subsequent drillings, as well as hydraulic and tracer testing. The targeted structures are expected to have contrasting geoelectric properties compared to the surrounding subsurface materials. We therefore measured a representative 2D electric resistivity tomography (ERT) profile with subsequent inversion to image the subsurface. The inversion result shows a resistivity anomaly interpreted as gravel filled paleo channel. Multiple parallel profiles and an inversion of measured data would then be required for a spatial delineation of the channel course. This, however, comes with long acquisition and inversion times.

We therefore developed the evaluation of anomaly effects to identify geoelectric anomalies and their lateral extent in raw data. For this, we compare each measured apparent resistivity in the representative ERT data to a background apparent resistivity value. The results are visualized in a pseudosection of anomaly effects and are used for precise determination of lateral anomaly extents. The spatial extents of these resistivity anomalies are then identified in a subsequent geoelectric mapping campaign with a fixed electrode spacing.

This approach proves to yield the same accuracy on lateral anomaly extent as an inversion in a fraction of the computational time. High ranges of anomaly effects in the pseudosection indicated most suitable electrode spacings for a subsequent geoelectric mapping campaign. Therewith, we mapped the spatial extent of the channel over an area of 300,000 m² within a few hours. Once identified and mapped, anomalies and project-relevant subareas can be targeted for ensuing more detailed investigations.

Estimation of the minimum level of the residual saturation of LNAPL in unsaturated soil by GPR

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Keywords: Gasoline, GPR, FDTD, CRIM, Optimization

Most Relevant Conference Theme: Remote Sensing

Abstract

Subsurface contamination by light non-aqueous phase liquids (LNAPLs) is a critical environmental issue that must be effectively managed. Ground Penetrating Radar (GPR) is a non-invasive, geophysical investigation technique, which can be used to detect LNAPL in the subsurface soil. The main goal of this paper is to show the possibilities of using GPR to estimate the presence of residual LNAPL, with emphasis on gasoline in the unsaturated soil. The developed technique involves the analysis of 2D synthetic surface-based reflection GPR data sets. The data sets have been generated by numerical modelling of Maxwell's equations using the finite difference time domain (FDTD) method using Matlab software. Analysis of the GPR data uses a four-phase volumetric mixing model, simplified to the complex refractive index model (CRIM) to estimate the dielectric constant of the soil mixture. Further analysis of the data estimates the residual saturation of the LNAPL in the soil. The residual saturation level in the soil has been estimated as a percentage of the calculated retention capacity (RC) of the soil model. Sensitivity tests have been conducted to optimize both the antenna frequency and the separation distance between the transmitter and the receiver.

Results of the sensitivity tests show that the optimum frequency was 1GHz with an optimum separation distance of 1m. Using the optimized frequency and separation distance gives a minimum detectible level of the gasoline residual saturation of 2100 $\mu g_N/g_{soil}$, which is approximately 1% RC. Even though this detection limit is higher than the allowable concentration of gasoline as total petroleum hydrocarbons in soil is 100 $\mu g_N/g_{soil}$ for most jurisdictions, the technique can be used to screen sites and evaluate if they are contaminated with residual gasoline. Overall, the paper will demonstrate a technique that provides new insights into how GPR scans can be used to monitor the presence of gasoline in the unsaturated zone.

Session 3

Site characterization, monitoring, and numerical modelling to determine public supply well vulnerability to depression focused recharge and a losing stream reach during large-magnitude hydrological events

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Keywords: Hydrological Event, Well Vulnerability, Pathogens, Depression Focused Recharge, Losing Stream

Most Relevant Conference Theme: Advances in groundwater–surface water interaction and critical zone monitoring

Abstract

The impact of large-magnitude hydrological events on well vulnerability has received little attention despite the May 2000 tragedy in Walkerton, Ontario, involving heavy rainfall (>100 mm in five days), a well managed cattle farm, and the contamination of a shallow public supply well by pathogenic bacteria. Since this event, temporary ponding of surface water has been observed near public supply wells screened in glacial overburden sediments in the cities of Woodstock and Kitchener, Ontario. In this study, the potential impact of depression focused recharge and a losing stream on well vulnerability were assessed via field instrumentation and solute transport modelling for a site near Kitchener. A transect of piezometers, soil moisture, and temperature instruments were installed perpendicular to a losing stream reach and through a shallow topographic depression that fills about four times per year. Both potential sources of surface contamination are within 50 m of a currently inactive public supply well classified as having effective filtration. Soil cores, event monitoring, and numerical modelling were used to assess the vertical hydraulic conductivity of the near surface soil layers above the water table. A fully integrated surface water and groundwater numerical model with a wedge-shaped grid was used to estimate the time to peak arrival and exposure time of the well related to hypothetical solutes added to surface water in the topographic depression and in the stream. This model was calibrated to a historical pumping test. Event simulations employed ponding depth and duration data collected by field instruments in the topographic depression. Field observations documented the development of saturated conditions from the surface to the pre-event water table position during some events with no pumping at the well. Numerical simulations show peak arrival times within 50 days for a conservative tracer and highlight the importance of the Vadose zone in protecting well water quality under pumping conditions.

An approach to estimate groundwater-surface water interaction

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Keywords: Groundwater-Surface Water, Interaction, Head Variation, Field Estimation, Challenges.

Most Relevant Conference Theme: Advances in groundwater-surface water interaction and critical zone monitoring

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Abstract

The interaction of groundwater (GW) and surface water (SW) is a complex phenomenon, but an understanding of their interaction is important for the both qualitative and quantitative determination of exchange processes (e.g. for water and solute fluxes). Most of the studies in GW-SW interaction, often use classical approach, $Q = C*(h_{River} - h_{Aquifer})$, for determining the flux across the riverbed (e.g. studies using RIV package MODFLOW). The riverbed conductance (C) being a lumped parameter involves uncertainty for the determination in the field.

The current study focuses on the development of an expression, which is the modification of the classical approach. The derived formulation relates hydraulic aquifer and riverbed properties and their geometrical features to exchange fluxes.

For evaluation of the new approach, a 2-dimensional, steady-state GW-SW model is developed in the numerical simulation tool OpenGeoSys. The setup consists of two components, a riverbed, and an aquifer, which are separated by a colmation layer. A sensitivity analysis was carried out to understand the relevance and impact on exchange fluxes of different geometrical (e.g. width and thickness of colmation layer) and hydraulic properties (e.g. hydraulic conductivities).

Results show that the estimated flux varies significantly from the flux calculated using the classical approach, but is similar to the flux calculated with the newly developed approach. The equation also indicates the required distance from the riverbed for the in-situ aquifer head measurement. Furthermore, the formulation provides an estimate for the riverbed conductance, based on measurement of flux and aquifer properties (e.g. width, thickness, hydraulic conductivity, and head).

Flood management and modeling method to assess flood-hazard areas in small ungauged basins. A case study of Tangier's basins –Northwestern Morocco.

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Keywords: Morocco, Ungauged Basins, Rainfall-Runoff Model, GIS

Most Relevant Conference Themes: Advances in groundwater –surface water interaction and critical zone monitoring, Specific monitoring requirements in Ecohydrology.

Abstract

The development of appropriate techniques for modeling flood events in ungauged basins remains a challenge. Many basins in the north of Morocco are considered "ungauged", since there are few gauging stations equipped with instruments measuring and collecting hydrological and hydraulic data; as a result, the determination of the watershed response at spatial-temporal scales is not accurate. The problem most often encountered in this area is the need to estimate runoff from a watershed in which there are records of daily rainfall, but no records of runoff. In this case, a large quantity of rainwater could be lost without any benefit due to evaporation and infiltration loss. For this reason, it is necessary to develop new technical tools based on modern methods and numerical modeling, allowing the digitization and collection of different physical components, with the aim of an integrated management of flood risks. On the other hand, using the detailed hydrological analysis techniques in the SCS TR-55 Bulletin for small watersheds, rainfall is described as one of the four standard 24 hours temporal distribution: type I, type IA, type II, and type III. This method was developed for the four storm types prepared for geographic regions of the United States. To apply the SCS TR-55 procedure outside the US, a local distribution of synthetic storms must be developed. The aim of the present study is to design a storm rainfall distribution curve for ungauged basins in the north of Morocco by which storm runoff can be predicted accordingly. The rainfall-runoff modeling is based on data from a storm event, which occurred on the 23th of October 2008 in Tangier city, the HEC-HMS rainfall-runoff model, GIS, and remote sensing. The results of this study show that the SCS-24 Type I storm represents the best distribution to simulate the rainfall-runoff event for each return interval, because it is the most similar to the observed instantaneous rainfall at the neighboring gauged watershed during the same storm event.

Session 4

Introducing a new concept for the reliable and efficient in-situ capturing and visualization of tracer distribution and spread in highly heterogeneous sedimentary deposits

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Keywords: Direct Push, Tracer Testing, Electrical Conductivity

Most Relevant Conference Theme: Emerging sensor technologies

Abstract

The reliable characterization of heterogeneous sedimentary deposits remains a great challenge in applied hydrogeology research and practice. However, reliable parametrization is a prerequisite for reliable simulation of flow and transport processes within the saturated zone. Thereby, tracer testing is a well-established and commonly applied technique for the hydraulic characterization of the subsurface. Nevertheless, in areas with limited or no prior knowledge about the hydraulic regime successful realization of tracer tests can be challenging.

A promising approach to simplify and increase the reliability of tracer testing is the combination of conventional salt tracer testing and direct push electrical conductivity logging. Initial tests have shown the large potential of the approach and the value of the obtained data. Based on this approach an advantageous concept was developed and successfully tested to reliably capture tracer distribution in highly heterogeneous sedimentary deposits in-situ and visualize tracer distribution and spread over time. Additional measurements, such as surface geophysics, were used to validate obtained results.

Determination of vertical hydraulic gradient in clay till using a MiHPT advanced Direct-push technology

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Keywords: Vertical Hydraulic Gradient, Direct-Push, Dissipation Test

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone monitoring, Hydrological, hydrochemical and hydrogeological investigation techniques, Direct-push technology

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Abstract

Direct-push (DP) methods are widely used in field investigations at contaminated sites for continuous characterization of the subsurface geology and contamination. One frequently used DP technique is the Membrane Interface Probe (MIP), which indicates contaminant levels. Another method is the Hydraulic Profiling Tool (HPT) used to obtain information about subsurface permeability and estimate hydraulic conductivity. Hence, combining these methods (MiHPT) provides continuous information on both subsurface hydrogeology and contamination.

At contaminated sites, in clay till settings, solute transport is complex due to the presence of fractures and sand lenses. In past years, usage of contaminant mass discharge to evaluate the risk of groundwater contamination has increased. To estimate the vertical contaminant mass discharge from the source into the groundwater key parameters are the vertical flow velocity, contaminant concentration and source area. The vertical velocity can be determined by a Darcy approach using the vertical hydraulic gradient and the vertical hydraulic conductivity. Alternatively, the infiltration of water can be used as a surrogate; however, the prediction of infiltration is highly uncertain in clay till settings. This study demonstrates how to determine the vertical hydraulic gradient using an already existing DP tool.

