APCAMM

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ABSTRACTS

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Abstracts

Managing coastal aquifers in Asia, South America and Europe in a changing climate – exchanging experiences and recommendations

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Population growth in coastal regions, climate change and sea level rise pose increasing challenges to the sustainable management of coastal aquifers and ecosystems globally [1-7]. The project “Water4Coasts” of the “ecoinnovation” program of the Danish Ministry of Environment, which includes partners from Brazil, China and Denmark seeks to develop new innovative monitoring, data handling, modeling and management solutions, and share experiences on sustainable management of coastal water resources and ecosystems in a changing climate. The main objectives of the project is to evaluate and promote innovative solutions within: 1) Techniques for controlling seawater intrusion and land subsidence; 2) Efficient methods for early warning and flood risk reduction from streams and canals; 3) Methods for reducing nutrient loadings to surface waters and 4) New efficient monitoring, data handling and visualization techniques. The study focuses on investigations in three coastal aquifers at Laizhou Bay, China; Recife, Brazil and Marielyst/Falster, Denmark. The three study sites are located in very different climatological and hydro(geo)logical settings in the northern and southern hemisphere, with annual precipitation ranging from around 600 mm (evaporation > 1600 mm / drought conditions in Laizhou, China) up to more than 2000 mm (Recife, Brazil), and at three different seas: The Pacific ocean, the Atlantic ocean and the Baltic Sea.

The Water4Coasts project will evaluate different methods for controlling seawater intrusion, such as rainwater and wastewater injection for creation of positive hydraulic barriers to control seawater intrusion. Such systems have been in operation in for instance Northern Spain [8], while artificial recharge in coastal dunes is well known from the Netherlands [9]. Rainwater harvesting and injection is a relevant option for the Recife site with annual precipitation of up to more than three meters in wetter years, but it may also be a relevant option at both of the other sites. For the Danish site at the Baltic Sea, regional climate models have estimated that the current winter precipitation may increase by about 50% in this century. Rainwater harvesting, storage and injection in aquifers may be an option both for controlling seawater intrusion and for flood risk reduction. Likewise, direct injection of treated wastewater to coastal aquifers or managed aquifer recharge is considered to be a realistic option to control seawater intrusion in all three investigated sites in order not only to control seawater intrusion and reduce flooding risks, but also to further reduce nutrient loadings to coastal waters and mitigate or reduce the risk of land subsidence [10]. The Water4Coasts project considers different options for all three study areas and compares experiences for monitoring and controlling seawater intrusion gained at the three study sites. Initial results from analyses of contaminants (e.g. pesticides, chlorinated solvents, pharmaceuticals, pathogens and trace elements) from agriculture, industry and private households measured in treated wastewater and drain ditches at the Danish study site indicate that the main pollution concern in the Danish site are pathogens and pharmaceuticals. In addition, injection of oxic surface water into anoxic groundwater environments may mobilize trace elements such as As and Ni e.g. from oxidation of pyrite, and create other severe groundwater quality problems. Hence, required wastewater treatment, transport and fate of contaminants and naturally occurring trace elements in groundwater need to be carefully assessed before designing full scale pilot studies. Preliminary findings and comparisons for the three study sites are presented in this paper.

Keywords: seawater intrusion, flooding, land subsidence, eutrophication, managed aquifer recharge

References

[1] Wu, J. C., Meng, F. H., Wang, X. W., and Wang, D.: The development and control of the seawater intrusion in the eastern coastal of Laizhou Bay, China, *Environ. Geol.*, 54, 1763-1770 (2008).

[2] Rasmussen, P., Sonnenborg, T. O., Goncear, G., and Hinsby, K.: Assessing impacts of climate change, sea level rise, and drainage canals on saltwater intrusion to coastal aquifer, *Hydrol. Earth Syst. Sci.*, 17, 421-443 (2013).

[3] Montenegro, S., and Ragab, R.: Impact of possible climate and land use changes in the semi-arid regions: A case study from North Eastern Brazil, *J. Hydrol.*, 434, 55-68, (2012).

[4] Sonnenborg, T. O., Hinsby, K., van Roosmalen, L., and Stisen, S.: Assessment of climate change impacts on the quantity and quality of a coastal catchment using a coupled groundwater-surface water model, *Clim. Change*, 113, (2012).

[5] da Silva, G. C., Bocanegra, E., Custodio, E., Manzano, M., and Montenegro, S.: State of knowledge and management of Iberoamerican coastal aquifers with different geo-hydrological settings, *Episodes*, 33, 91-101 (2010).

[6] Hinsby, K., Markager, S., Kronvang, B., Windolf, J., Sonnenborg, T. O., and Thorling, L.: Threshold values and management options for nutrients in a catchment of a temperate estuary with poor ecological status, *Hydrol. Earth Syst. Sci*, 16, 2663-2683 (2012).

[7] Hinsby, K., E. Auken, G. H. P. Oude Essink, P. de Louw, F. Jørgensen, B. Siemon, T. O. Sonnenborg, A. Vandenbohede, H. Wiederhold, A. Guadagnini, and J. Carrera: Assessing the impact of climate change for adaptive water management in coastal regions. *Hydrol. Earth Syst. Sci*, 149, special issue (2011).

[8] Ortuno, F., Molinero, J., Garrido, T., and Custodio, E.: Seawater injection barrier recharge with advanced reclaimed water at Llobregat delta aquifer (Spain), *Water Sci. Techn.* 66, 2083-2089 (2012).

[9] Karlsen, R.H., F.J.C. Smits, P.J. Stuyfzand, T.N. Olsthoorn, B.M. van Breukelen. A post audit and inverse modeling in reactive transport: 50 years of artificial recharge in the Amsterdam Water Supply Dunes. *J. Hydrol.*, 454–455, 7–25 (2012).

[10] Wu, J.C., Shi, X.Q., Xue, Y.Q., Zhang, Y., Wei, Z.X., Yu, J.: The development and control of the land subsidence in the Yangtze Delta, China., *Environ. Geol.*, 55, 1725-1735 (2008).

Analytical Assessment of Injection Well Performance in Protecting Seawater Intruded Pumping Well

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The objective of this study is to investigate hydraulic issues of an optimal injection subject to a condition of no saltwater-intrusion into one or two over-exploiting pumping wells in a coastal aquifer with ideal hydrogeologic properties. Analytical solutions are derived for the minimum injection rate and the corresponding injection location. Net benefit, defined as the difference between over-pumping (in excess of optimal pumping) rate and the injection rate is used to quantify the effect of injection. Design charts of variables of primary interest are presented to demonstrate the effects of injection.

The analytical solutions reveal several interesting points. For one over-pumping well cases, the pumping well can always be protected using an injection rate smaller than the over-pumping rate (i.e., with positive net benefit). The optimal injection well corresponding to the minimum injection rate is always located between the coastline and the pumping well. The minimum injection rate decreases as the pumping well moves farther inland. Larger over-pumping rate results in larger optimal injection rate and net benefit. But the growth of net benefit becomes smaller as the over-pumping rate increases. For two over-pumping wells, one injection well can protect both wells when the distance between pumping wells is less than the critical distance. In this case, the optimal injection rate and location behave similar to those of one over-pumping well cases. When the distance between pumping wells increases, the optimal injection well moves farther inland and the optimal injection rate increases.

The analytical solutions reveal effectiveness of injection schemes for ideal conditions. For complex problems, use of a simulation/optimization (S/O) model is needed. The analytical solutions are used to verify solutions of an S/O model. The S/O model, based on a sharp-interface groundwater flow model and a genetic algorithm, is able to accurately reproduce analytical solutions. Therefore, the S/O model may be applied to find optimal injection schemes for real-world problems.

Numerical studies of vertical chloride concentration profiles in the aquitards in the Pearl River Delta by diffusion-sedimentation model

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The effect of sedimentation on solute transport in the aquifer-aquitard system in the Pearl River Delta has not been considered in previous studies. However, sedimentation could have an important influence on the transport of solutes in sediments. A one-dimensional numerical diffusion-sedimentation model is built to reconstruct the observed vertical chloride concentration profiles in a borehole in the Pearl River Delta and a finite difference scheme is applied to solve the model. The model simulates the evolution of the vertical chloride concentration profiles in the last 10,000 years. Sea-level curves given by previous studies are used to interpret the sedimentation stages and the upper boundary condition. A constant chloride concentration is assigned to the sea water. The lower boundary is set at the bedrock surface and it is treated as a no-flow boundary. Sedimentation is modeled as a moving boundary problem with the moving rate equal to the sedimentation rate. The sedimentation rate is assumed to be uniform during the time of sedimentation. Initially, the system is assumed to be filled with fresh water because the sea level at that time is much lower than present and it have been exposed to a terrestrial environment for a long time. Transport parameters are obtained by the trail and error method. A reasonably well agreement is obtained between the observed and simulated chloride concentration profiles. The model also presents the chloride concentration profiles at different times of sedimentation. The variation of effective diffusion coefficients and porosities with depth are also included in the numerical simulations. Sensitivity of groundwater velocity on chloride distribution is studied to investigate the effect of groundwater flow on the evolution of the chloride concentration profiles. Results show that the flow of groundwater only has a relatively minor influence on the distributions of the chloride concentrations and diffusion is the dominant mechanism for the transport of chloride. This study presents a theoretical basis for the evolution of chloride distributions in the sediments of the Pearl River Delta.

Keywords: chloride; aquitard; Pearl River Delta; sedimentation

A new method to monitor a freshwater-saltwater interface and the thickness of the freshwater lens at coastal area

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The importance of monitoring the coastal aquifer is increasing under changing circumstance of global climate. Sea level has been rising due to global warming and expected to increase up to 25-50cm by 2100. Excessive pumping at coastal aquifer results in salt water intrusion and salt water up-coning at many places. Coastal area within 100 km is occupied by about 39% of world population. Over 180 cities, which are corresponding to 2/3 of the cities of over 50,000 populations, are threatened by sea level rise and salt water intrusion. Therefore, many countries have installed monitoring wells along coastal line, especially at agricultural or urbanized area.

Most of the monitoring wells are equipped with a single sensor at specific depth for water pressure, temperature and/or electrical conductivity. However, single depth method can give us only the information that the interface is up or down from the sensor. Multi-depth method which is equipped with several sensors at different depth can be used to monitor the freshwater-saltwater interface. The method, however, has blind zone between the sensors and economic problems to get high resolution vertical profile data. Geophysical logging can be used to monitor the interface, but it gives us a vertical location of the interface only at a specific time instead of time series data. A new method using a floating device to monitor the time series change of the freshwater-saltwater interface is suggested in this work.

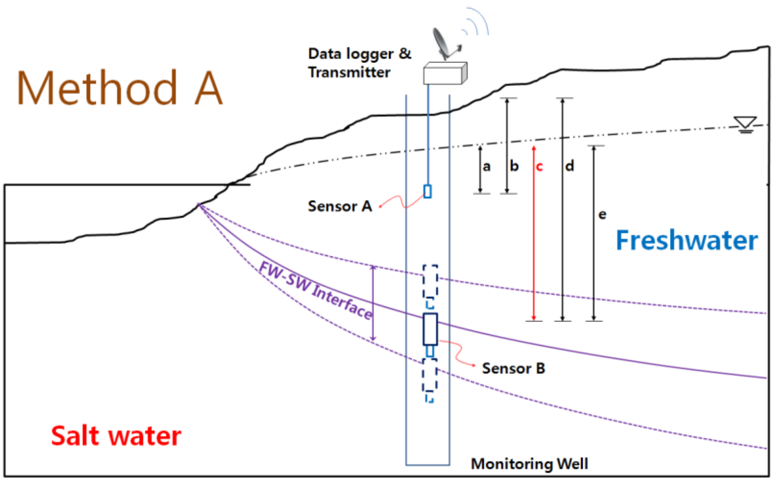

Fig. 1. Schematic description to get a time series data of the freshwater-saltwater interface location and thickness of the freshwater by using a floating device (B) and a fixed sensor (A).

The floating device is located in the water between freshwater and saltwater because it has intermediate density between freshwater, about 1.0 kg/L, and saltwater of about 1.025 kg/L. The floating device can move up and down along with the freshwater-saltwater interface movement. Although in case that there is more or less wide transition zone between freshwater and saltwater, it can give us the real time location of the sharp interface or the interface of pre-assigned specific density. If two more sensors are installed at a fixed depth in the freshwater body and in the air of the monitoring well, the thickness of freshwater lens in addition to the depth of the interface can be detected at a real time as follows.

$$\text{Depth to interface } (d) = [b-a(t)]+c(t) \qquad (1)$$

$$\text{Thickness of the freshwater lens } (e) = c(t) \qquad (2)$$

Where, $a(t)$ is the pressure of freshwater column above the sensor A (variable), b is the depth to the sensor A (fixed), $c(t)$ is the pressure above the interface (sensor B) (variable) and t is time.

It is expected that it help government office to give an alarm or a notice for saltwater intrusion and/or freshwater decline to the people who are using groundwater at coastal area if the floating method are integrated with a wireless remote communication technologies.

Effects of inorganic carbon limitation on nitrite oxidizing bacteria

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Nitrite oxidizing bacteria (NOB) participate in nitrification by converting nitrite, the end product of ammonia oxidation, into nitrate. NOB gain energy from nitrite oxidation and fix carbon dioxide via the Calvin-Benson-bassham (CBB) cycle for cell synthesis [1]. Although, much is known about the nitrogen metabolic pathways and regulation of NOB, little work has examined the carbon cycle in these organisms. In high nitrogen loaded systems such as combined nitritation- ammonia oxidation (anammox) process, inorganic carbon (IC) limitation is a plausible scenario given mass transfer restrictions, but investigations into the impact of dissolved CO_2 limitation have rarely been performed [2]. Since Anammox, ammonia oxidizing bacteria (AOB) and, NOB all rely on an autotrophic metabolism, a deeper understanding on how energy and carbon fixation pathways are linked can yield into a better control of the system and hence into stable nitrogen removal efficiencies. In this study, *Nitrobacter winogradskyi* Nb255 was selected as a model NOB to assess the impact of IC limitation on the biokinetics, metabolism and molecular responses related to chemolithoautotrophic nitrite oxidation.

When the reactors were subjected to IC limitation (day 26-31, Figure 1), nitrite oxidation efficiencies were compromised. Nitrite effluent concentrations rapidly increased, resulting in maximum accumulation of 206 ± 11.0 mg-N/L after 3 SRTs, corresponding to a nitrite removal efficiency of 26 ± 4.0%. Simultaneously cell concentrations declined steadily to a minimum value of 3.3 x 10^9 cells/L, prior to re-introduction of CO_2. After CO_2 from air (day 32-50) was provided, a quick recovery was established yielding a stable nitrite oxidation performance (below 1.0 mg-N-NO_2^-/L) within 6 days (at 3 SRTs). Cell concentrations sharply increased up to 68 ± 16 % when compared to initial cell concentrations and finally recovered to a similar (not significant at α=0.05) cell concentration as measured before the limitation test (Figure 1). Similar studies with a mixed culture showed that IC limitation did not give a significant impact on NOB activity in a combined nitritation- ammonia oxidation (anammox) process [3]. Also, it was observed that IC limitation had a stronger effect on the nitritation than on the nitratation [2]. This suggests that continuously carbon-limited environments might present a suitable ecological niche for the nitrite oxidizing *N. winogradskyi*.

In sum, IC limitation had an adverse impact on nitrite oxidizing performance, leading to cell washout by a decrease in cell synthesis rates. However, adaptation to IC limitation was not observed and nitrite oxidation recovered only after re-supplying CO_2. These results provide insights into coupled N- and C- cycling in NOB and could help to interpret their dynamics in complex engineered biosystems where Anammox, AOB and NOB could compete under transient IC limitation. In parallel, in order to link between reactor performance and the molecular-level activity of NOB, functional gene expression will be determined by reverse transcription quantitative PCR (RT-qPCR) specifically targeting nitrite oxidation (*nxrA*) and carbon fixation (*cbbLS*) genes in NOB.

