Characterizing regional groundwater flow systems:

Insight from practical applications and theoretical development

Symposium Agenda and Abstracts

Organized by:

Regional Groundwater Flow Commission of

International Association of Hydrogeologists

26–28 June 2017

Calgary, Alberta, Canada

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Welcome note of the Symposium

This international symposium examines the current state of the regional groundwater flow concept, discusses recent theoretical advancement, and shares experiences from applications spanning energy exploration to environmental management. Gravitational systems of groundwater flow are generally understood in terms of their structure, hydrologic effects and controlling factors of flow patterns; yet, there is an ever-broadening scope of application across neighbouring disciplines. The aim of this symposium is to bring together influential researchers and practitioners from the hydrogeological community to learn about the past, present, and future of the regional groundwater flow concept.

In the early 1960's József Tóth published seminal work on the concept of regional scale flow and nested flow systems. His work built on the "fluid potential term" by M.K. Hubbert, and seemed to come along just at the right moment in the history of hydrogeology. Armed with József Tóth's work, geologists and engineers began to see a bigger picture than revealed by aquifer tests, one that functionally related flow systems and natural processes and phenomena. Championing this concept, the mission of the IAH's Regional Groundwater Flow Commission (RGFC) is to internationally foster the research and practical application of regional groundwater flow.

This symposium was sponsored by the Canadian National Chapter of the International Association of Hydrogeologists. The symposium is organized by the IAH Commission on Regional Groundwater Flow. We thank Dr. Diana Allen and the IAH-CNC board for the generous support of this unique scientific meeting and the opportunity to gather and celebrate the regional groundwater flow concept.

We hope you enjoy the high-quality technical agenda and the time to connect with colleagues.

Brian Smerdon
Organizing Chair

Ádám Tóth
Symposium Secretary

Tuesday 27 June, 2017

8:00	Brian Smerdon, Diana Allen Judit Mádl-Szőnyi	Welcome and Introductory Remarks
8:15	Okke Batelaan	**KEYNOTE:** Regional Groundwater Flow Systems: Past, Present and Future
Session 1: Groundwater Flow Fundamentals Session Chairs: Judit Mádl-Szőnyi, Alfonso Rivera		
8:45	Xiao-Wei Jiang	Characterizing nested flow systems in a large watershed using geophysical, hydrochemical and flow modelling approaches
9:00	Dan Palombi	Advancing Methods for Basin Hydrodynamics to Support Integrated Subsurface Management
9:15	K. Udo Weyer	Revisiting the 'Henry Problem' of density-driven groundwater flow: A review of historic Biscayne aquifer data
9:30	Cathy Ryan	Towards a conceptual model for free gas transport in the subsurface
9:45	Charles Lawrence	Regional groundwater flow: history, refinements and ramifications in Australia
10:00	Morning Break (30 min)	
Session 2: Near Surface Processes Session Chairs: Brian Smerdon, Ben Rostron		
10:30	Masaki Hayashi	Meaning of recharge in the context of regional groundwater management framework: Alberta example
10:45	Abe Springer	Comprehensive Methods to Conduct Landscape-Level Analyses for Improving Springs Ecosystems Stewardship
11:00	Alanna Felske*	Evaluating groundwater-surface water interactions at a large permanently flooded wetland in the Canadian prairies
11:15	Igor Pavlovskii*	Depression-focussed recharge in the prairies of Alberta: Insights from stable isotope data
11:30	Terri Cheung*	Establishing chemical and isotopic baseline conditions in a shallow bedrock aquifer at a gas migration field research station in south-eastern Alberta, Canada
11:45	Marek Marciniak	Direct measurements of submarine seepage of groundwater into the Puck Bay, Poland
12:00	Lunch (60 min)	

Session 3: Site Characterization Session Chairs: Masaki Hayashi, Ádám Tóth		
1:00	Gavin Jensen	Hydrogeology of Phanerozoic strata in Saskatchewan: Province-wide Hydrogeologic Mapping
1:15	Menggui Jin	Groundwater mixing and flow system evolution in the Quaternary aquifers of Manas River Basin, arid northwest China: Hydrochemistry and environmental tracer indicators
1:30	Brian Smerdon	Multiple lines of evidence for nested groundwater flow in west-central Alberta
1:45	Samantha Morgan*	Using airborne time-domain electromagnetic data and normalized gamma-ray logs to interpret the internal stratigraphy of a buried valley network
2:00	Rachel Lauer	Investigating the utility of airborne electromagnetic surveys for mapping local and regional hydrogeology in the Edmonton-Calgary corridor
2:15	Amir Niazi	Conditioning the geostatistical simulation of Paskapoo formation with lithologs, Paleo-current statistics and pumping test for stochastic regional groundwater modeling
2:30	**Poster Session 1** & Afternoon Break (60 min)	
Session 4: Geochemistry and Numerical Simulation Session Chairs: René Lefebvre, Xiao-Wei Jiang		
3:30	Payton Gardner	Using synoptic river surveys to characterize groundwater systems
3:45	Dirk Kirste	The chemical and isotopic composition of groundwater in Northeast British Columbia: implications for local and regional groundwater flow systems
4:00	Éowyn Campbell*	"Old" water in mountain streams: a case study of the Elbow River and its river-connected alluvial aquifer
4:15	Debora János	Numerical simulation of regional groundwater flow and residence time distribution in the Chaudière-Appalaches region, Québec
4:30	Zhi-Yuan Zhang*	The variations of flow rates and solute concentrations with depth in open flowing wells

4:45 Regional Groundwater Flow Commission General Meeting (30 min)

Poster Session 1

James Ellis	Variable Density Groundwater Flow: Are equivalent freshwater heads necessary or misleading?
K. Udo Weyer	Dynamics of subsurface flow of fluids of different densities
Márk Szijártó	The interaction of basin-scale gravity-driven groundwater flow and free thermal convection
Viktor Balogh*	Effect of different driving forces in large sedimentary basins
Brigitta Czauner	Application of the regional groundwater flow concept in the hydraulic evaluation of a partially confined carbonate area (Budapest, Hungary)
Marek Marciniak	Variability of hydraulic conductivity in the hyporheic zone
Aaron Mohammed*	Vadose zone dynamics governing snowmelt infiltration and depression-focused recharge in prairie landscapes
Michael Moncur	Regional distribution of arsenic in the Cold Lake – Beaver River watershed: Implications of groundwater – surface water interactions
Marc Laurencelle	Paleo-hydrogeological evolution of a fractured-rock aquifer following the Champlain Sea Transgression in the St. Lawrence Valley (Canada)

Wednesday 28 June, 2017

8:00	Grant Garven	**KEYNOTE:** Geofluids leakage along an active plate boundary, southern California
Session 5: Economic Reserves Session Chairs: Dan Palombi, Okke Batelaan		
8:30	Ben Rostron	Hydrogeological characterization of the Aquistore site: Canada's first CO 2 storage project associated with a commercial-scale coal-fired power plant.
8:45	Hanneke Verweij	Improved assessment of the basin hydrogeologic framework by combining hydrodynamic and petroleum dynamic analysis methods, Dutch case studies
9:00	Steve Shikaze	Insights Gained from Resource and Reserve Estimates in Brine Deposits
9:15	David Barton*	Geochemistry of fluids from an unconventional gas field in New Brunswick, Canada: Identification of unique tracers for migration to shallow groundwater
9:30	Ádám Tóth*	Geothermal potential assessment of the carbonate Hungarian Transdanubian Range
9:45	Judit Mádl-Szőnyi	Significance of the understanding of regional pressure regimes in geothermal exploration for confined carbonate reservoirs
10:00	Morning Break (30 min)	
Session 6: Oil Sands Session Chairs: Hanneke Verweij, Brent Welsh		
10:30	Jon Fennell	Pathways and Connections: enhancing knowledge of Alberta's groundwater resources through Canada's Oil Sands Innovation Alliance (COSIA)
10:45	Cynthia McClain	Alberta Oil Sands Area Regional Groundwater Quality
11:00	John Wozniewicz	Lower Prairie Evaporite Aquifer System Underlying the Mineable Athabasca Oil Sands Area
11:15	Pascale St-Germain	Geological controls on the distribution groundwater flow systems within the Middle-Devonian strata of the Northeast Athabasca Region
11:30	Louis-Charles Boutin	COSIA Regional Groundwater Solutions Project for the Southern Athabasca Oil Sands – Evolution of A Numerical Model
11:45	Brent Mooder	Post-mining hydrogeology in Alberta's mineable Athabasca oil sands region
12:00	Lunch (60 min)	

Session 7: Geochemical Characterization Session Chairs: Menggui Jin, Diana Allen		
1:00	Judit Déri-Takács*	The geochemistry of springs and surface waters of Wood Buffalo National Park, Canada
1:15	Ben Rostron	Unusual calcium-rich formation-waters from Devonian aquifers in the Western Canada Sedimentary Basin: possible relict seawater?
1:30	Daniel Skoreyko*	Hydrochemistry of the Bakken aquifer in the Williston Basin – Canada and USA
1:45	Petra Bodor*	In situ measurement and modeling of physicochemical parameters at discharging thermal water – Experimental study 1
2:00	Katalin Csondor*	Flow system interpretation of the second largest karst system of Hungary – hydraulic and hydrogeochemial characterization
2:15	Krzysztof Dragon	Use of chemical data for verification of the groundwater flow conditions (Lwówek region, Poland)
2:30	**Poster Session 2** & Afternoon Break (60 min)	
Session 8: Water Management and Numerical Simulation Session Chairs: John Molson, Dirk Kirste		
3:30	Maxime Claprood	Importance of local-scale geological features in regional-scale groundwater modelling
3:45	Mike Callaghan	Integrated Surface-Subsurface Hydrologic Modeling to Evaluate Risks to Agricultural Production at Regional Scales
4:00	Polina Abdrakhimova	Numerical simulation of long-term pumping in a heterogeneous sandstone aquifer
4:15	Matthew Simons*	Numerical modelling of highly saline wastewater disposal in Northeast British Columbia
4:30		Closing Remarks

Poster Session 2

Petra Bodor	Evolution of biogeochemical precipitation at discharging thermal water – Experimental study 2
Anita Erőss*	Flow system analysis of the Villány karst region (Hungary) using hydraulic methods and natural tracers
Marie-Amélie Pétré	Geological, hydrogeological and numerical models of the transboundary Milk River Aquifer system (Alberta, Canada - Montana, USA)
Bhagwan Chaudhary	GIS based spatio-temporal studies of groundwater quality and depth in Kaithal District of Haryana, India
Samendra Sherchan	Best Management Practices on fecal contamination reduction in Lake Pontchartrain
Józef Górski	Wells location as a factor of contaminant removal during river bank filtration (Mosina-Krajkowo well field, Poland)
Sean Funk*	HYDROSCAPE: A new versatile software program for modeling contaminant transport in groundwater
Lucien Lyness	Principles of Aquifer Management as Contextualized and Highlighted by a Municipal-Supply Case Study
Shyamaprasad Sinharay	Integrated Watershed management in Water Stressed Western Tracts of West Bengal, India — a Bonanza for Water Resources
Jiann-Mou Chen	Analytical Solutions for pollution transfer with Arbitrary Time-Dependent Surface Fluxes

* Presenting Author is an Early Career Hydrogeologist.

Regional groundwater flow systems: Past, present and future

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ABSTRACT

The self-organisation of groundwater flow in nested systems (Tóth, 1963) is arguably one of the most fundamental properties of groundwater flow. In this contribution, we will reflect on regional groundwater flow systems in terms of its concept and theory, its acceptance in science and its significance of practical usage in the past and present. We also critically review the future need for further development of the theory as well as how regional groundwater flow systems can play an enhanced role in groundwater science, practice and policy.

A number of observations emerged from the reflection and review of the literature. First is that overwhelmingly, a specified-head top boundary condition has been used for the water table. This specified condition, often topography, can induce important errors in the flow solution, as the water table is in reality a function of the system's properties and stresses. More research is needed to elucidate the general properties of nested groundwater flow systems under a free-surface water table condition, which should lead to scaling laws to describe the characteristics of nested groundwater flow systems. Second, most studies on nested groundwater flow systems considered cross-sectional conditions; we should tackle problems in three dimensions. Third, the effects on regional groundwater flow systems of the spatial distribution of recharge, the interaction with surface water and vegetation, the fractal characteristics of topography, and subsurface heterogeneities all have barely been investigated. Fourth, the impact of pumping and climate change on the hierarchical organisation of flow systems is largely unknown, and hence deserves more attention if we want to tackle the challenges posed by the current world's pressures. While technical difficulties may have hampered advances on this topic in the past, a myriad of methods and computing power are now available to make this research possible.

Characterizing nested flow systems in a large watershed using geophysical, hydrochemical and flow modelling approaches

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ABSTRACT

Characterization of nested flow systems is difficult due to the limited availability of field data and the influence of aquifer heterogeneity on groundwater flow and solute transport. Geophysical, hydrochemical and flow modelling approaches were developed and successfully applied in the Dosit River watershed inside the Ordos Plateau, which is mainly composed of relatively homogeneous sandstone aquifers.

Due to the homogeneous Cretaceous aquifer with uniform porosity, the variation in bulk resistivity of the aquifer is mainly caused by groundwater salinity. The magnetotelluric technique is used to obtain the apparent resistivity of a profile across the Dosit River. The basin-bottom hydraulic trap below the river has been detected, and its size has been found to be large enough for possibe deposition of large ore bodies. The boundaries between local and regional flows have also been identified, which would be useful for groundwater exploration and calibration of large-scale groundwater models.

In the Dosit River watershed, there are numerous domestic wells with different depths ranging from several meters to almost one thousand meters, which provides a great opportunity to collect water samples with depth-dependent hydrochemistry. Cluster analysis of pH and major ions leads to five clusters with drastically different hydrochemistry [Wang et al., 2015], which could be related to the development of nested flow systems.

We also built a 3D numerical model of groundwater flow in the Dosit River watershed. Due to the complicated structure of nested flow systems in the 3D domain, it is difficult to directly partition the different flow systems based on the numerical model. The existence of one distinct late-time peak shown on the RTD indicates that the Dosit River Watershed has a two-order nested flow structure with local and regional flow systems. The results based on RTD are found to be basically consistent with hydrochemical results.