A part of the MiHPT investigation is to perform dissipation tests that describes the change in pressure over time after turning of the water flow in the probe. The test provides an absolute hydrostatic pressure from which the hydraulic head can be estimated. Currently, the dissipation test is used only to adjust information about the permeability. The use of estimated hydraulic head gained from dissipation tests to estimate the vertical hydraulic gradient have not been applied in site investigations.

To investigate the potential for determination of vertical hydraulic gradient using the MiHPT method, a study was carried out at a contaminated site, where the groundwater aquifer is overlain by a 12 m thick clay till with sand lenses embedded. Several MiHPT logs were conducted and multilevel-screened wells were installed. The aim was to investigate if the dissipation test and permeability data from the MiHPT logs can give a reliable estimate of the vertical hydraulic gradient between the aquifer and sand lenses above. Estimated hydraulic head and hydraulic gradient were in accordance with those gained from the multilevel-screened wells. Thus, the study showed that the MiHPT can estimate reliable vertical hydraulic gradients between the sand lenses and the aquifer using the suggested approach. With the efficient use of the MiHPT it is to some extent possible to eliminate expensive installations of multilevel-screened wells when assessing vertical hydraulic gradients at a site.

This method adds value to the widely used MiHPT, and provides crucial information. It is cost saving and leads to better risk assessment of contaminated sites in clay till setting.

Rapid DNAPL Source Zone Characterization with Dye-Enhanced Laser Induced Fluorescence (DyeLIF)

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Keywords: DNAPL; High-resolution; Characterization; Direct-Push; Remediation

Most Relevant Conference Theme: Emerging Sensor Technologies

Background/Objectives. Dense non-aqueous phase liquid (DNAPL) source zones pose one of the biggest characterization challenges in the environmental industry. Conventional methods like monitoring wells are poorly suited to mapping DNAPL due to the highly heterogeneous distribution of DNAPL. Other high-resolution characterization tools, like the membrane interface probe, provide rapid screening-level assessments of dissolved phase mass, but do not directly detect DNAPL. Laser-induced fluorescence (LIF) is a successful, mature technology, with wide application for mapping non-aqueous phase liquids (NAPLs). However, LIF was limited to hydrocarbon LNAPL and tar-based DNAPLs only, until the recent development of the dye-enhanced LIF (DyeLIF) tool. DyeLIF combines standard LIF technology with injection of a fluorescent, hydrophobic dye ahead of the LIF window to render non-fluorescent NAPLs such as chlorinated solvents fluorescent and measurable. The probe functions by injecting an aqueous delivery fluid containing the hydrophobic dye through a small injection port situated below the LIF window. As the probe is advanced through the subsurface, the injected dye contacts the soil and quickly partitions into any present DNAPL. A slightly modified TarGOST® is used to detect the dye-labeled DNAPL's fluorescence.

Approach/Activities. DyeLIF was used at a former chemical manufacturing plant to refine the distribution of DNAPL prior to any evaluation of potential remediation options. The DNAPL was thought to be located on top of an interbedded clay zone, and consisted of a mixture of chlorinated compounds such as 2-chloroethanol, dichloroethane, trichloropropane, and bis(2-chloroethoxy)methane. As the probe was advanced, fluorescence waveforms consistent with the site DNAPL were detected, along with other non-DNAPL sources of fluorescence (e.g., organic material). The differences between target and non-target fluorescence allowed real-time non-negative least squares analysis of the DyeLIF logs, which in turn allowed an adaptive investigation strategy. During the advancement of the probe, pressure associated with the injection of the dye was logged, and was used to interpret changes in relative permeability, similar to the commonly available direct-push injection logging tools on the market. By simultaneously interpreting both the relative permeability and the DyeLIF fluorescence log, it was possible to locate the DNAPL and the relative transport potential in the same boring.

Results/Lessons Learned. DyeLIF borings demonstrated that the historical delineation of DNAPL, which was based on measurable presence in monitoring wells, did not represent the actual distribution of DNAPL. The DyeLIF results indicated the DNAPL was present in the complex interbedded soils underneath the site, which could be mapped using the pressure response on the DyeLIF tool. Three-dimensional interpretation of the hydrostratigraphy and DyeLIF results provided an unprecedented understanding of the extent and distribution of DNAPL within the subsurface. And, because DyeLIF provides real-time results, the investigation was able to delineate the extent of DNAPL in a single mobilization.

Session 5

Using High Resolution Site Characterization for Real Time Data Acquisition and Decision Making

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Keywords: Real Time Data, Environmental, Characterization

Most Relevant Conference Theme: Real time decision making, Emerging Sensor technologies, Big data synthesis

Abstract

It is much easier to make good decisions if you have good data in real time. Environmental assessment and remediation programs can fail from the lack of a thorough understanding of subsurface conditions. Contaminant distribution and subsurface permeability can be complex and traditional sampling and testing techniques can result in high variability and large data gaps. In-situ high resolution site characterization (HRSC) has become a key component of site assessment and decision making in support of site assessment. HRSC, as part of a Phase II Environmental Site Assessments (ESAs), can greatly enhance the understanding of the presence, concentration and distribution of contaminants (and hydrogeological settings) in the subsurface with large high quality data acquisition.

HRSC technologies commonly used to enhance understanding include the Membrane Interface Probe (MIP) for dissolved-phase contamination, the Laser-Induced Fluorescence (LIF) probe for light non-aqueous phase liquid (LNAPL) contamination, and the Hydraulic Profiling Tool (HPT) for subsurface permeability and estimating hydraulic conductivity. All three probes are advanced using direct push methods and provide real-time data in large quantities. These technologies allow the gathering thousands of data points on a centimeter scale in a day and can rapidly delineate impacts and hydrogeological variability horizontally and vertically. With the real time high data acquisition from these tools and intelligent in-field decision making allows for the HRSC programs to be adaptable and not constrained to traditional ESA thought processes and execution.

These large datasets can be rendered into 3D visualizations to supplement Conceptual Site Models (CSMs) and optimize potential remedial designs.

This presentation will showcase the various HRSC tools and how they facilitated successful subsurface delineation programs. The LIF was used to better understand and characterize an unknown historical LNAPL plume on a former rail yard. The MIP was used to delineate a large and complex dissolved-phase petroleum hydrocarbon plume and then utilized to optimize a successful in-situ chemical oxidation remediation program. The HPT was used to characterize and measure the subsurface and ultimately estimate hydraulic conductivity variances for a successful funnel and gate permeable reactive barrier (PRB) optimization and installation.

Real-Time Data Collection and Visualization Technologies for Emergency Spill Response Projects

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Keywords: Real-Time, Data, Monitoring, Characterization

Most Relevant Conference Theme: Emerging sensor technologies

Abstract

During the response and management of small to large scale chemical spills potentially impacting the environment and/or human health, collecting data in a fast and efficient manner is critical to making time sensitive decisions to minimize or eliminate the risks. It is equally important to collect and store this data in an effective manner to generate figures that illustrate the data in a clear manner to help incident commanders and first responders make effective data driven decisions and to engage with the public in a meaningful way. This presentation will review several innovative technologies used on recent emergency response projects related to real-time data collection, unmanned aerial vehicles (UAVs), and 3D visualizations.

During a large-scale facility fire that resulted in the evacuation of a local town, GHD was tasked with collecting and managing soot deposition data in areas downwind of the facility. GHD activated survey teams to conduct investigations in areas downwind of the facility during the Incident and based on potential soot deposition modelling. Using custom mobile applications to record observations of soot deposition, soil characteristics, and sample locations, which continuously transfers entries to a remote database. The data collected by the survey teams is uploaded to the database real-time and can be accessed by members of the joint incident command team in order to get real-time progress, document conditions, support management of incoming claims and drive potential remedial action.

During a train derailment that resulted in the release of crude oil in close proximity to a water body, GHD implemented daily UAV flights to map out impacted areas in order to document potential subsurface impacts, to document site conditions and facilitate remedial activities. GHD prepared daily figures to map spill pathways, initial extents of impacts, to show daily progress of excavations to remediate the subsurface, and to assist with future remediation planning. UAV flights were also completed to estimate soil volumes for disposal to assist with planning and budgeting needs. GHD developed digital terrain models of the Site from UAV collected data to ensure topography was restored to pre-existing conditions. GHD's efforts contributed to effective communication amongst stakeholders related to remediation activities, and future planning for the project.

To assist with a public consultation for a remediation work plan related to a historical spill that was adjacent to a waterbody and public beach, GHD provided modelling and 3D visualization services showing site geology, hydrogeology, and a rendering of the subsurface remediation system. Using geostatistics and 3D kriging, a model and animation of the contaminant migration and a rendering of the proposed system was developed and presented to the public to engage with the public and get feedback related to the project.

Synchrotron X-ray Microtomography at Sirius, the Brazilian Light Source – in situ, time-resolved and multiscale experiments for subsurface characterization

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Keywords: X-Ray Microtomography, Time-Resolved and In-Situ Experiments, Multiscale Characterization

Most Relevant Conference Theme: Multiscale monitoring in fracture rock environments

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Abstract

Historically, between the 1960s and 1970s, the rapid development of X-ray tomography occurred because of its great use in medicine as a non-invasive method of analysis of the interior of the human body. Although the focus has been on this area for many years, it was in the 2000s that the possibility of obtaining inside information from a sample without destroying it drew the attention of different areas of science such as soil science, meteorology, paleontology, geotechnology, petroleum geology, and others. Today, however, a more recent technique known as 4D microtomography represents the frontier of knowledge in this area, and it is now possible to study different materials during a mechanical, thermal or chemical load.

The goals of this work are (a) to present this cutting-edge technique, which will be soon available for the world research community at Sirius, the new Brazilian synchrotron light source, (b) to discuss what type of information can be obtained from 4D images; (c) to brainstorm ideas for new experiments and applications. In addition, a few illustrative examples of what will be achievable at Mogno beamline, the Micro and Nanotomography beamline of Sirius, will be presented: (i) a simple multiscalar 3D analysis of a rock sample, with resolution varying between nanometric and micrometric scales, with no extra need for sample preparation, and (ii) the flow of different fluids inside a porous media in real time, i.e. one full 3D image created in a few seconds.

Session 6

Comparison of Groundwater Velocity Profiles by Different Methods with Other Profiles of Hydrogeologic and Hydrogeophysical Properties

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Keywords: High-Resolution Site Characterization, Groundwater Velocity, Electrical Resistivity, Oxidation-Reduction Potential, Hydraulic Conductivity

Most Relevant Conference Theme: Multiscale monitoring in fracture rock environments

Abstract

Adequate delineation of subsurface heterogeneity is essential for effective environmental remediation and sustainable basin management. Groundwater velocity is one of the most critical state-variable, dictating the advective transport processes. Its spatial variability is high at many sites, especially in fractured rock. At a fractured rock site in California, groundwater velocity was measured by the Point-Velocity Probe (PVP) method and the Passive Flux Meter (PFM) method at different elevations in a well to a depth of approximately 150 feet. The PFMs were installed in the well and were removed after 14 days. The measured velocity profiles measured by both methods are slightly different but are consistent at large. The PVP method was also employed to measure the groundwater flow direction. However, the measured direction is different from the estimated hydraulic head gradient. The well is instrumented with multiple-purpose sensors for tracer-enhanced time-lapse electrical resistivity (ERT) tomography data collection. An electrical resistivity (ER) profile and an oxidation-reduction (ORP) profile were monitored. The monitored ORP showed the impact of PFMs after the installation. At some depth locations, the ORP impact was recovered within a month after the PFMs were removed. At other depth locations, the ORP impact is still present even more than two months after the PFMs were removed. A potential hypothesis for such persistent impact is that some of the PFM materials/particles were washed out and trapped in the sand pack surrounding the well casing. Besides, the PVP method was also used to measure groundwater flow velocity and direction in another open hole nearby, where FLUTe transmissivity logging was performed. Such FLUTe transmissivity logging was also performed at three other open holes in the proximity. In an area downgradient of these wells/open holes, groundwater velocity profiles at several locations in the same fractured rock formation were measured by colloidal borescope. We will present a comprehensive comparison of the groundwater flow velocity and direction profiles, ORP profiles, ER profiles, FLUTe profiles, and geologic logs obtained by a number of methods. This comparison will be followed with a description their similarities and differences, as well as with our interpretations of the results.