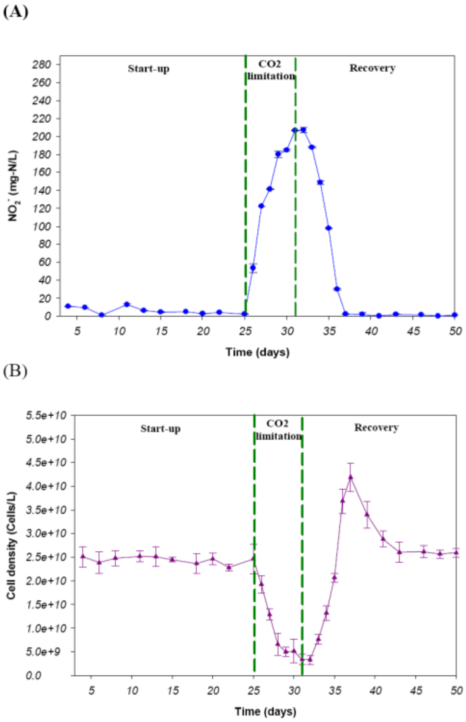

Figure 1. Effect of inorganic carbon limitation on (A) nitrite conversion and (B) cell concentration on *Nitrobacter winogradskyi* Nb-255 chemostat cultures

Keywords: Nitrite oxidizing bacteria; Nitrobacter winogradskyi; inorganic carbon limitation.

References

[1] S.R. Starkenburg, S.G. Chain, L. Hauser, M.G. Klotz, J. Arp, W. Hickey, Genome sequence of the chemolithoautotrophic nitrite oxidizng bacterium *Nitrobacter winogradskyi* Nb-255, *Appl. Environ. Microbiol.* 72, pp. 2050–2063 (2006).

[2] A. Guisasola, S. Petzet, J.A. Baeza, J. Carrera, J. Lafuente, Inorganic carbon limitations on nitrification: Experimental assessment and modeling, *Water Res.* 41, pp. 277–286 (2007).

[3] Y. Ma, H. Park, S. Sundar, K. Chandran, The effect of inorganic carbon limitation on the specific activity of a completely autotrophic nitrogen removal over nitrite (CANON) biofilm process, *Annual Water Environemnt Federation conferece 2012.*

Impact Assessment of outfall discharge at Paraquita Bay, British Virgin Island

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To meet the rapid growth of population at coastal areas in the world, desalination using reverse-osmosis (RO) technique becomes increasingly popular. The effluent from a RO plant typically has very high salinity concentration and thus high fluid density. The effluent is commonly disposed through either deep injection wells or submarine outfall discharge offshore. If not appropriated designed, the discharge could pose serious ricks to coastal water quality and marine life of receiving water body.

The Paraquita Bay concentrate disposal system should include a straight run of pipe into the sea with a multiport structure at the end of the diffuser system. A concentrate flow rate of approximately 3.4 million gallons per day (MGD) will be generated when the plant is operating at its maximum capacity. The anticipated concentrate concentration will be 37000 mg/l. The potential environmental impacts of the proposed concentrate disposal system include those that occur during construction and long term impacts due to the concentrate discharge. Long term impacts are anticipated to be minimal since the proposed diffuser design results in rapid blending and dilution with the ambient sea water. Water quality impacts will be restricted to a small mixing zone around the discharge structure.

The US EPA proved CORMIX expert system was used to determine outfall brine discharge dilutions from the RO plant. The North Equatorial Current (NEC) and the steady-easterly wind push the discharge plume away from the intake. All the analysis results indicate that discharge salinity drops quickly with distance from the outfall, so it is unlikely to pose an adverse impact to the marine environment. The excessive salinity decreases from 37 ppt to below 1 ppt within 10 m from the outfall. After 1000 m from the outfall, the excessive discharge salinity reduces to only 0.15 ppt, which is a very small value comparing with the ambient salinity of 39 ppt. The modeling results show it is unlikely that discharge plume will migrate towards the location of the proposed intake. Based on the modeling analysis, however, an extended outfall location is strongly recommended to minimize the possibility of the recirculation between the outfall and the intake.

Key words: outfall, concentrate discharge, water quality, modeling

Hydrogeochemical and geostatistical studies for groundwater contamination sources at a marine city, Korea

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This study used hydrogeochemical and geostatistical methods for the identification of groundwater contamination sources at the Masan City along the Namhae Sea, Korea. Two processes of groundwater evolution and the groundwater contamination sources were analyzed by Piper's trilinear diagram. The ratios of ionic concentration related with chloride were very helpful for our study, i.e., Cl/HCO_3 mole ratio for the determination of the degree of seawater intrusion, and Na/Cl mole ratio, SO_4/Cl concentration ratio and Br/Cl concentration ratio for the origin of chloride in groundwater. Kriging was used to produce the distribution maps of three groups classified by cluster analysis and four types of groundwater classified by Piper's trilinear diagram. The origins of contamination source, i.e., seawater or anthropogenic complex origin were determined by the distribution maps using kriging. The contamination sources of groundwater along the Masan Bay were derived mainly from seawater and partly from human activities. The groundwater at the inland and along the Namhae Sea were mostly fresh, but a little contaminated by various sources of groundwater contamination, i.e., farming, livestock, factory, sewage, landfill, vehicles and deicing. This study showed the usefulness of hydrogeochemical methods such as Piper's trilinear diagram and the ratios of ionic concentration related with chloride, and geostatistical methods of kriging, cluster analysis and factor analysis in identifying the groundwater contamination sources at a marine city, Korea.

Keywords: Piper's trilinear diagram, Ratios of ionic concentration, Kriging, Cluster analysis, Factor analysis

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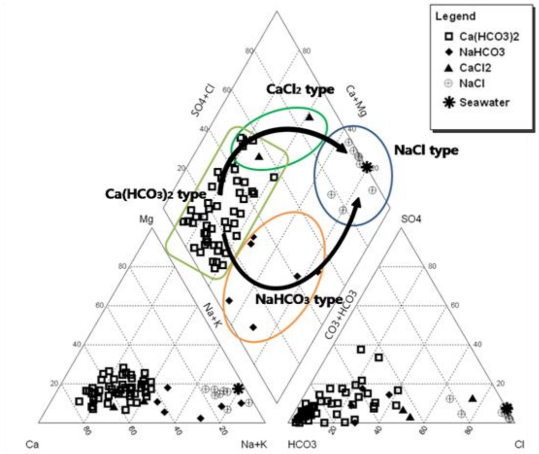

Fig. 1. Piper’s trilinear diagram of groundwater quality.

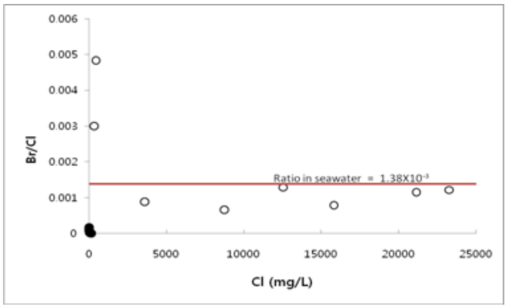

Fig. 2. Br/Cl versus CL concentration

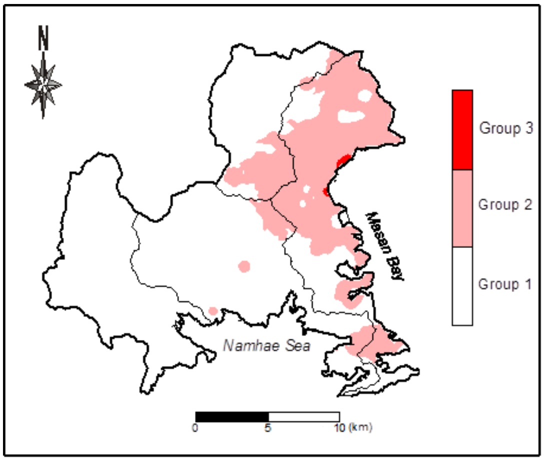

Fig. 3. Distribution map of three groups classified by cluster analysis.

Geochemical Signature of Pore Water from Core Samples and its Implications on the Origin of Saline Pore Water in Cangzhou, China

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Groundwater is found to have TDS over 5 g/L at depths down to 160 m in Cangzhou, which is about 70 km away from the coast, in the North China Plain. Ongoing is the debate on the origin of this saline water. Two commonly suggested causes are intensive evaporation in the Late Pleistocene or transgression in the Quaternary. Core samples from a borehole drilled down to 450 m were collected for pore water extraction, allowing the first high-depth-resolution geochemical and isotopic profiling of aquitards in the region. Na^+/Cl^- mass ratio indicates the possibility of seawater-freshwater mixing due to transgression. The high Ca^{2+} and SO_4^{2-} concentrations, together with high Cl^-/Br^- mass ratio, suggest evaporation origin of the saline pore water. ^2H and ^{18}O isotope analyses further support these findings. It is believed that most of the saline pore water is resulted from re-dissolution of evaporites while some is probably originated from seawater trapped during transgression. High levels of NH_4^+, NO_2^- and NO_3^- imply deposition of organic rich sediments in lake or swamp environments in the Late Pleistocene and still active microbial oxidation. Also, the Na^+/Cl^- mass ratio and F^- concentration suggest strong water-rock interaction.

Keywords: Pore water, Salinity, Transgression, Arid climate, North China Plain

Geochemistry of clayey aquitard pore water as archive of paleo-environment, Western Bohai Bay

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Abstract : The record of paleo-environment in clayey aquitard pore water is much more effective relative to aquifer groundwater owing to the low permeability of clayey aquitard. Oxygen-18 (^{18}O), deuterium (D), and chemical patterns were determined in pore water samples extracted from two 500-m depth boreholes, G1 and G2, in western Bohai Bay, China. Shallow pore water samples (depth <100m) are saline water, with the TDS (Total dissolved solids) of 3.69~30.75g/L, and deeper ones (depth=100~500m) are fresh water, with the TDS <1g/L. Content of major ions (i.e., Cl^-, Na^+, K^+, Mg^{2+}, SO_4^{2-}, Ca^{2+}) is high in marine sediment pore water samples and gradually decrease towards to terrestrial sediment pore water, together with the Cl/Br and Sr/Ba ratios changing significantly in different sedimentary facies along the study profile, indicating that pore water may be paleo-sedimentary water and not replaced by modern water. $\delta^{18}O$ profile and positive correlation between $\delta^{18}O$ and Cl^- of shallow saline pore water indicated diffusion as the main transport mechanism. Four transgressive layers were distinguished by the pore water isotopic analysis, further supporting the finding that pore water retained the feature of paleo-sedimentary water. Climate was identified as the main influence on the isotope signature of deeper pore waters and three climate periods was found by $\delta^{18}O$ profile.

Keywords: Aquitard, Pore water, Paleo-environment, Geochemistry, Bohai Bay

References

[1] Dansgarrd, W., 1964. Stable isotopes in precipitation. Tellus, 16,436–468.

[2] Edwards T.W.D., Wolfe B.B., MacDonald G.M., 1996. Influence of changing atmospheric circulation on precipitation delta 18O-temperature relations in Canada during the Holocene, Quaternary Research 46(3):211-218

[3] Chen ZY, Qi JX, Xu JM et al., 2003. Paleoclimatic interpretation of the past 30ka from isotopic studies of the deep confined aquifer of the North China Plain, Applied Geochemistry, 18: 997-1009

[4] Kreuzer AM, Rohden CV, Friedrich R et al., 2009. A record of temperature and monsoon intensity over the past 40kyr from groundwater in the North China Plain, Chemical Geology, 259: 168-180

[5] Fontes, J.Ch., Stute, M., Schiosser, P., Broecker, W.S., 1993. Aquifers as archives of paleoclimate. EOS Trans. AGU. 74, 21‑22.

[6] Hendry M.J. and Wassenaar L.I., 1999. Implications of the distribution of δD in pore waters for groundwater flow and the timing of geologic events in a thick aquitard system, Water Resources Research, 35(6): 1751-1760

[7] Husain, M.M., Cherry J.A., and Frape S.K., 2004. The persistence of a large stagnation zone in a developed regional aquifer, southwestern Ontario. Canadian Geotechnical Journal, 41, 5: 943–958.

Biodegradation of Nitrate in Alluvial Aquifer Recharged with River Water

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Aquifer in alluvial soil is a good source for drinking water. However, alluvial aquifer in estuary is susceptible to seawater intrusion. It is prone to biological and chemical contamination as well, especially when cities and industrial complexes are located along the river that contributes building of alluvial soil. This study investigated nitrate biodegradation using laboratory-scale soil reactors that simulated alluvial aquifer of a managed aquifer recharge (MAR) system. The MAR system was supposed to use river water for recharge. The soil reactors were recharged with river water contaminated with nitrate similar to average nitrate concentration for last 23 years. Recharged water was recovered periodically from the soil reactors and the recovered water was analyzed for nitrate concentration. The analysis results showed decrease in nitrate concentration in test reactors. However nitrate concentration did not decrease in control reactor that contained sterilized soil, supporting nitrate biodegradation in test reactors. Nitrate biodegradation in the alluvial aquifer was affected by environmental factors such as concentration of dissolved total organic carbon and temperature.

Keywords: nitrate; biodegradation; alluvial aquifer; MAR.

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References

[1] D. Li, M. Alidina, M. Ouf, J.O. Sharp, P. Saikaly, J.E. Drewes, Microbial community evolution during simulated managed aquifer recharge in response to different biodegradable dissolved organic carbon (BDOC) concentrations, *Water Res.*, 47(7), pp. 2421-2430 (2013).

[2] J.L. Vanderzalm, D.W. Page, K.E. Barry, P.J. Dillon, Application of a probabilistic modeling approach for evaluation of nitrogen, phosphorus and organic carbon removal efficiency during four successive cycles of aquifer storage and recovery (ASR) in an anoxic carbonate aquifer, *Water Res.*, 47(7), pp. 2177-2189 (2013).

Impact of land-surface inundation due to sea-level rise on seawater intrusion: Shallow and deep aquifers

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The influence of sea-level rise (SLR) on seawater intrusion (SWI) has been the subject of several publications, which consider collectively a range of functional relationships within various hydrogeological and SLR settings. Most of the recent generalized analyses of SWI under SLR neglect land-surface inundation (LSI) by seawater. A simple analytical method is applied to quantitatively assess the influence and importance of LSI on SLR-SWI problems under idealized conditions for shallow unconfined aquifers. The same assessment has been performed for fresh groundwater lenses (FGLs). The FGLs of small islands can be highly vulnerable to climate change impacts, including SLR. Many real cases of atoll or sandy islands involve two-layer hydrogeological conceptualizations. In this paper, the influential factors that effect FGL in two-layer small islands subject to SLR are investigated. An analytical solution describing FGLs in circular islands, composed of two geological layers, is developed for the simplified case of steady-state and sharp-interface conditions.

For shallow unconfined aquifers, the results demonstrate that LSI induces significantly more extensive SWI, with inland penetration up to an order of magnitude larger in the worst case, compared to the effects of pressure changes at the shoreline in unconfined coastal aquifers with realistic parameters [1].

For the FGLs, sensitivity analyses are used to assess the importance of LSI caused by SLR, relative to other parameters (i.e. thickness of aquifer layers, hydraulic conductivity, recharge rate, and land-surface slope) that influence the FGL. Dimensionless parameters are used to generalize the findings. The results demonstrate that LSI has a considerable impact on a FGL influenced by SLR, as expected, although the FGL volume is more sensitive to recharge, aquifer thickness and hydraulic conductivity than SLR impacts, considering typical parameter ranges. The methodology presented in this study provides water resource managers with a rapid-assessment tool for evaluating the likely impacts of SLR and accompanying LSI on FGLs.

The authors believe that the simplicity of the provided formulation is an advantage of the method described in this paper, as using the simplest possible mean provides an important and novel insight into the problem of SLR impacts on SWI.

Keywords: Seawater intrusion; Climate change; Seawater overtopping; Coastal aquifer; Sea-level rise.

References

[1] Ataie-Ashtiani B, Werner AD, Simmons CT, Morgan LK, Lu C. 2013c. How important is the impact of land-surface inundation on seawater intrusion caused by sea-level rise? *Hydrogeology Journal* DOI: 10.1007/s10040-013-1021-0 (2013).