ECHN

A modeling analysis of the effects of production-well location in a large-scale groundwater system

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ABSTRACT

Unit-basin groundwater flow models of the plains regions of Alberta, Canada, are analyzed by numerical simulation. The relationship between the location of water wells, and well yield and basin stability in a large-scale groundwater system is evaluated. Two basin hydrologic parameters, namely transitional basin yield (TBY) and sustainable basin yield (SBY), are employed to measure the development potential of the system's groundwater resources under continuous production. TBY is the net cumulative inflow of water into the system, induced by and during development at a particular site, from an initial to a final steady-state condition. SBY, on the other hand, is the amount of water captured from precipitation due to production at a particular site under the newly established steady-state conditions.

The models produced key relations in optimizing the development potential of the groundwater resources in extensive unconfined basins. TBY is found to be highest for well locations in the discharge area and decreases gradually as the sites are moved toward the recharge area. On the other hand, SBY is greater if the wells are located in recharge areas than if they are in the discharge areas. The models show also that under conditions of restricted rainfall, a recharge-area development results in unstable basin hydrological conditions sooner than when development takes place in the discharge area. It is suggested that regional groundwater exploitation should be initiated in discharge areas and moved towards recharge regions gradually, and only for compelling reasons.

Revisiting the 'Henry Problem' of density-driven groundwater flow: A review of historic Biscayne aquifer data

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ABSTRACT

Coastal groundwater flow investigations at Biscayne Bay, south of Miami, Florida, gave rise to the concept of density-driven flow of seawater into coastal aquifers creating a saltwater wedge. Within that wedge convection-driven return flow of seawater and a dispersion zone were assumed by Cooper et al. (1964) to be the cause of the Biscayne aquifer 'sea water wedge'. This conclusion was based on the chloride distribution within the aquifer and on an analytical model concept assuming convection flow within a confined aquifer without taking non-chemical field data into consideration. This concept was later labelled the 'Henry Problem', which any numerical variable density flow program has to be able to simulate to be considered acceptable.

Revisiting the above summarizing publication with its record of piezometric field data (heads) showed that the so-called sea water wedge has been caused by discharging deep saline groundwater driven by gravitational flow and not by denser sea water. Density driven flow of seawater into the aquifer was not found reflected in the head measurements for low and high tide conditions which had been taken contemporaneously with the chloride measurements. These head measurements had not been included in the flow interpretation. The very same head measurements indicated a clear dividing line between shallow local fresh groundwater flow and saline deep groundwater flow without the existence of a dispersion zone or a convection cell.

The Biscayne situation emphasizes the need for any chemical interpretation of flow patterns to be backed up by head data as energy indicators of flow fields. At the Biscayne site density-driven flow of seawater did not and does not exist. Instead, this site and the Florida coastline in general are the end points of local fresh and regional saline groundwater flow systems driven by gravity forces and not by density differences.

Towards a conceptual model for free gas transport in the subsurface

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ABSTRACT

Subsurface free phase gas (FPG) transport is evident by bubbles in springs, wetlands, and as free gas 'breakouts' during excavations and drilling. Evidence for episodic FPG fluxes has also been observed in micro- and macroscopic seeps in soil, offshore mud volcanoes, cold-water geysers, and lakes that regularly discharge biogenic and geogenic gases to the atmosphere. Fugitive methane emissions around leaky petroleum wells have brought the issue to the forefront of groundwater quality concerns in some parts of Canada. To date there is no published conceptual model that details the geochemical and physical processes involved in FPG transport despite the fact that it involves orders of magnitude higher mass fluxes than dissolved phase transport.

This presentation will review relevant physical and chemical processes in FPG transport, and present conceptual models for discussion. Relatively new concepts to hydrogeologists include total dissolved gas pressure, bubbling pressure (summation of the water pressure, atmospheric pressure, and capillary pressure), the effect of FPG in water well columns on hydraulic head measurement, and relevant small-scale interactions at the gas-water interface of bubbles. The potential role of FPG transport in dissolved gas compositional changes, gas mass fluxes, and FPG detection (or measurement) and management methods will also be discussed.

Regional groundwater flow: history, refinements and ramifications in Australia

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ABSTRACT

Following the advance of the regional groundwater flow system (RGFS) theory developed by Tóth in the 1960s and the subsequent numerical analysis by Freeze and Witherspoon, researchers in Australia, beginning with Hodgson and Hitchon (1965), Hitchon and Hayes (1971) and Lawrence (1973, 75), were soon applying this theory to many of the 21 large sedimentary basins. In particular, Tóth's theory helped to define regional hydrodynamics, to trace hydrochemical evolution, to explain petroleum migration and to recognize and understand groundwater discharge features.

Evidence from groundwater discharge features, mostly as playas and particularly in the Murray Basin, demonstrated a dynamic hydrologic history of interplay between groundwater and surface water over at least the last 40 000 years. This temporal variation has swung between fresh water lakes, when the surrounds could be colonized by aborigines, to drying playas underlain by dense reflux brines driven counter to the upward flowing RGFS.

European settlement brought hydrologic changes, by extraction of fresh groundwater and increased recharge through the widespread clearing of deep-rooted native vegetation and surface water irrigation. This increased recharge, generated and reactivated local and intermediate GFS, mobilizing saline stores and causing salinization of land and streams. Much of this salinization is related to groundwater flow systems in low permeability weathered and fractured indurated rocks.

By the late 1990s and early 2000s, application of the RGFS had become mainstream in Australia. At the national level, with Coram as a major contributor, frameworks based on groundwater flow systems enabled development of strategies for salinization control. Also mapping coverage of RGFS across Australia for the National Land and Water Audit was published (in CD form) as the "Australian Groundwater Flow Systems contributing to Dryland Salinity". Furthermore, 1:250 000 hydrogeological map series, included fundamentals of RGFS with hydrostratigraphic cross sections depicting salinity classes and groundwater flow directions.

Meaning of recharge in the context of regional groundwater management framework: Alberta example

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ABSTRACT

Groundwater recharge is an important component of the hydrologic cycle linking atmospheric and soil processes with groundwater processes. However, a wide variety of views exists in the literature concerning the meaning of recharge in the context of groundwater management, ranging from having minimal influence to being fundamentally important. We suggest that the diverse viewpoints reflect different hydrological and geological settings, which influence how groundwater interacts with surface water and how different aquifers in a region interact with each other. For example, in an alluvial aquifer adjacent to a large river flowing through a dry region, the amount of recharge on uplands away from the river may have little relevance compared to induced infiltration of river water. In contrast, for aquifers relying on local recharge, the amount of recharge puts a major constraint on the permissible rate of groundwater extraction without causing environmental harms, such as the reduction of baseflow in local streams. In other cases, groundwater extraction from deep, confined aquifers may induce additional downward flow from shallower unconfined aquifers, thereby creating semantic arguments about whether recharge refers to inter-formational flows as well as water inputs to the water table. Using case study examples from Alberta and numerical model simulations, we will explore the meaning of recharge in the context of regional groundwater management framework. Our intent is to present a kernel of ideas for further thoughts and stimulate discussion among the group of hydrogeologists interested in regional groundwater flow system and water resources management.

Comprehensive methods to conduct landscape-level analyses for improving springs ecosystems stewardship

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ABSTRACT

Springs are places where groundwater discharges at or near the Earth's surface. Springs support a wide diversity of species and cultures across all landscapes. At least thirteen spheres of discharge have been proposed to classify spring ecosystems. Comprehensive inventory and assessment techniques have been developed and used to describe 56 springs in Alberta, Canada, and 1,000s more across Western North America. Springs support the headwaters of most perennial streams, but the location and identification of springs continues to be limited by the adoption of a universal classification system and database by hydrogeologists. Less than 10 % of the springs on most landscapes have been identified and even fewer have been comprehensively inventoried and assessed. Springs support some of the most productive, biologically, and socio-economically important and threatened ecosystems on Earth. Although springs occupy far less than 1 % of the land area, Inventories of springs across landscapes indicate that up to 25 % of all plant species are supported at springs. Comprehensive inventory and assessment data are accessible on the secure, cloud-sourced Springs Online database of the Springs Stewardship Institute. Inventory and assessment techniques have been adapted and adopted by many land and resource management organizations, including many indigenous nations. Prioritization techniques developed with assessment measures can be used to prioritize stewardship action for springs across landscapes. Stewardship prioritization is an essential component of successful landscape conservation design planning.

Evaluating groundwater-surface water interactions at a large permanently flooded wetland in the Canadian prairies

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ABSTRACT

The goal of this study was to examine the role a permanently flooded wetland plays in local and regional groundwater cycling in the Alberta prairies. Low permeability glacial till sediments underlie most of the prairies and poor drainage development results in the formation of permanent and seasonal ponds across the landscape. At a prairie grassland site in southern Alberta, the hydrology of a permanently flooded wetland and dynamics of its interaction with the surrounding landscape were investigated. The wetland is situated upon a veneer of glacial till (approx. 4-16 m in thickness) overlying 30m of interbedded fluvial sandstone and mudstone of the Paleocene Paskapoo Formation. We used hydraulic, thermal and chemical methods to assess the water budget of the wetland as well as evaluate interactions with shallow groundwater in the till and potential exchange with deeper regional groundwater flow systems. Results indicate that groundwater fluxes between the wetland and surrounding uplands occur on a local scale, with snowmelt infiltration forcing fluxes during spring and riparian evapotranspiration demand driving local fluxes in summer. Analysis revealed that the water cycled through the wetland does not contribute to groundwater recharge on a regional scale, but plays a vital role in sustaining the local habitat necessary for migratory and endangered bird species. Compared to ephemeral ponds present at the site, which show evidence of contributing to groundwater recharge during spring melt events, permanent ponds in the prairies may play a different hydrologic role from seasonal ponds when it comes to their contribution to regional flow systems and groundwater recharge. This research will provide an improved understanding of the contribution of prairie wetlands to the regional groundwater system.

ECHN

Depression-focussed recharge in the prairies of Alberta: Insights from stable isotope data

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ABSTRACT

Large numbers of rural communities and individual households in the prairie region of Alberta depend on groundwater extraction to meet their needs. However, uncertainty persists regarding the contribution of different pathways to the groundwater recharge in the area. Previous studies in this region showed using isotopic techniques that as much as half of shallow groundwater is sourced from snowmelt. As only a small fraction of annual precipitation comes in winter, the strong role of snow-derived water in recharge is believed to be the consequence of ponding of numerous small depressions abundant in this part of Alberta. These findings prompt the question of whether recharge not derived from snow also occurs through depression ponding or through other mechanisms. The goals of this study are to evaluate a possible role of spatially distributed (diffuse) recharge, as well as to confirm an existence of the link between the high fraction of snow-derived groundwater and depression-focussed recharge. Field studies were conducted at three study sites in the fringe of the prairies close to its transition into boreal forest. At each site a depression catchment was chosen, where two alternative recharge pathways were identified: depression-focussed and diffuse recharge. All media along alternative recharge pathways were sampled including snow, snowmelt runoff, water ponded in depressions, vadose-zone water and groundwater. The samples were analysed to infer the signatures of stable isotopes of water associated with different recharge pathways. The results were compared with isotopic composition of water samples from a number of domestic wells in the areas surrounding the study sites. The isotopic signature of diffuse recharge differed from one of depression-focussed recharge, allowing for separation of the two recharge components. The isotope data also indicated that groundwater in a number of domestic wells had even higher snowmelt-derived fraction than thought previously.

ECHN

Establishing chemical and isotopic baseline conditions in a shallow bedrock aquifer at a gas migration field research station in south-eastern Alberta, Canada

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ABSTRACT

Subsurface storage of CO_2 and hydraulic fracturing of shale gas has the potential to cause adverse environmental impacts due to mobilization of entrapped gases into shallow groundwater. To detect gas migration and determine impacts from anthropogenic activities, a scientifically reliable baseline assessment of subsurface gas distribution is required. The objective of this ongoing study is to develop depth-resolved chemical and isotopic baseline assessments of the fresh groundwater zone in an area where gas migration will be investigated in the future.

CMC Research Institutes Inc. (CMC) has established a multi-disciplinary field research site dedicated to advancing state-of-the-science approaches for gas migration monitoring. Currently the site is comprised of one 300 m deep gas injection well, two 350 m deep monitoring wells, a 65 m deep domestic water well and a depth-discrete multi-level Westbay™ system with 26 sampling ports distributed throughout the uppermost 106 m. From borehole drilling, methane depth-profiles of C isotope ratios were determined using multiple approaches: (1) mud gas samples in Isotubes, (2) outgassing of cuttings and crushed rock core in Isojars and VOA vials and (3) intact rock cores in degassing cells. The C isotope ratios and trends were consistent between methods and reveal $\delta^{13}C\text{-}CH_4$ values for the upper 106 m range naturally from -85‰ to -65‰, indicating a biogenic origin. Additionally, quarterly Westbay and bi-monthly domestic well groundwater samples have been collected and analyzed. The Westbay well $\delta^{13}C$ values of dissolved methane in samples follow a similar trend to rock core sample results, although some samples were enriched in ^{13}C. Aqueous geochemistry data from the Westbay ports and the landowner well samples suggests the groundwater is at favourable redox conditions for in-situ methanogenesis. The outcome of this research will be an unprecedented depth-resolved baseline characterization of the shallow groundwater, against which future fugitive gas migration impacts can be tested.

ECHN

Direct measurements of submarine seepage of groundwater into Puck Bay, Poland

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ABSTRACT

Many long-term studies at the Institute of Oceanography University of Gdansk (Jankowska-Piekarek 1994) were carried out to investigate groundwater discharge into the bottom of Puck Bay in the southern Baltic Sea. These studies usually focused on the changes in water chemistry and salinity. In many cases, data from submarine and coastal drillings were also analyzed. In August 2015, thermal imaging was applied to seek regions of groundwater seepage into the bay. Aerial photographs made in summer using a thermographic camera feature dark blue spots, which represent regions with cooler waters (<15°C), and yellow, orange or red spots, which represent regions with waters that are warmer (>18°C). Areas where intensive seepage of water into Puck Bay takes place are cooler relative to adjacent areas.