Development of a Downhole Trichloroethene Diffusion Test for Fractured Sedimentary Rock Matrix

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Keywords: Diffusion, Sorption, Trichloroethene, Chlorinated Volatile Organic Contaminants,

Most Relevant Conference Theme: Multiscale monitoring in fracture rock environments

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Abstract

Back diffusion occurs when contaminants that have earlier diffused into low permeability regions of an aquifer later diffuse back into flowing groundwater. Back diffusion of trichloroethene (TCE) and other chlorinated volatile organic contaminants can sustain groundwater plumes for decades to centuries in dual permeability flow systems such as fractured sedimentary rocks. Back diffusion poses a significant challenge for remediation and can require significant investment in long term management. Approaches to measure the site specific rock matrix properties controlling diffusion and quantify the processes are needed.

We developed a dual packer system and methodology that uses an existing borehole to measure the effective diffusion coefficient and retardation factor of trichloroethene and its degradation products in the low permeability matrix of a fractured sedimentary rock aquifer. The TCE and cis-dichloroethene biodegradation kinetic form and rate coefficients in borehole groundwater are also determined. A numerical model of radial diffusion was developed to extract best-fit parameters describing the processes. In addition to test data, the model relies on historical concentration data from the borehole (i.e. monitoring data). The apparatus and method were developed through repeated cycles of testing and modification at the former Naval Air Warfare Center (NAWC), Trenton, NJ. The aquifer underlying NAWC is within the Lockatong Formation of the Newark Basin and legacy TCE contamination.

The transport parameters determined from results of near replicate tests, which are tests conducted at adjacent depths in the same borehole, differ modestly and are consistent with differences in the pre-test TCE concentrations and/or lithologic variability. The best-fit TCE sorption coefficients and biodegradation rates are consistent with the results from independent laboratory measurements using field materials. The parameterized model can be used to quantify the pre-test TCE concentration distribution in the matrix, diffusive mass flux, and other quantities that are useful for developing and refining the site conceptual model and informing remedial decisions. This project is a collaborative effort between the authors and US Geological Survey staff, including: A. Fiore, D. Goode, P. Hsieh, T. Imbrigiotta, M. Lorah, A. Shapiro, and C. Tiedeman.

Well Flow Dynamics During Groundwater Sampling: Comparison of Purge and Passive Sampling Approaches

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Keywords: Groundwater Sampling, Passive Sampling

Most Relevant Conference Theme: Hydrological, hydrochemical and hydrogeological investigation techniques

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Abstract

Contaminated groundwater decision trees depend on accurate and reliable groundwater sampling data. Low flow purging and sampling techniques were introduced to improve sampling data, limit purge volumes, reduce turbidity and agitation during sampling, and to improve repeatability. Passive, no-purge, approaches have likewise been introduced to improve sampling by limiting waste generation, and improving cost structures. How do these methods reflect aquifer concentrations? Do they represent aquifer concentrations differently? How do the different approaches assure reliable groundwater data for remedial decision-making?

US Department of Defense Strategic Environmental Research and Development Program (SERDP) project ER-1704 tested passive and dynamic sampling procedures in the lab, in the field, and in model domains to better understand flow dynamics in wells. Results describe a flow field where water flows largely horizontally from the formation to the well, then flows vertically in the well bore to the pump intake during pumping; and also vertically due to tiny density contrasts when not pumping. Sampling results rely on these downhole flow dynamics. Normally, these effects are not known.

Passive sampling approaches regularly yield similar results without purging, but care is necessary to understand whether stratification in the aquifer is maintained or homogenized in the unpurged well, or if stratification is partially maintained. Determination of these effects requires substantial effort and is probably not warranted for standard monitoring. However, the study is informative in that it explains some of the dynamics associated with why passive and active samples often yield similar chemical results, and illustrates why practitioners still must always pay attention to seemingly unimportant details such as slow purge parameter drift.

Session 7

Groundwater-Derived ^{90}Sr in Tree Swallow Nestlings

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Keywords: Groundwater Transport, Radio-Strontium, Tree-Swallow, Skeletal Dose

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone monitoring

Abstract

Discharge of groundwater plumes has resulted in elevated concentrations of strontium-90 (^{90}Sr) in some surface waters and aquatic sediments at Chalk River Laboratories (CRL). Radiation was measured as gross beta (^{90}Sr and ^{90}Y) in the bone of tree swallow nestlings (*Tachycenita bicolor*) in areas with elevated and near-background levels of gross beta in aquatic sediments. During the feeding of their young, tree swallows forage on insects, the larvae of which develop in wetland soils and aquatic sediments. Most foraging is within 400 m of the nest. Nesting boxes were installed as close as feasible to groundwater discharge areas or in areas having sediments affected by upstream discharge of contaminated groundwater. For comparisons, nest boxes were also installed far from the contaminated areas. Nestlings reared near sediments with groundwater-derived ^{90}Sr had elevated levels of gross beta in their bone. The Perch Lake catchment includes the majority of the waste management areas at CRL and has been contaminated with groundwater-transported ^{90}Sr since the late 1950s. The bone of nestlings from the margin of Perch Lake had the highest gross beta concentrations (maximum of 29 Bq/g fresh weight), providing a maximum calculated skeletal dose rate of 9 µGy/h. This is about ¼ of the ecological effect threshold of 40 µGy/h. Nestlings along the Ottawa River shoreline, where the NRX Rod Bay plume discharges, had up to 8.4 Bq/g of gross beta in their bone. Gross beta concentrations in nestling bone at background or near-background areas ranged generally from 0.1 to 2.4 Bq/g fresh weight, although there were a few higher values - up to 5.5 Bq/g - possibly due to uptake of carbonate rich bits of snail and clam shell, and/or unusually long distance foraging. Reproductive success of the tree swallows was similar regardless of their nesting location at CRL. There were no indications of DNA damage, as measured by the frequency of micronuclei in red blood cells.

Evaluating Long-Term Stability of Sites for Deep Storage Using the $\delta^{44}Ca$ Isotope Signature of Calcite, Fluorite, and Groundwater from the Stripa Mine, Sweden

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Keywords: Calcium, Radiogenic Strontium, Bedrock Stability

Conference Theme: Advances in Isotope Tracers for Subsurface Characterization and Fingerprinting

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Abstract

An objective of this study was to re-visit a site that set the foundations for a variety of subsequent hydrogeology research projects concerning nuclear waste disposal in crystalline rock. Stripa was an active iron ore mine (from 1450 – 1976) and represents a disturbed environment. The primary focus of this investigation used $\delta^{44}Ca$ of calcite and fluorite to evaluate geological processes and water-rock interaction, as they impact fluid evolution over time.

The current understanding of calcium isotopic systematics in continental weathering is limited (Gussone et al., 2016). These authors have requested a multi-proxy approach to further investigate fluid mixing versus $\delta^{44}Ca$ fractionation mechanisms in Earth systems. The present study uses $\delta^{44}Ca$, $^{87/86}Sr$, $\delta^{13}C$, and $\delta^{18}O$ to assess water-rock interaction. Fluid inclusion data (Blyth et al., 2009) and Rare Earth Element data (Frape et al., 1992) of calcite were also used to assist in the hydrochemical interpretation. Paleohydrological information was compared to present-day groundwater conditions, to evaluate long-term stability of the bedrock at Stripa, and potential fluid movement along fracture pathways. Results from this work have wide ranging implications for understanding water-rock interaction and transport processes, not limited to deep paleohydrological flow systems. When combined in a multi-tracer approach, $\delta^{44}Ca$ is a potentially useful tool in assessing contaminant transport and/or regional flow system dynamics.

Fracture mineral investigations were first conducted by Fritz et al. (1989) at Stripa, using carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) stable isotope geochemistry. This study identified three distinct families of calcite: 1. chlorite-epidote associated calcite; 2. fluorite associated calcite; and 3. calcite with no mineral association. Stripa has the most extended range of $\delta^{13}C$ and $\delta^{18}O$ isotopic values found in calcite mineralogy of all crystalline rock sites studied to date (Blyth et al., 2009). Further still, bedrock fractures contain a variety of calcium-bearing secondary minerals (e.g., calcite, fluorite, and epidote). Stripa presents a unique opportunity to evaluate calcium isotope geochemistry in conjunction with carbon, oxygen, and radiogenic strontium isotopic systems at a crystalline rock site that has had a complex fluid history.

The $\delta^{44}Ca$ signature of hydrothermal calcite veins is indicative of fractures that have not had significant fluid flow since the hydrothermal episodes during which those fracture infills crystallized. This holds true during the Quaternary period where the bedrock was subjected to repeated ice-sheet loading and unloading. Groundwater $\delta^{44}Ca$ signatures reveal that the shallow and deep flow systems are not connected. Narrow intervals in upper portions of the V2 borehole (mine-level 410 m) contain fracture calcites and waters with similar $\delta^{44}Ca$ signatures. This observation identifies calcites potentially in chemical equilibrium with present-day groundwaters. Calcium isotopes of fracture minerals and groundwaters can be used as a sensitive tracer that can elucidate information about hydrogeological activity over very long periods.

Subsurface leakage along abandoned oil and gas wells

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Keywords: Methane Emissions, Oil And Gas Wells, Subsurface Leakage; Groundwater Contamination

Most Relevant Conference Theme: Advances in isotope tracers for subsurface characterization and fingerprinting

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Abstract

Oil and gas wells and geologic faults can act as conduits for fluid leakage to overlying aquifers and gas emissions to the atmosphere. Leaking fluids include methane, other hydrocarbon gases (e.g., ethane, propane), oil, and water. Methane is a potent greenhouse gas with a global warming potential 34 to 86 times that of carbon dioxide; therefore, reducing methane emissions can substantially reduce global warming. In addition, subsurface leakage of methane can be an indicator of other hydrocarbon and contaminant leakage to groundwater. Millions of abandoned oil and gas wells exist across Canada, the United States and abroad as legacies of decades to more-than-a-century of oil and gas production. Recent studies show that these abandoned wells are emitting methane to the atmosphere and contributing to groundwater contamination. In this presentation, field studies quantifying and characterizing methane emissions from abandoned wells in Pennsylvania and British Columbia will be presented. The presentation will include direct measurements of methane fluxes, hydrocarbon ratios, methane isotopes, and noble gases, which provide information on processes governing methane emissions and potential groundwater contamination. Then, the use of the measurement data in modeling and database analysis studies will be discussed, along with their implications on oil and gas development, regional greenhouse gas emissions inventories, and groundwater protection.