Saltwater upconing zone of influence

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In this study, we define and characterize the saltwater upconing zone of influence (SUZI), which is the extent of impact in terms of saltwater rise attributed to pumping. While the zone of influence of a pumping well can be clearly defined in terms of hydraulics (e.g. drawdown), the zone of influence in terms of upconing has received considerably less attention. In coastal areas where a threat of saltwater intrusion and upconing exists, characterization of the salinity zone of influence of a pumping well would provide an improved basis for coastal aquifer management decision-making, e.g. relating to the salinity implications of pumping well operations. Both radial and three-dimensional numerical modelling of saltwater upconing at the field scale were undertaken. The extent of impact in terms of saltwater rise was found to be dependent on the relative magnitudes of the pumping rate and the lateral flow. The three-dimensional coastal setting simulations revealed an elliptical shape of the lateral extent of the SUZI, which is a result of the lateral flow towards the coast. The lateral flow elongated the saltwater cone in the lateral flow direction, causing salinization of a larger proportion of aquifer between the well and the coast. The steady-state simulations were also compared to the predictions by the Ghyben-Herzberg approximation, which provided a reasonable first-order insight into the nature of the magnitude of the SUZI. Observations from this study offer an insight into the formation and extent of the SUZI below pumping bores. Furthermore, the extent of saltwater upconing impact was found to be highly influenced by the lateral flow, implying that lateral flow should be considered in the saltwater upconing studies. Further simulations are needed to explore the effects of multiple-bore pumping as well as transient effects due to intermittent pumping.

Keywords: saltwater upconing; coastal aquifer; numerical modeling.

The Development of a New Index to Quantify Aquifer Stress

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The World Water Development Report (WWDR UNESCO, 2003) reports that at the beginning of the 21st Century the Earth with its diverse and abundant life forms including six billion humans is facing a serious water crisis. Moreover the report clearly indicates that the crisis is one of governance, essentially a result of mismanagement of our fresh water resources. The brunt of this impact is borne by the world's poor who suffer from water-related disease and economic deprivation. Concurrently the impact is being felt on the natural environment with degradation of our natural resource base, water environments and fragile ecosystems.

Since the WWDR report which was published in 2003, what has changed? We have an additional 1 billion people in the world, a more rapid pace of development despite the economic slow-down due to the Global Financial Crisis, greater investment in mining and expansion of urban areas, and increased demand of both surface and groundwater resources with little progress in improved governance in the rapidly developing countries of the world.

In the not too distant past right up till the 1990's in Australia we were developing new groundwater resources to meet increased demand. However, over the past two decades, the demands on our surface and groundwater resources have risen, thus outstripping our ability to make new sources of water available. This growth in demand from cities, agriculture, industry and mining is placing pressures on our water resources, and in order to continue to meet rising demand we need to drive the development of innovative approaches for management of water resources. In Australia, the National Water Initiative has been at the forefront in providing the resources and the vision for improving the way we manage our water resources.

With increasing demand on our natural resources the need for effective management of our resources is becoming imperative. In semi-arid regions of Australia where water resources are limited and in many cases over-allocated, the need for effective management of groundwater resources is an important issue. The Lower Murray aquifer system has been designated as a potential high risk aquifer system both in terms of entitlements and groundwater quality. A groundwater model was developed for the Lower Murray region so that it could be used to assist resource managers and the community to better manage the groundwater resources of the region. The model comprises three layers each representing an aquifer corresponding with the Shepparton, Calivil and Renmark system. The model was used to assess the impact of various scenarios of groundwater pumping and climatic conditions, and to assess the sustainable yield for the aquifer system. The model will also be an important tool for assessing the upper limit for entitlements for the aquifer (Punthakey 2012).

The aim of this paper was to investigate new techniques for improved management of stressed groundwater resources. The research on development of indicators was developed for extending modelling results to assess the condition of groundwater resources and to be able to provide early warning on the onset of stress on the groundwater system (Punthakey 2007).

The development of indicators for managing water resources has been recognised as the cornerstone of the World Water Assessment Programme (WWAP). Although difficult to identify and develop, indicators are increasingly playing a significant role in assessment of water resources. Indicators can be used to serve a variety of technical and policy goals, such as the improvement of water resource management policy through better assessment of the water resource situation.

A new indicator, the Aquifer Stress Index (ASI) was developed primarily as a tool for evaluating the level of stress in an aquifer. The ASI can be used to assess individual cells or a group of cells or zones in an aquifer layer to determine the level of stress being experienced. The ASI is a useful tool for identifying the spatial response of pumping or climate induced stress on the groundwater system. The ASI gives snapshot of the condition of the aquifer for a specified planning period relative to the base scenario. This approach provides the Resource Manager with a quantitative mechanism for evaluating level of stress in an aquifer, allows the impact of managing the aquifer to be assessed and allows the resource manager to adopt a flexible approach to aquifer management. The Aquifer Stress Index provides powerful insights to the level of stress being imposed on the aquifer, thus allowing the Resource Manager to make a judgment on whether there should be pumping redistribution, or whether increased pumping will have a significant impact on the aquifer.

Selecting suitable indicators for assessing groundwater management requires an understanding of key groundwater management issues. These include the use of groundwater, the demands on the aquifer, possible threats to the aquifer, and the impacts of measures on the overall functioning of the aquifer systems under consideration. For indicators to be useful they must be able to support sustainable management of groundwater resources. The indicators and the framework developed here can be applied to improve sustainable management of high-value aquifer systems and will be beneficial for communities who need to balance the groundwater take to meet irrigation water demand. Getting the balance right is the key to improving water and food security and leads to better economic , environmental and social outcomes.

References

[1] J.F. Punthakey, The Application of Early Warning Indicators to assess the condition of Groundwater Resources. Groundwater & Ecosystems, IAH 2007 Lisbon Portugal, XXXV IAH Congresss, International Assoc. Of Hydrogeologists. IAH Portugal (2007).

[2] J.F. Punthakey, Sustainable Groundwater Management for the Lower Murray Region: Estimating the sustainable yield for water planning. Ecoseal Water Resources Management, WRM 2012.118, 125 p (2012).

Adjusting Coastal Heads for Groundwater Flow Models

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We introduce a correction on coastal heads for groundwater flow models that contain a coastal boundary, based on the single-potential theory developed by *Strack* [1976]. Analytical solutions suggest that for confined aquifers, coastal heads can be corrected by an equivalent freshwater head subtracting a term $B/2\alpha$, in which B is the aquifer thickness, and α is the density factor, while for unconfined aquifers coastal heads can be corrected by multiplying a factor $[(1+\alpha)/\alpha]^{1/2}$. With these corrections, the conversation between the freshwater flux and hydraulic heads can be achieved rapidly by the direct application of the classical Darcy's law for constant-density flow. The accuracy of using these corrections has been demonstrated by comparing analytical solutions with those from numerical simulations of a variable-density flow and solute transport model. The relative errors in the estimation of the freshwater discharge to the ocean by neglecting the density effects and by employing an equivalent freshwater correction on coastal heads have been evaluated quantitatively and respectively. Sensitivity analysis shows that for confined aquifers the relative error of using the former estimation method is larger than the latter, while for unconfined aquifers the two estimation methods produce similar results. The location of the toe relative to the head measurement is a key factor controlling the estimation error. For some parameter values that lead to a short distance between the interface toe and the head measurement, the relative errors in the estimation of the freshwater flux could be larger than 100%. The correction method introduced in this study is expected to offer a better approximation for the coastal boundary, which facilitates the rapid and accurate estimation between the freshwater flux and hydraulic heads, and the analysis of regional groundwater flow models that include a coastal boundary.

Keywords: Coastal aquifers; Groundwater flow model; Potential theory; Freshwater flux.

References

[1] O.D.L. Strack, A single-potential solution for regional interface problems in coastal aquifers, *Water Resour. Res.* 12 (6), pp. 1165–1174 (1976).

Submarine groundwater discharge estimation in an urbanized embayment, Hong Kong via short-lived radium isotopes and its implication of nutrient loadings and primary production

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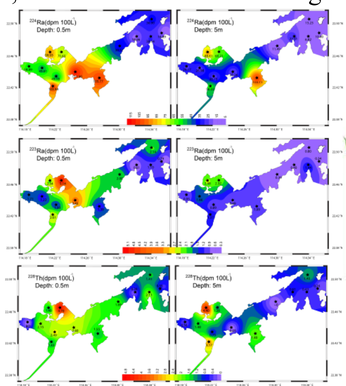
Short-lived radium isotopes (^{224}Ra and ^{223}Ra) are adopted as tracers to qualify submarine groundwater discharge (SGD) in highly urbanized embayment- Tolo Harbor in Hong Kong. Based on the sampling data, a double-layered radium mass balance model is set up to estimate lateral SGD and bottom SGD respectively. Based on two radium isotopes, the total SGD is estimated to be 1.77~3.17 cm d^{-1}, including lateral SGD of 6.31 ~8.18 cm d^{-1} and bottom SGD of 0.95~2.25 cm d^{-1}. The fresh SGD is estimated to be (3.22~6.20) $\times 10^5$ m^3 d^{-1}, which is around 35% of all total SGD and around 2-5 times of total river discharge to the harbor. DIN, DIP, DSi loadings from SGD are estimated to be (4.58~8.22)$\times 10^4$ mol d^{-1}, (3.68~6.60)$\times 10^2$ mol d^{-1}, (9.93~17.82)$\times 10^4$ mol d^{-1}, respectively. On the basis of DIP budget, the primary productivity in this area is estimated to be (1.5~15.4)$\times 10^6$ gC d^{-1} or (0.029~0.3) gC $m^{-2}d^{-1}$, in which SGD accounts for a sizable fraction of 3%~49.5%. The study reveals that lateral SGD can be dominant compared to the bottom SGD. The study also indicates that SGD can be a significant source of coastal nutrients and will cause an obvious increase of primary production, which could throw some light on the future coastal ecological management.



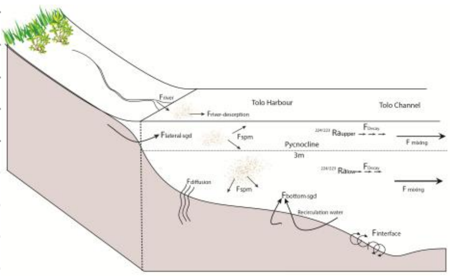


Figure 1. ^{224}Ra, ^{223}Ra and ^{228}Th distribution at the depths of 0.5m and 5m in Tolo Harbor

Figure 2. Schematic depiction of two-layer radium balance model for Tolo Harbor

Keywords: Short-lived radium isotopes; mass balance model; submarine groundwater discharge; nutrient loadings; primary production.

Hydrogeology and Geochemistry of Coastal Aquifer-Aquitard System in Pearl River Delta, China

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This presentation summarizes our comprehensive research on the hydrogeology and geochemistry in the aquifer-aquitard system in Pearl River Delta (PRD) in China since 2007. The geochemistry of the Holocene-Pleistocene aquitard-aquifer system in PRD is characterized by abnormally high ammonium concentration and salinity and fairly high arsenic in the groundwater. The project has been carried out to understand the generation and migration of salinity, ammonium and arsenic in the aquitard-aquifer system.

Total 40 boreholes were drilled to take core samples of the aquitard and groundwater samples in the basal aquifer and two key sites equipped with nested multi-level piezometers were constructed to provide long-term monitoring information on the water level and geochemistry. The core samples were used for extraction of pore water for centrifugation and bulk chemical analyses in laboratory. PRD is dominated by two thick layers of aquitards of mainly marine origin and below that is an areally extensive basal aquifer. Unlike previous studies which focused mainly on the aquifer, this study treated the aquitard-aquifer system as a hydrogeochemical continuum. Regional groundwater flow is very stagnant due to clay-rich aquitard materials and gentle topography. The system is under extreme reducing environment and the aquitard has high content of organic matter. The high salinity is caused by the palaeo seawater intrusion in the Holocene. Ammonium occurred at concentrations up to 390 mg/L in the basal sand Pleistocene aquifer 20-50 m deep. This ammonium was natural, areally extensive (1600 km2) and originated in the overlying Holocene-Pleistocene aquitard and entered the aquifer by groundwater transport and diffusion. The arsenic with a concentration up to 161 ug/L in the aquifer is also associated with the organic matters. The regional fault zones and palaeo-river channels at the early stage of Holocene control the deposition environments and subsequently the overall spatial distributions of geochemistry in the aquifer-aquitard system.

References

[1] Wang XS, JJ Jiao, Y Wang, JA Cherry, XX Kuang, K Liu, CM Lee and ZJ Gong, 2013, Accumulation and transport of ammonium in aquitards in the Pearl River Delta (China) in the last 10,000 years: conceptual and numerical models, *Hydrogeology Journal*, V21, P961-967

[2] Wang Y, JJ Jiao, SY Zhu and YL Li, 2013, Arsenic K-edge X-ray absorption near-edge spectroscopy to determine oxidation states of arsenic of a coastal aquifer-aquitard system, *Environmental Pollution*, V179, P160-166.

[3] Wang Y, JJ Jiao, JA Cherry, and CM Lee, 2013, Contribution of the aquitard to the regional groundwater hydrochemistry of the underlying confined aquifer in the Pearl River Delta, China, *Science of The Total Environment*, V461-462, p663-671.

[4] Wang Y, JJ Jiao, JA Cherry, 2012, Occurrence and geochemical behavior of arsenic in a coastal aquifer-aquitard system of the Pearl River Delta, China, *Science of The Total Environment*, V427 P286-297 DOI: 10.1016/j.scitotenv.2012.04.006.

[5] Wang Y, and JJ Jiao, 2012, Origin of groundwater salinity and hydrogeochemical processes in the confined Quaternary aquifer of the Pearl River Delta, China, *Journal of Hydrology*, v438-439, p112-124

[6] Jiao, JJ; Y Wang, Y, JA Cherry, XS Wang, BF Zhi, HY Du, DG Wen, 2010, Abnormally high ammonium of natural origin in a coastal aquifer-aquitard system in the Pearl River Delta, China, *Environmental Science & Technology*, 44, 7470-7475.

Estimation of SGD based on observed groundwater head in a tidal mudflat

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Despite their importance in the global water circulation, marine environments and ecology, submarine groundwater discharges (SGD) in tidal flats are poorly understood [Watabe and Sassa, 2008]. This paper estimated SGD using field observations of groundwater heads at six locations W1-W6 along a cross-shore transect in a tidal mudflat in Laizhou Bay of Bohai Sea, China (see Figure 1) during the summer of 2012. The tidal mudflat systems usually consist of high-permeability sand and surface mud layer [Xia and Li, 2012] and so does the tidal flat considered here. Due to the low-permeability covering layer and the very gentle slope of the tidal flat around 0.1%, the beach surface was still saturated when the tidal level fell below the beach surface. Thus, large scale of seepage face appears in this gentle tidal flat and thus the groundwater head on the beach surface simply equals the surface elevation. This facilitates the estimation of SGD at each well location.

Take the well W2 as an example, the observed head at W2 kept falling with the tide to a certain level little higher than the beach surface, and then became approximately constant until the subsequent rising tide arrived there (see Figure 2a). Neglecting the density difference, and using Darcy's law, the groundwater flow rate (Darcy velocity) normal to the ground surface at W2 is given by

$$q_{\mathrm{n}} = K\frac{h_{\mathrm{W}} - \max\{h_{\mathrm{surface}},\ h_{\mathrm{tide}}\}}{\Delta l} \tag{1}$$

where K is vertical hydraulic conductivity of the mud layer between the well location and ground surface; h_{W} is the observed groundwater head at the well location; h_{surface} is the elevation of the beach surface corresponding to the well; h_{tide} is the observed head of the tide; Δl is the depth of transducer at the well from the beach surface. If q_{n} is positive, it represents outflow rate (SGD); otherwise, if it is negative, it represents inflow rate.

The inflow q_{in} and outflow q_{out} averaged over the observation time at W2 were defined as

$$q_{\mathrm{in}} = \frac{1}{t_{\mathrm{e}} - t_0}\int_{t_0}^{t_{\mathrm{e}}} \max_t\{0,\ -q_{\mathrm{n}}(t)\}dt \qquad q_{\mathrm{out}} = \frac{1}{t_{\mathrm{e}} - t_0}\int_{t_0}^{t_{\mathrm{e}}} \max_t\{0,\ q_{\mathrm{n}}(t)\}dt \tag{2}$$

where t_0 and t_{e} are the initial and end times for the observation, respectively. The same procedures were repeated for other wells W3-W6. The results were shown in Figure 2b.

From W2 to W6, the outflow decreased first and then increased, while the inflow increased first and then decreased. The values of inflow and out flow between W2 and W6 can be approximated by linear interpolation. Then the total outflow and total inflow between W2 and W6 can be estimated by the integral between W2 and W6 along the seaward direction. The results are: total outflow (SGD) between W2 and W6 = 12.21$m^3d^{-1}m^{-1}$ and the total inflow =12.19$m^3d^{-1}m^{-1}$. Optimal balance between inflow and outflow is achieved during the observation time. But field observation is not longer enough to one spring-neap tidal cycle, and the water exchanges landward of W2 and seaward of W6 were not considered. Further investigations and numerical simulations are required to fully understand the balance between SGD and inflow in the whole tidal mudflat.