The results of thermal imaging were verified by in situ measurements of the direction and intensity of water flow in the bottom sediments of the bay. These measurements required designing and constructing two new devices - the gradientmeter, which measures the direction of water flow, and the filtrometer, which allows determining the intensity of this flow. Both devices are briefly presented in this paper. Moreover, in areas where such measurements were performed, water was sampled at two depths: near the bottom of the bay and at the surface. The low salinity of deeper water confirmed the presence of submarine groundwater seepage into Puck Bay.

Maps of hydraulic gradient variability, groundwater seepage intensity and the spatial distribution of hydraulic conductivity of bottom sediments were developed. The research revealed a high correlation between the results of thermal imaging interpretation and the results of in situ measurements of submarine groundwater seepage. It can be hypothesized that thermal imaging can accurately characterize such seepage once the seepage intensity is properly calibrated based on measurements of the hydraulic gradient and the intensity of water flow in bottom sediments

Hydrogeology of Phanerozoic strata in Saskatchewan: Province-wide Hydrogeologic Mapping

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ABSTRACT

Subsurface fluid migration and water chemistry play a major role in hydrocarbon migration and entrapment. A province-wide hydrogeological and geological mapping project (Saskatchewan Phanerozoic Fluids and Petroleum Systems Assessment) was conducted to integrate the regional geology, hydrogeology, and hydrochemistry of Phanerozoic formation-fluids across Saskatchewan. One main objective of the project was to use a consistent geological framework to combine all previous hydrogeological maps and fill missing areas to create complete maps for the province of Saskatchewan.

The subsurface geological framework of Saskatchewan was refined into a hydrostratigraphic column consisting of 14 major aquifers. Detailed mapping of hydraulic head and water chemistry for aquifers ranging in age from Cambrian to the upper Cretaceous was completed. Hydrochemistry was mapped after using a culling process on the raw data to eliminate non-representative samples. Mapped formation water salinities range from 2 to 471 g/L and indicate significant density variations between formations and across the province. Four distinct formation water types are identified based on ion chemistry: (1) Ca-SO_4 fresh, (2) Na-SO_4 brackish, (3) Na-Cl brines, and (4) Na-HCO_3 fresh waters brines. Fluid flow directions were determined using measured pressures that were culled to remove production-influenced values. Distributions of equivalent fresh-water hydraulic-head indicate generally that flow conditions are up dip from SW to NE across the province. Density corrected water driving force (WDF) maps were constructed to identify areas where density dependent flow is significant. These WDF maps will help to elucidate migration patterns within the province.

This hydrogeological characterization provides new insights into the spatial distribution and mixing of formation waters. Results from this project will provide a better understanding of the fluid migration in the province as well as aid in investigating reservoir response for enhanced oil recovery techniques such as water flooding and CO_2 injection.

Groundwater mixing and flow system evolution in the Quaternary aquifers of the Manas River Basin, arid northwest China: Hydrochemistry and environmental tracer indicators

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ABSTRACT

Groundwater flow system characterization and evolution are critical for developing sustainable groundwater use strategies in arid water-stressed basin. For this end, hydrochemistry (major ion and selected trace elements) and environmental tracers (^{2}H, ^{18}O, $^{87}Sr/^{86}Sr$, CFCs, ^{14}C) of various waters from precipitation, river, reservoir and groundwater have been used to investigate groundwater mixing and flow system evolution in the Manas River Basin (MRB), a typical mountain-oasis-desert ecosystem in the arid region of northwest China.

Stable isotopes reflect a meteoric origin and little evaporation or isotope exchanges between groundwater and rock and soil minerals throughout the MRB. Groundwater $\delta^{2}H$ and $\delta^{18}O$ values show more homogenized values along the groundwater flow paths and with well depth, indicating inter-aquifer mixing processes. A regional contrast in the Quaternary aquifers allows the $^{87}Sr/^{86}Sr$ ratios and $\delta^{18}O$ values to be useful in a combination with selected ion concentrations. Both the groundwater mixing and flow system characteristics are identified. Lateral flow mixing and local groundwater flow systems with groundwater ages younger than 55 a are delineated in the piedmont alluvial-oasis plain. Leaching and vertical mixing in the intermediate and regional groundwater flow systems corresponding to the longer flow paths and residence times (e.g. groundwater ages between 1.16 and 11.96 ka) from the north oasis plain to the desert. Three regimes are identified in the local groundwater flow system based on the CFC-12 and CFC-113 binary mixing model. 1) A recharge zone with fraction of 0.70-0.83 young water (groundwater ages of 29-35 a) is from the south mountain to the Shihezi (SHZ) west. 2) A discharge zone is characterized by a mixing fraction of 0.37-0.64 young water (37.5-42.5 a) in the SHZ north to the piedmont oasis plain. 3) A stagnant zone with fraction of 0.09-0.50 young water (40-55 a) is in the SHZ east and Manas River east.

Multiple lines of evidence for nested groundwater flow in west-central Alberta

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ABSTRACT

As part of evaluating Alberta's groundwater inventory, the Alberta Geological Survey (AGS) has recently completed a hydrogeological characterization project for a 22,000 km^2 region in west-central Alberta. This forested region is relatively unpopulated and has become a focal point for unconventional shale-gas development, which uses large volumes of water. Headwater rivers in this region rely on baseflow sourced from bedrock formations, which appear to exist within a nested groundwater system. For such a large area of interest, we bring together multiple lines of evidence to support our conceptualization of the nested groundwater system. Geological characterization of bedrock formations to a depth of nearly 1.5 km show a highly heterogeneous shallow unit of varying thickness (Paskapoo Formation) over a more extensive 2-layer mudstone/sandstone sequence (Wapiti Formation). Hydraulic heads within the shallow unit generally reflect present-day topography. Groundwater sampling indicates TDS is less than 800 mg/L in the shallow groundwater, and ^{3}H and SF_6 concentrations having an apparent age of 30 to 50 years. More detailed pressure-vs-depth measurements suggest localized groundwater flow adjacent to the headwater rivers, whereas dominantly vertical (downward) groundwater flow across the shallow unit. In the deeper 2-layer formation, hydraulic heads mimic the regional upland areas somewhat, but also indicate an underpressured region associated with the Western Canadian Sedimentary Basin. In this deeper portion of the groundwater system, provincial-scale mapping indicated that TDS varies from 600 to 8,000 mg/L, and opportunistic sampling found elevated ^{4}He concentration, corresponding to an apparent age of about 135,000 years. The combination of geological and hydrogeological information including tracer-based residence time provides multiple lines of evidence for the nested groundwater flow, which has important implications for regulating groundwater, and in-turn unconventional shale-gas development in Alberta.

Using airborne time-domain electromagnetic data and normalized gamma-ray logs to interpret the internal stratigraphy of a buried valley network

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ABSTRACT

Buried valleys have been identified in glaciated terrains in North America and northern Europe, and can have complex internal stratigraphy and heterogeneous fill. Permeable sediments within their fill can be attractive targets for groundwater exploitation, but the potential level of development of buried valley aquifers depends on their extent and continuity. In this study, high-quality geophysical datasets are used to delineate and examine the internal stratigraphy of a large buried valley network in the Peace River region of Northeast British Columbia. The geophysical datasets include airborne time-domain electromagnetic (TEM) interpretations from a SkyTEM survey conducted over the study area, and gamma-ray logs from oil and gas wells that have been normalized to remove the attenuation of the gamma-rays caused by the steel casing in the upper portion of the well. The airborne TEM interpretations of resistivity data are used to differentiate fine and coarse-grained material within the valley fill, and lithological differences in bedrock. The normalized gamma-ray logs supplement the airborne TEM data by confirming the depth to bedrock, and verifying the geological interpretation from the TEM data. The combination of the normalized gamma-ray logs and TEM data also allow the visualization of the structure of the buried valleys. The geophysical interpretation of the internal stratigraphy and the delineation of permeable units within the buried valleys are conducted using the reservoir modeling software Petrel.

ECHN

Investigating the utility of airborne electromagnetic surveys for mapping local and regional hydrogeology in the Edmonton-Calgary corridor

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ABSTRACT

Airborne magnetic and electromagnetic (EM) data were collected between 2007 and 2010 as part of a large-scale mapping program designed to better characterize subsurface lithology in the Edmonton-Calgary corridor (ECC). In this region, it is hypothesized that the contrast in subsurface resistivity can be used to identify boundaries between the sandstone and mudstone portions of the Paskapoo formation manifesting as a transition from higher to lower resistivity. Given these contrasts, significant potential exists for improving the characterization of the regional hydrogeology, which is controlled by the distribution of the two lithologic units that comprise the Paskapoo formation. In order to fully exploit the resolution potential of the airborne dataset, we have selected a 10-km × 10-km subset as a test case for numerical inversion, which will be constrained by ground-based electrical resistivity and electromagnetic measurements conducted within the test area. The resulting 3D volume will be evaluated for its potential in further resolving the spatial distribution of the lithologies that control groundwater flow in this region.

A long (1650-m) resistivity profile and nanoTEM survey were completed in Fall 2016. The survey was centered along a transect that corresponds with a transition in the airborne data from lower to higher resistivity. Preliminary results suggest that the transition evident in the 2D slices of the airborne EM data are consistent with those collected with the ground-based geophysical methods. We will present our findings from ongoing analysis including the inversion of the ground based nanoTEM and airborne datasets, in an effort to quantify the resolution capacity of these methods and their ability to further refine our geologic and hydrogeologic models for this region.

Conditioning the geostatistical simulation of the Paskapoo formation with lithologs, paleo-current statistics and pumping tests for stochastic regional groundwater modeling

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ABSTRACT

In the conventional modeling approach, a single hydrogeological model is constructed based on a single geological model and the uncertainty in geological heterogeneity is not explicitly taken into account. In contrast, Monte-Carlo analysis (MCA) is a method to account for the uncertainty associated with heterogeneity of local geology in groundwater models. In MCA, a suite of stochastic representations of the geology is generated by geostatistical simulation. In this presentation, we present a Markov chain method to generate and condition a suite of stochastic representations of the highly heterogeneous and non-stationary fluvial bedrock aquifer in the Paskapoo formation. All available information, including paleo-current statistics, sand fraction, lithologs and pumping tests, are used to generate the simulations.

In this methodology a lithologic model is constructed and conditioned with hard data using transition probability geostatistics. Subsequently, a segment of the simulation around a pumping well was used to generate a numerical groundwater flow model. A single well pumping test was modelled using the flow model, and hydraulic conductivity and specific storage of sand channels and mudstone were estimated by using an inverse model. The original simulated lithology model was updated to match the pumping test results by locally deforming the lithology distribution using the probability perturbation method and again iteratively performing the inverse parameter estimation. This loop was executed until our optimization function was minimized and our prior knowledge about hydraulic properties of the hydrofacies was satisfied.

By using this method, we constrain the uncertainty in the lithologic model and obtain estimates of local hydraulic properties of the hydrofacies (sandstone and mudstone) in the aquifer which later can be used to calibrate a regional groundwater model.

ECHN

Using synoptic river surveys to characterize groundwater systems

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ABSTRACT

Synoptic sampling of stream chemistry is a common methodology for estimating the volume of groundwater discharge to a stream over a variety of scales. The principal behind the technique is to find a suitable tracer that is present in the groundwater system at a known concentration, and then infer the amount of groundwater in surface water from the concentration of the tracer in the surface water. The concentration of the tracer in groundwater may encode information on the groundwater system discharging to the stream, such as the groundwater residence time, provenance, quality, and chemical evolution. In many cases, it would be beneficial to know the tracer concentration or distribution of concentrations in groundwater feeding the stream; however, regional scale sampling in groundwater is always limited by the location and amount of groundwater wells. Here, we flip the paradigm of stream tracer surveys, by using stream discharge and chemistry to estimate the tracer concentration of groundwater feeding the stream. Groundwater discharge to the stream can then be estimated using one set of environmental tracers, applied tracers, synoptic stream gauging or other methods, and the concentration of a tracer of interest in the groundwater then estimated using the measured groundwater discharge and river chemistry. In this paradigm, the stream becomes an easily accessible location to sample the distribution of groundwater flow paths discharging to the stream, and thus to estimate the flow-weighted average concentration of tracer in that groundwater. We will develop the theory behind the method and demonstrate its application in several groundwater systems of local to regional scale.

The chemical and isotopic composition of groundwater in Northeast British Columbia: implications for local and regional groundwater flow systems

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ABSTRACT

Water demand in Northeast British Columbia (NEBC) is increasing due to a growing population and increasing agricultural and industrial needs. Groundwater is critical to meeting that demand, and gaining a better understanding of the groundwater flow systems is vital for resource management. In this study, 243 groundwater, spring and surface water samples as well as 3 years of monthly atmospheric precipitation samples from the Peace River Regional District of NEBC were collected and analyzed for the chemical and isotopic composition. These data were used to identify the relationships between the different aquifer systems and the chemical composition and mean residence time of the groundwater. The groundwater composition is strongly controlled by the lithologies that constitute the two near surface aquifer systems recognized in NEBC. The Quaternary sediment aquifers are dominated by Ca-Mg-HCO_3 to Ca-Mg-HCO_3-SO_4 type waters reflecting the role of carbonate and gypsum dissolution in the near surface systems. In the Cretaceous bedrock aquifers, cation exchange, calcite dissolution and pyrite oxidation result in the shift to Na-HCO_3 and Na-SO_4-HCO_3 type waters. Recharge appears to be dominated by spring and fall rain even though the region has the highest rainfall during the summer months. The presence of tritium in the Quaternary hosted groundwater suggests relatively recent recharge while the bedrock-hosted groundwater typically contained little or no tritium indicating a much longer mean residence time. The groundwater chemistry supports that the Quaternary aquifers are local and discontinuous and the bedrock aquifer systems tend to be more regional and have very low flow rates.

"Old" water in mountain streams: a case study of the Elbow River and its river-connected alluvial aquifer

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ABSTRACT

We investigate the connections between isotopically "old" mountain stream water and the structure of river-connected alluvial aquifer sediments in eastern-slopes rivers. Glaciers are thought of as the source of eastern-slopes rivers, but climatic change has significantly diminished the Rae Glacier (traditionally described as the source of the Elbow) without reducing streamflows. Worldwide, mountain streams have less than 5% "young" (<2.3 months) water (Jasechko et al. 2015). Both of these points indicate that there must be significant detention or storage of precipitation inputs in headwater catchments before that water reaches the open stream. Here we present results from our first year of isotope data and geophysical surveys carried out in Spring 2017. These results follow up on our findings from our first year of data collection. Preliminary water level data show changes in the slope of local water table surfaces, indicating seasonal changes in source influence, and water chemistry data show that the chemistry of samples from Elbow Falls (where all waters from the headwater catchment are integrated) is heavily influenced by that of groundwater from the river-connected alluvial aquifer. Delineating the sources, storage processes, and dynamics of groundwater/stream water interactions in the Elbow river system is important to resource use and water security, and also helps answer the intriguing fundamental scientific question of why high-gradient mountain streams contain mostly "old" water.