Session 8

The benefit of using a novel CPT-based seismic tomographic system for geotechnical subsurface characterization

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Keywords: Direct Push Technique, Cross-Hole Seismic Tomography, Damping Ratio, Soil Stress History

Most Relevant Conference Themes: Near-surface and borehole geophysics

Abstract

The thorough understanding of the spatial distribution of geotechnical parameters in the shallow subsoil is essential for site specific risk assessment studies and construction projects. However, the small-scale heterogeneity in the subsurface makes reliable predictions of geotechnical parameters between point measurements often difficult and sometimes questionable.

Seismic methods determining spatial information of the investigated area due to their measuring principles can support the interpolation of geotechnical parameters gathered at point locations by means of site specific correlation functions between those parameters and the small strain stiffness obtained based on seismic velocities. Among the seismic methods the cross-hole tomography between boreholes provides seismic velocity images with the highest resolution and is therefore a first-rate candidate to establish a correlation function. Down to the present days seismic tomography depends on the availability of boreholes while material strength and stiffness, at least in soft soils, can be alternatively also determined by means of cone penetration tests (CPT). CPT is in general considered as more cost-effective than borehole based methods.

In the frame of the R&D project CPTTOMO a novel CPT-based seismic tomography system has been developed. By integrating three-component geophones at different CPT rod levels as well as P- and S-wave sources in small-bore Direct-Push CPT rods seismic measurements are available between two nearby CPT locations. The application of S-waves in comparison to P-waves increases the geotechnical benefits gained particularly from tomographic studies due to their improved spatial representation and the immediate possibility to derive soil dynamic properties.

Our paper presents this novel approach, discusses the benefits and limitations of the combined evaluation of CPT and cross-hole seismic tomographic measurements. The combined technique has been successfully applied at a test site in Germany close to Wittenberg. Results show that the joint evaluation of geotechnical and seismic parameters is going to improve the spatial representation and informative value of the subsurface data.

Optical Image Profiler (OIP) Technical Advances and Field Experience

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Keywords: Fluorescence, Logging, Direct Push, Optical Images

Most Relevant Conference Theme: Emerging Sensor Technologies

Abstract

The Optical Image Profiler (OIP) was originally introduced to the market by Geoprobe Systems in 2016. This probe is unique for its ability to obtain photographic images of soil and unconsolidated formations on a percussion driven tool. The OIP system uses a downhole CMOS camera mounted behind a sapphire window. Images are captured at 30 frames per second and analyzed by digital filters to identify and quantify nonaqueous phase liquid (NAPL) fluorescence. The original version of this tool was configured with a 275nm UV light source to induce fluorescence of fuel hydrocarbon NAPLs and a visible light source to obtain images of soil texture and color at selected depths. Since the time of introduction the OIP tool line has been expanded. The OIP-G (green) uses a 525nm light source for fluorescence of creosotes and coal tars and an infrared LED for images of soil texture. The original OIP included an electrical conductivity (EC) array to provide information on bulk formation EC to assess formation lithology. Now all OIP probes also include a hydraulic profiling tool (HPT) screen and down-hole pressure sensor to obtain information about formation permeability and enhance lithologic interpretation.

This presentation will review case histories of OIP investigations using both 275nm and 525nm light sources. EC and HPT data obtained during these investigations will be reviewed to assess lithologic control on NAPL migration. Unique applications of the tool will also be discussed including using the tool to verify the extent of material movement from the injection of tracer dyes and remediation materials.

Low Altitude Aerial Thermal Infrared Surveys to Detect Groundwater Discharges and Thawing Permafrost

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Keywords: Groundwater-Surface Water Interactions, Thermal Infrared, Permafrost, Groundwater Discharge

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone monitoring; Characterizing frozen and thawing soils

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Abstract

In permafrost areas of the Northwest Territories, Canada, changes in climate and land use associated with oil and gas exploration have the potential to melt permafrost and alter groundwater-surface water (GW-SW) interactions. Thawing of permafrost will result thicker active zones and potentially increase the size of taliks which may allow deep GW to more easily reach the ground surface. In this study a low-altitude (< 300 m) aerial thermal infrared (TIR) survey was undertaken to detect and delineate GW discharge zones to provide insights regarding (GW-SW) interactions occurring in the Bogg Creek watershed, in the Central Mackenzie Valley of the Northwest Territories. A handheld FLIR Model T650sc camera and helicopter were used in the summer to detect areas of colder water where water from thawing permafrost or deep GW reached the ground surface or SW bodies. Survey traverses were performed along: the main channel of Bogg Creek, tributaries of Bogg Creek; at the edges of lakes; along the headwaters of several streams; where distinct changes in surficial geology occurred; in areas of potential icings that were previously identified using satellite images; and across roads and cut lines through the trees. The TIR survey was able to successfully identify: 1) groundwater seeps and springs long streams and lakeshores; 2) tributaries or drainage swales fed by cooler GW or active zone water discharge; 3) seeps and discharges associated with cut lines and suspected winter icings (aufeis) locations, 4) curvilinear features onshore that may be the boundaries between permafrost and non-permafrost terrain (e.g., at small breaks in slope where active thawing may be occurring); and 5) linear features that may represent water filled paths created by animals. The survey method provided much higher resolution images than were available from satellite imagery but it covered a much smaller area of the watershed. Within wet and boggy areas that visually seem to be uniformly wet, the method was able to identify specific areas of discharge and potential thawing. This information was used to strategically sample GW and SW to test hypotheses regarding deep or shallow sources of the water. In other instances, it was also possible to infer locations of active thawing of permafrost adjacent to SW bodies. The TIR survey proved to be a very valuable, non-invasive, real-time, reconnaissance method for identifying and inferring GW discharges in this type of terrain.

Session 9

CMT multilevel systems installed using inflatable rubber packers for small-diameter bedrock boreholes suitable for limited access field sites

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Keywords: Fractured Bedrock, High-Resolution Characterization, Multilevel Systems, Limited Access Investigation

Most Relevant Conference Theme: Hydrological, hydrochemical and hydrogeological investigation techniques

Abstract

Depth-discrete multilevel monitoring systems (MLS) provide opportunities for collecting multi-dimensional datasets while maximizing the value of a single borehole for most groundwater investigations. Many MLS systems are commercially available today for installation into unconsolidated and bedrock boreholes. The use of MLS systems by groundwater professionals and consultants is becoming more frequent and has progressed towards being a standard instrument in the hydrogeologists toolbox for groundwater resource assessment and site investigations.

Over the past decade a popular commercial option for MLS has been the continuous, multi-chamber tubing (CMT) provided by Solinst© (Einarson and Cherry, 2002), which consists of an extruded length of polyethylene tubing with 3 or 7 internal channels and uses sand packs and bentonite seals to discretize the monitoring and sealed zones within the borehole. In many cases this system can cover a multitude of engineering and monitoring requirements for overburden and rock boreholes, both shallow and intermediate in depth. However, improvements by way of usage in small diameter bedrock boreholes, removability of the system, and possible re-purposing of the borehole for other monitoring devices provides additional advantages and improves the cost effectiveness of high-resolution characterization and monitoring in bedrock environments.

In this field study, several shallow 2-inch diameter boreholes were drilled using a portable drill (the Shaw Portable Core Drill™) to a depth of 10-meters into dolostone bedrock where a stand of poplar trees prevented access of traditional drilling rigs into a toluene contaminated source area. 7-channel CMT systems adapted with low-profile inflatable rubber packers were installed in each borehole. The packer lengths were easily customized to the desired length based on core and geophysical data sets, and therefore produced a low-cost multi-depth sampling and monitoring instrument tailored to the site study objectives.

The CMT installations with packer adaptation allowed increased flexibility to site and borehole conditions, providing high resolution datasets of hydraulic head, contaminant and hydrochemistry profiles of the shallow dolostone and contributed to a robust conceptual model of the site and evaluation of phytoremediation influences on site hydraulic fluxes. Removal of these systems for use of the open boreholes remains possible to adapt to evolving site conditions during remediation.

Reference

Einarson, M. D., & Cherry, J. A. (2002). A new multilevel ground water monitoring system using multichannel tubing. *Groundwater Monitoring & Remediation*, *22*(4), 52-65.

Use of digital outcrop photogrammetry to inform fracture network characteristics for discrete fracture network modelling of a sandstone aquifer

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Keywords: Remote Sensing, Photogrammetry, Discrete Fracture Networks, Fractured Rock

Most Relevant Conference Theme: multiscale monitoring in fractured rock environments, emerging sensor technologies

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Abstract

Discrete fracture network matrix (DFN-M) modelling quantifies the interaction between the rock matrix and discrete fracture networks to simulate flow and transport through fractured rock systems. However, the functionality of DFN-M simulations are often constrained by the availability of the field data used to build and calibrate the models. Typically, the primary source of fracture information is obtained from vertical boreholes that are poorly suited for characterization of three-dimensional fracture networks. Recent advances in close-range terrestrial photogrammetry (CRTP), a remote sensing technology, have drastically improved the method's capabilities and make it potentially valuable as a fracture network characterization tool.

The utility of CRTP was tested as part of an ongoing study of a contaminated site where the Wonewoc Sandstone, a regionally significant aquifer across the American Midwest, underlies a DNAPL source zone and dissolved phase plume covering ~ 4 km^2. High-resolution head profiles collected at the site using multilevel systems show head loss across a very small interval (< 1 m) near the middle of the Wonewoc Sandstone. The head loss is indicative of a thin aquitard, but comprehensive characterization data from continuous cores and borehole geophysics at 12 locations do not show any evidence of a low hydraulic conductivity material in this interval. Therefore, it has been hypothesized that the head loss is caused by poor vertical connectivity between adjacent fracture networks in the upper and lower sections of the aquifer. However, the existing network of vertical boreholes at the study site are not able to provide the fracture data required to test this hypothesis. To provide these data and obtain the necessary inputs to construct a DFN-M model of the aquifer, fracture measurements were collected from six outcrops of the Wonewoc Sandstone using CRTP.

Results indicate that measurements of fracture spacing, orientation, and persistence collected using CRTP are accurate to the real-world distances and orientations, and are well within the range of natural variability observed in the fracture sets. Distance measurements from across the six outcrops had an average error of 2%. Dip and dip-direction error averaged 3.1° and 7.1°, respectively. The only fracture parameter required for DFN-M modelling that was inadequately resolved by CRTP was hydraulic aperture, which was instead estimated from packer tests completed in boreholes at the contaminated study site. Ultimately, this study demonstrated the efficacy CRTP to collect measurements of fracture orientation, spacing, and persistence at an acceptable accuracy for DFN modelling, using only standard survey equipment and a digital SLR camera.

How shall we be characterizing, monitoring and modeling groundwater flow and transport through fractured rocks?