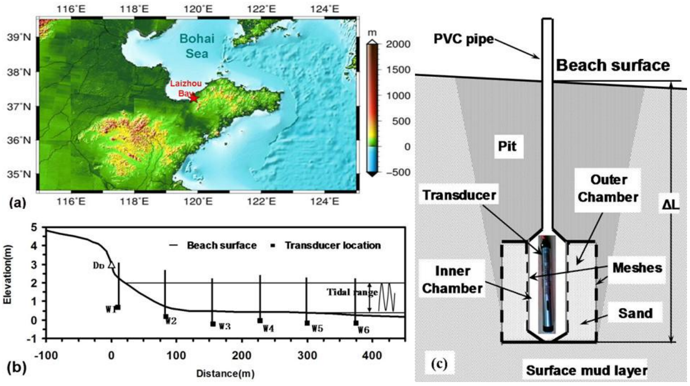

Figure 1. (a) Location of the studied tidal flat in Laizhou Bay of Bohai Sea, China. (b) Locations of W1-W6 along transect. (c) Schematic of transducer installation for measuring groundwater head.

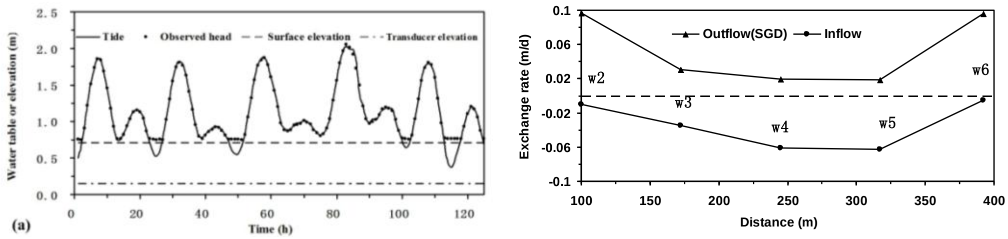

Figure 2. (a) Observed tide and head at W2. (b) The inflow and outflow rate averaged over the observation time at locations W2-W6

Keywords: Field measurements; Tidal flat; SGD; Groundwater exchange; Laizhou Bay.

References

[1] Y. Watabe, S. Sassa, Application of MASW technology to identification of tidal flat stratigraphy and its geoenvironmental interpretation, *Mar. Geol.* 252, pp. 79-88 (2008).

[2] Y. Q. Xia, H. L. Li, A combined field and modeling study of groundwater flow in a tidal marsh, *Hydrol. Earth Syst. Sci.* 16, pp. 741-759 (2012).

A precautionary note on the interpretation of coastal aquifer water level trends and water balances

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It is common for coastal aquifer management studies not to consider seawater intrusion-induced interface movements and the associated changes in seawater volume. However, it is not well understood when this simplified approach may result in erroneous estimates of freshwater volumes and flawed interpretations of water level trend analyses. In this study, we address this gap using a simple steady-state, sharp-interface, analytic modelling approach [i.e., 1] to generate idealised relationships between seawater volume, freshwater volume and water levels.

For a number of cases, water level trends were found to be increasingly insensitive to reductions in freshwater volume and, as such, changes in seawater volume need to be considered when using water level trends as a measure of sustainability (e.g., within trigger-level management approaches, as commonly applied in Australia). The conditions under which seawater volume changes have greatest impact on water level trends are also described. Further, for the cases considered, it is shown that changes in seawater volume need to be included within water balance assessments. Changes in seawater volume (over an assumed timescale) were found to represent 10% to 30% of freshwater discharge under realistic water table decline scenarios. These results have wide-sweeping implications for coastal aquifer management, demonstrating that seawater volume changes may, in many cases, need to be included to avoid over-allocation of groundwater.

In view of the short-comings associated with using water level trends to assess coastal aquifer status, we recommend an approach involving the comparison of groundwater levels relative to the hydraulic head imposed by the ocean, accounting for density effects. A representative head for the coastal boundary in freshwater-only representations of unconfined aquifers is proposed that produces reasonable fluxes of freshwater discharge to the sea. The new coastal head adds to the Post et al. [2] discussion of freshwater head calculations and provides a first-order estimate of the value that near-shoreline watertable levels should exceed in order to maintain a discharge to the sea and avoid SWI issues.

The analytic solution used for this study involves an assumption of quasi-equilibrium conditions between the water table and interface. Transient simulations were carried out to evaluate this assumption, and it was found to be a reasonable approximation in the majority of case studies. As such, the analytic methods presented here can, in many cases, be rapidly applied to assess the need to consider seawater volumes within specific cases.

Keywords: Seawater intrusion; seawater volume; freshwater storage; sharp interface; vulnerability.

References

[1] O.D.L. Strack, A single-potential solution for regional interface problems in coastal aquifers, *Water Resour. Res.* 12 (6), pp. 1165–1174 (1976).

[2] Post, V., Kooi, H., Simmons, C., Using hydraulic head measurements in variable-density ground water flow analyses. Ground Water 45(6), pp. 664-671 (2007).

Potential Seawater Intrusion of Groundwater in New Zealand and Regulatory Responses: Case Examples

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This paper presents three case examples of groundwater in proximity to the coast in New Zealand where the circumstances have raised concerns about the potential for seawater intrusion. In each case, Regional Councils have instituted measures to monitor groundwater near the coast. In one of these cases, the Regional Council has instituted regulatory procedures to limit groundwater extraction to levels intended to protect sustained use. The cases are:

1. A heavily used geothermal coastal aquifer at Waiwera (north of Auckland).
2. A shallow coastal aquifer used for residential water supply at Papamoa Beach on the Bay of Plenty.
3. A shallow coastal aquifer in south Dunedin.

1. Waiwera

The aquifer at Waiwera was heavily used historically to supply geothermal water for recreational purposes and for bottled water. Overuse led to substantial reduction in head and intervention by the Auckland Regional Council (now Auckland Council). To remedy this situation and prevent seawater intrusion, the Council established consent requirements that limited usage and installed monitoring wells with a minimum water level criterion of 0.5 m above mean sea level (MSL). Reduction in usage has resulted in compliance with the minimum water level criterion and water quality data indicate that, as the water being pumped has a geothermal rather than a seawater signature, this has been successful in avoiding seawater intrusion. The diffusivity equation was used to estimate aquifer hydraulic properties. Results were compared with other available information including a historic pumping test (Zemansky, 2005 and Rose and Zemansky, 2013).

2. Papamoa

The Bay of Plenty Regional Council (BOPRC) previously monitored shallow groundwater a short distance from Papamoa Beach in a shallow well used for agricultural purposes. The data indicated an increasing trend in water quality variables associated with possible seawater intrusion. However, the farm on which the well in question was located took the well out of operation. In order to further evaluate the potential for seawater intrusion with respect to residential water supply wells at Papamoa Beach, a seawater intrusion monitoring well was installed at Taylor Reserve within 100 m of the shoreline. Due to the size range of aquifer materials encountered, this well was screened at a number of different depth ranges instead of having one continuous screen. Different depth intervals were sampled for water quality and hydraulically tested. Vertical profiles of temperature and conductivity were also recorded. After installation and initial sampling and testing, BOPRC installed automatic water level, temperature, and conductivity monitoring equipment with temperature and conductivity monitoring occurring at two different depth levels. Problems have been encountered with the deeper depth interval monitoring. This paper reports on the data obtained to date (Zemansky, Rose, and Tschritter, 2012 and Hutchby, 2013) .

3. Dunedin

Dunedin has a growing population which was estimated at 122,300 in the 2006 census (Dunedin City Council, 2012). That portion of the total living in the South Denedin coastal aquifer area was estimated at about 10,000 in 2006, living in 4,800 occupied dwellings (Rekker, 2012). The south Dunedin coastal aquifer underlying this area is distinquished by two key features (Fordyce, 2013): (1) a low elevation above sea level; and (2) a groundwater level within 1 m of the ground surface. This aquifer is not beneficially used; however, the potential for seawater intrusion as sea level rises in association with climate change accompanied by groundwater inundation and land flooding has drawn attention to this area and this potential has been the subject of study by both the Otago Regional Council (ORC) and the Dunedin City Council (DCC). As noted by Rotzoll and Fletcher (2013), in circumstances such as this:

> As sea level rises, the water table will rise simultaneously and eventually break out above the land surface creating new wetlands and expanding others, changing surface drainage, saturating the soil, and inundating the land depending on local topography. Flooding will start sporadically but will be especially intense seasonally when high tide coincides with rainfall events.

In 2009 the ORC installed three shallow monitoring wells along a transect at distances of 0.12, 0.9, and 1.6 km from the coast. The water table identified in these wells range from 0.34 to 0.68 m below ground level (BGL). Water levels in the two closest wells to the coast, evidence an oscillating tidal signal while none was found in the farthest inland well. In the absence of any aquifer testing data, the diffusivity equation was used to estimate hydraulic properties (Rekker, 2010 and Fordyce, 2013).

Two additional studies have been undertaken by the ORC and DCC since the monitoring wells were installed. The ORC assessed the potential for land flooding caused by sea level rise under scenarios having different rates of sea level rise. As a result of this modelling work, the ORC concluded that "Even the most moderate (potential) rise in sea level… would result in saturation… including the development of ponding at the land surface" with the degree of ponding increasing substantially as the rate of sea level rise increases (Rekker, 2013). In the work sponsored by the DCC, an additional 13 very shallow monitoring wells were installed in two transects roughly both parallel and perpendicular to the shoreline. This study focussed on the impact of rainfall recharge on groundwater levels in the south Dunedin coastal aquifer and involved aquifer testing. It found that there were two general cases: (1) areas of silty sediments where groundwater rainfall recharge was slow and lagged rainfall events; and (2) more sandy areas where groundwater rainfall recharge was relatively rapid. In the latter case, groundwater level rise of 0.13 m to 0.47 m was observed after rainfall events of 80 mm. There is, therefore, the potential for a combined increase in groundwater levels from sea level and rainfall recharge effects sufficient to cause land flooding. This potential will increase with time as sea level rise results in increased groundwater elevations (Fordyce, 2013).

Keywords: Saltwater intrusion, groundwater, case examples, geothermal aquifer, coastal

References

[1] Zemansky, G. 2005. Hydrogeologic evaluation of the Waiwera geothermal aquifer. GNS Client Report 05/131. Prepared for Waiwera Infinity Ltd. GNS Science, Waireakei, 36 pages.

[2] Rose, J. and G. Zemansky. 2013. Updated hydrogeologic evaluation of the Waiwera geothermal Aquifer. Consultancy Report 2013/67, GNS Science, Wairakedi, 26 pages.

[3] Zemansky, G., J. Rose, and C. Tschritter. 2012. Installation of wells at Taylor Reserve and Otamarakau marae for seawater intrusion monitoring. Consultancy Report 2012/34, GNS Science, Wairakei, 109 pages.

[4] Hutchby, B. 2013. E-mail dated 1 May. Environmental Data Officer, BOPRC, Whakatane.

[5] Dunedin City Council. 2012. Dunedin: revised population predictions positive. 12 October press release. Scoop: regional independent news. Accessed 30 May at http://www.scoop.co.nz/stories/AK1210/ S00343/dunedin-revised-population-projections-positive.htm.

[6] Rekker, J. 2012. The south Denedin coastal aquifer and effect of sea level fluctuations. Resource Scient Unit, Otago Regional Council, Dunedin, 25 pages.

[7] Fordyce, E. 2013. The response of the water table to rainfall events in south Dunedin, New Zealand. Draft report prepared for the DCC. Otago University, Dunedin, 32 pages.

[8] Rotzoll, K. and C.H. Fletcher. 2013. Assessment of groundwater inundation as a consequence of sea-level rise. Nature Climate Change, Vol. 3, May, pages 477-481.

[9] Rekker, J. 2010. The utilization of tidal fluctuations in an urban coastal aquifer: south Dunedin urban area. Paper presented at the 49th Annual Conference of the New Zealand Hydrological Society, Dunedin, New Zealand.

Microbiology in an Ammonium-rich Aquifer-aquitard System in the Pearl River Delta, China: Lithology-Controlled Bacteria Community and Anammox-Induced Ammonium Loss

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Geomicrobial processes play an important role in groundwater chemistry. The aquifer-aquitard system in the Pearl River Delta (PRD) was reported containing the highest concentration of natural ammonium in groundwater, which was generated in the aquitards and released into the aquifers. To investigate bacterial community structures in the ammonium-rich aquifer-aquitard system and the impact of bacterial activities on ammonium concentration, sediment and groundwater samples were taken from representative locations in the PRD at different lithological units. Bacterial 16S rRNA gene clone libraries were constructed to analyze microbial identifications and community structures in different strata. Absolute abundances of anammox bacteria 16S rRNA gene and bacteria *amoA* gene in both sediment and groundwater samples were quantitatively analyzed with ^{15}N isotope at the same depth. Canonical correlation analysis between bacterial linages and environment factors showed that community structures were significantly modified by geological conditions. High bacterial diversity was observed in samples from the Holocene aquitard M1, while in the aquifer T1 and the older aquitard M2, bacterial diversities were much lower. *Chloroflexi*, *γ-proteobacteria* and *δ-proteobacteria* were the dominant phyla in the aquitard sediment. *β-proteobacteria* was the dominant phylum in sediment which was strongly influenced by fresh water. Anammox was the controlling biochemical process in microbial-derived ammonium loss, demonstrated by gene abundance coupling with ^{15}N isotope and ammonium concentration. The 16S gene abundance of anammox bacteria ranged from approximately 10^5 to 10^6 copies/g in aquitard sediment, and ranged from 10^4 to 10^5 copies/g in aquifers. Bacteria *amoA* gene abundance was 1-2 orders lower than anammox bacteria 16S in aquitard sediment, but in aquifers, the gene abundances of *amoA* and anammox 16S were similar. The interface between aquifer and aquitard was biochemically enhanced. The results of this study demonstrated that microbial activities significantly influenced the chemical distribution of ammonium in the aquifer-aquitard system in the PRD, and provided new perspectives on groundwater research and management from molecular/genetic microbiology.

Keywords: Groundwater; Pearl River Delta; ammonium; anammox; *amoA*

The Current Quality Survey of Soil-Water Resource in Huanghua Area

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Regional water cycle affected by land use change. In many areas land use patterns restricted by water resources, so soil and water resources in a reasonable match would promote healthy and sustainable development of regional economy. By studying land and water resources in Bohai Bay coastal area to clear their water and land resources characteristics, will help plan coastal areas of water resources and land use rationally and effectively and make land and resources for the region's scientific planning to provide technical support.

1. Study area

Huanghua in Hebei Province is flanked to Bohai, between longitude 117 °05 '~ 117 °49', latitude 38 °09 '~ 38 °39' and in the "Bohai Sea, around Beijing and Tianjin," the "double loop" hub area and Northeast Asia economic circle center. Huanghua become a city in 1989.Urban population is 200,000 (2010).The existing total land area is 1,544.7 square kilometers with 65.8 km of coastline.

2. Water and soil resources survey

Soil and water resources for human survival and development play an important role. In agricultural production, they are the most core resources (Yu Lei, 2007), characterized by changes in the ecological environment. They are sensitive indicators.

2.1 Current situation of water resource

Huanghua area is an area of serious water shortage, with many local rivers (mainly in the northwest of the study area). There are Jiedijian River, Ziyaxin River, Beipai River, Nanpai River, Canglang sewers, Dalangdian drain, Liaojiawa draining , Wangjiagouzi drain , Xinshibei river, Laoshibei river (21 rivers) which are Belong to the haihe river basin south canal river system. These rivers is 543.3km in total length and total flow is 2147.3m^3/ s. There are also Huangzao reservoir and Lee Guanzhuang reservoir , 16 big salinization draining and 1150 pits within the border. So total surface water resources is 89,759,000 m$^{3.}$

The development of deep water utilization increased significantly in past two decades. Deep water is sharp decrease. The study area is located in Cangzhou funnel range, deep confined water level decreased greatly. The third group of water belongs to the deep water. Aquifer is mainly sand and silt; rich in water; permeability and supply conditions are poor; single well water inflow is 5-10m3/ h • m, locally less than 2.5m^3/ h • m (QianYong,2007). Compared deep water with shallow water in TDS distribution varies greatly (Figure 3) and the water level change is also very different with the first and the second aquifer group which obvious impacted by whether they were mined. Mining areas and non-mining area changes in water level is very different. The third group water level dynamic in mining areas were not impacted by local precipitation at the very year and mainly impacted by the intensity of artisanal mining. The mining were small, the artificial impacts are small, water level falling is relatively slow; water level process is a straight linear shape. The intensity in the mining areas is strong, the water table which was seasonal variation is mainly controlled by the mining of agricultural irrigation. Groundwater mining is strong in first half year, the water level fell significantly and groundwater decreased slowly in the latter half of the year. After stopping irrigation, water level came picked up state to next 1-2 months and reached the highest values. In the non-mining areas, groundwater level remained stable.