ECHN

Numerical simulations of regional groundwater flow and residence time distributions in the Chaudière-Appalaches region, Québec

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ABSTRACT

Regional groundwater flow and advective-dispersive residence time distributions have been simulated within the Chaudière-Appalaches region, south of Quebec City, Canada. Demands on water supply are growing within the basin, including increasing agricultural, municipal and industrial use, while shallow groundwater is also at risk from potential resource development (ex. shale gas). The study falls in part within the framework of the Quebec provincial PACES program of regional aquifer and groundwater characterization. Specific objectives include estimating the maximum depth of active groundwater flow, investigating the influence of normal faults on regional flow, and understanding the links between the scale-dependent flow systems and the aqueous geochemistry.

A three-dimensional groundwater flow model of the entire Chaudière River watershed was first developed using the WATFLOW finite element model to gain insight into the active flow systems at the basin and sub-watershed scales, including the primary water supply aquifers within the fractured sedimentary rock and Quaternary sediments. The watershed model covers an area of 6,700 km^2 and extends to a depth of 500 m. Groundwater flow and mean residence times within a representative 2D vertical section extending 65 km from the upper basin to the St. Lawrence River, and to a depth of 8 km, were then simulated using the FLONET/TR2 simulators.

The simulations show dominant sub-regional scale flow systems on maximum scales of 10-20 km, including significant flow through the upper 50-100 m of the fractured rock aquifer. Deeper regional flow systems extend to depths of a few kilometers but have very slow flow rates with groundwater ages reaching several millions of years. Regional groundwater discharge zones near the St. Lawrence River are perturbed by low-permeability faults that can help explain some of the geochemical signatures observed in the shallow flow systems, which suggest mixing of young and older water.

The variation of flow rates and solute concentrations with depth in open flowing wells

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ABSTRACT

Intensive groundwater sampling with depth-dependent hydrochemistry in deep basins could aid in interpreting the pattern of groundwater circulation. Unfortunately, sampling from existing deep production wells with a long screen would probably lead to mixed groundwater from different depths over the screen, which causes ambiguity of the depth-dependent hydrochemistry. Based on the MODFLOW 2005 and MNW2 Package, we simulated the groundwater flow to open flowing wells in the unconfined aquifer of 3-D unit basins under different ratios of basin length to depth, water table undulations, distances of wells away from the valley and well depths. Numerical results show that a flowing well has the characteristics of groundwater inflow in the lower part outweighing outflow in the upper part. According to the vertical profiles of flow rate in flowing wells, it was found most water at the outlet is from the deep part of the well. Moreover, for fully penetrating flowing wells, the vertical profiles of the ratio of unit flow rate to the maximum unit flow rate in the inflow segment almost coincide, which are independent of the ratios of basin length to depth, water table undulations and distances of wells away from the valley. Taking the directly modeled groundwater age and ^{14}C concentration as examples representing the components subject to zeroth-order accumulation and first-order decay, respectively, it was found the water sampled at the outlets of flowing wells can represent the groundwater quality near the base of the well, which is little affected by the ratios of basin length-depth and water table undulations. Therefore, sampling groundwater at the outlets of open flowing wells could be employed to understand the groundwater circulation in deep basins.

ECHN

Variable density groundwater flow: Are equivalent freshwater heads necessary or misleading?

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ABSTRACT

Variable density flow of subsurface fluids, such as fresh water, brackish water, and brines, may occur in areas with salt layers, salty tailings, up-coning effects of saline water, contamination, as well as in deep groundwater flow systems and in hydrocarbon reservoirs. There are a number of computer programs available (SUTRA and others) all purporting to be able to calculate adequate flow patterns for freshwater and saltwater. These programs make use of velocity potentials [energy/unit volume] to determine gradients for subsurface flow. The use of velocity potentials requires three basic assumptions: (1) the energy within the gravitational field relates to unit volumes, (2) underground fluids are incompressible, and (3) equivalent fresh water heads stand for the actual energy conditions in a flow field. Equivalent freshwater heads do not, however, correctly represent the energy conditions in flow fields in the subsurface and all underground fluids are compressible.

The above assumptions are not necessary when flow calculations are based on force potentials [energy/unit mass]. As the mass is measured in kilograms and a mass of 1 kg is independent of pressure, density, and temperature of the fluid the actual heads measured in piezometers containing fluids of any density, compression, or temperature are the correct head values and can directly be used in flow calculations by programs based on force potentials. Thereby the use of equivalent fresh water heads is unnecessary and misleading. When using force potentials, buoyancy forces can be directed in any direction in space and are integrated in the resultant calculation for the head and density-dependent pressure potential forces driving variable density subsurface flow, together with gravitational forces under heterogeneous, hydrodynamic conditions.

Clear and simple diagrams will demonstrate the differences between the two approaches and the advantages of using mathematically- and physically-correct force potentials over only mathematically-correct velocity potentials.

Dynamics of subsurface flow of fluids of different densities

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ABSTRACT

Building an understanding of the actual physics of subsurface flow is a confusing experience at the best of times, exposing one to conflicting statements from the sides of engineers, hydrogeologists, and, for a decade or more, by the followers of free convection and density-driven flow. In case of variable density flow involving salt water and brines, the confusion is magnified. It is generally assumed that, due to their higher density, two systems of forces act upon salt water and brines, namely piezometric head forces and buoyancy forces. Presently, the buoyancy forces are always assumed to be directed vertically downwards for fluids heavier than the host fluid, or upwards for lighter fluids. These assumptions are widely applied in mathematically dominated fluid dynamics.

Hubbert (1953) has shown, however, that vertical buoyancy forces (balanced by gravitational forces) exist only in the hydrostatic case but not under hydrodynamic conditions. In the hydrodynamic case forces due to density differences are directed along the piezometric pressure potential force of the host fluid and integrated into the resultant force calculation.

Hydrostatic (no-flow) boundary conditions for mechanical forces usually exist in laboratory tests and under oceans (off-shore). Hydrodynamic subsurface flow conditions exist in on-shore areas with topographical relief.

The presentation will shed light on the maze of conflicting statements issued within mathematically-dominated engineering hydraulics and groundwater dynamics, and will help foster the understanding of the correct physics involved and how this physics can be beneficially applied to practical cases regarding subsurface flow in general, hydrodynamic migration of contaminants, variable density flow, migration of hydrocarbons and CO_2, and to scientific processes in the present and within the geological past. It will also introduce a practical field case involving the numerical modelling of variable density flow at a major industrial landfill site in Europe.

The interaction of basin-scale gravity-driven groundwater flow and free thermal convection

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ABSTRACT

Two-dimensional numerical model calculations have been carried out to investigate the distortion of basin-scale groundwater flow system driven by water table differences due to heterogeneous temperature distributions. A Tóthian homogeneous unit basin (1962) with constant slope of the water table was used for the simulations. Equations of the conservation of mass, heat transport and Darcy's law with temperature-dependent water density were solved to handle the problem of interaction of different driving forces, free thermal convection and water table gradients.

Temperature differences between the bottom and the surface of the basin (ΔT) were systematically varied to reveal the influence of thermal convection on the observed parameters such as the Darcy velocity components, hydraulic head, temperature, and heat flux time series. For the chosen model parameters, the groundwater system converged to a stationary solution for $\Delta T<60$ °C and if the heat was advected toward the discharge area dominantly by 'gravitational flow'. In the case of $\Delta T=60$ °C, a stationary equilibrium formed in the recharge area where the hot upwelling water from the lower boundary was balanced by the cold downwelling water from the surface. In this model, the thermal Rayleigh number was approximately 750 indicating the effect of free convection. Time-dependent solutions were found for those scenarios where $\Delta T>60$ °C. Hot upwellings formed from the base and were swept toward the discharge area by gravitational flow. However, a pulsating long-lived hot plume also evolved beneath the recharge area as a result of a dynamic equilibrium between the hot upwelling and cold downwelling water. Dominant frequencies of the time series of the monitoring parameters reflect the dynamics of the system that reflects plume formation, migration by gravitational flow and pulsation. Discontinuous increases in the quasi-stationary solution of the observed parameters (Darcy's velocity, hydraulic head, temperature and heat flux) define the conditions where the role of the free thermal convection becomes commensurable with the groundwater flow controlled by water level differences. The theoretical simulations represent the consequences of the interaction of the different driving forces in space and time for the simulated domain.

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Effect of different driving forces in large sedimentary basins

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ABSTRACT

Sedimentary basins usually have complex groundwater flow systems, which are driven by different forces. The most frequent driving force is gravity, but overpressure caused by compression and compaction, as well as variable density can also have important effects. In large basins, various effects are present concurrently. Numerical modelling is a perfect tool to recognize and distinguish between these different driving forces. In addition, the geological history of the area is a key factor in understanding the distribution of flow systems. The Great Hungarian Plain, Hungary, is an ideal study area to examine the complexity of flow regimes governed by different driving forces.
This detailed modelling study shows that not only gravity, but compression/compaction and density also influence the active flow paths.

ECHN

Application of the regional groundwater flow concept in the hydraulic evaluation of a partially confined carbonate area (Budapest, Hungary)

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ABSTRACT

The main focus of this work was the investigation of groundwater flow systems at Budapest (Hungary) and in its western surroundings where an active hypogenic karst area, the Buda Thermal Karst can be found. During the research, hydraulic interpretation of measured, pre-production well data was carried out by the joint application of pressure versus elevation [p(z)] profiles, tomographic fluid-potential maps, and hydraulic cross-sections. The application of these basic hydrogeological research techniques has resulted in a transparent, regional flow pattern representing gravitational flow systems in a topographically and geologically complex area built-up by confined and unconfined carbonates, which proved to be hydraulically continuous. Namely, heterogeneities of the hydrostratigraphic build-up (i.e., aquitard units, faults) do not cause compartmentalization in the flow field, just intensify vertical hydraulic gradients which otherwise depend on the flow regime (i.e., recharge or discharge), and generate typical p(z) profile patterns and fluid-potential anomalies on tomographic fluid-potential maps and hydraulic cross-sections. Consequently, the previously well-known location of natural discharge areas, as well as the differences in the discharge distribution (one and two-component) and related cave forming processes between them could be explained. In addition, among the premises of hypogenic karstification, regional upward flow conditions were confirmed along the main discharge zone of the area.

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Variability of hydraulic conductivity in the hyporheic zone

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ABSTRACT

The aim of this research was to investigate the variability of hydraulic conductivity in the hyporheic zone and its impact on the diurnal fluctuations of the water level. Four experimental series were performed in laboratory conditions using seepage columns, similar in size to the original Darcy columns. Four types of sand sediments, with a hydraulic conductivity ranging from $6 \cdot 10^{-6}$ to $5 \cdot 10^{-4}$ m/s, were tested. Experiments were performed at room temperature and in a cold room – at 10°C, which is similar to the temperature of the hyporheic zone.
The obtained values of hydraulic conductivity depended on the sand size, temperature of water and sand, the direction of the hydraulic gradient, and the fluidization of the sediment (liquefaction of the sand). For all tested sands, higher hydraulic conductivity values were obtained for experiments conducted when water was set to flow in the opposite direction to gravity (water was seeping out of the sediment) relative to experiments with water flow in the same direction as gravity (water seeping into the sediment). Before fluidization, with an increase of the hydraulic gradient, values of hydraulic conductivity were two times higher in experiments when water seeped out of the sediment, relative to experiments performed for water flowing in the opposite direction. After fluidization, when analyzing a decrease in the hydraulic gradient, the obtained values of hydraulic conductivity were roughly 12 times higher. The initiation of the fluidization process in the tested columns has been observed at a hydraulic gradient close to unity. This observation has been confirmed by a mathematical model of sediment fluidization, which is based on the momentum balance and the effective stress law for a homogeneous porous material saturated with a liquid that flows at a constant velocity. Mathematical predictions of critical hydraulic gradient values and flow velocities at which fluidization is initiated have been confirmed by the column experiments.

Vadose zone dynamics governing snowmelt infiltration and depression-focused recharge in prairie landscapes

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ABSTRACT

Groundwater recharge is a critical component of aquifers' water budgets, and understanding its rate and mechanisms is vital for water-resource management. Snowmelt is a major source of recharge in the Canadian Prairies. Meltwater runoff from uplands collects in topographic depressions, resulting in infiltration and groundwater recharge through partially frozen soil. Snowmelt infiltration and unsaturated zone fluxes are strongly affected by soil hydraulic and thermal regimes during snowmelt. Field studies were conducted to investigate vadose zone dynamics governing snowmelt infiltration and recharge over a range of conditions in the Alberta Prairies. Meteorological and subsurface measurements provided insights into the hydraulic and thermal processes governing water movement in these landscapes. Analyses reveal that a complex interplay between antecedent moisture, soil thermal regime and preferential flow govern the subsurface dynamics during snowmelt and the partitioning of water between upland infiltration and runoff, which contributes to depression-focused infiltration and recharge. At all sites, thermal and hydraulic responses to snowmelt were observed at depth prior to ground thaw in uplands and depressions. At one site, meltwater runoff bypassed the frost zone via macropore flow, and depression-focused infiltration and recharge occurred through a layer of frozen soil. However, infiltrating water may freeze in macropores and reduce the capacity for vertical preferential flow. At another site, re-freezing of infiltrated meltwater prevented water from moving deeper in the soil profile, and recharge occurred only after ground thaw. Results indicate that both diffuse and preferential flow play significant roles in the infiltration and redistribution of snowmelt under frozen soil conditions, and shallow groundwater recharge. The partitioning of snowmelt depends on the dynamic and interacting effects of soil freeze/thaw and macropore flow across the upland-depression landscape transition. A detailed understanding of the critical hydrological processes in these landscapes is crucial for appropriate model development and prediction at the watershed scale.