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Keywords: Fractured Rocks; Heterogeneity; Hydraulic tomography; Inverse Modeling; Geostatistics

Most Relevant Conference Theme: Multiscale monitoring in fractured rock environments

Abstract

Over the last several decades, considerable effort has gone into better predicting groundwater flow and contaminant transport through fractured rocks. However, significant heterogeneity causes formidable challenges in characterization, monitoring, and modeling. Numerous techniques have been developed to obtain hydraulic conductivity (K), specific storage (S_s), and other parameters at various spatial scales in both unsaturated and saturated zones. On the modeling front, the difficulty in capturing heterogeneity has spawned numerous approaches for conceptualizing flow and transport through fractured rocks. Generally, conceptual models fall under three categories: Equivalent Continuum Models (ECM), Discrete Fracture Network Models (DFNM), and Stochastic Continuum Models (SCM), each with varying parameterizations leading to different characterization requirements. ECMs are typically built with data from single-hole packer or cross-hole pumping tests that can yield biased estimates of hydraulic parameters. For example, a scale effect in hydraulic parameters can result when pumping tests are interpreted with models that treat the medium to be homogeneous. This could have significant impacts on groundwater flow and contaminant transport predictions. DFNMs require detailed fracture geometry data that can be difficult to obtain and its correlation with hydraulic parameters (i.e., K) can be weak or nonexistent. DFNMs are useful for the stylistic understanding of flow and transport behavior, but their calibration and validation are rarely discussed. SCMs built with parameters from single-hole tests can capture the heterogeneity along boreholes. If data from multiple boreholes are available, geostatistical analysis can yield maps of heterogeneity in hydraulic parameters, although connectivity is inferred through information on spatial correlation. Efforts have also been spent on Hydraulic Tomography (HT), which utilizes pressure signals from multiple pumping tests to characterize the spatial heterogeneity in hydraulic parameters through inverse modelling. One could utilize the ECM, DFNM, SCM or a hybrid approach (e.g., combination of DFNM and SCM) for HT analysis. Research to date conclusively reveals that HT yields the most accurate hydraulic parameter estimates in unconsolidated deposits, but further research is necessary in fractured rocks. One issue is that HT yields smooth hydraulic parameter estimates, when the monitoring resolution and number of pumping tests available for inverse modeling are limited. Moreover, because HT relies on pumping tests, matrix K may not be accurately mapped for certain rock types. However, data fusion of other available site information such as groundwater flux has shown promise in improving parameter estimates and in turn the predictive capabilities of groundwater flow models. Other data could also be used to better condition inverse models, but great care needs to go into data selection as each measurement technique yields parameters that are method-dependent. Overall, research to date suggests that inverse modeling and data fusion are necessary steps in building robust groundwater flow and transport models in fractured media.

Session 10

Understanding and Managing Source Water in Sedimentary Rock Aquifers using Airborne Electromagnetic Surveys

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Keywords: Airborne Electromagnetics; Bedrock Valleys; Groundwater Quality and Quantity; Heterogeneity; Hydrostratigraphy

Most Relevant Conference Theme: Multiscale monitoring in fracture rock environments

Abstract

Groundwater practitioners and water resource managers tasked with understanding and mitigating risks to public water supply rely on regional-scale groundwater flow models typically constructed using sparse or low-quality boreholes. Additional higher-quality geological logs obtained using borehole geophysics or continuous core logs may be required to reduce uncertainties in hydrostratigraphic boundaries especially in the vertical direction; however, data gaps between direct measurement points can hinder confidence in the lateral interpretations of lithofacies. Airborne electromagnetic (AEM) surveys are increasingly being used in the development and validation of regional-scale groundwater flow models for this purpose. This study represents the first regional-scale evaluation of the Resolve™ frequency-domain AEM system within a bedrock-groundwater-dependent region that is currently undergoing a detailed water budget and water stress assessment under the Ontario Safe Drinking Water Act (2006). Through a detailed comparison of the airborne magnetic and electrical resistivity data with a regional lithostratigraphic model, we assess the utility of this geophysical approach to characterize local and regional scale hydrogeologic features with a focus on a buried bedrock valley and it's sediment infill. The objective of this study is to evaluate the capacity of a commercially available geophysical tool for regional groundwater resource assessments and monitoring activities. Resolve™ AEM data are compared with high-resolution geological, hydrogeological, and ground-based geophysical information collected over a 50 km2 study area. Inverted 1D and 2D models of the AEM data are assessed through direct comparison with an existing lithostratigraphic model that was subsequently used to constrain a Tier-3 Water Budget and Local Area Risk Assessment. Our integrated hydrogeophysical analysis will be used to validate the areal geophysical measurements. It will also ultimately provide those responsible for the long-term management of Ontario's groundwater resources (e.g., municipalities, government agencies and industry stakeholders) – with a more robust understanding of the utility of AEM surveys in the future assessment and management of local groundwater resources.

Advancing magnetic resonance geophysical methods to characterize groundwater systems

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Keywords: Geophysics, Magnetic Resonance, NMR, Porosity, Permeability

Most Relevant Conference Theme: Sensor Technologies

Abstract

Magnetic resonance geophysical methods allow efficient in-situ characterization of key hydrogeologic properties including porosity, pore size, permeability, and specific yield. Precise downhole measurements can be carried out with small-diameter borehole tools and non-invasive profiling can be achieved using multi-channel surface instrumentation. Recent hardware advancements have focused on accelerating measurements speed, reducing impacts of near-borehole disturbance, and reducing hardware cost. These advancements have enabled use of borehole and surface magnetic resonance across a wider range of environmental and geologic conditions, with applications in water resources, environmental remediation, engineering, and mining. In addition to characterization of static hydrogeologic properties, we have recently investigated methodologies to characterize dynamic systems. Extending from advanced techniques in medical MRI, we have tested implementation of magnetic resonance measurements that are synchronized with fluid injection. These experiments aim to determine dynamic parameters including flow velocity, flow distribution, and dispersion. Meso-scale laboratory experiments in a PVC flow cell have yielded promising results indicating the ability to characterize flow inside the formation both qualitatively and quantitatively. Dynamic experiments on unsaturated systems undergoing drying also demonstrate the capability to monitor fractionation of water between different pore sizes as saturation decreases. Field implementation of these flow injection methods will combine borehole magnetic resonance measurements with specially designed packer systems.

High resolution characterization of time-lapse tracer experiments using crosshole GPR full-waveform inversion: A synthetic study

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Keywords: Hydrogeophysics, Full-Waveform Inversion, Tracer Test

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone monitoring

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Abstract

Time-lapse geophysical methods are used in hydrogeophysical and environmental science to monitor e.g., tracer migration, contaminant leaks, and tide-driven salinity changes. In the last decade, crosshole ground penetrating radar (GPR) full-waveform inversion (FWI) has shown a high potential to characterize, map, and monitor the critical zone with a decimeter-scale resolution and improved our understanding of dynamic processes that are taking place in the critical zone. The GPR FWI can retrieve two physical soil properties at the same time: the permittivity and electrical conductivity. While permittivity is mainly linked to soil water content and porosity, the electrical conductivity depends on soil properties such as soil texture, clay content and on the electrical conductivity of the pore water. The GPR FWI method demonstrated especially the potential to detect small-scale high contrast layers that can be related to zones of high porosity, zones of preferential flow or clay lenses.

Here, we want to investigate the possibilities of the crosshole GPR FWI to monitor and map different tracer plumes during time-lapse experiments. Thereby, three different synthetic tracer tests are investigated that influence either the permittivity or the electrical conductivity of the FWI results. Based on the large hydrological and geophysical dataset available for the Krauthausen test site in Germany, a detailed high resolution hydrological model was set up. The synthetic transport model was used to derive for three different tracer experiments synthetic time-lapse GPR data at several time steps after inserting the tracer within the aquifer. We performed the FWI for the background GPR data set and at different time steps individually and independent from each other. Thereby, we investigated different starting model inversion strategies to guarantee a stable, fast, and reliable FWI for the different time steps. To visualize the tracer plume, the FWI results are subtracted from the background FWI results. Important questions that were addressed with these synthetic tests are: How much tracer is necessary to be detected by the FWI; What is the optimal borehole setup and acquisition strategy. The results of these synthetic tests will be used for designing upcoming field experiments at the Krauthausen site where all the different traces will be applied to enhance our understanding of the Krauthausen aquifer.

Session 11

Water Level Responses to Natural Signals at Multiple Temporal Scales

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Keywords: Water Levels, Monitoring Frequency, Hydraulic Parameter Estimates

Most Relevant Conference Theme: Multiscale monitoring in fracture rock environments

Abstract

Well water levels are constantly changing due to natural stresses such as earthquakes (subsecond-hours), barometric pressure (seconds-days), Earth tides (hours-years), evapotranspiration (hours-days) and precipitation (seconds-years). Monitoring water levels every hour or even every minute may miss an entire response, portions of a response, or add uncertainty to interpretations. The water level contribution due to a change in the natural system may be realized instantaneously or may present itself incrementally over the short or long term, and be small or large in magnitude. With improved technology and analysis methods, high precision (< 1 millimeter) and high frequency monitoring (< 1 min) will become more common leading to the ability to detect and analyze responses to smaller and more distant stresses. Higher frequency monitoring allows for shorter duration signals to be analyzed and improved understanding of the contributors to the measured water level.

All water levels respond to natural signals and therefore a thorough evaluation of their effect at multiple temporal scales is necessary. At a fractured sandstone site in California, water levels were monitored every second for multiple years to capture multiple temporal scales of response. By monitoring at high frequency a more complete record of the water level fluctuations were obtained which can be related to different input signals with more confidence. To demonstrate the value of collecting water levels at high frequency we examine the water level response to barometric pressure under different monitoring frequencies. We then present the full barometric pressure response from seconds to days, a function useful for parameter determination. In the model fitting process we obtain Earth tide amplitudes and phase shifts and the resulting residuals can be utilized for further analysis.

Establishing a Baseline Groundwater Monitoring Network in the Transboundary Liard Basin

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Keywords: Baseline Monitoring, Multi-Levels, Sandstone Core Sampling

Most Relevant Conference Theme: Multiscale monitoring in fracture rock environments, Emerging sensor technologies, Near-surface and borehole geophysics

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Abstract

Located in the northwest corner of the Western Canadian Sedimentary Basin within the borders of British Columbia (BC), the Yukon (YT) and the Northwest Territories (NWT), the Liard Basin contains the second largest shale gas reserve in Canada. The main regional water supply aquifer in the basin is the Dunvegan Sandstone Formation. Existing agreements between BC, YT and NWT require transboundary freshwater resources be monitored if they serve as current or potential sources of drinking water and could potentially be impacted by hydraulic fracturing activities. The NWT government has initiated a baseline groundwater monitoring program to evaluate current and future impacts on water quality and quantity due to conventional or unconventional oil and gas development in the region. The proposed groundwater monitoring program will utilize state-of-the-science, high resolution core sampling and geophysical methods developed for contaminant hydrogeology and groundwater resource protection in fractured sedimentary rock environments to develop an advanced understanding of the groundwater quality and flow system conditions prior to oil/gas development in the southwest corner of NWT. The establishment of a groundwater monitoring network will allow for long term monitoring through the collection of multiple-depth hydraulic and hydrochemical data for the government and local communities. Due to the complexity of sedimentary rock environments an approach developed by Parker et al. (2012) using high resolution conventional and innovative methods, termed the Discrete Fracture Network-Matrix (DFN-M) approach, will be applied at multiple sites in and around the Hamlet of Fort Liard and along the Liard River. Based on a review of the geological maps, five potential study sites have been identified and evaluated with surface geophysical surveys. To confirm the presence and estimate the depth and thickness of the fresh water bearing Dunvegan Formation, preliminary work involving surface electrical resistivity imaging was initiated in 2018 at the proposed groundwater monitoring sites. Geophysical results indicate the presence of the Dunvegan Formation at four of the five locations at depths ranging from 15 to 180 m below ground surface. This information will be used to inform drilling locations and targeted drilling depths with the purpose of advancing at least one cored borehole where continuous core will be logged in detail and subsampled for porewater chemistry/isotopes, natural gas concentrations (C1 to C3 gases) and carbon isotope composition. Datasets from these initial locations will inform the communities of their natural groundwater resource quality and quantity and provide critical information about the position and thickness of high and lower permeability layers serving as aquitards, which will inform local and regional groundwater flow system conditions and vulnerability.