2.2 Current situation of soil resources

Huanghua soil pH between at 7.84-9.87, land was in a state of salinization. Close to the southwestern region, salinization is particularly serious and is consistent with chloride salt fluvo-aquic soil type. Regional soil cation exchange capacity (CEC) generally less than 20coml/kg, and only in some areas of Lvqiao Township and Guangzhuang country is more than 20coml/kg. Soil fertilizer capacity is lower-middle. In layer cultivate, organic matter content is generally lower than 2.7×10^{-2} mg / kg, which belongs to typical poor fertility soils. The study area is basically in weak soil fertility state.

In terms of spatial distribution of the nutrition of the soil, the N and K_2O content of the soil is high to low from the north to the south and the distribution of P and Cl is the converse. The hydrolytic N of the soil gradually becomes low from the southeast to the northwest and effective P and available K are low in the central. Besides, the other regions are higher. The spatial distribution of the effective factor in soil is consistent with the regularities of distribution in the agriculture that Huang Huaahi researched. In other word, the use of agriculture fertilize has an important on the quantity change of N、P、K、NO_3^-、SO_4^{2-} in the soil.

3 Conclusions and recommendations

The spatial distribution of the land and water resource in Huanghua has good consistency: the land resource is rich in the district of having abundant water resource and the soil texture is a litter better. Huanghua is an agriculture town, has large agriculture land, mostly dry land, and develops the deep underground fresh water as the irrigation water, which has an effect on the groundwater and soil. In the study area, develop and use degree of the middle shallow salt water is very low, and the water quality is the worst. At the same time, PH in the soil is higher and the farmland salinization risk is high.

Water resources influence each other in the whole region. On the one hand, the distribution of water resource decides the ways of the land use, on the other hand, the change of the land use have an effect on the water resource and water environment. The current land use design doesn't consider the constraint of water resource, So we suggest that paid attention to the water resource constrains in the making the planning scheme.

Keywords: Huanghua; land use change; water resource constraints

References

[1] Wang Bin, Zhang Fawang, Chen Li, Cheng Yanpei Evaluation of comprehensive quality of soil and water resources in Heilonggang region based on the entropy value, *Soil and Water Conservation*, , 32 (6).（2012）
[2] Shen Liying, Xu Dongrui, Li Nan, Study on water and soil resources coupling in Huanghua City, *Land and Natural Resources Research*, 03(2013)
[3] Yu Lei, Qiu Dianming, Water simulation in Zhangweinan basin based on SWAT model, *Journal of Jilin University (Earth Science Edition)*, 05(2007)
[4] Liu Zhiguo. Study on the sustainable utilization of groundwater resources in Hebei plain. Shenyang: Northeastern University dissertation ,pp. 23 -24(2007)
[5] Zhang Zhaoji, Luo Guozhong, Wang Chao, etc. Study on the sustainable utilization of groundwater resources in the North China Plain, *Resource Sciences*, 31 (3),pp.355-360(2009)
[6] Qian Yong. Study on the evolution of shallow groundwater system in the North China Plain under the mining condition. Beijing: Chinese Academy of Geological Sciences Thesis, (2007)
[7] Xiong Shungui. Basis Soil. Beijing: China Agricultural University Press ,pp.199 -200(2001)

Density Dependent Flow Correction for Sharp Interface Solution

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Ghyben-Herzberg theory together with the Dupuit's approximation for freshwater-saltwater interface depth estimation are available for seawater intrusion in coastal aquifers. This approximated solution shows deviations with respect to the solution obtained from the density dependent flow approximation. In the present work a density dependent correction factor based approach is utilized for modelling. The model has been implemented for regional scale hypothetical aquifer. Density dependent flow corrections are suggested for the sharp interface solution of seawater intrusion in coastal aquifers. Correction factors are based on benchmark solutions for density dependent flow problems. This approach reduces the computational burden for simulation. Moreover, this approximate solution can be effectively utilized for saltwater intrusion management problems.

Keywords: Groundwater; Seawater; Density Dependent Flow; Sharp Interface

Estimation of SGD using ^{226}Ra in Laizhou Bay, China

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As a major component of the hydrological cycle, submarine groundwater discharge (SGD) has been widely recognized as a significant source of water and dissolved material transport from land to ocean [Moore, 1996; Burnett et al., 2003]. This paper presents an estimate of the SGD flux into Laizhou bay using radium isotope method, ^{226}Ra. Laizhou bay, located in the north part of Shandong peninsula, China, is one of the three important bays in Bohai Sea. We collected 44 surface seawater samples from Laizhou Bay, 8 groundwater samples and 6 river water samples along the shoreline during 19-27 August 2012 (Figure 1a). Radium isotopes were collected using the methods established by Moore [1976] and were measured in laboratory. Figure 1b shows the distribution of ^{226}Ra in the Laizhou Bay.

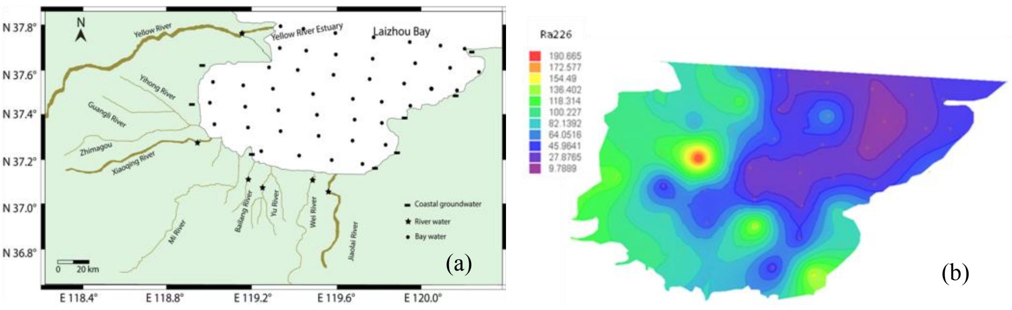

Figure 1. (a) Map of the Laizhou Bay. The dots, rectangles and pentagrams represent sampling stations for seawater, groundwater and river water, respectively. (b) Distribution of ^{226}Ra in the Laizhou Bay.

In a defined system (i.e. bay) with an assumed steady state, the gain of radium is equal to the loss [Moore et al., 2006]. Neglecting the decay of ^{226}Ra (half-life 1600 a) and other sources, the mass balance equation for ^{226}Ra in Laizhou bay system is:

$$V_{SGD} Ra_{GW} + \sum_{i=1}^{n} Ra_{R-i} V_{R-i} + M_{sed} \alpha_{desorp} = \frac{V_{bay}(Ra_{bay} - Ra_{OP})}{T_f} \qquad (1)$$

where Ra_{GW}, Ra_{R-i}, Ra_{bay} and Ra_{OP} is the average ^{226}Ra activity in the groundwater, river water, Laizhou Bay and open sea, respectively, V_{SGD}, V_{R-i} and V_{bay} is the volumetric flux of SGD, river and the bay, respectively. M_{sed} is the mass of the suspended particle through rivers, α_{desorp} is the parameter of desorption. T_f is the flushing time, which can be calculated by [Moore et al., 2006]:

$$T_f = \frac{\left[F(^{223}Ra/^{226}Ra) - I(^{223}Ra/^{226}Ra)\right]}{I(^{223}Ra/^{226}Ra)\lambda_{223}} \quad (2)$$

where $F(^{223}Ra/^{226}Ra)$ is the $^{223}Ra/^{226}Ra$ activity ratio of the flux into the bay, $I(^{223}Ra/^{226}Ra)$ is the $^{223}Ra/^{226}Ra$ activity ratio in the bay, λ_{223} is the decay constant of ^{223}Ra (0.061d^{-1}). Figures 2a and 2b are plot of ^{223}Ra versus ^{226}Ra for groundwater and surface seawater samples, respectively. The terms of $F(^{223}Ra/^{226}Ra)$ and $I(^{223}Ra/^{226}Ra)$, based on Figure 2, can be calculated.

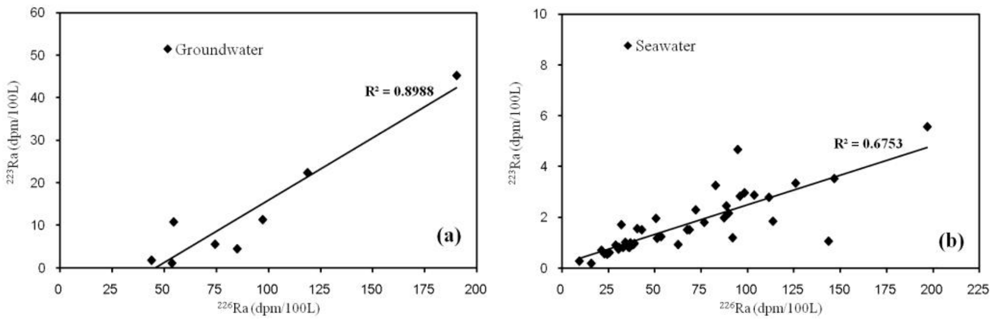

Figure 2. Plot of ^{223}Ra versus ^{226}Ra for (a) groundwater samples, (b) surface seawater samples.

The flushing time estimated by Eq. (2) is 55±7 days. The total riverine flux is 1311 m^3/s. The total mass of the suspended particle through rivers is 4099 kg/s. The average ^{226}Ra activity in the groundwater, Huang river water, Laizhou Bay and open sea is 89.64±7.32 dpm/100L, 133.9±10.31 dpm/100L, 64.07±4.40 dpm/100L, and 19.71±3.75 dpm/100L, respectively. Thus, the estimate of SGD from Eq. (1) ranges from 1730 m^3/s to 3600 m^3/s with an average of 2665 m^3/s, which is more than 2 times the total riverine flux into the Laizhou bay. Of course, the SGD here is a mixture of the terrestrial freshwater and the re-circulated seawater in the aquifer near shore. The large volume of SGD confirms its importance in delivering nutrients to the bay.

Keywords: Submarine groundwater discharge; Radium isotope; Groundwater; Laizhou Bay.

References

[1] Moore, W. S. (1996), Large groundwater inputs to coastal waters revealed by Ra-226 enrichments, *Nature*, *380*, 612-614.10.1038/380612a0.

[2] Burnett, W. C., H. Bokuniewicz, M. Huettel, et al. (2003), Groundwater and pore water inputs to the coastal zone, *Biogeochemistry*, *66*, 3-33.

[3] Moore, W. S. (1976), Sampling 228Ra in the deep ocean, Deep Sea Research and Oceanographic Abstracts, 23, 647-651.

[4] Moore, W. S., J. O. Blanton and S. B. Joye (2006), Estimates of flushing times, submarine groundwater discharge, and nutrient fluxes to Okatee Estuary, South Carolina, Journal of Geophysical Research-Oceans, 111. C09006 10.1029/2005jc003041.

Observed water head, salinity in a thick tidal mudflat abutting a reclamation area

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Although the tidal flats are considered to be the key elements in marine environments [Watabe and Sassa, 2008], the influence of large-scale reclamations on the groundwater-seawater circulation in a tidal mudflat is rarely studied. The low-permeability covering layer and gentle slope of the thick tidal mudflat will greatly influence the water exchange between seawater and groundwater. Due to the large-scale reclamations, the originally wide intertidal zone was changed into a very narrow zone, which inevitably leads to great changes of the groundwater dynamics and chemical reactions in the coastal area. Generally, the salt water interface will move toward the sea and the water level will increase [Guo and Jiao, 2007]. At the same time, the extent of the upper saline plume induced by the periodical tidal submersion will decrease. The objective of this paper is to present some qualitative description of the groundwater dynamics based on field observations of water head and salinity at three wells W1-W3 along a cross-shore transect in a thick tidal mudflat with gentle slope around 0.37% abutting a reclamation area in Caofeidian, Hebei Province, China during the summer of 2012 (Figure 1).

Figure 2a reports the variations of observed water head with time at the three wells. Near each of the lower low tide, the water head at W1 was higher than the beach surface. It became almost constant for about 3 to 4 hours until the subsequent rising tide. On the other hand, seepage face appeared wherever the tidal flat at W1 emerged from the seawater. Namely, the groundwater with high pressure head flowed out from the beach surface during low tides. Thus the observed groundwater head at W1 higher than the ground surface during low tides implies significant submarine groundwater discharge (SGD). The same phenomena were observed at W2 and W3.

Figure 2b shows the measured salinity variations with time in the three wells. The seawater salinity in the beach was 28.6g/L. On the whole, the salinities at W1 and W2 were very close to each other. The former ranged from 26.63g/L to 27.69g/L with a mean value of 27.34g/L, and the latter, from 27.10g/L to 27.98g/L with a mean value of 27.54g/L. The pore water salinity at W3 was less than half of those at W1 or W2, with its average being only 13.04g/L (Figure2.b1). It is also found that the salinities at the three wells fluctuated slightly and were in phase with the tides, although their fluctuation amplitudes were small (Figure2.b2 and b3). The fluctuation amplitude ranged from 0.06g/L to 0.45g/L with a mean value of 0.25g/L at W1, from 0.07g/L to 0.17g/L with a mean value of 0.12g/L at W2, and from 0.03g/L to 0.82g/L with a mean value of 0.42g/L at W3. Furthermore, the slight salinity fluctuation in phase with the tide strongly indicates vertical advective flow. That is, during low tides, the salinity decreases since groundwater of lower salinity flows upwards. On the contrary, during high tides, the salinity increases since seawater of higher salinity infiltrates into the aquifer.

The salinity at W3 much lower than those at W1 or W2 is most probably due to the existence of the upper saline plume and the freshwater discharge "tube" [Robinson et al., 2007]. Numerical simulations are required to obtain detailed quantitative description of the full groundwater dynamics beneath the tidal mudflat.

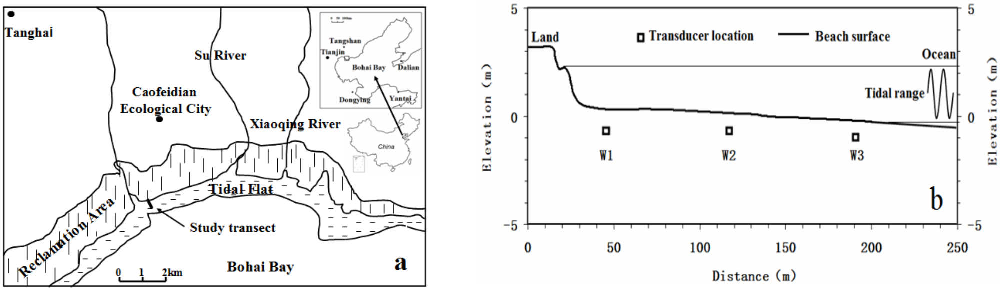

Figure1. (a) Location of the study transect in Caofeidian. (b) Locations of W1-W3 along transect.

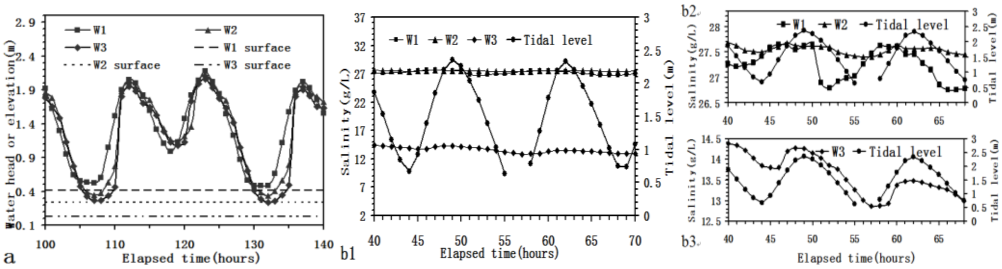

Figure2. The initial time t=0 h represents 17 September 2012, 11:00A.M. The sensor measured tidal level was placed above the beach surface at W1 and only the data during submergence was used. (a) Observed water head, tidal level and surface elevation at W1-W3 from t=100 h to t=140 h. (b) Salinity variations with time at W1-W3 from t=40 h to t=70 h.