ECHN

Regional distribution of arsenic in the Cold Lake – Beaver River watershed: Implications of groundwater – surface water interactions

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ABSTRACT

Elevated arsenic (As) concentrations are widely observed in shallow groundwater across the Cold Lake-Beaver River Basin (CLBR), Alberta. Occupying 3% of the province, the CLBR spans portions of both the Athabasca and Cold Lake Oil Sands Regions. Here, groundwater and surface water are used for a variety of activities including domestic, municipal, industrial and agricultural use, as well as recreation. Surficial geology is comprised of up to 200 m of unconsolidated glacial deposits, with six regional interglacial sand and gravel aquifers, underlain by marine shale. Arsenic concentrations in unconsolidated glacial sediments generally range between 1 and 17 ppm. A sampling survey of 800+ water wells throughout the basin revealed that 50% of wells contained As concentrations in water exceeding drinking water guidelines of 10 μg/L. Arsenic speciation of 175 groundwater samples showed that As(III) was the dominant species in 76% of wells. Higher As concentrations in groundwater were associated with increasing depth and reducing conditions. The distribution of As did not show any obvious spatial pattern or trend along groundwater flow paths suggesting heterogeneities in the aquifer mineralogy. Within near-surface weathered sediments, the oxidation of arsenian pyrite was the source of As released to shallow groundwater whereas in unweathered sediments below the water table, reductive dissolution of Fe oxy-hydroxides was likely the main source of As in groundwater. Water samples collected from 61 lakes across the CLBR showed an average As concentration of 2.3 μg/L (max. 19.4 μg/L), elevated compared to average concentrations for lakes located elsewhere across the province (1.3 μg/L). Water isotopes reveal that evapoconcentration is not a factor contributing to elevated As in lakes. In general, lakes with higher As tended to be in contact with deeper aquifers, suggesting that groundwater discharge with elevated As may contribute to greater loading of As to lakes in the region.

Paleo-hydrogeological evolution of a fractured-rock aquifer following the Champlain Sea Transgression in the St. Lawrence Valley (Canada)

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ABSTRACT

A conceptual and numerical model of seawater invasion and subsequent leaching have been developed to understand the processes involved in the evolution of groundwater salinity within a regional sedimentary rock aquifer system. In the St. Lawrence Valley, large paleo-environmental changes have occurred during the last glacial-deglacial cycle and the ensuing postglacial period. The region was covered by the Laurentide Ice Sheet until about 13 ka BP, at which time it was invaded by an arm of the Atlantic Ocean, thus forming the Champlain Sea. The seawater salinity eventually decreased, due to sustained meltwater inflow and isostatic rebound, until it formed a shallow freshwater basin, Lake Lampsilis. Subsequently, the drainage system evolved towards its present-day configuration. Along with these spatio-temporal variations in water level and salinity, silts and clays settled at the base of the water bodies. These fine-grained sediments formed thick low-permeability units that retarded the transfer of saline seawater into the underlying fractured rock aquifer, and later impeded the flushing of brackish water from the rock aquifer, which hence still contains brackish groundwater of marine origin over a 2,200 km^2 area. A fully coupled vertical 2D density-dependent flow and mass transport numerical model was set up to simulate the marine and post-marine subsurface migration of salt within the study area. The relative influence of various processes and parameters was then assessed. Results show that salinization of the rock aquifer was a density-driven convection process, and that the accumulation of fines had a profound influence on salt migration, leading to the currently incomplete and uneven desalinization of the regional aquifer system. In practical terms, this study offers a better understanding of regional groundwater dynamics and quality changes, which are key to sustainable management of the resource amid conflicting uses.

Geofluid leakage along an active plate boundary, southern California

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ABSTRACT

Faults have profound controls on fluid migrations at all depths in the Earth's crust. Faults affect regional groundwater flow, sediment diagenesis, brine and petroleum migration, and the movement of the deepest hydrothermal-metamorphic-magmatic fluids. Fluids lubricate fault zones, and fluid pressures modulate stress/deformation. In southern California the vertical migration of petroleum and noble gases can be used to constrain fault permeability in a seismically active plate boundary. In the offshore Santa Barbara basin, ocean tidal signals and rates of vertical petroleum leakage can be used to constrain an intrinsic permeability ~30 millidarcys for the South Ellwood Fault. In the Los Angeles Basin, large faults formed a lateral barrier for petroleum migration, which resulted in the vertical stacking of oil reservoirs to produce the world's richest petroleum field along the Newport-Inglewood Fault zone (NIFZ). Mantle-derived helium along the NIFZ is a significant component of the helium casing gas from deep production wells, as high as 5.3 Ra, indicating up to 66% mantle contribution (Boles et al., 2015). Using basic theory for reactive fluid flow, one can calculate a maximum inter-seismic Darcy flow rate ~ 2.2 cm yr^{-1} and vertically-averaged permeability of ~160 microdarcys ($1.6 \cdot 10^{-16}$ m^2). Based on the Peclet number and numerical modeling of the basin, regional fluid flow is still too slow to perturb the local heat flow around the NIFZ. Although heat flow data are sparse, there generally doesn't appear to be any clear association of anomalous heat flow with the large strike-slip faults of southern California, suggesting that neither the effects of Tóthian regional flow nor frictional heating alter the mostly conductive temperature regime.

Hydrogeological characterization of the Aquistore site: Canada's first CO_2 storage project associated with a commercial-scale coal-fired power plant

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ABSTRACT

The Aquistore project in southeast Saskatchewan, Canada, is the CO_2 storage component of SaskPower's Boundary Dam Integrated Carbon Capture and Storage (CSS) Demonstration Project – the world's first commercial-scale, post combustion CCS project from a coal-fired electrical generation station. Aquistore consists of both a research component for CCS and a secure storage alternative and buffer protection option for the CO_2-EOR client during operational interruptions to avoid venting CO_2 to the atmosphere. Carbon dioxide is captured at the power station and pipelined 2.8 km to the Aquistore injection site where it is injected into a 3400 m deep injection well. Since April 2015, more than 100,000 tons of CO_2 have been injected into the to the subsurface storage zone.

An extensive geological, geophysical, petrophysical, hydrogeological and geochemical characterization program was undertaken using both pre-existing and newly acquired data at this site. Hydrogeological characterization efforts were divided into four parts: i) regional hydrogeological and hydrochemical mapping of the site; ii) hydraulic characterization of the storage zone during drilling/testing of the 3400 m deep injection and nearby 3400 m deep observation well; iii) installation of an extensive shallow groundwater monitoring network; and iv) on-going hydrogeological and hydrochemical monitoring of the shallow groundwater in the area. Hydrogeology played a key role in the project: i) supporting planning, risk assessment, and permitting of the site; ii) demonstrating the overall storage integrity of the site; and iii) for measurement, monitoring, and verification of CO_2 storage. All of the hydrogeological characterization work at the site thus far indicates strongly favorable conditions for geological CO_2 storage in the subsurface at Aquistore.

Improved assessment of the basin hydrogeologic framework by combining hydrodynamic and petroleum dynamic analysis methods, Dutch case studies

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ABSTRACT

The development of an extensive integrated pressure database in combination with integrated approaches to characterize and interpret current basin hydrodynamic systems in onshore and offshore Netherlands have resulted in knowledge and understanding of spatial variations in hydrodynamic and pressure conditions in relation to its geological framework and burial history (Verweij et al., 2012).

The spatial distribution of gas and oil accumulations in the Netherlands on- and offshore has provided insight into the location and lateral extension of the main reservoirs and the sealing capacity of caprocks, intraformational seals and faults. Petroleum system studies included, amongst other things, assessment of fluid migration and gas leakage paths by using seismic and petroleum geologic methods. Petroleum accumulations may not be totally closed, isolated, and sealed compartments. Gas frequently leaks from reservoirs through caprock seals over geological history. Current or past leakage paths are the direct link between deeper petroleum accumulations and gas accumulated at shallower depths along the migration path. Direct and indirect indicators of such leakage systems include seismic chimneys, pockmarks, and gas shows.

Hydrodynamic conditions are known to affect the sealing capacity of caprocks, intraformational seals, and faults to a greater or lesser extent, and consequently influence the holding capacity of hydrocarbons of structural, stratigraphic and combination traps and the creation of gas leakage systems. Significant influences on the sealing capacity of low-permeability stratigraphic units occur where large groundwater potential gradients prevail over these units.

This paper shows an integrated approach to improve the assessment of the basin hydrogeologic framework (long term integrity of low permeable stratigraphic units/aquitards and fault zones; hydraulic continuity of reservoirs/aquifers) by integrating the knowledge and understanding of the hydrodynamic and pressure systems in the Dutch sedimentary basins with results of petroleum system studies. The approach will be illustrated with case study examples from onshore and offshore Netherlands.

Insights gained from resource and reserve estimates in brine deposits

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ABSTRACT

While Canadians have mined minerals from the earth for centuries, the concept of extracting minerals from brines is relatively new. Of particular interest for brine mining is the extraction of lithium for use in battery development (e.g., electrical vehicles, portable consumer devices). The first NI 43-101 report for lithium resources and reserves in a brine deposit (as required by the Toronto Stock Exchange) was published in 2012 and set the bar for estimation procedures and approaches.

For brine deposits, estimates of a mineral resource (i.e., how much is in the ground) requires detailed site characterization of geology (e.g. sequence stratigraphy consistent with depositional environment), hydrogeology (e.g., delineation of aquifer and aquitard units, drainable porosity) and the distribution of dissolved mineral grade concentration. A mineral reserve estimate (i.e., how much of the deposit can be extracted) requires a rigorous three-dimensional numerical model to simulate groundwater flow and brine transport at the level of detail incorporated within the characterization. Detailed modelling is required to design well networks that balance the number of extraction locations with total pumping requirements, while maintaining a high mineral grade; the total mass that is practically extractable defines the value of the application. Uncertainty analysis, facilitated through modelling, provides investors with a scientific basis to understand potential risks associated with a proposed mine.

Through case studies in North and South America, insights gained from evaluating brine deposits are presented. Case studies include the development of the first NI 43-101 report for reporting lithium resources and reserves in a brine deposit, as well as highlights from several similar applications in a variety of locations. While the primarily targeted sites are dried salt lakes (salars), where brine concentrations can be very high (>300,000 mg/L), the same principles for resource and reserve estimates can be applied to brine deposits in deeper geologic units.

Geochemistry of fluids from an unconventional gas field in New Brunswick, Canada: Identification of unique tracers for migration to shallow groundwater

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ABSTRACT

Natural gas has been produced commercially from hydraulically fractured wells in the McCully gas field in New Brunswick since 2001. Despite the economic potential of this resource, development of the McCully field has been met with public resistance and a provincial moratorium on hydraulic fracturing due to concerns over impacts to fresh water resources. A joint research project between Natural Resources Canada and the University of Ottawa was initiated in 2014 to characterize local shallow groundwater and deep formation fluids of the gas field to assess any potential impacts to fresh water resources.

Thirteen gas and nine formation water samples were collected from production wells drilled into Carboniferous fluvio-lacustrine shale and overlaying sandstone units of the Albert Formation (Horton group) in the McCully gas field in 2015/2016. Hydrocarbon concentrations and stable isotope ratios ($\delta^{13}C$, $\delta^{2}H$) of the natural gas were measured using gas chromatography and IRMS. Major ion and trace metal concentrations as well as isotope ratios ($\delta^{18}O$, $\delta^{2}H$, $^{87}Sr/^{86}Sr$) of the water samples were measured using ICP-MS and IRMS.

Analysis of the natural gas samples reveals a thermogenic origin and a partial isotopic inversion of the hydrocarbon gases ($\delta^{13}C\ CH_4 > \delta^{13}C\ C_2H_6 \leq \delta^{13}C\ C_3H_8$). The unusual isotopic signature of the hydrocarbons is thought to result from late-stage pyrolysis of liquid hydrocarbons under conditions of high thermal stress. The formation water samples display chemical signatures similar to seawater but with variable salinities. The marine signature of the water in the fluvio-lacustrine strata of the McCully field suggests infiltration and mixing of water from overlaying marine rocks (Windsor group) with low salinity connate water. The chemical and isotopic signatures of the formation fluids will be used as tracers to identify possible sources and pathways of deep-sourced contamination to shallow groundwater resulting from gas production activities in the McCully field.

ECHN

Geothermal potential assessment of the carbonate Hungarian Transdanubian Range

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ABSTRACT

For economic geothermal production, natural reservoirs with suitable hydraulic parameters, and a favorable quantity of heat and production fluids are necessary. These parameters need to be investigated in the reconnaissance phase of fluid-based geothermal exploration. Generally, observation wells are used to identify the subsurface conditions and evaluate the preliminary geothermal potential. Without proper borehole information, the evaluation of reservoirs, especially heat and fluid fluxes are quite complicated, almost impossible.

In turn, springs, which are natural discharge points of flow systems, can reflect the subsurface flow and temperature conditions, therefore they can provide information about the groundwater flow pattern. Springs in the Transdanubian Range were grouped by multidimensional data analysis based on elevations of spring outlets, volume discharge, temperature and chloride ion content to characterize the subsurface temperature conditions and flow systems.

The Transdanubian Range, situated in Central Hungary, is mainly built up of Mesozoic confined and unconfined carbonates with hydraulic conductivities of 10^{-6}–10^{-5} m/s. Therefore, there is a regional aquifer which can be characterized by sufficient hydraulic parameters. Joint interpretation of springs and numerical simulations revealed that at the unconfined parts the highest temperature is only ~30 °C. Consequently, the geothermal investment in unconfined regions would not be economic in spite of 1000–m–thick carbonate with suitable hydraulic parameters.

In the Budapest region the position of springs is complex. In the unconfined part, cold karstwater can be found but under the siliciclastic cover, a considerable heat accumulation occurs in carbonates of at least 100 °C. In this adjoining confined and unconfined area conditions regarding reservoir, fluid and heat are all suitable for economic geothermal production.

The reinterpreted conclusion of the previous studies and our study is that the siliciclastic cover is responsible for heat accumulation in carbonates therefore the position of the unconfined and confined parts is critical for geothermal heat utilization in carbonates.

The research was supported by the NK 101356 OTKA Hungarian Research Grant.