The development of multi-test, straddle packer testing equipment and procedures to improve high-resolution transmissivity measurements

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Keywords: Fractured Rock, Packer Testing, Hydraulically Active Fractures, Transmissivity

Most Relevant Conference Theme: Multiscale monitoring in fracture rock environments

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Abstract

Discrete fracture network numerical (DFN) models have long been available to simulate groundwater flow and transport in fractured rock, however these models are rarely applied at field sites because input parameters such as fracture aperture, length, and spacing are difficult to quantify. Because simulation results are strongly sensitive to fracture aperture there is need to decrease errors and uncertainty in aperture estimates. Hydraulic apertures derived using the cubic law using T values from straddle-packer tests are the most practical way to obtain aperture input. Errors in the estimation of hydraulic apertures are derived from uncertainty in the measured transmissivity (T) value and the estimation of the number of 'active' fractures participating in the hydraulic response. Over the last 10 years we have worked on improving our straddle-packer testing equipment design and testing procedures to better understand the fluid mechanics assumptions regarding the flow of water passing through the test equipment and the fractures intersecting the tested interval while improving testing efficiency. Selective packer testing using previously collected borehole data (i.e., contaminant analysis, image logs, FLUTe profiling, ALS temperature logging, caliper log) allows reducing the number of zones to be tested in the borehole without missing any major flow zones. Insights concerning the nature of test conditions are obtained using a multiple-test approach to evaluate the inherent mathematical assumptions used to determine T, including Darcian flow, horizontal radial flow, and steady flow. Using this equipment, we have shown that when constant head step tests and "stepped" slug tests at different initial displacements are carefully conducted in the same test interval, the Darcian assumption can be easily validated, and T values from these tests are typically within 10-15%. However, when short circuiting to the open hole above and/or below the packers, the radial flow assumption is violated and T values are biased high. These tests can be corrected using a steady-state model developed for multi-aquifer wells to calculate the flow required to cause the head change observed in the open hole. More recently we have improved the test equipment by adding two packers to the straddle packer assembly thereby creating two sentinel intervals, one above and one below the tested zone, in order to contain the hydraulic response into the three intervals. This system has multiple advantages over a straddle packer system including i) better isolation of the tested zone to obtain better head values, ii) limiting the portion of the rock exposed to the hydraulic stress to improve short circuiting corrections, and iii) collection of data that allows calculation of vertical K values between the three packed off zones.

Session 12

Visual Analytics and Information Management for Comprehensive Geothermal Reservoir Characterization

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Keywords: Visual Analytics, Information Management, Geothermal Reservoir Characterization, Spatial Data Mining

Most Relevant Conference Theme: Big data synthesis and aspects of artificial intelligence

Abstract

We developed the modular software application GeoReVi (Geothermal Reservoir Virtualization), an integrated visual analytics and information management tool for comprehensive geothermal reservoir characterization. The tool accelerates analytics and visualizations of all scales of reservoir-related data by an integrated implementation of the Knowledge Discovery in Databases process.

NoSQL and relational databases provide formalized data warehouses. Among others, numerous types of laboratory measurements, borehole geophysical logs, lithological logs and well test data can be managed in self-adaptive forms custom-made for the specific requirements. The graphical user interface comprises customizable controls for interactive visualization of geothermal field parameters.

Large data sets can be uploaded in custom upload dialogs and analyzed with multivariate (geo)statistics, and multi-relational data mining algorithms. Multi-threading algorithms split up computationally intensive tasks to obtain a significant data analysis acceleration. Analysis results can be visualized in scatterplots, box-whisker-plots, lithological sections, histograms, time-series charts, cross-sections and 3D charts. Visualization algorithms can be triggered while navigating through the data sets or explicitly by deployment of commands. The tool can be used online in a multi-user environment as well as offline in the field.

Being tested in multiple field and laboratory studies, we present the capability of the tool to assess and visualize a geothermal reservoir's quality focusing on spatial heterogeneity and structural anisotropy in two case studies. Investigations were carried out in a multi-user environment including data from both reservoir and outcrop analogue rocks on the reservoir-, outcrop- and sample scale.

Applying Innovative Digital Technologies to Communicate Complex Subsurface Features

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Keywords: In-Situ Measurements; Geostatistics; Innovative Digital Solutions; 3D Conceptual Site Model; Stakeholder Engagement

Most Relevant Conference Theme: Big data synthesis

Abstract

At contaminated sites with a complex subsurface features, understanding potential migration pathways, and effectively transferring this understanding to stakeholders, is crucial for successful project outcomes. However, projects have finite resources available, meaning that extensive site characterization is often not feasible. Therefore, the collection of data using relatively low-cost, in-situ methods can be key in maximizing the use of available resources. A case study is presented where relatively low-cost, in-situ hydraulic profile testing was completed at an industrial waste site to characterize potential groundwater migration pathways. In-situ profiling has the advantage of providing high-resolution data.

At the Site, an innovative digital approach was developed by incorporating a diverse set of environmental data into an interactive 3D conceptual site model and augmented reality virtual reality platforms. This suite of innovative digital solutions helped streamline communication with all stakeholders, driving future environmental decision-making at the site. The hydraulic profiling data were grouped into representative categories, and indicator kriging was then used to create a geostatistical 3-dimensional model of the subsurface hydraulic conductivity at the site. The 3D hydraulic profile was combined with laser induced fluorescence results, soil contaminant concentrations, and groundwater elevation data in an interactive 3D model, which was used to identify potential contaminant migration pathways. The interactive 3D model was presented to site stakeholders, and proved a vital tool in allowing them to grasp the important aspects of the complex subsurface conditions, and agree on appropriate remedial action. This approach for the synthesis of relatively large amount of different data into a simple, visual, conceptual model improves the ability for stakeholders to grasp subsurface complexities.

Tomographic Characterization of Hydraulic Parameters Using Groundwater Extraction/Injection Operational and Monitoring Data

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Keywords: Site Characterization, Inversion, Pump-And-Treat, Modeling, Heterogeneity, Hydraulic Conductivity

Most Relevant Conference Theme: Big data synthesis and aspects of artificial intelligence

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Abstract

The delineation of hydraulic conductivity (K) heterogeneity is essential to support effective remediation of environmental sites and sustainability management of groundwater basins. However, K characterization by conventional methods is a difficult and expensive task at sites with complex hydrogeology. Inadequate K characterization has resulted in poor remediation performance at many legacy environmental sites and excessive potentiometric head decline at many over-drafted wellfields. Recently, a technique based on sequential pumping tests and stochastic hydraulic tomography (HT) inversion using successive linearization estimator (SLE) has been demonstrated to be effective for delineating K heterogeneity. The HT technique was initially developed to treat the K-distribution in a groundwater model as a correlated random field and to invert the model stochastically using the hydraulic head response data from individual aquifer pumping/injection tests. Although many environmental sites with pump-and-treat systems and water suppliers with production wellfields have collected an abundant amount of operational and monitoring data, sequential pumping tests by temporarily shutting down individual wells might not have been performed. Performing such tests might not be possible due to operational constraints. Even if they have been performed, the duration of operational changes might have been too short. The monitoring data during a temporary operational change always contain the complex signature of previous operations prior to the change. Although all historical data can be theoretically utilized for HT inversion, the computational effort needed is practically infeasible.

We will present a computationally efficient approach based on a combination of Transfer Function Noise (TFN) analysis and Hydraulic Tomography (HT) analysis to estimate the spatial K-distribution and the associated uncertainty using abundant extraction/injection operational and monitoring data. We will use the operation and monitoring data collected at an environmental site in Arizona as an example. The TFN technique can be applied to estimate the hydraulic head response to constant-rate pumping/injection at each relevant well through convolution integration. Such step-response functions are equivalent to the data collected from individual aquifer pumping/injection test without carrying any long-duration pumping/injection operations signals and can be utilized directly in HT analysis. We will present an efficient approach to simplify the HT computations by incorporating principal component analysis (PCA) to reduce the numbers of parameters and the number of calibration targets. This method allows for the removal of both parameter and calibration target dependencies without losing significant information. In addition, we will present a Markov Chain Monte Carlo (MCMC) approach for HT inversion. This approach can be easily adopted to use any forward simulation models.

Session 13

‘Urban Karst’ – Investigation and Monitoring of an Urban Till Aquitard Groundwater System

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Keywords: Storm Sewer Exfiltration, ‘Urban Karst’

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone monitoring

Abstract

Increasing impermeable surfaces in urban settings and installation of storm sewers and other urban infrastructure can affect groundwater flow and quality in urbanized watersheds. Although interaction between storm sewers and the groundwater system is widely recognized in the literature, there are few studies that have investigated in detail how the storm sewer system ‘karstifies’ a till aquitard groundwater system. This abstract presents a unique case study of an urban groundwater system in Southern Ontario, Canada. The study used different monitoring and investigation methods to understand the groundwater pathway between storm sewers and a foundation drainage collection (FDC) system that were designed to operate as hydraulically separate entities.

Three different types of groundwater monitoring installations were used: standard monitoring wells installed with geotechnical drill rig; wells installed with a hydrovac method; and shallow drive-point piezometers. A key consideration for these installations was access and avoidance of underground utilities. Parameters monitored at a 10-minute interval included water level, temperature and conductivity, with records spanning from 2012 till present.

In addition to this monitoring, field-scale storm sewer exfiltration tests were completed to identify the flow path between the storm sewer and the FDC. These comprised controlled filling of storm sewers using a large-diameter packer system and dye release. The importance of each installation type was demonstrated with the results of these exfiltration tests. This shows that a multi-component toolkit is required to understand the karst-like behavior of the groundwater system in response to storm sewer system exfiltration.