Keywords: Field measurements; Tidal flat; Reclamation; Groundwater exchange; Caofeidian.

References

[1] H. Guo, J. J. Jiao, Impact of coastal land reclamation on ground water level and the sea water interface, *Ground Water*, 45(3), pp. 362-367(2007).

[2] Y. Watabe, S. Sassa, Application of MASW technology to identification of tidal flat stratigraphy and its geoenvironmental interpretation, *Mar. Geol.* 252, pp. 79-88 (2008).

[3] Robinson, C., L. Li, and D.A. Barry, Effect of tidal forcing on a subterranean estuary. *Advance in Water Resources*, 30(4), pp.851-865(2007).

Influence of slopes on submarine groundwater discharges driven by density difference

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Submarine groundwater discharges, known as SGD, which consist of terrestrial fresh groundwater component Q_f and the seawater-circulation component Q_s, have great impact on the coastal ecological environment. Although SGD have been widely studied, few studies discussed the influence of beach slopes, especially very mild beach slope, on SGD. Smith 2004 [1] studied the impact of various hydrogeological model parameters on the density-driven SGD while the seabed considered was flat. Liu et al. 2012 [2] investigated tidal effects on groundwater dynamics in coastal aquifers with different slopes, but they did not report slope effects on SGD. This study considered homogeneous, isotropic unconfined aquifer with different seabed slopes from 0.005 to vertical (see Figure 1 and Table 1), different hydraulic conductivities (10^{-2} m/s, 10^{-4} m/s), different longitudinal dispersivities (2m, 10m) and different inland water table (46m, 48m) to figure out the influence of beach slope and different parameters on total SGD. Here the tides and waves are ignored so the seawater-circulation Q_s is driven only by the seawater-freshwater density difference.

Numerical results showed the following results. (1) When the left inland water table increases from 46m to 48m, the freshwater recharge Q_f, the seawater-circulation component Q_s and total SGD increases by 460%, 60% and 270%, respectively, and the ratio RSF=Q_s/Q_f decreases by a factor of 70%. (2) The isoconcentration contours are insensitive to the variation of the hydraulic conductivity K when it ranges from 10^{-4} m/s to 10^{-2} m/s. The values of Q_f, Q_s and total SGD linearly increase with K. (3) When the longitudinal dispersivity α_L increases from 2m to 10m (with the ratio α_L/α_T fixed at 10), the value of Q_f keeps essentially constant, but Q_s increases, leading to the increases of both total SGD and RSF. (4) When the slope θ<10%, its variation has no influence on SGD, when θ>10%, SGD and RSF decreases as θ increases. They can be matched by a parabolic curve (Figure 2). (5) For all of the models, Q_f ranges from 0.177 m^2/d to 100 m^2/d, Q_s from 0.17 m^2/d to 48.0 m^2/d, the total SGD from 0.3 m^2/d to 140 m^2/d, and RSF from 20.66% to 153.74%.

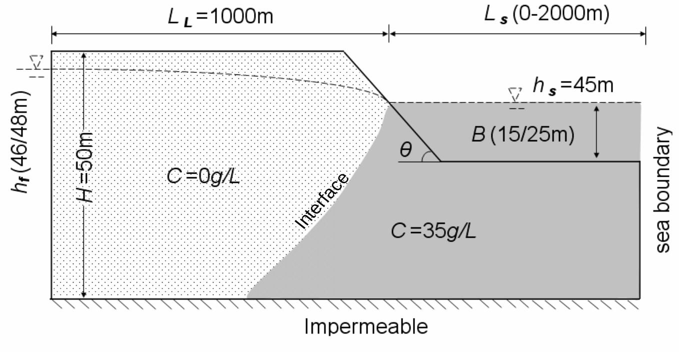

Table 1. Parameters used in the model.

Parameter	Physical meaning	Value
θ	Slope	0.005 to vertical
K	Hydraulic conductivity	10^{-2} m/s, 10^{-4} m/s
α_L	Longitudinal dispersivity	2m, 10m
α_T	Transverse dispersivity	0.2m, 1m
n	Porosity	0.3
D_m	Molecular diffusivity	10^{-9} m

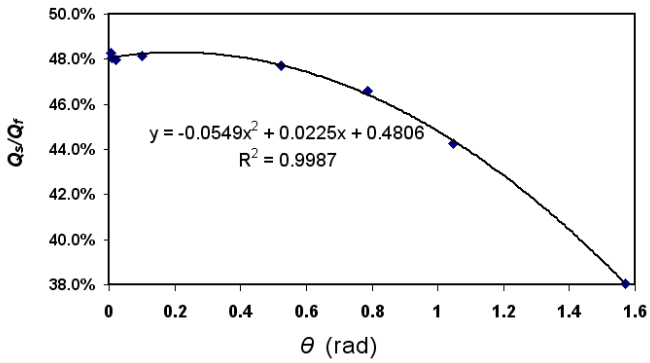

Figure2. Effects of θ on the ratio when K=10^{-2}m/s, α_L =10m, h_f =48m.

Keywords: SGD; slope; density difference; coastal area

References

A.J.Smith, Mixed convection and density-dependent seawater circulation in coastal aquifers, *Water Resour. Res.* 40: W08309, doi:08310.01029/02003WR002977 (2004).

Liu Yi, S. S.-h., Mao Xiao-min, Tidal effects on groundwater dynamics in coastal aquifer under different beach slopes. *Jounal of Hydrodynamics* .24 (1), pp. 97-106 (2012).

Abnormality of heavy metal concentrations in groundwater of the mangrove transect at Dongzhaigang National Nature Reserve (DNNR), Hainan, China

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Mangroves mainly distribute in tropical and subtropical zones. Mangroves are mainly found in six provinces along the coast of China (Fig.1A). Two transects labeled as B-B' (the bald beach transect) and M-M' (the mangrove transect) in Dongzhaigang were selected for conducting a comparative study (Fig. 1A). Eight (B0-B7) and nine (M0-M8) observation wells were installed in B-B' and M-M', respectively (Fig. 1B). Boreholes were drilled to install observation wells. Installation details were described by Xia and Li[1]. The observation period lasted for three days in December 2007. ICP-AES was used to measure the concentrations of the heavy metals Ba, Mn, Pb, Sb and cations K^+, Na^+, Ca^{2+}, Mg^{2+} in the groundwater samples. The anions Cl^-, Br^- and SO_4^{2-} were measured by DX-120 ion chromatograph (American D10NEX).

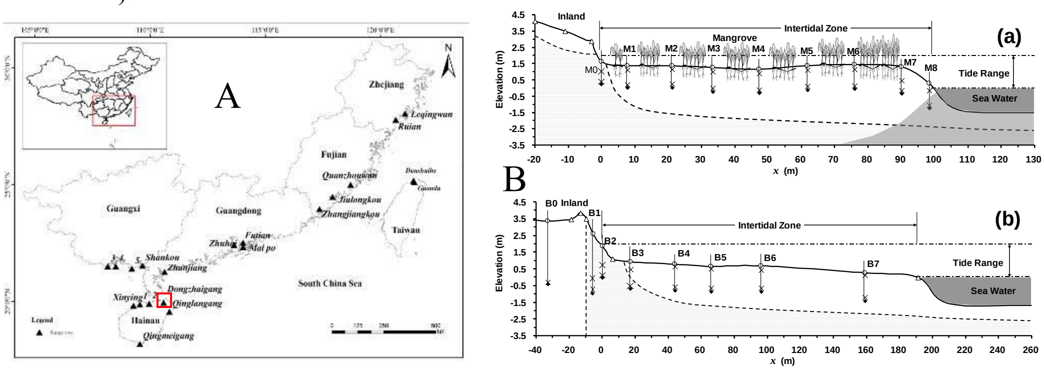

Fig.1 (A) Location of DNNR (indicated by red square) and map of mangrove distribution along the coast of China (six provinces including Hainan, Guangxi, Guangdong, Fujian, Taiwan island, Zhejiang). Some places are indicated by numbers: 1 = Xinying, 2 = Huachang bay, 3 = Beilunhe, 4 = Qinzhouwan, 5 = Daguansha. (After Li and Lee [2]). (B) The cross-sectional view of the M-M' (a) and B-B' (b) transects

in Dongzhaigang (After Xia and Li [1]).

The results indicate that the concentrations of common ions such as K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, Br^- and SO_4^{2-} are significantly higher along B-B’ than along M-M’. Details were reported in Li et al.[3]. Take the concentration of Cl^- as an example (Figure 2a), one can see that the concentration of Cl^- in most samples in B-B’ were larger than 12 g/L, with an average value of 15.34 g/L, but in M-M’ the concentration of Cl^- ranged from 1.78 to 18.79 g/L with an average of 12.93 g/L. The salinity of the groundwater in wells of M-M’ was significantly lower than that of B-B’[1]. It also reflected that the concentrations of Cl^- and other common ions in B-B’ were higher than those of M-M’ simply because the salinity is mainly determined by the concentrations of Cl^- and other common ions.

As depicted in Figures 2 (b, c, d), most points of Ba, Sb, Pb, Mn were abnormally located in the bottom right of each square, especially in Figures 2 (b, d). The average concentrations of Ba, Sb, Pb, Mn in M-M’ were 0.13, 0.32, 0.25, and 0.83 mg/L, respectively, and in B-B’ were 0.09, 0.21, 0.19, and 0.27 mg/L, respectively. They illustrate that M-M’ has higher concentrations of Ba, Sb, Pb, and Mn than B-B’.

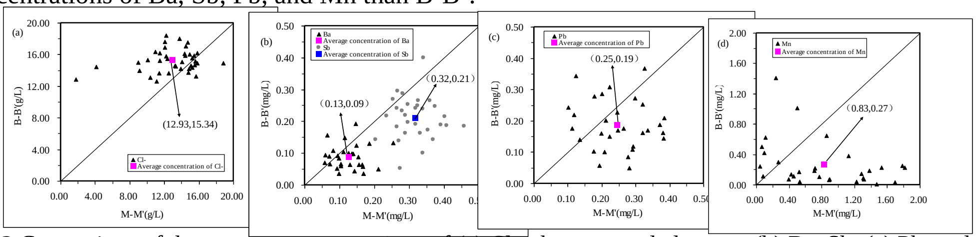

Fig. 2 Comparison of the average concentrations of (a) Cl^-; heavy metal elements (b) Ba, Sb; (c) Pb; and (d) Mn of groundwater samples of the mangrove transect and the bald beach transect.

In the literature, Mn, Ba, Pb in subsurface core sediments from Sunderban Mangrove Wetland in India were reported to have a high content[4], which is mainly attributed to the intense industrial and agricultural activities as well as drainage of untreated domestic sewage to the coastal region. Harbison[5] investigated the concentrations of heavy metals (Pb, Zn, Cu, Fe, Mn) in the mangrove wetland, sea pasture and the intertidal zone sediments in Barker port, Australia. He found that the ability of mangrove wetlands enriching heavy metals was larger than that of the bald tidal beach and sea pasture. He suggested that this phenomenon was mainly ascribed to the high content of organic matter, fine particulates, sulfides, and extreme variations in Eh and pH which could also alter the concentration of dissolve metals. Sometimes, the human activity must be considered, which may be the main factor when the study area is polluted. The sediment has a close connection with groundwater, the lixiviation action, iron exchange process and a series of other biogeochemical actions occur between sediments and groundwater. So the factors determining the concentrations of heavy metals in groundwater may be similar to those in sediments. But what is more important and interesting is probably the question where the heavy metals firstly accumulate, in the sediments or in the is probably the question where the heavy metals firstly accumulate, in the sediments or in the pore water, or in both simultaneously. Thus, this research is likely to remain an active and exciting field in the future.

Keywords: Mangroves; Groundwater; Heavy metals; Comparative study; Dongzhaigang National Nature Reserve (DNNR)

References

[1]. Xia, Y. Q. and H. L. Li, "A combined field and modeling study of groundwater flow in a tidal marsh." Hydrology and Earth System Sciences. 16(3), pp. 741-759 (2012).

[2]. Li, M. and S. Lee, "Mangroves of China: a brief review." Forest Ecology and Management. 96(3), pp. 241-259.(1997)

[3]. H. L. Li, Y. Q. Xia, X. L. Geng, "Hydrogeology and hydrochemistry along two transects in mangrove tidal marsh at Dongzhaigang National Nature Reserve, Hainan, China." In: Groundwater in the Coastal Zones of Asia-Pacific, Series: Coastal Research Library, Vol. 7. Wetzelhuetter, Christoph (Ed.). pp 11-25. 382 p. Springer. Dordrecht, Heidelberg, New York, London. (2013).

[4]. Jonathan, M. P., S. K. Sarkar, P. D. Roy, M. A. Alam, M. Chatterjee, B. D. Bhattacharya, A. Bhattacharya and K. K. Satpathy, "Acid leachable trace metals in sediment cores from Sunderban Mangrove Wetland, India: an approach towards regular monitoring." Ecotoxicology. 19(2), pp. 405-418 (2010).

[5]. Harbison, P, "Mangrove muds - A sink and a source for trace-metals." Marine Pollution Bulletin. 17(6), pp. 246-250. (1986).

Laboratory measurements of hydraulic conductivity of intertidal sandy sediments

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The hydraulic conductivity *K* of the beach sediments is of great significance in study of SGD and interactions among many factors in the intertidal zone (Li., et al. 2010). In laboratory, the well-known falling-head method or grain-size analysis method are usually used in estimating the *K*-values. Here, we estimated the *K* values using three laboratory methods, ie., two different falling-head methods, and the Konzey-Carman formula based on grain-size analysis (Carrier 2003). The schematic for our falling-head methods were shown in Figure 1. Figure 1(a) is the normal falling-head method with a constant water level outside the pipe. Figure 1(b) is the free drainage falling-head method, the water head at the bottom of the sediment column is zero (free drainage without any control) during the experiment.

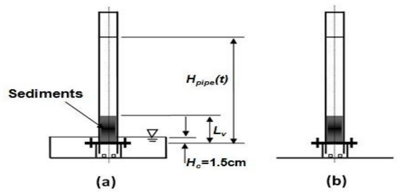

Figure 1. Schematic for two falling-head methods used. (a) Normal falling-head method; (b) Free drainage falling-head method.

Each of the three methods were applied to measure 9 intertidal sediment samples (S_1-S_9) from a sandy beach of Laizhou bay of Bohai Sea, PR China. For each sample, the same method was repeated three times and the three values were averaged to obtain the final *K*-values.

The analytical solution for describing the falling-head method is

$$H_{pipe}(t) = H_c + (H_0 - H_c)\exp(-Kt/L_v) \tag{1}$$

where $H_{pipe}(t)$ is water head inside the pipe at the time t , and H_0 is the initial head; H_c is the constant water head outside the pipe and equal to 1.5cm for normal method and 0cm for free drainage method; K is the hydraulic conductivity of the sample, and L_v is the length of sample column. In each experiment, a series of *K*-values was obtained using eq. (1) and the time series data recorded in the experiment. Finally, the series of *K*-values was averaged and the results (K_1 for the normal method and K_2 for the free drainage method, respectively) were reported in Figure 2.

The classical Konzeny-Carman formula to estimate the hydraulic conductivity is

$$K = 1.99\times10^{4}\left(100\% \Big/ \left\{\sum\left[f_i \Big/ \left(D_{li}^{0.5}\times D_{si}^{0.5}\right)\right]\right\}\right)^{2}\left(1/SF^{2}\right)\left[e^{3}/(1+e)\right] \qquad (2)$$

where f_i is fraction of particles between two sieve sizes (%); SF is the shape factor and e is the porosity. Fair and Hatch (1933) gave the shape factor SF as follows, spherical—6.0; rounded—6.1; worn—6.4; sharp—7.4; and angular—7.7. Here, considering the effects of tides and waves, particles are worn and SF is taken as 6.4. The grain-size analysis data was processed by eq. 2 and results recorded as K_3 (see Figure 2).