ECHN

Significance of the understanding of regional pressure regimes in geothermal exploration for confined carbonate reservoirs

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ABSTRACT

The goal of the study was the evaluation of regional pressure regimes for different regions of confined carbonates and understanding the influence of pressure conditions on geothermal exploration. The confined basement carbonate region with its adjacent unconfined part and siliciclastic confining strata were examined based on the application of the hydrodynamic approach. The research could reveal different pressure regimes for the study area of the Paleogene Basin, Hungary. The location of these regimes depends on the elevation of basement carbonates, the structures and thickness, hydraulic conductivity and the heterogeneity of the covering layers. The effects of gravity-driven regional groundwater flow systems were proven down to an elevation of -500 m asl including recharge and discharge areas. Down to this elevation, both vertical and horizontal hydraulic communication exist. This area is characterized by close to hydrostatic pressure conditions. Nevertheless, a hydraulic boundary (a colinear ridge in the north and sink in the south) was delineated in the study area. This impedes horizontal hydraulic communication between the shallower unconfined-confined carbonates in the west and the deeper confined carbonates in the east. Below -500 m asl elevation southeast through-flow can be observed, terminating in a regionally underpressured zone caused by the presence of a regional aquitard in the uplifted eastern region. Both underpressured and overpressured blocks determined by faults were found to influence vertical connections between siliciclastic confining layers and carbonates in the vicinity of a significant strike-slip fault. The differently pressurized regions (underpressured, close-to hydrostatic and overpressured) influence the geothermal exploration possibilities of the basement carbonates (production and injection). The research was supported by the Hungarian Research Fund (NK 101356).

Pathways and Connections: enhancing knowledge of Alberta's groundwater resources through Canada's Oil Sands Innovation Alliance (COSIA)

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ABSTRACT

Knowledge of hydrogeological conditions within Alberta's oil sands has often been constrained by fragmented datasets. The result has been conflicting interpretations regarding real or perceived interactions between distinct hydrostratigraphic intervals and the potential consequences for development. Compared to other oil sands development areas, the Southern Athabasca Oil Sands (SAOS) region has experienced the highest rate of thermal in situ development over the last decade. Groundwater extraction to support steam generation, and injection of related wastes, has raised some concerns regarding risk to the subsurface environment.

To gain a better understanding of these risks (and potential opportunities), COSIA commissioned a project to combine disparate geochemical datasets of regional groundwaters into one unified database. The input for this database was acquired from participating operators and public domain sources, with the objective to identify areas of potential connectivity across key bedrock aquifers and provide a more refined understanding of flow system interactions to enhance the ability of thermal in-situ operators to responsibly manage groundwater resources.

InnoTech Alberta and Integrated Sustainability were commissioned to conduct this work. The resulting database was used to evaluate conceptual models of groundwater flow by identifying the origin, age, and mixing between various major hydrostratigraphic intervals through a forensic evaluation. The existing conceptual model of topographically-influenced groundwater flow systems was refined to include areas of suspected cross-formational flow and pore water mixing, as well as zones of flow stagnation linked to the presence of buried pre-glacial channels. Salinity patterns, along with hydrochemical facies mapping, geochemical fingerprinting, and isotopic tracer analysis substantiated the general down-dip pattern of increasing mineralization towards the southwest in all formations. However, areas displaying substantially different pore water conditions were also identified, implying influence from deeper formations in some locations, extended water/rock interaction in others, and discrete areas of interactions with the near-surface environment.

Alberta Oil Sands Area regional groundwater quality

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ABSTRACT
This study aims to investigate regional groundwater quality in the Athabasca Oil Sands (AOS) area of northern Alberta, Canada, in light of mining activities and regional land use planning. Within the 50,000 km^2 AOS area, a database of 546 water quality parameters measured in 5,118 water wells between the 1960's and 2015 was compiled, cleaned and analyzed by hydrostratigraphic unit (HSU), including the main Quaternary and Cretaceous aquifers. Among the 12 main HSU's there are a variety of distinct water types including Ca-bicarbonate, Na-bicarbonate, mixed-cation bicarbonate and Na-Cl, reflecting variable lithology, ion exchange, and mixing. Geochemical anomalies within each HSU were identified by Principal Components Analysis. For example, within the Empress Formation geochemical anomalies in Total Dissolved Solids (TDS) and Cl likely result from mixing with the Colorado Group Shales. Spatial (within and between HSU's) and temporal trends in water quality were assessed using (geo)statistical methods in ArcMap and R, and compared to "interim trigger values" (concentrations specified by the Lower Athabasca Regional Plan Groundwater Monitoring Framework to detect changes in water quality). Median concentrations for multiple water quality parameters exceeded interim trigger values. For example, in most HSU's, median TDS concentrations exceeded interim trigger values. Statistically significant temporal changes in water quality were detected in the 2000's in small areas of shallow surficial sand aquifers and the McMurray Formation. The surficial sands exhibited increasing Na, Cl, and HCO_3 concentrations while the central McMurray Formation exhibited increasing TDS, Cl, B, and alkalinity concentrations. The compiled dataset highlights the lack of publically available data for some aquifers, particularly in the central portion of the study area, where in situ oil sands mining activity is located. Thus, recommendations for enhancing understanding of regional groundwater quality in the Athabasca Oil Sands area include: continued groundwater monitoring (with expansion of monitoring in the central area, and to regions with surface water-groundwater interaction), collection of a consistent set of water quality parameters, and continual database maintenance and analysis.
ECHN

Lower Prairie Evaporite Aquifer System underlying the Mineable Athabasca Oil Sands Area

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ABSTRACT

A regional and highly transmissive aquifer has been identified within the Devonian-aged Prairie Evaporite Formation in the Mineable Oil Sands Area (MOSA) in northeast Alberta. Through dissolution of evaporites by down-dip groundwater flow over geologic timescales, a process of dedolomitization has created a high transmissivity aquifer system (10^{-4} to 10^{-1} m^2/s) within the laminites in the lower Prairie Evaporite Formation. Flow patterns are circuitous and well scale heterogeneity is very high. However, regional connectivity has been well established, at least in a north-south direction.

Groundwater chemistry in the Prairie Evaporite aquifer system evolves along the regional flowpath from east to west, controlled by the mineralogy and dissolution history. Near the basin edge in the east, dolomite is the primary soluble mineral, and waters tend to be dominated by bicarbonate. Farther to the west, waters interact with anhydrite and are dominated by sulphate with total dissolved solids (TDS) typically in the 4 to 8 g/L range. Near the Athabasca River, the waters have a signature of halite dissolution: sodium and chloride dominance with TDS approaching 100 g/L. Stable isotopic signatures indicate recharge from the Laurentide continental ice sheet, contrasting with the warmer signature of more modern shallower groundwaters and sluggish formation waters of the deep basin groundwaters to the west. Radiocarbon data indicates residence times of approximately 5,000 to 30,000 years. The halite dissolution signature and TDS higher than the saturation limit of anhydrite (about 5 g/L) reflect either pockets of halite that are not encountered during drilling or ongoing diffusion from the lower-permeability matrix and, in the area of the Athabasca River, mixing with deep basin flow systems. Reactive transport modelling and consideration of the full data set suggests that the halite dissolution signature (e.g., higher TDS east of the Athabasca River) is due to ongoing diffusion from the lower-permeability matrix.

Geological controls on the distribution of groundwater flow systems within the Middle-Devonian strata of the Northeast Athabasca Region

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ABSTRACT

The middle Devonian aquifer system north of the Clearwater River and east of the Athabasca River has been the subject of regional and local scale hydro-geological investigations since the 1950's, mainly driven by oil sands development. Although areal distribution of hydro-geological and hydrochemical data is non-uniform, it is sufficient to provide a reasonable foundation for characterization of regional and local systems. The Devonian aquifer system was developed and enhanced by dissolution of the Prairie Evaporite Formation east of the Athabasca River. This hypogenic karstification resulted in a variably developed network of brecciation and fracturing of the over-lying strata. Both regional and local hydrochemical facies distribution patterns, as well as local stable isotope data, indicate that hypogenic karst processes are on-going. Pore pressure and hydrochemistry data suggests that the nested local and regional groundwater flow systems within the Devonian are gravity driven and connected to present day topography and water table configuration. Long-term depressurization monitoring indicates localized hydraulic connections between the Lower McMurray and the Devonian aquifers. The local groundwater flow systems within the Devonian aquifer/aquitard complex have important implications for the development of the Athabasca Oil Sands from a water management and geotechnical/mining risk aspect. Our research has allowed us to develop project-specific practical solutions to oil sands mining in a regional hydrogeological context.

COSIA Regional Groundwater Solutions Project for the Southern Athabasca Oil Sands – Evolution of a numerical model

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ABSTRACT

The COSIA RGS project was established to evaluate the potential range of aquifer pressure changes resulting from groundwater withdrawals and disposal associated with future in situ bitumen production within the Southern Athabasca Oil Sands (SAOS) region. The main objectives of this project were: provide COSIA members with a regional groundwater risk assessment and management tool; set a baseline to answer groundwater resource availability questions; and evaluate realistic water source and disposal forecasts for industry growth.

The SAOS numerical groundwater flow model was originally developed for the Government of Alberta (GoA) in 2009. The model was loaned to COSIA for the RGS project, where it was updated and re-calibrated to the most recent industry water use data. In 2016, Matrix Solutions Inc. was retained to undertake the model update and the computationally intensive coupled steady-state and transient calibration using PEST software.

As a first step, the numerical model's material property zones, numerical settings, and boundary conditions were modified from its initial state. The number of adjustable parameters was also modified, and Cauchy boundary condition transfer rates were tied to element hydraulic conductivities.

Calibration targets for the inversion included, water table depth, 209 measured hydraulic heads in industrial groundwater wells, 724 hydraulic heads inferred from drill stem tests, and 13 years of transient hydraulic head data that was reduced to 21,782 monthly changes in hydraulic head. The calibration process required harnessing the power of cloud computing, allowing for up to 100 model runs to be solved simultaneously for a total of 3,310 hours (equivalent to 138 days of continuous CPU time if the model had been solved in series). This presentation describes challenges in the calibration optimization processes and an innovative approach to computing an arbitrary Global Transient Misfit Quality Indicator (GTMQI) allowing visualization of the spatial distribution of transient misfits, based on statistics.

Post-mining hydrogeology in Alberta's mineable Athabasca oil sands region

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ABSTRACT

The Athabasca oil sands region is a global hydrocarbon resource located in northeastern Alberta. The surface mineable area is 4,800 km^2. Devonian carbonates and evaporates overlie the Precambrian basement. The overlying Cretaceous-age sedimentary sequence hosts the oil sands ore within the McMurray Formation at its base. Glacial and glacio-fluvial Quaternary deposits up to 40 m thick cap the bedrock sequence. Local topographic relief is limited, except for the deeply incised Athabasca River that bisects the mineable region. The deep Devonian-Cretaceous aquifer-aquitard sequence is characterized by intermediate to regional scale groundwater flow systems and brackish to brine water quality. Local-scale groundwater flow systems, with fresh to brackish water quality, occur in the Quaternary-Cretaceous aquifer-aquitard sequence.

Mining removes geologic materials to the base of the Cretaceous deposits, up to 100 m depth. Overburden is placed in dumps up to about 50 m high. Oil sands ore is mined and processed to extract bitumen. Residual tailings and process water are deposited in above-ground tailings storage facilities and within mined-out pits. Many mined-out pits will be capped with water, which is projected to create over 30 new lakes under current mine reclamation plans. Hydrostratigraphy, morphology, and water quality of the post-mining landscape will differ from the pre-disturbance landscape.

This talk explores how post-mining groundwater flow systems will evolve. New gravity-driven flow systems will develop in response to reclaimed topography and hydrostratigraphy. However, long-term consolidation and settlement will modify the land surface and the gravity-driven flow system for centuries. Water quality along groundwater flow paths will evolve in response to flushing of tailings deposits and weathering in dumps. Meeting the water quantity and quality needs of the reclaimed landscapes will require groundwater engineering and flow-system reconstruction on scales of hundreds to thousands of square kilometres, integrated with multi-disciplinary mine and reclaimed landscape engineering.

The geochemistry of springs and surface waters of Wood Buffalo National Park, Canada

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ABSTRACT

Wood Buffalo National Park (WBNP) is Canada's largest national park with an areal extent of almost 45,000 km^2 encompassing millions of hectares of boreal forests, extended wetlands and prairie, karstic landforms, and groundwater-dependent ecosystems. Geochemical compositions of groundwaters and surface waters in the region were mapped, and used to investigate possible rock-water interactions. Surface waters and springs in the area show significant variability in geochemical characteristics, i.e., total dissolved solids ranging from less than 1,000 mg/L to more than 300,000 mg/L. Hydrochemical facies of the waters varies from end-members of Ca-HCO_3-type to more evolved Na-Cl-type waters. Analysis of oxygen and hydrogen stable isotopes revealed that groundwater in the region has a strong correlation with the average isotopic composition of local precipitation, thus it is believed that groundwaters originate from meteoric water, rather than from formation waters of the Alberta Basin. Dissolved NaCl content of groundwaters in WBNP is not related to evaporation of seawater; instead, the dominant processes affecting the waters are dissolution of halite, sulphate minerals and carbonates. The source of solutes in the groundwater is thought to be Devonian evaporites and carbonates; however, halite-bearing units can only be found 70-100 km west of the brine springs discharging at the eastern edge of the area. It follows that these waters must have traveled in the subsurface from the halite dissolution edge to their discharge location; consequently, they are thought to form a regional-scale flow system.

ECHN

Unusual calcium-rich formation-waters from Devonian aquifers in the Western Canada Sedimentary Basin: possible relict seawater?

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ABSTRACT

There has been a lot of controversy regarding the question of secular changes in Phanerozoic seawater and whether seawater chemistry has remained similar to today (i.e., Mg-SO_4 type) or was for periods of time of fundamentally different composition (i.e., Ca-Cl_2 type). This issue has been exacerbated by many studies of formation-waters collected from geologic basins that have failed to find evidence of widespread Ca-Cl_2 type brines, and have thus concluded there is little or no evidence to support Ca-Cl_2 type seawater during the Phanerozoic.