Application of Hydraulic Tomography for Subsurface Heterogeneity Characterization using Long-term Water-Supply Pumping/Injection Records: Numerical Experiments and a Field Application

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Keywords: Aquifer-Aquitard Heterogeneity, Municipal Well Records, Geostatistical Inverse Modeling, Hydraulic Tomography

Most Relevant Conference Theme: Big data synthesis and aspects of artificial intelligence

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Abstract

The sustainable management of groundwater resources is of paramount importance to municipalities worldwide due to the increasing water demand from dramatic population growth, protection of groundwater resources from contamination, and increasing energy costs of community water systems. Planning for the optimized use of groundwater resources requires a sound understanding of hydrogeology and reliable estimation of hydraulic conductivity (K) and specific storage (S_s), which are two important hydraulic parameters in predicting groundwater flow and solute transport. In this study, hydraulic tomography (HT) is applied to estimate the heterogeneous K and S_s distributions using long-term water-supply pumping/injection records at the Mannheim East wellfield in Kitchener, Ontario. Such records are typically not considered for pumping test analyses and have not previously been applied for subsurface heterogeneity characterization. Moreover, conducting dedicated pumping tests in municipal wellfields could present significant challenges.

To investigate the performance of HT and the feasibility of utilizing long-term water-level records in revealing subsurface heterogeneities, we first generated synthetic data modelled after the operation of the Mannheim East wellfield and simultaneously calibrated four groundwater models with varying parameterizations using six datasets consisting of different time durations, periods within a given year, and densities of observation data. Specifically, one effective parameter model, one geology-based zonation model, and two geostatistical models with/without geological data as prior information are calibrated with wellfield operation data. Knowledge gained through the numerical experiments is then utilized to characterize the subsurface heterogeneity at the Mannheim East wellfield using real data. Our study reveals that: 1) the HT analysis of municipal well records is feasible and yields reliable heterogeneous K and S_s distributions where drawdown records are available; 2) the geostatistical inverse models are able to adequately delineate the K and S_s heterogeneities, while the inclusion of geological information provides significant improvement in terms of model calibration and validation; 3) head data should be carefully examined and selected for inverse modeling to avoid ill-posed problems, information overload and to achieve better results. This study also illustrated that municipal well records should be kept and utilized for automatic groundwater model calibration and validation. However, new approaches need to be developed for big data synthesis and intelligent data selection for inverse modeling.

Climate Change Effects on Coastal Groundwater in Yemen during 1981 to 2016

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Keywords: Climate Change; Groundwater Recharge; Yemen Coastal Wetlands, GIS

Most Relevant Conference Theme: Advances in GW-SW interaction and critical zone monitoring

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Abstract

The climate change impacts have strong upon water resources availability because it threats the different environmental, economic, and political impacts in the whole world. Groundwater resources are related strongly with climate change; direct interaction through surface water resources; and indirect interaction through the recharge process. Moreover, demanding for freshwater for human become worst because of groundwater reserves has been depleted that may create serious problems especially in coastal areas. Yemen faces many risks such as water crises, food insecurity and widespread poverty. These risks will be increased because of climate change like high temperatures, sea level rise and a lack of adequate environmental policies. These became more complicated and difficulties in the coastal zones because the main source of drinking water is groundwater. Furthermore, more than 75% of population lives in rural area especially in western side and almost all coastal areas are rural region. The research aim is to present a comprehensive overview of the impact of climate change on coastal region based on literature, technical papers and expert reports. In general, two climate change scenarios used. This study described Yemen hydrogeology especially in the coastal zones. In addition, the study investigated the relationship between climate change and loss of fresh groundwater resources by using GIS method to map coastal watersheds. The result shows that many future issues due to climate change will be appeared such as the main annual temperature will be increased from 1.2℃ to 3.3℃ by 2060, the rainfall rate increased in various lands or reduced in others, and the sea level raised about (0.30 - 0.54 m) by 2100 and the drinking water from wells continue to be more salt since last decade because of seawater intrusion in the coastal aquifer. The consequences of sea level raising were many such as loss of wetlands, the retreat of shorelines and intrusion of salt water into aquifers and estuaries. The situation can be worst because irrigation requirements increased. Finally, the recommendations, which includes some adaptation measures for climate change impacts, would be suggested.

Session 14

Recent advances using fibre optic Active Distributed Temperature Sensing (A-DTS) to measure natural gradient flow in fractured bedrock aquifers

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Keywords: DTS, Sensor, Groundwater Flow Quantification, Bedrock Aquifer, Temperature

Most Relevant Conference Theme: Emerging sensor technologies

Abstract

Measuring in-situ groundwater flow rates under natural gradient conditions in bedrock aquifers is a persistent challenge due to the irregular distribution and discrete nature of fractures and other flow pathways. This presentation highlights progress over the past seven years on a technique to measure natural gradient flow rates along the full length of a temporarily sealed bedrock borehole using fibre optic Active Distributed Temperature Sensing (A-DTS). The technique utilizes heat as a tracer and involves lowering a custom designed composite cable containing both optical fibres and copper heating wires into the borehole, installing a flexible liner to hydraulically seal the borehole and to couple the cable against the borehole wall, and heating the cable using an electrical resistance method. The rate of temperature increase during heating is measured continuously along the full length of the optical fibre using a Distributed Temperature Sensor (DTS) (sampling and spatial resolutions of 0.13 m and 0.29 m respectively) allowing spatially continuous profiles of apparent thermal conductivity to be estimated. Enhancement of thermal conductivity occurs in zones of active groundwater flow and can be distinguished form no-flow zones by comparing the A-DTS derived profile to a rock thermal conductivity baseline generated from lab measurements. Quantification of flow rates from the thermal data has been achieved through a combination of numerical heat transport modelling, lab rock core measurements, and A-DTS field experiments. The flow estimates are validated with independently measured straddle packer point dilution flow estimates and show good agreement (within several L/day) in most intervals. Additional field tests to assess the sensitivity of the technique were conducted by measuring A-DTS tests under different hydraulic gradient conditions and confirm the technique is sensitive to changes in flow within the bedrock aquifer. Further advancements have demonstrated the potential for determining the natural gradient flow direction using simultaneous multi-borehole A-DTS tests. Thus, it may be possible to efficiently obtain information on the magnitude and direction of groundwater flow under natural gradient conditions. Certain challenges still exist, such as quantifying the lower sensitivity limit and uncertainty of the flow measurements and are the topic of ongoing research. Distributed fibre optic sensing is highly versatile, and this presentation highlights how these advanced sensing technologies can be utilized to help understand groundwater flow through one of the most complex aquifer types.

High-resolution Characterization and Geostatistical Analysis of Aquifer Structure Using Direct Groundwater Velocity Measurements

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Keywords: Geostatistics, Direct Groundwater Velocity, PVP, CFB Borden

Most Relevant Conference Theme: Emerging sensor technology

Abstract

Spatial variations in groundwater velocity (v) can strongly influence contaminant transport in the subsurface. Previously, the spatial distribution of groundwater velocity has been estimated indirectly, through statistical analysis of high-resolution hydraulic conductivity (K) datasets. Until recently, methods for the direct characterization of groundwater velocity at comparable resolutions were not available. The development of Point Velocity Probes (PVPs), introduced a little over a decade ago, has advanced to where they can now be used to acquire direct groundwater velocity measurements at the resolution necessary to support a detailed geostatistical description of a sandy aquifer. Here we compare PVP measurements from the well-characterized C.F.B. Borden Aquifer, Ontario, Canada, to a well-known dataset comprising K measurements at a similar measurement resolution. PVP measurements were regularly spaced at 1 m horizontal intervals and 0.08 m vertical spacings from a depth of ~ 2 to 4 m below ground surface, along a transect approximately perpendicular to the direction of known groundwater flow, controlled by two pumping and injecting well pairs. In total, 420 measurements of direct groundwater velocity were made along the 14-m long transect. From these data, 413 measurements are used to estimate the autocorrelation structure of the aquifer. The results are compared to the original geostatistical description of the aquifer, based on K measurements published by Sudicky (1986). The overall mean groundwater velocity measured is 20.5 cm day^{-1}. The groundwater velocity data are lognormal with an overall variance in ln(v) of 0.49. Exponential model fits of both the horizontal and vertical empirical semivariograms yield correlation lengths of 1.6 m and 0.13 m, respectively. These results compare well to those published by Sudicky (1986) (2.8 m and 0.12 m, respectively). The close agreement between the two datasets shows for the first time that in a relatively homogeneous and isotropic aquifer, high-resolution measurements of *in situ* groundwater velocity can yield very similar descriptions of the spatial structure of the aquifer and the associated flow field. These results demonstrate the efficacy of PVPs for high-resolution aquifer characterization, particularly in settings where anisotropy or heterogeneity in the aquifer make *ex situ* measurements of K problematic.

Use of Steady-State Hydraulic Tomography to Inform the Design of a Chaotic Advection System

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Keywords: Chaotic Advection, Groundwater, Hydraulic Tomography, Subsurface Heterogeneity, RPM Flow

Most Relevant Conference Theme: Hydrogeological investigation techniques

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Abstract

The concept of chaotic advection is a novel approach that has the potential to overcome some of the challenges associated with mixing of reagents that commonly occurs when injection based *in situ* treatment techniques are used. The rotated potential mixing (RPM) flow system is one configuration which has been theorized to achieve chaotic advection in porous media, and enhance reagent mixing by periodically re-oriented dipole pumping at a series of radial wells. Prior to field implementation of chaotic advection, the selection of an RPM flow protocol will likely require a numerical model that can adequately represent groundwater flow within the zone of interest. As expected, the hydraulic conductivity (*K*) field is the most critical input requirement for the selected groundwater flow model. Hydraulic tomography (HT) is an innovative characterization approach that has shown significant potential to provide more accurate information on heterogeneous *K* distributions (or tomograms) compared to traditional site characterization methods. In this investigation, we explored whether the same well system required to invoke chaotic advection can also be applied in a HT analysis, and evaluated the use of the generated *K* tomogram for the selection of RPM flow parameters that can enhance reagent mixing. A series of dipole pumping tests were conducted at the Borden site within an area of interest as defined by the limits of the circular network of eight injection/extraction wells used to invoke chaotic advection. Hydraulic head data collected from independent dipole pumping tests were used in an inverse model to perform steady-state hydraulic tomography (SSHT) analysis and generate the *K* tomogram. Both the *K* tomogram and effective parameter approach (i.e., a single *K* value assigned across the entire spatial domain as determined by single well pumping and slug tests) produced estimates of hydraulic head that closely resembled those observed due to the relative homogeneous nature of the aquifer and the small spatial scale of the area of interest. In contrast, particle tracking results showed that incorporating a heterogeneous *K* field significantly enhanced the spatial distribution of particle trajectories indicative of reagent mixing. These findings support the hypothesis that the same well system used to invoke chaotic advection can be combined with SSHT analysis as a viable site characterization tool for delineating the spatial variability of *K*. Incorporating this *K* tomogram in a groundwater flow model with a particle tracking engine can be used as a design tool to aid in the selection of a site-specific RPM flow protocol to achieve enhanced reagent mixing.