All results of hydraulic conductivity were shown in Figure 2(a). For each sample, to analysis the difference of K-values among three methods, we calculated the relative standard deviation *RSD*. The relative standard deviation *RSD* ranges from 2.88% to 40.21% and averages 23.33% for 9 samples. The differences among K values calculated by three methods are not large. Figure 2(b) is the comparison of K-values between falling-head method and free drainage falling-head method. The points (K_1, K_2) are close to the line $y=x$ and most of the points are above the line $y=x$. The K-values obtained by normal falling-head method was smaller than those of free drainage falling-head methods. Figure 2(c) shown compares K-values of normal falling-head method and Kozeny-Carman formula. All the points (K_1, K_3) are very close to the line $y=x$. The K-value discrepancy is adequately small.

The normal falling-head method and the Konzey-Carman formula based on grain-size analysis are effective and convenient in measuring the hydraulic conductivity of sediments. The K-values estimated by Konzey-Carman formula tend to be smaller. The free drainage falling-head method is simple and has certain feasibility as long as sediment sample is saturated during experiment.

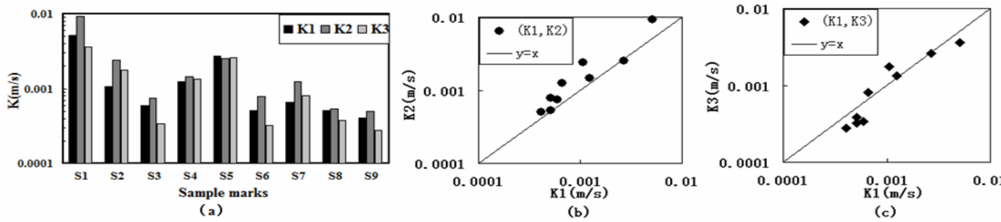

Figure 2. Comparison of K values of 9 samples. K_1: falling-head method, K_2: free drainage falling-head method; and K_3: Kozeny-Carman formula.

Keywords: Falling-head method; Kozeny-Carman formula; Free drainage falling-head method.

References

[1] Carrier, W. D. (2003). "Goodbye, Hazen; Hello, Kozeny-Carman." Journal of Geotechnical and Geoenvironmental Engineering 129(11): 1054-1056.

[2] Li, H., P. Sun, et al. (2010). "A Falling-Head Method for Measuring Intertidal Sediment Hydraulic Conductivity." Ground Water 48(2): 206-211.

Hydrodynamics and SGD estimation of a sandy beach in the east coast of Laizhou Bay, China

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Beach zones are dynamic areas with complex interactions among physical, chemical, and biological components in the presence of exchange of saltwater and freshwater. Understanding beach hydrodynamics is a crucial step for a variety of investigations [1]. The objective of this study is to present field data, simulations and SGD estimation of a sandy beach at the east coast of Laizhou Bay, Xinzhuang Town, Shandong Province, China (Figure 1a).

Field work was from August 14 to September 5 in 2012. Two cross-shore transects were selected in the beach and they are about 70 m away from each other. Along each transect five observation wells were set up (W1~W5 along the west transect and W6~W10 along the east one). To simulate the groundwater flow and solute transport in the beach, the two-dimensional finite element numerical model MARUN [1] was used. Four different boundary conditions [1] were used, which were shown in Figure 1b.

The tidal fluctuation used in beach boundary condition is a theoretical least-squares fitting to the observed tide data using five harmonic components [1]. The results are shown in Figure 2a. One can see that the least-squares fitting is in phase with the observed tidal fluctuation. However, there are obvious differences between the fitted and observed tidal fluctuation amplitudes. The main reason for this is probably due to significant waves which were not considered in the least-squares fitting. Figure 2b reports variations of the observed and simulated water table with time at the well W1. Similar to the tidal fluctuations, the simulated water table fluctuation is in phase with the observation. However, there are obvious differences between the simulated and observed water table fluctuation amplitudes. The differences between the simulated and observed water tables in other wells are very similar to those at W1, i.e., the simulated and observed water tables are in phase with each other and have obvious difference in amplitudes.

Figure 3 provides the Darcy velocity distribution averaged over a spring-neap tidal cycle (about 351 hours). The averaged velocity is much higher near the surface of the lower intertidal zone than in the other zones. The magnitude of the averaged velocity ranges from 10^{-7} m/s or less (in the unsaturated zone and most seaward part) to 10^{-5} m/s (near the surface of the lower intertidal zone). In the upper intertidal zone (X=10m~25m), velocity directions point to the aquifer, indicating that seawater flows into the aquifer. In the lower intertidal zone (X=25m~30m), velocity directions point to the sea, indicating that groundwater discharges into the sea. So there exists a distinguishing fresh groundwater discharge tube at X=25m~30m below the upper saline plume. Based on the simulation, the average total SGD during a spring-neap tide is 6.3 m^2/d, and tide-induced seawater re-circulation is 1.5 m^2/d, which accounts for almost 24% of the total SGD.

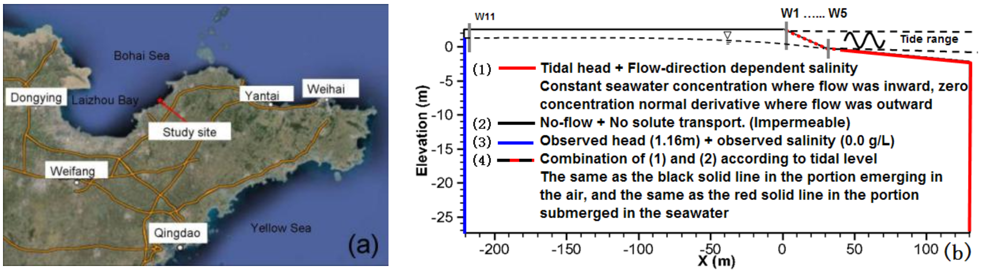

Figure 1. (a) Location of the studied beach at Xinzhuang, Zhaoyuan, Shandong Province. (b) The transect of the simulated domain, boundary conditions and positions of observation wells.

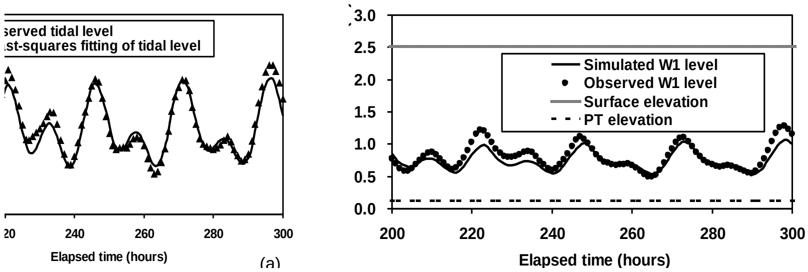

Figure 2. The observed and simulated tidal data (a) and water table at well W1 (b). The initial time t=0 h represents 15 August 2012, 11:00A.M. PT denotes pressure transducer.

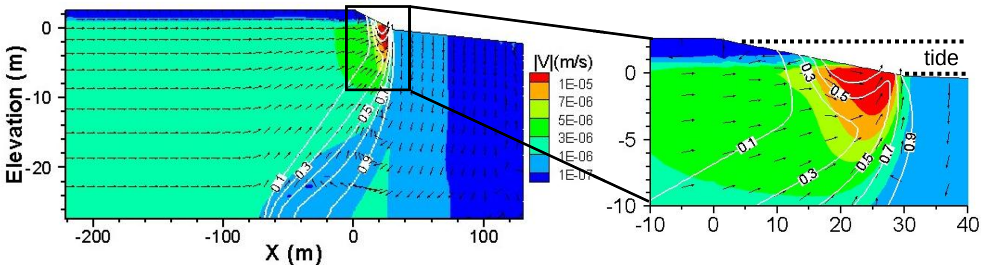

Figure 3. Darcy velocity (banded colored contours) in the transect averaged over a spring-neap tide cycle (about 351h). The arrows with uniform length are used to indicate the velocity direction only. White curves are contours of the pore water salinity.

Keywords: Field measurements, Numerical Simulation, Beach groundwater dynamics, SGD, Laizhou Bay, Tide-induced seawater re-circulation

References

[1] Guo, Q., H. Li, Boufadel, Michel C.,Sharifi, Youness, Hydrodynamics in a gravel beach and its impact on the Exxon Valdez oil. *Journal of Geophysical Research-Oceans* 115 (2010).

A numerical model for simulating transient evaporation from bare saline soil

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We present a mathematical model to simulate transient evaporation from bare saline soils. The exchange of water vapor between soil surface and atmosphere due to the evaporation was parameterized using aerodynamic formulations coupled with the model MARUN [1]. MARUN is a two-dimensional model for density-dependent water flow and solute transport below and above transient water table. Cauchy boundary condition was performed on the soil surface boundary to simulate the subsurface salinity distribution. Mass balance of water and salt was checked at each time step of the simulation. Small error (0.8% for water and 2.5% for salt) validated the accuracy of this model. Different scenarios were simulated in the model to quantify the effect of evaporation on subsurface water flow and associated salinity distribution with different atmospheric conditions and the capillarity characteristics of soils. The simulated results show that lower air humidity and/or lower value of sand capillary fringe parameter α causes a higher evaporation flux and higher subsurface salinity distribution in initially saturated soil.

Keywords: MARUN; Evaporation; Bare Soil; Salinity Distribution.

References

[1] M. C. Boufadel, M. T. Suidan, and A. D. Venosa, A numerical model for density-and-viscosity-dependent flows in two-dimensional variably saturated porous media. Journal of Contaminant Hydrology 37.1, pp. 1-20 (1999).

Seawater Intrusion for Dummies: Demystifying a Complex Subsurface Setting

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A proper understanding of coastal aquifer processes remains elusive for many of the stakeholders and managers of these freshwater resources worldwide. To bridge this gap, we develop a summarizing poster to communicate the fundamental aspects of seawater intrusion, for distribution to agencies, authorities, non-Governmental organizations and educational institutions. The poster includes a series of schematic conceptual models that capture the primary seawater intrusion processes of relevance to the management of coastal freshwater resources, and includes guidance for seawater intrusion investigations and management. The poster concludes that seawater intrusion management should rely on the application firstly of simple methods, before implementing more complex field-based and desk-top methodologies to enable prediction of the future performance of the aquifer to evolving land- and water-use changes. Various management options are recommended that commonly require long-term monitoring and investigation to assess water quantity and quality trends.

Keywords: Coastal aquifer; Seawater Intrusion, Groundwater management.

How the coarse interlayer in coastal aquifer influences seawater intrusion and contaminant migration?

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Coarse interlayer is commonly found in coastal aquifer. In order to indentify its influence on seawater intrusion and contaminant migration, vertical 2D slice laboratory experiments (see Figure 1) were carried out in both homogenous and layered sand tanks (with highly permeable coarse-grained sand interlayer).

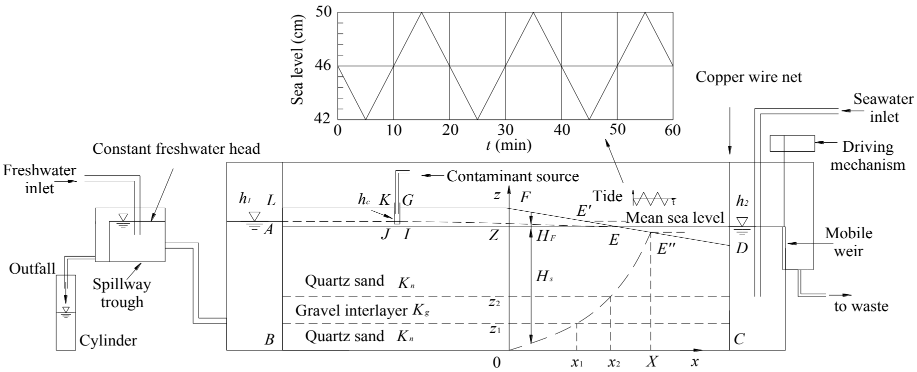

Figure 1. Sketch of the experiment setup. Tank is 160-cm long, 60-cm high and 10-cm deep.

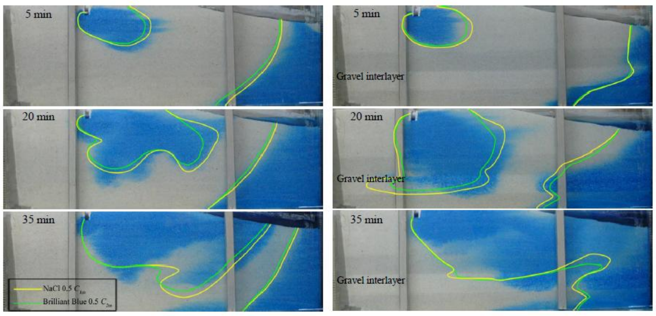

Figure 2. Contaminant transport results for simulation (lines) and experiment at low, medium and high tidal levels for (a) homogeneous sand and (b) sand with a gravel interlayer.

We observed that tidal fluctuations produced oscillations in the seawater-freshwater transition zone, fluctuations of the contaminant infiltration rate and a zigzag contaminant plume outline. The seawater wedge became discontinuous at the (vertical) edges of the interlayer due to increased lateral movement of the seawater-freshwater interface within the interlayer. The contaminant plume formed a tail within the interlayer depending on the tidal stage and, similarly to the wedge, its movement was accentuated (Figure 2).

Numerical modeling by FEFLOW confirmed the experimental findings, i.e., that a highly permeable interlayer can provide a rapid transit path for contaminants to reach the seaward boundary, and that the interlayer amplifies the effects of tidal fluctuations, resulting in wider transition zones for the seawater wedge and contaminant plume. Numerical simulations further showed that, with increasing interlayer hydraulic conductivity, the maximum seawater intrusion distance inside the interlayer increases approximately linearly (Figure 3), and contaminant infiltration increases approximately logarithmically for the fixed-head contaminant injection (Figure 4).

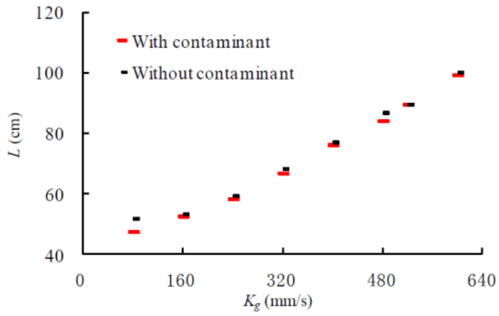

Figure 3. K_g vs. length of seawater intrusion

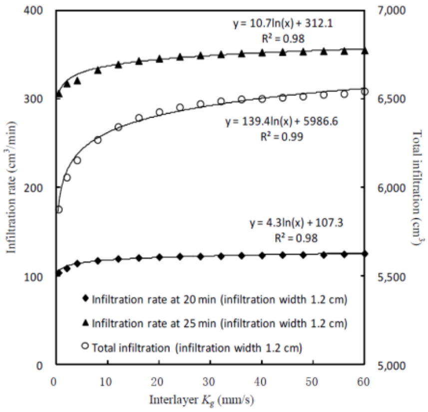

Figure 4. K_g vs. contaminant total infiltration and rate

Keywords: Seawater intrusion; contaminant transport; laboratory experiment; numerical simulation; stratified aquifer

References

[1] A. Brovelli, X. Mao, D. A. Barry. Numerical modeling of tidal influence on density-dependent contaminant transport. *Water Resour. Res.* 43: W10426. Doi:10.1029 /2006WR005173 (2007).

[2] M.C. Boufadel, Y. Q. Xia, H. Li. Modeling solute transport and transient seepage in a laboratory beach under tidal influence. *Environ Modell Softw* 26(7): 899-912. Doi:10.1016/j.envsoft.2011.02.005 (2011).

Field Experiment and Numerical Modeling of Tracer in a Gravel Beach in Prince William Sound, Alaska

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Oil from the 1989 Exxon Valdez oil spills persists in many gravel beaches in Prince William Sound (Alaska, USA), despite great efforts including bioremediation. This paper reports a field investigation of tracer (lithium) concentration in a tidal gravel beach in Knight Island, Prince William Sound during the summer of 2008. The tracer transports were successfully simulated using the two-dimensional numerical model MARUN. The simulated spatial distribution of tracer indicated that the nutrient applied along the transect would be washed to the sea very quickly (within less than one tidal cycle) by the combination of the two-layered beach structure, the tidal fluctuation and the freshwater flow from inland. If the tracer is approximately regarded as oils, oils in the upper layer would not enter the lower layer in the transect. This may qualitatively explain why the oil did not persist within the transect.

Keywords: Gravel beach; tide; tracer study; two-layered beach structure; freshwater recharge.