There are widespread, but aquifer-restricted Ca-Cl_2 type brines in the Alberta and Williston basins (Western Canada Sedimentary Basin). Samples include: two producing wells in the Alberta Basin; a potash mine-shaft in the Williston Basin; multiple unpublished Drill-Stem-Test data from the Williston Basin; and previously-known (albeit re-sampled and further analyzed) samples from potash mine-shafts in the Williston Basin. These samples are from aquifers of roughly similar (Devonian) stratigraphic age when seawater was reportedly of the Ca-Cl_2 type.

Results from across the basin are remarkably similar: calcium-chloride type brines (TDS > 425 g/L); calcium > 120 g/L; chloride >270 g/L; magnesium > 11 g/L; potassium >6 g/L; sodium < 10 g/L; bromine >6 g/L; and sulfate <100 mg/L. These data along with stable isotopic measurements and analyses of the regional hydrogeology of the basin support the conclusion that these samples are relatively unaltered highly evaporated Devonian seawater. Assuming that bromine has been relatively conservative in seawater through time, an evaporation factor can be calculated and then used to estimate the composition of the original Devonian seawater. The unique stratigraphic position of the host Devonian aquifer combined with the paleo-hydrogeology of the basin, has combined to preserve these fluids to the present time.

Hydrochemistry of the Bakken aquifer in the Williston Basin – Canada and USA

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ABSTRACT

Chemical composition and distribution of formation waters in the Bakken aquifer were investigated to understand their origin, migration, and evolutionary history. A basin-wide geochemical database was created, composed of nearly 2000 water analyses from drill stem tests, initial production recoveries, and wellhead production samples. An extensive, iterative culling procedure was used to remove all non-representative formation water analyses. From the remaining 167 water analyses, a detailed hydrochemical investigation was preformed including total dissolved solids (TDS) content and distribution, hydrochemical facies classification and distribution, and formation water origin utilizing Na-Cl-Br systematics.
Results show that the water composition and salinity within the Bakken aquifer is variable throughout the Williston Basin with TDS ranging from less than 10,000 mg/l, to over 300,000 mg/l towards the center of the basin. Formation waters from the Bakken aquifer are dominantly Na-Cl type however, Na-SO_4 type formation waters occupy the northwest of the study area near the transition of the Bakken Formation of the Williston Basin into the Bakken/Exshaw Formation of the Alberta Basin. Brine origin as determined from Na-Cl-Br systematics preformed on Na-Cl type formation waters reveal that Bakken Formation brines are of multiple origins. In the center of the Williston Basin, Bakken aquifer formation waters obtained their salinities from the evaporation of paleo-seawaters and appear to be near-relict connate water. Bakken Formation brines located outwards from the center of the basin show a mixing between brines resulting from halite dissolution as well as those from the evaporation of paleo-seawater. The overall distribution of formation waters in the Bakken aquifer today reflects a complicated mix of original connate brines mixing with salt-dissolution waters transported by a regional groundwater flow system.

ECHN

In situ measurement and modeling of physicochemical parameters at discharging thermal water – Experimental study 1

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ABSTRACT

Thermal springs are the terminal points of groundwater flow systems, and transfer allochthonous water onto the surface. The variation of physicochemical parameters at the discharge location of thermal springs is a significant influencing factor in the formation of precipitates. In this study, a canalized thermal spring outflow of the Buda Thermal Karst system was investigated in the tunnel of Gellért Hill, Budapest, Hungary. On the canal walls close to the outflow the development of a red, long filamentous bacterial biofilm can be observed. Further along the canal it changes into lighter red, crystalline but not so hard precipitate and then into white hard, dominantly carbonate crystalline precipitate. These changes indicate that the physicochemical parameters change significantly in this section of the canal. So the aim of our study was to determine how the changes of the physicochemical characteristics of the emerging spring water lead to the formation of the observed precipitates in the canal. The temperature, specific electric conductivity, pH, dissolved oxygen content, redox potential, concentration of major ions, dissolved carbon dioxide content, concentration of radium-226, uranium-234+238 and radon-222 were determined. Discharge volume and flow velocity of the flowing water were also measured. The experiment was conducted twice and the results were also evaluated by reactive transport modeling with PHREEQC. It is found that degassing of CO_2 is a key process controlling the water chemistry, including pH. Ingassing of oxygen also occurs and affects the redox state of the water along the canal. The conclusions of this study were used for the planning of further investigations to examine the formation and evolution of the red and white precipitates.
The research was supported by the NK 101356 OTKA research grant and by the European Union and the State of Hungary, co-financed by the European Regional Development Fund in the project of GINOP-2.3.2.-15-2016-00009 'ICER'.

ECHN

Flow system interpretation of the second largest karst system of Hungary – hydraulic and hydrogeochemical characterization

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ABSTRACT

The Bükk Mountains is the second largest karst system of Hungary where the karst waters are intensely utilized resources. Cold waters are used for drinking water supply and all around of the foothills lukewarm and thermal waters are used for balneological and geothermal heating purposes. Therefore, protection and sustainable use of these resources is an important issue, which requires good understanding on the hydrogeological functioning of the karst system.
During the hydraulic evaluation of the area the groundwater flow system was investigated based on measured hydraulic data. The Bükk Mountains have a complex geological history with complicated structures, so this study tried to analyse the role of the amending effects of these structures on the flow pattern. The research gives a spatial overview about the geochemical composition of the karst waters and examines the karst systems with radionuclides and organic parameters beyond the classical hydrogeochemical methods (in-situ field parameters, basic water chemistry) in order to identify different fluid components. During the evaluation of the data, multivariate data analysis (cluster analysis, discriminant analysis) was applied.
The radionuclide research in the Bükk area was supported by the European Union and the State of Hungary co-financed by the European Social Fund in the framework of TÁMOP-4.2.4.A/ 2-11/1-2012-0001 National Excellence Program.

ECHN

Use of chemical data for verification of groundwater flow conditions (Lwówek region, Poland)

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ABSTRACT

Regional recharge zones are characterized by high downward gradients which enable contaminants to migrate downward to deep parts of the flow system. In the areas dominated by agriculture the contamination is related mainly to nitrate. In the regional recharge zone of Quaternary aquifers located in central Wielkopolska (Lwówek region, Poland) relatively high nitrate concentrations (>15 mgNO_3/l) were detected at a great depth (>80 m). To explain the origin of high nitrate concentrations, multilevel piezometer nests were constructed for documentation of vertical nitrate migration at 3 selected locations, where hydrogeological windows were indicated (sands and gravels in the geological profiles). It was shown that in the shallow part of the aquifer, the concentration of nitrates exceeds 30 mgNO_3/l. The nitrates migrate downward to the deepest parts of the flow system in regions of groundwater extraction (where high nitrate concentrations are detected at a great depth). Under natural conditions (where the water extraction is not performed), this contamination is not yet observed in the deep part of the flow system. Based on this research, a conceptual model of groundwater circulation was formulated. The most intensive groundwater recharge occurs in the unconfined parts of the flow system in the regions of groundwater extraction. In the regions where natural gradients exist (without water extraction) the recharge in shallow parts of the aquifer is also intensive but young water does not reach deeper parts of the flow system, where stagnation zones typically exist (as defined by Tóth, 1963), and is manifested by completely different groundwater chemistry than in shallow parts of the aquifer. The presented research is a great example of how chemical data can be used to help investigate groundwater circulation.

This work has received funding from the National Science Centre of Poland (grant no. 2014/15/B/ST10/00119).

Importance of local-scale geological features in regional-scale groundwater modelling

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ABSTRACT

Groundwater flow models in the South Athabasca Oil Sands (SAOS) region inform the groundwater decision-making process. They aim at reasonably predicting regional changes in hydraulic heads and groundwater flux to assess potential cumulative environmental impacts. While the objective of such models is to reproduce regional-scale groundwater flow in major aquifers, local-scale geological features can have a significant impact on the behaviour of the regional groundwater flow system. Therefore, local features need to be adequately represented in numerical models in order to make reasonable, fit-for-purpose predictions.

Focusing on the thick Quaternary stratigraphic sequence in the SAOS region, local features identified through geologic characterization over the last decade include Quaternary glacial meltwater channel incisions cross-cutting multiple bedrock aquifers, aquifer outcrop areas and intersections with surface water bodies, and 'windows' of hydraulic connectivity through regionally-continuous till sheets. This presentation describes workflows and tools to take advantage of large regional datasets available from sources like the Alberta Geological Survey (AGS) that are combined with locally refined datasets of markers from geophysical well logs, seismic and airborne resistivity maps, to generate regional 3D geomodels. These geomodels will ultimately be used in the construction of numerical models of groundwater flow. The geomodels can have spatially variable meshes that are refined based on an understanding of the local features to capture. Datasets can be integrated using simple cokriging approaches to locally deform regional maps and honour all the available data. From the 3D geomodels, automated scripts are run to construct groundwater models in FEFLOW that honour the integrated geological interpretation, by assigning material properties to hydrostratigraphic units. These material property assignments can accurately represent aquifer pinch-outs and hydraulic connectivity between units even when continuous model layers are required. This expedites groundwater numerical model construction and ultimately results in more useful predictive tools.

Integrated surface-subsurface hydrologic modeling to evaluate risks to agricultural production at regional scales

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ABSTRACT

Providing a scientific basis for water management policy, and assessing the physical characteristics underlying hydrologic risk, typically requires watershed-scale assessments that encompass a few hundred km^2 at a minimum. However, agriculture-focused water resources challenges often encompass much larger areas, and can easily extend to major river basins (>100,000 km^2). Because of complex interactions between climate, surface water, groundwater, and soil moisture across much of the agricultural landscape, physics-based 3-D integrated surface-subsurface hydrologic models provide a holistic means of performing water-related risk assessment for these types of applications. Recent improvements in numerical techniques, access to high-performance computing resources and the increasing availability of large spatially distributed data sets has allowed fully integrated models to be applied at larger scales with a higher degree of spatial resolution than in the past. The integrated nature of these models implicitly includes hierarchical (regional to local) groundwater flow systems and their effects on water table levels and soil moisture.

In this presentation, we discuss a large-scale modelling-based agricultural risk assessment project whereby fully integrated surface/subsurface water models are being developed using the HydroGeoSphere (HGS) platform for the South Saskatchewan River Basin (SSRB, ~150,000 km^2) located in Western Canada. Recent advances in HGS model development include the implementation of water resources management such as reservoir operation and irrigation. Hydrologic responses within its major sub-basins are nested within the full-basin model in order to capture additional detail at an increased resolution. Visualization of transient model results includes spatially distributed soil moisture, groundwater levels, recharge and discharge patterns at high resolution in relation to surface topographic controls and water bodies. Once complete, the SSRB modelling platform will facilitate large-scale projections of excess soil moisture, drought, and other water-related risks to crop production.

Numerical simulation of long-term pumping in a heterogeneous sandstone aquifer

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ABSTRACT

Sustainable groundwater management practices are essential for ensuring future adequacy of water supplies and minimizing detrimental effects on aquatic ecosystems. One of the concepts for defining sustainable groundwater development is the safe aquifer yield, the pumping rate that does not create an excessive negative impact on the groundwater system on multi-decadal scale. Conventional methods for determining a safe yield often rely on idealized aquifer theory. The ideal aquifer assumptions are not valid in heterogeneous aquifers, such as the Paskapoo Formation, which is a source of groundwater for a number of rural communities in Alberta. The heterogeneity and internal boundary effects associated with an aquifer structure consisting of sandstone channels embedded in lower permeability mudstone and siltstone make the estimation of safe aquifer yield particularly challenging.

This work assesses the ability of conventional methods to evaluate safe aquifer yield in a heterogeneous channel in an overbank aquifer system by comparing the expected drawdown with that predicted using a numerical model. Two models with different levels of complexity are used for the evaluation, a synthetic bounded aquifer and the model of a real aquifer site close to Innisfail, Alberta. The aquifer belongs to the Paskapoo Formation. The numerical model was calibrated using 48-hour pumping test data and information from slug tests, a surface electrical resistivity tomography survey, gamma ray logging, lithological logs (core and cuttings description) and water-level time series. The results show that increased heterogeneity influences the ability of different methods to reliably predict aquifer response to long-term pumping and that the incorporation of various aquifer characterization techniques can greatly improve model predictions.

Numerical modelling of highly saline wastewater disposal in Northeast British Columbia

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ABSTRACT

In Northeast British Columbia, wastewater from hydraulic fracturing and oil and gas production is injected into deep groundwater or depleted hydrocarbon reservoirs for disposal. The wastewater typically has a salinity in excess of 100,000 mg/L, while the formation water may be significantly less saline. The injection of relatively dense wastewater into disposal formations has the potential to influence the pressure/head distribution in the aquifer within the disposal zone, potentially extending to the regional scale. At the same time, wastewater plume migration is influenced by subsurface pressure conditions and hydrogeological properties, which dictate regional groundwater flow characteristics of the deep formation. This study investigates the integration of wastewater disposal plumes into the Paddy-Cadotte formation in Northeast BC, where formation water, defined as "deep groundwater" under the Water Sustainability Act, has a relatively low natural salinity of approximately 10,000 mg/L, and in which seven disposal wells are currently operating. Geological, reservoir, and disposal well data on file at the BC Oil and Gas Commission are used to support development of a density-dependent flow and solute transport model using the code FEFLOW. Boundary conditions representing the conceptual regional deep groundwater flow system are employed. Model results are used to inform the understanding of potential implications of dense wastewater disposal on the regional deep groundwater flow regime and vice versa. Insights are also gained regarding the potential for regional intermingling of wastewater plumes from different disposal wells within the regional hydrogeological context.