Session 15

Field Methods for Developing a General Conceptual Model for Organic Contaminant Plume Transport & Attenuation in Fractured Rock

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Keywords: Plumes, Sedimentary Rock, Flow Systems, High Resolution, Transport & Reaction Processes

Most Relevant Conference Theme: Multi-Scale Monitoring in Fractured Rocks

Abstract

High-resolution field investigations at selected industrial properties contaminated with chlorinate solvents for several decades serve as long term, natural gradient tracer experiments and are the basis for a field-based research program regarding plume behavior in fractured sedimentary rocks. Their concentrations can be measured over many orders of magnitude for delineating and understanding plume behavior. In fractured sedimentary rocks the effects of diffusion cause two strong and useful effects: 1) complete dissolution of the DNAPL phase from fractures in the source zone and 2) strong plume front retardation due to transverse diffusion into the matrix. This results in nearly all the contaminant mass residing in the low permeability matrix where measurable diffusion halos identify hydraulically active fractures; many more than are found by conventional borehole measurements. The ability to distinguish the fractures important for contaminant transport are used to inform discrete fracture networks with matrix (DFM) numerical models for groundwater flow and transport, and show concentration distributions that match observations at these highly characterized and monitored field sites when informed with site-derived parameters. Multiple, high resolution spatiotemporal data sets are necessary to inform these models including parameters for the important processes and calibration targets, as well as sufficient data reserved for numerical model verification. Given that the time and distance scales for plume attenuation is site specific, improved field methods for informing DFM numerical models will improve science-based decisions for bedrock aquifer vulnerability assessments and wellhead protection zone delineations specific to various contaminant types that threaten groundwater resources. Results from a field-based research program where conventional and new borehole and laboratory methods have advanced the General Conceptual Model for organic contaminant plume behavior in fractured sedimentary rocks will be presented and suggestions for how these methods can be tailored to the range of contaminant and fractured rock conditions.

Assessment of Sources and Transformation of Nitrate in Sabkha Environment by Using Multi-Tracer Approach (Sabkha Matti, Saudi Arabia)

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Keywords: Isotopes, Nitrate, Denitrification, Sabkha

Most Relevant Conference Theme: Advances in isotope tracers for subsurface characterization and fingerprinting

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Abstract

An unusually high concentration of nitrate (NO_3) ranging between 291 and 6790 mg/L (as N) was observed during a review of solute data for brine samples from the inland Sabkha Matti, Saudi Arabia. A multi-tracer approach considering water chemistry, stable nitrate isotopes ($\delta^{15}N$ and $\delta\ ^{18}O$), and radioactive isotopes (^{3}H and ^{14}C) was utilized to evaluate the nitrate sources and transformation in this hydrogeological setting. The results from the shallow Sabkha Matti Aquifer (SMA) suggested that the source of nitrate in this aquifer must be a leakage from a recent manure/septic source near the proximal eastern edge of the Sabkha. However, another source of nitrate was observed in a relatively deeper formation (Dam). In the Dam, the nitrate concentrations were enhanced from dissolved soluble minerals on the sabkha surface by major rain events. The resultant dense, oxygenated water is then transported downward by a density-driven free convection. The impact of Sabkha's characteristics on biological denitrifications was also evaluated. Denitrification was not a major process in SMA. In contrast, brine samples from the Dam formation were significantly enriched in $\delta^{18}O$ and $\delta^{15}N$, which is an indication of denitrification. This result concluded that denitrification can occur in sabkha systems under certain chemical conditions.

Using virtual data sets to evaluate approaches for conceptual site model development and remediation design at DNAPL-impacted sites

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Keywords: Dense Non-Aqueous Phase Liquids (DNAPL), Site Characterization, Remediation, Groundwater Flow & Transport, Numerical Modeling

Most Relevant Conference Theme: Hydrogeological investigation techniques

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Abstract

The DIVER project (Data Information Value to Evaluation Remediation; SERDP ER-2313) focuses on the development of an optimized framework for the site characterization and remediation phases at dense, non-aqueous phase liquid (DNAPL)-impacted sites. Two different technical approaches were applied to evaluate the value of information/data that would be available at contaminated sites: Decision Theoretic (DT) and Evidence Based (EB). Four high-resolution, DNAPL-impacted virtual site datasets (VSDs) were created using the 3-D multiphase flow and transport model, DNAPL3D-RX*, to assess the applicability of both DT and EB methodologies. Each VSD provided different degrees of geological heterogeneity, hydrogeology, and the spatial/temporal distribution of DNAPL and dissolved plume(s).

In the EB approach, decision maker (DM) teams were tasked with developing site investigation strategies for each VSD using their professional intuition from their prior experience with similar scenarios. DM teams investigated each VSD using an available suite of virtual site investigation tools and developed conceptual site models (CSMs) which were evaluated against the "true" VSD parameter values and spatial extents. From the information gathered in the CSM phase, DM teams were asked to design enhanced in situ bioremediation (EISB) remedies to achieve site-specific remediation metrics. DM teams were evaluated based on cost, accuracy, and performance in their CSM development and remediation design phases at each VSD.

The results from both DT and EB methodologies will help to develop "best practice" approaches to site characterization and remediation at DNAPL-impacted sites. These "best practice" approaches will contribute to the reduction in contaminated site lifecycle costs and efforts, and recommendations for more effective strategies to site characterization/remediation. The initial results from DIVER also provided the basis for the development of a publicly-available interactive training tool (TEMPO**) which will be a learning platform for practitioners that emphasizes the importance of decision making and data collection during the site investigation phase at contaminated sites.

*Model has been developed and updated as described in Kueper and Frind (1991), Kueper and Gerhard (1995), Gerhard and Kueper (2003), Grant et al. (2007), West and Kueper (2012).

**The TEMPO interactive tool is available at the following URL address:
http://prjweb03.geosyntec.com/tempo/geoform/

Session 16

Exploring the subsurface: Monitoring below-ground colloid fate and transport using spectral induced polarization (SIP)

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Keywords: Geophysical Techniques; Spectral Induced Polarization; Nanoparticles; Microbial Activity.

Most Relevant Conference Theme: Advances in groundwater –surface water interaction and critical zone monitoring

Abstract

Our reliance on the subsurface as a resource and service provider (e.g., mining, agriculture, energy, groundwater, nutrient and contaminant attenuation) requires us to gain a detailed understanding of subsurface processes and properties. Currently, subsurface investigation techniques rely on invasive and destructive methods, which only provide limited information in space and time. Thus, our inability to capture information at the necessary resolution in space and time hinders the quantification and characterization of dynamic (bio)geochemical transport processes. Electrical geophysical methods, such as spectral induced polarization (SIP), offer a powerful alternative to commonly employed observational techniques. SIP provides high spatial and temporal resolution information of subsurface electrical properties which are modulated by (bio)geochemical processes at the particle-water interface. We present results from two experiments where SIP was used to monitor time-variable colloid concentrations of a suspension of coated-iron oxide nanoparticles (abiotic), and the growth and decay of organic carbon degrading microbes (biotic). By monitoring time-lapse signal changes, we were able to reliably remove background signal contributions and directly relate SIP signal changes to each target colloid. Furthermore, we show that coupling high-resolution reactive transport models with geophysical data yields a powerful tool for improving the quantitative interpretation of SIP datasets, as they relate to specific transport and/or reactive processes. Our experimental results support the feasibility of using SIP for the non-invasive (ex situ) monitoring of the subsurface transport of engineered nanoparticles, and the in situ growth and activity of subsurface microbial populations. Future work is needed to scale the experimental laboratory results up to mesocosms and, ultimately, field scale studies.

Revealing the hydrostratigraphic architecture of a buried bedrock valley through a comparison of helicopter-borne FDEM and multiple surface geophysical techniques

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Keywords: Airborne Electromagnetics; Surface Geophysics, Water Resource Mapping; Heterogeneity

Most Relevant Conference Theme: emerging sensor technologies

Abstract

Airborne geophysical surveys have the potential to help determine hydrostratigraphic frameworks that can assist in efficiently developing site conceptual models for numerical groundwater flow models. However, successful hydrogeological interpretations require access to adequate calibration points. An airborne electromagnetic (AEM) survey using the resolve system was completed over a 50 km^2 area of dense agricultural farmland adjacent to a city in southern Ontario, Canada, currently undergoing a Tier 3 water budget and local area risk assessment of their groundwater resources. The goal of the AEM survey was to assess potential structural controls on the local quaternary-bedrock groundwater flow system including identifying preferential pathways to bedrock aquifers and the influence of bedrock morphology on groundwater flow and transport. A current hydrostratigraphic model for the area used existing regional quaternary mapping which was based on existing water well records, geotechnical and consulting databases, achieved field descriptions of the surficial geology, and 43 new high-quality continuous cored boreholes (spaced ~3-7 km apart) across the region; however, resolution of this mapping might not be adequate for the complex heterogeneity of sediments encountered in the area. In this study, the results of the AEM survey are compared against the existing hydrostratigraphic conceptual model for the area as well as multiple surface geophysical surveys completed along two transects centred over a buried bedrock valley which serves as an example of a relatively complex hydrogeologically significant feature. Concurrently collected geophysical surveys including gravity, resistivity, electromagnetics, and seismic refraction were conducted along each transect to characterize the bedrock morphology and architecture of the quaternary infill. Surface geophysical measurements were jointly interpreted with historical geophysical datasets and the existing regional three-dimensional quaternary model to evaluate the capacity of the AEM survey to delineate the heterogeneity of aquifer-aquitard sequences. Given the geological and hydrogeological inputs required for a regional-scale groundwater flow model, we address the question of if an appropriately designed AEM survey can provide groundwater practitioners with useful hydrogeologic information.

Mapping Permafrost Continuity in the Central Mackenzie Valley Using Electrical Geophysical Methods

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Keywords: Permafrost, Groundwater, Electrical Methods, Geophysics, Conductivity.

Most Relevant Conference Theme: Characterizing frozen and thawing soils

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Abstract

Continuing research on permafrost related issues has contributed much to the scientific record directly related to climate change and the consequential effects that degrading permafrost content at a global scale. Permafrost melt is both an indicator and a contributor to the greater global climate change problem. Detecting changes in permafrost occurrence and continuity in remote environments remains challenging. In this work, we compare and contrast the performance of two conventional surface geophysical techniques; electrical resistivity tomography (ERT) and electromagnetic induction (EMI) in detecting permafrost continuity in the shallow subsurface. The ERT method, routinely used in the past to map shallow permafrost occurrence requires the installation of multiple metal electrodes along a horizontal profile, which is laborious and difficult to implement in wet or frozen soil conditions. The EMI method, on the other hand, does not need a direct connection with the subsurface and as such, may offer a more convenient and applicable option in some circumstances. The methods were applied at two different field sites within the Sahtu Settlement Area (SSA) located in the Central Mackenzie Valley of the Northwest Territories (NWT). The specific experimental sites are located within the Bogg Creek Watershed approximately 30 kilometers southwest of Norman Wells, NWT. The sites were chosen beneath or near landscape features that were anticipated to influence permafrost occurrence; a recently cleared forested setting (6 years) and the shoreline of a relatively large surface water feature. The results suggest that both the ERT and EMI methods were able to clearly delineate changes in permafrost depth and continuity in the shallow subsurface and that the geophysical profiles closely match manual measurements of permafrost depth made along the survey lines with a handheld, steel permafrost probe. As anticipated, permafrost degradation was documented both beneath the cleared site and adjacent to a large lake within the watershed. This study illustrates that the results gathered from the permafrost probe, ERT and EMI methods are in agreement and that these portable survey methods provide multiple lines of evidence of permafrost continuity in this remote setting without the necessity for more costly, intrusive methods such as drilling for core collection or the installation and monitoring of vertical thermistor strings.