Estimation of the fresh water-salt water interface in a coastal unconfined aquifer with a hydraulic head difference in the fresh water zone

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In coastal zones where groundwater discharges into the sea, vertical difference in hydraulic head always exists (i. e., the Dupuit assumption is not satisfied) and may have an important bearing on the fresh water-salt water interface and needs to be taken into account when location of the interface is determined. Examination of the equilibrium status of a point on the interface reveals that the location of the interface in a coastal homogeneous, isotropic unconfined aquifer can be determined based on both the fresh water head and the salt water head at the same point on the interface. Considering a linear increase or decrease in the hydraulic head in the fresh water zone, a method for estimating the location of the interface is described based on fresh water heads at two points in the fresh water zone and salt water head at one point in the salt water zone in the same vertical line in the coastal zone. The method using corresponding pressures at the points is also given. The Ghyben-Herzberg relation is a special case of the method. This method requires three nearest piezometric wells, two tapping the fresh water zone and one tapping the deeper salt water zone, or three transducers installed in one well, two in the fresh water zone and one in the deeper salt water zone. Observations obtained in the coastal aquifer in northwestern Beihai, China and in an experiment modeling the interface are used to illustrate the application of the method and reasonable results are attained.

Managing the Coastal Watershed WithReal-time Integrated Groundwater and Surface Water Monitoring and Modeling System

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Effective and economical operational management of coastal watersheds require the integration of real-time information on current conditions in the watershed with decision support tools that can reliably forecast the expected behavior of the watershed and evaluate the impact of operational decisions, such as alternative gate operations, in advance. This paper presents the application of state-of the-art real-time watershed management tools for operation of flood control, salt water intrusion, water conservation and environmental quality protection in the Big Cypress Basin of southwest Florida.

The Big Cypress Basin (BCB) is located in Collier County on the west coast of the Florida peninsula of the United States. The climate is subtropical and the region exposed to regular convective thunderstorms in the summer months with heavy rainfall and flooding. In addition, the region is vulnerable to frequent ravages of tropical cyclone activities of the Atlantic basin. While rainfall is abundant during the wet season, southern Florida is also subject to extended periods of low rainfall and droughts. The topography is characterized by low relief with very mild slopes. The landscape is dominated by wetlands with close connection between surface water and groundwater system. Many parts of wetlands have lately been drained by a large surface drainage network of man-made canals, with numerous and often complex water control structures to regulate water levels for flood protection and water conservation. There is relatively little storage capacity in the surface storage system, making both flood mitigation and water resource management a tough balancing act with competing needs and conflicting responsibilities.

A real-time monitoring network of over 100 meteorological, surface and groundwater level recorders, including gate position meters have been assimilated to a fully distributed and integrated modeling system to forecast the behavior of the watershed, and to make operational decision accordingly. A web based retrieval of the real-time monitoring and modeling information has also served as a useful public outreach tool. This has resulted in a major improvement in comprehensive real-time operational management of water resources and water quality within a coastal watershed.

Numerical Modelling of Seawater Intrusion in Coastal Aquifers, North of Chennai, India

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Groundwater has been overexploited for various purposes such as drinking, agriculture, domestic and industrial purposes in several coastal regions of tropical countries. These coastal aquifers are vulnerable to seawater intrusion due to over extraction of groundwater to meet the ever increasing demand. Chennai metropolitan city is located in the east coast of India with population of 5 million (Census of India, 2012). North of Chennai coastal aquifer contributes to about 10% of city's water requirement. Over extraction of groundwater from this aquifer caused decrease of groundwater table which led to seawater intrusion since 1981 (CMWSSB, 2007). The present study was carried out with the objective to understand the seawater and freshwater dynamics of north Chennai coastal aquifer by density dependent groundwater modelling. East side of the study area is bounded by Bay of Bengal Sea. FEFLOW (Finite element subsurface FLOW system) is used to simulate this density coupled groundwater flow. The governing equation for a mixed variable density (seawater and freshwater) flow is given in Huyakorn (1987).

An intensive field survey was carried out and 45 wells were identified for monitoring of groundwater level. Groundwater level was measured once in two months from the year 2011. The historical data such as rainfall, groundwater level, chloride concentration and total dissolved solids (TDS) were collected from different government agencies. Aquifer properties such as hydraulic conductivity and specific yield of the aquifer were taken from previous studies.

Groundwater head and chloride concentration of groundwater of March 1988 were considered as the initial condition and boundary conditions for the model area were assigned based on the flow and solute concentrations across the area. Tidal level variations were considered for the while assigning the boundary condition at the coast. After calibration, validation of the model was made by comparing the simulated and observed groundwater levels from the year 2003 to 2010. Simulated and observed groundwater head and chloride concentrations were matched. Seawater and freshwater dynamics was assessed for different recharge and pumping rates of groundwater. Model result shows that seawater is intruding inland up to 12 km during summer seasons and is pushed seawards to around 6 km during monsoon season. This study is helpful in understanding the seawater and freshwater dynamics of coastal aquifer system under different hydrological stresses.

Keywords: Seawater intrusion; density dependent; Chennai.

References

[1] Census of India, 2012

[2] Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) report, 2007.

[3] P. S. Huyakorn , P. F. Andersen, J. W. Mercer, H. O. White Jr. Saltwater intrusion in aquifers: development and testing of a three-dimensional finite element model. Water Resour Res 23 (2), pp. 293-312 (1987).

Effects of tidal salinity fluctuations on groundwater dynamics in shallow beaches

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Numerical simulations of tidally influenced groundwater flow and solute/contaminants transport in beaches have attracted great attention of mathematicians, hydrologists, and engineers over past three decades. However, previous studies have almost focused on the effects of tidally varying hydraulic head but with a constant seawater salinity condition. In this paper, numerical experiments were conducted to explore the effect of the salinity fluctuations of tidal creeks synchronous with the tides, i.e. tidal salinity fluctuations, on the groundwater flow and salinity distributions in shallow sandy beaches. The results showed that, similar to the constant creek salinity case, two saline plumes (upper saline plume and classical saltwater wedge) and fresh groundwater discharge tube confined by them also appeared under the tidally varying salinity conditions. However, the tidal salinity fluctuations induced the highest salinity only occurring near the high tide mark rather than covering the entire area of two saline plumes under the constant creek salinity case. Quantitative calculations indicated that the tidal salinity fluctuations affected the magnitude and distribution of seawater-groundwater circulation across the beach-creek interface. Sensitivity analyses of hydraulic conductivity and inland freshwater recharge further clearly demonstrated that the submarine groundwater discharge (SGD) under the tidal salinity conditions was larger than that under the constant creek salinity case.

Keywords: Tidal salinity fluctuations; Saline plumes; Submarine Groundwater Discharge (SGD); Shallow beaches; Numerical simulation.

References

[1] M. Lenkopane, Influence of variable salinity conditions in a tidal creek on riparian groundwater flow and salinity dynamics, *Journal of Hydrology*, 375, pp. 536-545 (2009).

[2] H. L. Li, M. C. Boufadel, J. W. Weaver, Tide-induced seawater-groundwater circulation in shallow beach aquifers, *Journal of Hydrology*, 352, pp. 211-224 (2008).

[3] A. D. Werner, D. A. Lockington, Tidal impacts on riparian salinities near estuaries, *Journal of Hydrology*, 328, pp. 511-522 (2006).

Measuring in-situ vertical hydraulic conductivity in tidal environments

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The hydraulic conductivity of intertidal sediments plays an important role in quantifying seawater-groundwater interactions. Li et al. [2010] proposed a falling-head method for measuring the in-situ vertical hydraulic conductivities of sediments in the intertidal zone where the tidal level varies with time and adopt the least-squares fitting method to estimate this key parameter. The least-squares fitting method is complex and inconvenient since one needs to solve a least-squares inverse problem to minimize an objective function including nonlinear, complex analytical solution for describing the falling-head experiment. Here we present a new apparatus (Figure 1) and propose a simple, finite-difference data analysis method. The new apparatus is easy to operate and is able to measure in-situ vertical hydraulic conductivity ranging from 10^{-7} m/s to 10^{-2} m/s in tidal environments within one hour.

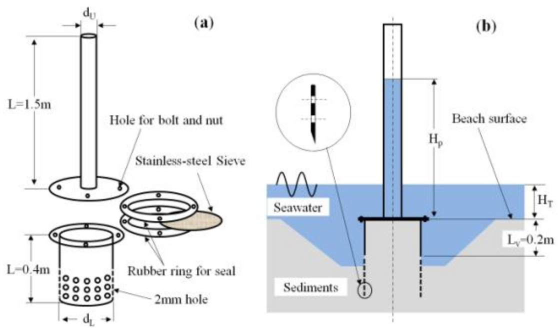

Figure 1. Schematic of (a) the apparatus, and (b) the in-situ installation of the apparatus for measuring hydraulic conductivity.

Finite-difference estimates are given by the following equations:

$$K = \frac{1}{N-1}\sum_{i=1}^{N-1} K_i \quad (4)$$

$$K_i \approx \frac{2R_d^2 L_V}{\Delta t_i} \frac{H_p(t_i) - H_p(t_i + \Delta t_i)}{H_p(t_i) - H_T(t_i) + H_p(t_i + \Delta t_i) - H_T(t_i + \Delta t_i)} \quad (5)$$

where $H_p(t_i)$, $H_T(t_i)$ is the water level inside and outside the water-container pipe at time t_i, respectively, Δt_i is observation time interval, N is the total number of water level measurements for the considered experiment, R_d is the diameter ratio of the upper water-container pipe to the lower sediment-container pipe, L_V is the length of the working part of the sediment-container (see Fig. 1b). The value of K can be quickly calculated using a pocket calculator or an Excel worksheet by the simple Equations (4) and (5).

A posteriori error of the finite-difference approximation method is estimated to have the same magnitude order as the square of the nondimensionalized observation time interval $K\Delta t/(L_V R_d^2)$, which is usually a very small number.

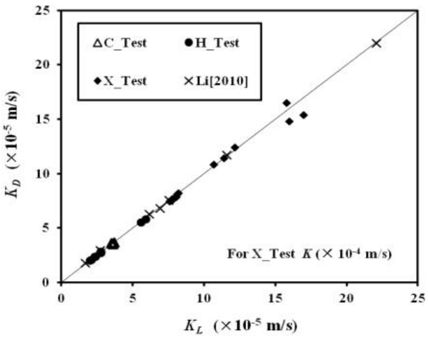

Figure 2. A plot of the K-values estimated by two methods (K_L is values of least-squares method, and K_D, values of finite-difference method). C_Test, H_Test, and X_Test denote the tests at Caofeidian, Haimiao, and Xinzhuang, respectively.

Numerical simulations were also conducted using COMSOL-Multiphysics software to validate the assumption that the effect of the horizontal flow in the sediment-container pipe is negligible. The new apparatus and finite-difference method were verified by many in-situ experiments in several coastal case study sites of Bohai Sea, PR China. The results include the K-values estimated by the least-squares method (K_L) and the finite-difference method (K_D), and the relative error Re which is defined as 100% $(K_D - K_L)/K_L$. The relative error was less than 9.41% and averages 1.22% for all experiments. Averagely, the finite-difference method produces estimates very close to those of the traditional least-squares method. Here we present a plot of the K estimated by two methods (see Figure 2). We recommend the new apparatus and simple finite-difference method for in-situ experiment that have many advantages such as economy, efficiency, reliability, and simplicity.

Key words: Multi-diameter falling-head method; Hydraulic conductivity; Least-squares method; Finite-difference estimates; Intertidal sediments

References

[1] Li, H. L., P. Sun, S. Chen, S. Chen, Y. Xia, and S. Liu (2010), A Falling-Head Method for Measuring Intertidal Sediment Hydraulic Conductivity, Groundwater, 48, 1-6.

Application of Groundwater Sustainability Indicators to the Upper Pliocene Aquifer in Ho Chi Minh city, Viet Nam

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Groundwater plays an importance role for domestic, industrial, and agricultural uses in Ho Chi Minh city, Viet Nam. This study is objected to evaluate the sustainability of groundwater by using groundwater sustainability indicators (GWSIs) defined by UNESCO/IAEA/IAH Working Group on Groundwater Indicators at aquifer scale (the Upper Pliocene aquifer). There are four main indicators selected and one new indicator designed for the particular characteristic of Ho Chi Minh City which is under influence of by saline-water intrusion. The results indicated that groundwater of the Upper Pliocene aquifer, the main groundwater supply source, is generally in the unsustainable state. The abstraction of groundwater, which was much greater than its capability, is probably causing the serious state of annual groundwater depletion and saline-water intrusion. The GWSIs, which expressed in such a simple way but scientifically-based and policy-relevant, proved its usefulness in evaluating the sustainability of groundwater at the aquifer scale in Ho Chi Minh city, and subsequently should be incorporated in water resource management practices.

Keywords: Groundwater Sustainability Indicators (GWSIs), Saline-water Intrusion, Ho Chi Minh city, Upper Pliocene Aquifer

References

[1] Dan NP, Ha NTV, Than BX, Nga NV, Khoa LV, Sustainable groundwater management in Asian Cities: a final report of research on sustainable water management policy, water resources management in Ho Chi Minh City. IGES, Hayama, Japan: 68–79 (2007).

[2] Jorreto S, Pulido-Bosch A, Gisbert J, Sánchez-Martos F, Francés I, The fresh water-seawater contact in coastal aquifers supporting intensive pumped seawater extractions: A case study. *C. R. Geoscience* 341:993–1002 (2009)

[3] Kim YJ, Lee KS, Koh DC, Lee DH, Lee SG, Park WB, Koh GW, Woo NC, Hydrogeochemical and isotopic evidence of groundwater salinization in a coastal aquifer: a case study in Jeju volcanic island, Korea. *J. Hydrogeol* 270:282-294 (2003)

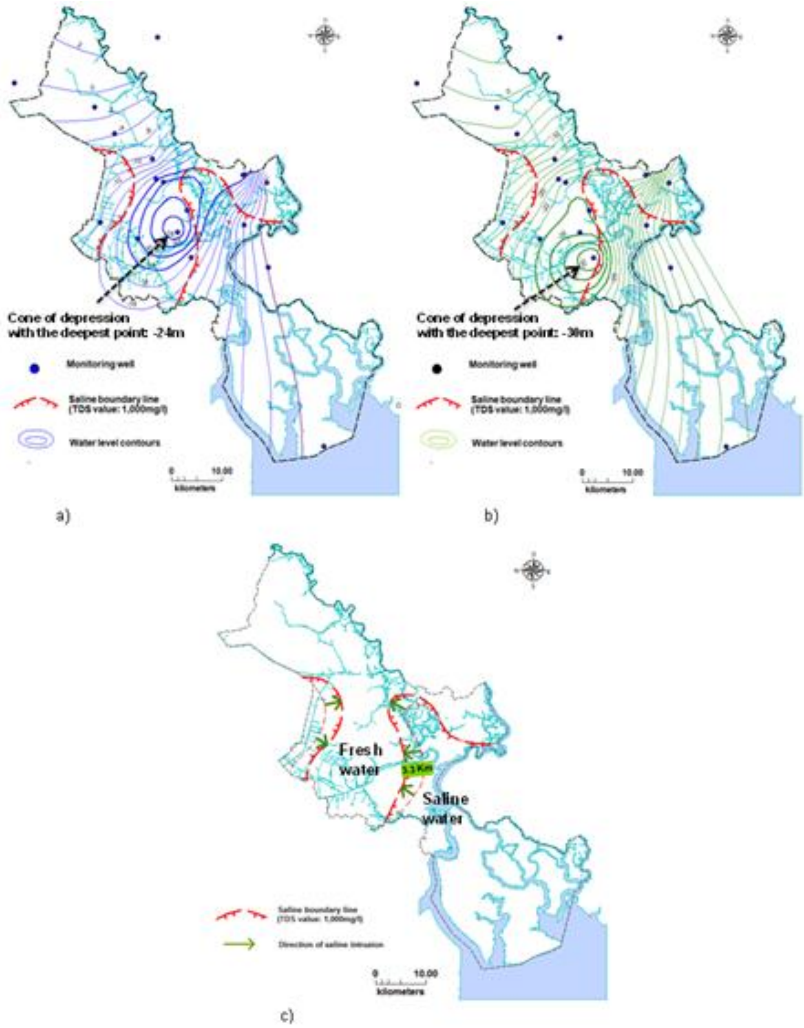

Figure 1. (a) & (b) Water level and saline boundary of aquifer (n_2^2) in April, 2004 and in April, 2009.

(c) Movement of saline water boundary


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