ECHN

Evolution of biogeochemical precipitation at discharging thermal water – Experimental study 2

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ABSTRACT

Biofilms exist in many thermal spring caves and even in thermal water wells of the Buda Thermal Karst, Hungary. Chemolithoautotrophic bacteria form these biofilms as no light penetrates into the spring caves. The biofilms have low TOC content, their inorganic part mainly consists of calcium, silicon, iron and magnesium. The main iron-bearing phases are ferryhidrite and goethite providing for the red color and the adsorption capacity of the biofilm. Trace elements like radium, tin, lead, zinc, arsenic, titanium etc. are usually adsorbed by the biofilm with high enrichment factors compared to the water they exist in. Though many properties are known about the existing biofilms, their evolution and their interaction with the water is less studied. The aim of our research was to study the formation and evolution of precipitates by a 12 week-long in situ experiment in the tunnel of Gellért Hill, Buda Thermal Karst, Hungary. During the experiment the precipitates and the water were monitored in time and along the flow path (a 120 m long canal) of the thermal spring in a controlled environment. Temperature, pH, specific electric conductivity and dissolved oxygen content were monitored continuously at the beginning and at the end of the studied section of the canal. Other parameters (redox potential, concentration of major ions, dissolved carbon dioxide content, concentration of radium-226, uranium-234+238 and radon-222, TOC and TN content, concentration of trace elements) were measured three times during the experiment (0, 6th, and 12th week). The evolved precipitates were sampled twice (6th, 12th week) and were analyzed by XRD, SEM, ICP-MS, Mössbauer spectroscopy and gamma spectroscopy. The controlled environment helps to interpret the results and the influencing factors regarding the evolution of the precipitates. The research was supported by the NK 101356 research grant co-financed by the European Regional Development Fund, GINOP-2.3.2.-15-2016-00009 'ICER'.

Flow system analysis of the Villány karst region (Hungary) using hydraulic methods and natural tracers

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ABSTRACT

The outcropping Mesozoic carbonates and their subsurface extension covered by young sediments in the adjacent basin basement form a thick (up to 1700 m) karst reservoir in the Villány Hills (South Hungary). The area is characterized by natural thermal water discharge at the boundary of outcropping carbonates and an adjacent sedimentary basin. These regional discharge areas are favourable sites for hypogenic cave development as well. Some caves here are characterized by phenomena related to thermal waters: tectonically controlled maze-like patterns, morphological features (spherical niches), and minerals (huntite, aragonite, calcite as cave popcorns). Some of the caves are connected to thermal waters even today. The groundwater flow system in the Villány area is characterized as a gravity and temperature (density)-difference driven flow system based on earlier research, where infiltrating meteoric waters circulate on the surface of bare carbonates and discharge in karst springs with different temperatures. Lukewarm springs dominate throughout the area, with natural thermal water discharge occurring only in Harkány, as a marshland. Recent studies emphasize the effect of fluids from the adjacent sedimentary basin on the karst reservoir.

The thermal waters and the caves were hitherto investigated separately. However, all these phenomena belong to one single system, a hypogenic karst system and they can be evaluated only if their context is understood, i.e. if their common cause is revealed: the pattern of groundwater flow and its thermal and geochemical characteristics. The aims of the present study in the Villány thermal karst area are 1) to evaluate the groundwater flow system based on measured hydraulic data, 2) to characterize the geochemical composition of the waters, using natural tracers to identify different fluid components, and 3) to evaluate the cave forming processes.

The National Research, Development and Innovation Fund has provided financial support to the project under the grant agreement no. PD 116227.

ECHN

Geological, hydrogeological and numerical models of the transboundary Milk River Aquifer system (Alberta, Canada - Montana, USA)

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ABSTRACT

The Milk River Aquifer (MRA) is a regional confined sandstone aquifer (26,000 km^2), spanning southern Alberta (Canada) and northern Montana (USA). Previous studies were limited by the international border, thus preventing a complete understanding of the global dynamics of the aquifer. The present study overcomes transboundary limitations by providing a comprehensive portrait of the aquifer. The stratigraphic framework of the study area was first unified in a geological model of the aquifer system. Then, the conceptual hydrogeological model of the MRA was developed by gathering hydrogeological and geochemical data from both sides of the Canada/USA border. Recharge occurs in the subcrop areas of the aquifer, where unconfined conditions and modern waters are present. Groundwater inflow into the MRA also occurs from overlying geological units in the topographic highs of the area. Two transboundary fluxes were defined from the potentiometric map of the aquifer, which closely mimics the topography. The Milk River intercepts a major part of the groundwater flux coming from the south. Another natural discharge mechanism corresponds to vertical leakage through the aquitards, especially along the bedrock valleys, which act as drains. The geological and conceptual models of the MRA form the basis of the numerical groundwater flow model of the aquifer. The 3D steady-state groundwater flow model represents pre-development conditions. The numerical model shows that the conceptual model of the aquifer is hydraulically plausible by successfully representing the main components of the conceptual model and the groundwater budget. Furthermore, the numerical model quantifies the vertical fluxes through the aquitards as well as the groundwater inflow from the overlying units near the topographic highs. Being a transboundary groundwater resource, a joint management of the MRA would be warranted, especially in the area between the recharge area in Montana and the southern reach of the Milk River in Alberta.

GIS-based spatio-temporal studies of groundwater quality and depth in Kaithal District of Haryana, India

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ABSTRACT

Haryana is one of the northern states of India and is dominantly covered by Indo-Gangetic alluvium. It is well known for its rich granary and ranks second among the contributors of wheat to the central pool of India. The present study pertains to the Kaithal district of the state covering an area of 2317 km^2 and is famous for wheat and paddy crops. The change in rainfall pattern over a period of more than 35 years and with concomitant changes in the groundwater conditions both quantity and quality are posing a new threat for sustained production of agriculture. To address the problem, analyses of groundwater depths and quality from 1974 to 2009 have been carried out. Land use, geomorphology, seasonal fluctuations and groundwater prospects, depth and quality maps were generated in a GIS environment. The study reveals a recession of groundwater levels from 6.21 meters in 1974 to 19.16 meters in 2009 with a net average decline of 1.5 m/year during 1974-1999 as compared to more than 11 m in the next ten years. Up to 1998, the rainwater was able to recoup the ground water to some extent, however during the last decade, even the post-monsoon depths were found greater than the pre-monsoon depths. Moreover, the value of pH has changed from 8.1 in 1997 to 7.54 in 2007. Similarly, the TDS has changed from 637 to 1360 mg/l, TH from 172 to 173 mg/l, EC from 1061 to 2267 μS/cm, SAR from 5.6 to 16, RSC from 1.4 to 2.8 meq/l whereas PS changed from 44 to 81 percent over a period of 10 years from 1997 to 2007. It has been observed that the decline in depth to water level is associated with the decline in the quality, which poses a threat to the farmers for its use in agricultural activities.

Best Management Practices on contaminant reduction in the New Orleans aquifer

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ABSTRACT

Due to the fast urbanization in the city of New Orleans along with salt intrusion problems, the aquifer system is deteriorating. Over the last year, physical, chemical, and biological parameters of groundwater have been monitored. This research sought to evaluate the current water condition and provide recommendations for developing best management strategies. Fecal coliform was present in 26 out of 41 well water samples at levels ranging from 1 to 2450 CFU/100 ml. The average pH value ranged between 8.7 and 10.0. The values of electrical conductivity (EC) measured varying between 334.3 and 2660.0 mS, with the highest value found in well which is located on the west shore of Lake Pontchartrain. Similarly, water salinity ranged between 0.17 and 1.31 ppt, with the highest value found in same well. These results suggest that the presence of fecal indicators at different sampling sites in the New Orleans aquifer. In order to develop effective pollution control strategies, further research is needed to determine the source(s) of fecal contamination in the region.

Well locations as a factor of contaminant removal during riverbank filtration(Mosina-Krajkowo well field, Poland)

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ABSTRACT

Due to poor water quality, abstraction of surface water for water supply purposes usually requires the use of complicated and expensive methods of water treatment. One of the natural methods used for surface water treatment is riverbank filtration (RBF). The treatment efficiency of surface water after RBF depends of many factors which include water residence time in the aquifer, which in turn depends on distance of the wells from the river channel and hydraulic properties of the aquifer, as well as on its geochemical conditions.
This work presents the variability of river water treatment efficiency in the case of macro and micro components as well as organic micropolutants and bacteria, based on a two-year investigation performed at the RBF site located in Krajkowo, which supplies the city of Poznan (central Poland). The research shows that in wells located within 70–80 m of the river channel, the influence of contamination from river water is considerable (especially in case of bacteria, plankton as well as micropollutants and nitrates). Water quality from a well located 250 m from the river is much better and is similar to typical groundwater. In wells located 480-1100 m from the river, the contaminants that are observed in river water (e.g. nitrates and micropollutants) do not exist, however the aquifer is enriched in organic matter (relatively high COD, occurrence of sulphides and organic plankton remains). The research presented shows that the most favorable distance of the well from the river channel (from a water quality point of view) is 150-250 m (which corresponds to residence times of at least 6 months).
This work was made possible by financial support from the AquaNES project. The AquaNES project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no. 689450.

HYDROSCAPE: A new versatile software program for modeling contaminant transport in groundwater

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ABSTRACT

Understanding how contaminants are transported in the subsurface is a major problem in hydrogeology. To help resolve the uncertanties associated with groundwater transport, complex numerical models are often used to predict how a contaminant plume evolves through time. However, numerical simulations can be costly to develop and time consuming. Analytical solutions to the advection-dispersion equation (ADE), a partial differential equation that governs solute movement in groundwater, are invaluable for rapid and inexpensive assessments of contaminant scenarios and for verifying numerical models. These solutions often require simplified representations of the aquifer (homogeneous) and source region (constant concentration throughout time) which restrict their applicability to real-world systems.

We present HYDROSCAPE, a new easy-to-use software package that contains a library of analytical solutions to the ADE. The program produces high-quality outputs such as contour maps of the plume, breakthrough curves, concentration profiles and videos of the plumes progression. Unlike other programs that use analytical solutions, HYDROSCAPE utilizes novel mathematical techniques to circumnavigate some of the limitations of the solutions. These new features allow the user to: 1) build a fully customized source region, and 2) implement horizontal layers, with different hydraulic conductivities, within the domain. By allowing the domain to be heterogeneous and the source region to vary in shape, concentration and time, more complexity is possible in these models and they are then more applicable to real-world settings. Additionally, HYDROSCAPE also allows the user to place the plume into real-world regional context by importing maps from Google Maps™. This visualization allows the user to evaluate how the plume evolves relative to real-world boundaries and objects. While some limitations still exist within the models, HYDROSCAPE represents a bridge between simple models using analytical solutions and complex numerical simulations, and may be a valuable tool for hydrogeologists in the future.

ECHN

Principles of aquifer management as contextualized and highlighted by a municipal-supply case study

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ABSTRACT

Sound development of groundwater resources requires implementation of a sequential process whereby three major phases are entered and executed. Ideally, expertly guided exploration is conducted to seek and find a suitable aquifer (Phase A). Next, evaluation of a now-identified candidate resource will culminate in establishing the aquifer's yield prospects and sustainability via fuller characterization (Phase B). Lastly, the resource will be exploited within a Phase B-informed management plan that embraces societal needs and preferences, while preserving reliant ecosystem components (Phase C).

Most obviously, an exploration phase will occur in either a random or an organized fashion as dictated by an initial demand associated with, for example, a fledgling community. As decades of municipal growth unfold, further exploration phases are implemented, but potentially with diminishing returns if proximal deployment of new water wells is overly repeated. At some point in such a scenario, likely promoted by shortfall-triggered restrictions, a need for evaluation of the aquifer in terms of its more exact capacity becomes evident (i.e. a need for Phase B). In turn, a need for an actual management plan becomes more compelling. Thus, a community may be struggling to meet its groundwater supply requirements, while yet to introduce Phase B. Community leaders may also recognize the need for a management plan, but again there may be little Phase B characterization material with which to enable sufficiently informed decision-making.

In this presentation, principles of aquifer management are highlighted by comparison with the progress made by the Town of Edson, Alberta, in implementing its aquifer management plan.

Integrated Watershed management in Water Stressed Western Tracts of West Bengal, India — a Bonanza for Water Resources

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ABSTRACT

In chronically water-stressed areas, water harvesting and artificial recharge have been important for sustainable water resources development. Rainwater harvesting and conservation of water resources essentially involve collection of rainwater and storage both in surface and sub-surface reservoirs.

The acutely water-stressed tracts of Paschim Medinipur, Bankura, Purulia and Birbhum districts of the western part of West Bengal, India, suffer from extreme moisture stress during March-June every year. Being underlain by hard granitic rocks, ground water resources are very limited. The river water flowing through the area remains almost dry during these lean months. This has caused a perpetual water crisis in the area even for safe drinking water supply. Agriculture in non-monsoon seasons is almost negligible. Bestowed with an average annual rainfall of 1200 mm and large tracts of cultivable lands, the agro-economic situation can change considerably, if additional water is made available during non-monsoon seasons.

With these issues in mind, a program of Integrated Watershed Development was initiated with the primary objective of conservation, development and sustainable management of water resources in consideration of priority areas of extreme drinking water scarcity, and extension of limited agricultural activities through available additional water resources.

Twenty existing ponds have been re-excavated in a Public-Private Partnership mode keeping with regard of the average decadal ground water level in the driest period so that the water harvesting capacity of these reservoirs can be maintained even during the driest months with at least 2 to 3 meters of water in the reservoirs. This endeavour has enabled to store and recharge 5 million cubic metres of additional water which is being used for limited agriculture and pisciculture activities in the region. This simple intervention with reasonably minimum expenditure can significantly improve the socio-economic conditions of the communities.

Analytical solutions for pollution transfer with arbitrary time-dependent surface fluxes

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ABSTRACT

1991 Taoyuan factory of Radio Corporation of America (RCA) at Taiwan due to organic chemical waste discharged into the factory caused serious groundwater pollution; many scholars have begun to study groundwater pollution simulation analysis of RCA Taoyuan factory. Although many studies have explored groundwater flow pollution simulation analysis but focused on the saturated aquifer and numerical simulations. And few scholars discussed analytical solutions of the groundwater flow pollution at unsaturated aquifer, so this paper will study the analytical solutions for pollution transfer with arbitrary time-dependent surface fluxes at unsaturated aquifer. This research is a prolongation of Chen et. al.'s (2001a, 2001b) papers and Ogata et. al.'s (1961) paper. Chen et. al.'s papers have obtained a convenient solution for arbitrary surface fluxes before ponding. Ogata et. al.'s paper has obtained an analytical solution of 1D Advection-Dispersion Equation, and by means of combination of Chen et. al.'s and Ogata et. al.'s solution, this paper has been extended to derive analytical solutions for pollution transfer with arbitrary time-dependent surface fluxes in unsaturated soil. For example of loam soil, it can simulate variation of concentration of pollution at unsaturated aquifer in the soil profile before ponding. The analytical solutions of this paper reflected real situation simulated, and can be applied to verify those complicated solution from other analytical models.